# Tripartite Evolutionary Game of Government-Industry-University in Seasonal-Transportation of Freight Enterprises Under the Background of Carbon-Peaking and Carbon-Neutrality Goals

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**Abstract.** China is now the world's highest carbon emission country. All circles focus is how to achieve carbon neutrality in just 40 years. China's carbon neutrality path will directly affect the future of the global industrial layout and investment direction. It is an important measure to promote the realization of carbon neutrality in the Chinese transportation industry through the collaborative innovation of seasonal transportation and government-industry-university. In this paper, under the dual-carbon background, the tripartite collective innovation game payment matrix of quarterly transportation of freight enterprises, universities, and governments is established. Using the triple evolutionary game method does not appear to modify the subject of the evolutionary stability of each participant's strategy selection. The influence of relevant parameters on the tripartite strategy selection is studied by Matlab numerical simulation. The results show government's incentive cost to enterprises and universities will affect the probability of the government's choice of incentive behavior. The amount of carbon tax paid by freight transportation enterprises can affect the probability of seasonal transportation and government incentive and supervision behavior of freight transportation enterprises. The research funds paid by freight transport enterprises to universities will affect the probability of strategic choice of both enterprises and universities.

**Keywords:** tripartite evolutionary game · government-industry-university collaborative innovation · seasonal transportation · carbon peaking and carbon neutrality


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## 1 Introduction

"Carbon peaking" and "Carbon neutrality" are the dual carbon targets set by China in 2020; that is, they strive to stop the growth of carbon dioxide emissions in 2030 and then start to decline after reaching the peak. By 2060, it will offset its carbon dioxide emissions through afforestation, energy conservation, and emission reduction and realize "zero emissions" of carbon dioxide. In 2020, the total carbon emission of the Chinese transport industry was about 9.9 million tons, making it the third largest source of greenhouse gas emissions after industrial and buildings. Among them, logistics and road transport accounted for 84.1% of the total carbon emissions of the transport industry [1]. At current rates, without intervention, global logistics emissions will double by 2050 from 2019 levels, according to the International Transport Forum. The low-carbon process of the freight transportation industry is slow; the main reason is that fossil energy consumption still occupies a dominant position, green energy vehicle coverage is low, the infrastructure required for new energy vehicles could be better, etc. However, the popularity of electric vehicles faces many challenges. For example, the cold weather in the north can significantly reduce the battery activity of trams, and the range of a full charge in winter can only reach a tenth of the distance in summer. Therefore, the seasonal transport mode of the freight industry (that is, electric trucks are used from late spring to late autumn of the year, and fuel trucks are used from winter to spring of the following year) can not only achieve significant results in the green transformation of the industry but also alleviate the problem of insufficient power of electric cars in extreme weather. At the same time, enterprises cooperate with universities to study and solve the difficulties of low-temperature environment battery storage capacity is weak, collaborative innovation, mutual benefit and win-win. As the initiator and executor of the dual carbon targets, the government encourages and supervises the relevant behaviors of enterprises and universities to promote the comprehensive electrification process of road transport. Therefore, it is of great practical significance to study the strategic choices of freight transport enterprises, universities, and governments under bounded rationality for freight transport enterprises to develop low-carbon transport systems at the present stage.

The research on the game theory of industrial carbon reduction under dual carbon targets is pervasive. Junhua Guo et al. analyzed the carbon emission reduction decision-making of supply chain duopoly enterprises through the evolutionary game model participated by both parties [2]. Guochang Fang et al. built an evolutionary game model of government-enterprise carbon emission reduction driven by carbon trading based on the system dynamics theory and solved an equilibrium strategy with stability [3]. Ke Fan and Eddie C.M. Hui studied the decision on government incentives and low carbon and energy consumption in the construction industry by establishing a game model between the government and the construction industry [4]. The game analysis with multi-agent participation is more helpful in describing complex problems. The three-party evolutionary game is an effective method to study the dynamic changes of multi-agent strategies with limited rationality in repeated long-term games and has applicability to the study of quarterly transportation strategies of freight enterprises. For example, Mirzaee Hossein et al. established a tripartite evolutionary game model among manufacturers, carbon emission verification third parties, and the government and proposed the most effective punishment scheme for the cooperation between manufacturers and verification institutions [5]. The tripartite evolutionary game model constructed by Lilong Zhu et al. offered regulatory suggestions for rent-seeking in drug testing [6]. By establishing an evolutionary game model involving the government, the public, and the construction industry, Gao Xin et al. analyzed the preconditions, decision-making behaviors, and key influencing factors for maximizing green benefits [7]. It can be seen that the triple evolutionary game is suitable for analyzing the collaborative innovation decision-making problems of freight transport enterprises, universities, and governments.

Government-Industry-University collaborative innovation can give full play to the innovation advantages of enterprises, universities, governments, and other cooperative subjects and contribute to promoting the transformation of scientific research achievements and technological innovation. Among them, Junmin Wu et al. studied the new mechanism of collaborative innovation in the post-subsidy era, indicating that the status of the government should be transformed from a coordinator to a vital participant and its functions should be changed from guidance, coordination, and supervision to supervision and incentive [8]. Based on cellular automata theory, Tuochen Li and Xinyu Zhou concluded that increasing cooperative innovation income distribution fairness can consolidate industry-university collaborative innovation cooperation [9]. Karolin Sjoo and Tomas Hellstrom summarized seven factors that affected industry-academia collaborative innovation and discussed the degree of government policy intervention in aspects [10]. Huaiying Lei et al. used the government-industry-academia cooperative innovation theory to construct a transferable revenue relationship model of the triple-helix game [11]. They chose Shapley value and nucleolus value in-game analysis as metrics to measure the synergy effect of the innovation system. The results showed that the government could make benefits to universities and enterprises. It can stimulate the enthusiasm of universities and enterprises to participate in collaborative innovation and enhance the stability of collaborative innovation alliances. It can be seen that the cooperation mode of government, industry, and academia is of great significance in promoting the innovation and development of various sectors.

Current research on low-carbon transportation mainly focuses on transportation route optimization and low-carbon site-routing problems. Shun Wang et al. proposed a super-inspired algorithm based on an ant colony selection mechanism to solve and compare the models aiming at the minor carbon emissions and the least cost, respectively [12]. The results show that the site-path model considering carbon emissions can effectively reduce carbon emissions. Longlong Leng et al. proposed a comprehensive optimization model of low carbon site-routing problem based on the cold chain to minimize the total logistics cost and the waiting time of customers and vehicles, improve the efficiency of the cold chain logistics network and reduce fuel consumption and carbon emissions by mixing the types of goods arranged in one vehicle [13]. It can be seen that most existing studies reduce carbon emissions by planning the running trails of trucks to avoid repeating routes. Based on the factors affecting freight transport enterprises' willingness to purchase new energy vehicles, this paper proposes a quarterly transportation strategy. It improves the low-carbon transportation system by changing the types of energy consumed by cars.

Therefore, based on the evolutionary game theory, this paper constructs a three-party game model of quarterly transportation of freight enterprises, collaborative innovation of universities, and government incentive supervision. Compared with previous studies, this paper has the following differences: First, this paper considers the strategic stability of each game party and the influence of each element on strategy selection. Secondly, the influence of different initial conditions on the tripartite strategy selection is analyzed by Matlab numerical simulation, and suggestions and prospects are put forward.

## 2 Model Hypothesis and Construction

### 2.1 Model Hypothesis

Hypothesis 1 There are three players in the game model: freight transport enterprises, university research institutions (after this referred to as universities), and the government. Therefore, the freight enterprise is set up A, the university is B, and the government is G. All three parties are bounded, rational participants. The strategy selection gradually evolves and stabilizes to the optimal strategy over time.

Hypothesis 2 The freight transport enterprises have two options: seasonal transportation and non-seasonal transportation, which means using fossil fuel trucks all year round, the set of strategies is (Seasonal transportation, Non-seasonal transportation). There are two strategies for universities to choose from: cooperate with freight transport enterprises to innovate new-energy trucks or not to innovate cooperatively; the strategy set is (Collaborative, Non-collaborative). The government has two strategy choices: incentive and non-incentive supervision policies. And its strategy set is (Incentive, Non-incentive). Therefore, x represents the probability that freight enterprises choose seasonal transportation, y means the probability that universities choose collaborative innovation, 1-x means the probability that freight enterprises choose non-seasonal transportation, and 1-y represents the probability that universities choose non-collaborative innovation. Set z represents the probability that the government chooses incentive supervision, and 1-z represents the probability of choosing non-incentive supervision. Here $x,y,z \in [0,1]$.

Hypothesis 3 $R_1$ is the inherent revenue of freight transport enterprises before they choose seasonal transportation, $R_2$ is the inherent revenue of colleges and universities before they participate in collaborative innovation, $R_3$ is the revenue of the government when it chooses incentive behavior, $R_4$ is the revenue of the government when it chooses no incentive behavior, and $R_3 > R_4$.

Hypothesis 4 When freight transport enterprises choose seasonal transport and universities choose collaborative innovation, benign synergistic benefits will be generated, and the distribution coefficient of benefits is $\gamma_i$ (i = A, B). Among them, the benign synergetic benefits distribution coefficient of freight transport enterprises is $\gamma_A$, the benign synergetic benefit distribution coefficient of universities is $\gamma_B$, and $\gamma_A + \gamma_B = 1$. When the quarterly transportation of freight enterprises and the collaborative innovation of colleges and universities produce peaceful synergistic benefits, the freight enterprises can gain benefits $\gamma_A V$, and the colleges can gain benefits $\gamma_B V$. At the same time, the government gains future long-term benefits M.

Hypothesis 5 Assume that the cost of seasonal transportation is $C_A$, mainly the one-time expense of purchasing pure electric trucks. The cost of collaborative innovation in universities is $C_B$, including the expenditure of human and material resources during research and development. Because the carbon emissions generated in the research and development process are far less than the carbon emissions that the freight transport enterprise can reduce after successful research and development, it is ignored.

Hypothesis 6 The government will pay corresponding incentive and supervision costs when it chooses incentive supervision. Suppose the incentive cost of the government's choice of incentive behavior is W, and the supervision cost is $C_G$. The proportion of government incentives $\mu_A$ obtained by freight transport enterprises when they choose seasonal transportation, and the proportion of government incentives accepted by universities when they choose collaborative innovation is $\mu_B$. Among them, the incentive award for freight transport enterprises is the purchase subsidy for enterprises to buy pure electric vans. The incentive award for universities is the research fund and $\mu_A + \mu_B = 1$.

Hypothesis 7 $R_A$ is the long-term earnings freight enterprises can obtain when they choose seasonal transportation, such as corporate goodwill, environmental protection title, commercial earnings from research and development results, etc. When an enterprise decides off-season transportation, the carbon tax to be paid is 4S. When the government chooses not to incentivize the behavior, the carbon tax payable by the enterprise for seasonal transportation is S. Under government incentives, enterprises are exempt from carbon tax when they choose seasonal carrier and get incentive reward $\mu_A W$.

Hypothesis 8 When colleges and universities research the battery performance of pure electric trucks purchased by freight transport enterprises, enterprises pay research funds F to colleges and universities. At the same time, freight enterprises and universities will sign collaborative innovation contracts. When one party breaks the agreement, the other can collect liquidated damages K.

### 2.2 Model Construction

According to the above assumptions, the strategic game matrix of freight enterprises, universities, and the government can be obtained, as shown in Table 1.

## 3 Model Analysis

### 3.1 Analysis of Strategic Stability of Freight Transport Enterprises

Expected returns of freight transport enterprises choosing seasonal transport or non-seasonal transport $E_{A1}$, $E_{A2}$, the average expected returns $\overline{E_B}$ are respectively:

$$\begin{cases} E_{A1} = yz\left[R_1 + \gamma_A V - C_A + \mu_A W - F + R_A\right] \\ \quad + y(1-z)\left[R_1 + \gamma_A V - C_A - F + R_A - S\right] \\ \quad + (1-y)z[R_1 - C_A - F + R_A + K] + (1-y)(1-z)[R_1 - C_A - S + R_A + K] \\ E_{A2} = yz[R_1 - 4S - K] + y(1-z)[R_1 - 4S - K] + (1-y)z[R_1 - 4S] \\ \quad + (1-y)(1-z)[R_1 - 4S] \\ \overline{E_A} = xE_{A1} + (1-x)E_{A2} \end{cases} \tag{1}$$

**Table 1.** The game matrix of quarterly transportation of freight enterprises and collaborative innovation of universities under government incentive supervision and non-incentive supervision

| | | | | Freight Enterprise A | |
|---|---|---|---|---|---|
| | | | | Seasonal x | Non-seasonal 1-x |
| Government G | Incentive supervision z | University B | Collaborative y | $R_1 + \gamma_A V - C_A + \mu_A W - F + R_A$ | $R_1 - 4S - K$ |
| | | | | $R_2 + \gamma_B V - C_B + \mu_B W + F$ | $R_2 - C_B + \mu_B W + K$ |
| | | | | $R_3 + M - W - C_G$ | $R_3 - C_G + 4S - \mu_B W$ |
| | | | Non-collaborative 1-y | $R_1 - C_A + \mu_A W + R_A + K$ | $R_1 - 4S$ |
| | | | | $R_2 - K$ | $R_2$ |
| | | | | $R_3 - \mu_A W - C_G$ | $R_3 + 4S - C_G$ |
| | Non-incentive supervision 1-z | University B | Collaborative y | $R_1 + \gamma_A V - C_A - F + R_A - S$ | $R_1 - 4S - K$ |
| | | | | $R_2 + \gamma_B V - C_B + F$ | $R_2 - C_B + K$ |
| | | | | $R_4 + M + S$ | $R_4 + 4S$ |
| | | | Non-collaborative 1-y | $R_1 - C_A - S + R_A + K$ | $R_1 - 4S$ |
| | | | | $R_2 - K$ | $R_2$ |
| | | | | $R_4 + S$ | $R_4 + 4S$ |

The dynamic replication equation of freight enterprise strategy selection is as follows:

$$\begin{aligned} F(x) &= dx/dt = x\left(E_{A1} - \overline{E_A}\right) \\ &= x(1-x)\left[y(\gamma_A V - F) + z(\mu_A W + S) - C_A + K + 3S + R_A\right] \end{aligned} \tag{2}$$

The first derivative of x and the set G(y) are, respectively:

$$\begin{aligned} \frac{d(F(x))}{dx} &= (1-2x)\left[y(\gamma_A V - F) + z(\mu_A W + S) - C_A + K + 3S + R_A\right] \\ G(y) &= y(\gamma_A V - F) + z(\mu_A W + S) - C_A + K + 3S + R_A \end{aligned} \tag{3}$$

According to the stability theorem of a differential equation, the probability that freight transport enterprises choose seasonal transport strategy is in a stable state must meet: $F(x) = 0$, $d(F(x))/dx < 0$. Because of $\partial G(y)/\partial y > 0$, G(y) is an increasing function

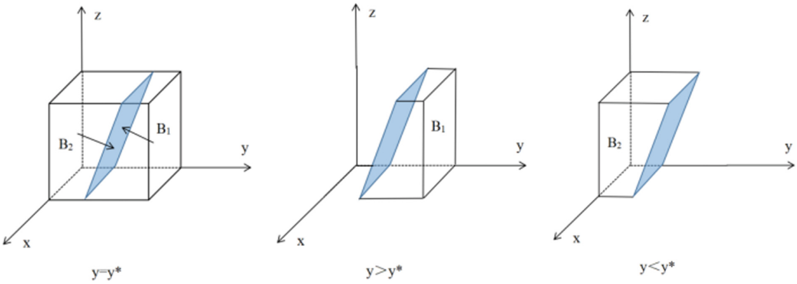


**Fig. 1.** Phase diagram of freight enterprise strategy evolution

of y. Therefore, $y = [R_A + K + 3S\text{-}C_A + z(\mu_A W + S)]/(F\text{-}\gamma_A V) = y^*$, $G(y) = 0$, at this time, $d(F(x))/dx \equiv 0$, freight enterprises can not determine the stability strategy. Then $y < y^*$, $G(y) < 0$, at this time, $d(F(x))/dx|x = 0 < 0$, $x = 0$ is the Evolutionarily Stable Strategy (ESS) of the freight transportation enterprise. Conversely, $y > y^*$, then $x = 1$ is ESS. The phase diagram of the strategic evolution of freight transport enterprises is shown in Fig. 1.

As shown in Fig. 1, the probability of the freight transport enterprise stably choosing the seasonal transport strategy $B_1$ is the volume of $V_{B1}$, and the likelihood of the freight enterprise stably choosing the non-seasonal transport strategy $B_2$ is the importance of $V_{B2}$. The calculation can be made as follows:

$$\begin{aligned} V_{B1} &= \int_0^1 \int_0^1 \frac{R_A + K + 3S - C_A + z(\mu_A W + S)}{F - \gamma_A V} dxdz \\ V_{B2} &= 1 - V_{B1} \end{aligned} \tag{4}$$

Corollary 1 The probability of shipping enterprises choosing a seasonal transportation strategy is positively related to the carbon tax, long-term income, synergistic benefit, and government incentive, while negatively related to the cost of seasonal transportation and the research funds paid by enterprises to universities.

According to the probability expression of the freight forwarder's choice of seasonal transportation strategy $V_{B1}$, the first partial derivative of each element can be obtained: $\partial V_{B1}/\partial S > 0$, $\partial V_{B1}/\partial R_A > 0$, $\partial V_{B1}/\partial V > 0$, $\partial V_{B1}/\partial W > 0$, $\partial V_{B1}/\partial C_A < 0$, $\partial V_{B1}/\partial F < 0$. Therefore, carbon tax, long-term income, synergistic benefits, increased government incentives or the cost of seasonal transportation for enterprises, and reduced research funds paid to universities can all increase the probability of freight enterprises choosing a seasonal transportation strategy.

### 3.2 Analysis of the Strategic Stability of Universities

Expected returns of collaborative innovation or non-collaborative innovation in colleges and universities $E_{B1}$, $E_{B2}$, the average expected returns $\overline{E_B}$ are:

$$\begin{cases} E_{B1} = xz\left[R_2 + \gamma_B V - C_B + \mu_B W + F\right] + x(1-z)\left[R_2 + \gamma_B V - C_B + F\right] \\ \quad +(1-x)z[R_2 - C_B + \mu_B W + K] + (1-x)(1-z)[R_2 - C_B + K] \\ E_{B2} = xz[R_2 - K] + x(1-z)[R_2 - K] + (1-x)zR_2 + (1-x)(1-z)R_2 \\ \overline{E_B} = yE_{B1} + (1-y)E_{B2} \end{cases} \tag{5}$$

The dynamic replication equation of university strategy selection is:

$$\begin{aligned} F(y) &= dy/dt = y\left(E_{B1} - \overline{E_B}\right) \\ &= y(1-y)\left[x(\gamma_B V + F) + z\mu_B W - C_B + K\right] \end{aligned} \tag{6}$$

The first derivative of y and the set J(z) are, respectively:

$$\begin{aligned} \frac{d(F(y))}{dy} &= (1-2y)\left[x(\gamma_B V + F) + z\mu_B W - C_B + K\right] \\ J(z) &= z\mu_B W + x(\gamma_B V + F) - C_B + K \end{aligned} \tag{7}$$

According to the stability theorem of the differential equation, the probability of universities choosing a collaborative innovation strategy in a stable state must meet: F(y) = 0, d(F(y))/dy < 0. Because of ∂J(z)/∂z > 0, J(z) is an increasing function of z. Therefore, z = [$C_B$-K-x($\gamma_B$V + F)]/$\mu_B$W = z*, J(z) = 0, at this time,d(F(y))/dy≡0, the university can not determine the stability strategy. Then, z < z*, J(z) < 0, at this time, d(F(y))/dyly = 0 < 0, y = 0 is ESS. Conversely, z > z*, then y = 1 is ESS. The phase diagram of the university strategy evolution is shown in Fig. 2.

Figure 2 shows that the probability of a university's stable choice of collaborative innovation strategy $C_2$ is the volume of $V_{C2}$, and the likelihood of a university's tough choice of non-collaborative innovation strategy $C_1$ is the volume of $V_{C1}$, the calculation can be made as follows:

$$\begin{aligned} V_{C1} &= \int_0^1 \int_0^1 \frac{C_B - K - x(\gamma_B V + F)}{\mu_B W} dxdy \\ V_{C2} &= 1 - V_{C1} \end{aligned} \tag{8}$$

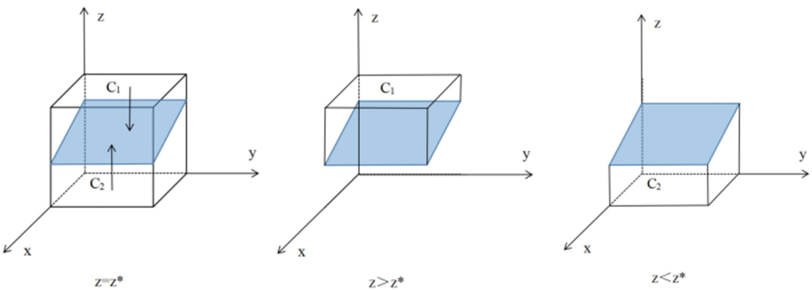


**Fig. 2.** Phase diagram of university strategy evolution

Corollary 2 The probability of colleges and universities choosing a collaborative innovation strategy is positively related to liquidated damages, combined benefits, research funds paid by enterprises to colleges and universities, and government incentives and negatively associated with the cost of colleges and universities choosing a collaborative innovation strategy.

According to the probability expression of the university's choice of collaborative innovation strategy $V_{C2}$, the first partial derivative of each element is obtained: $\partial V_{C2}/\partial K > 0$, $\partial V_{C2}/\partial V > 0$, $\partial V_{C2}/\partial F > 0$, $\partial V_{C2}/\partial W > 0$, $\partial V_{C2}/\partial C_B < 0$. Therefore, liquidated damages, synergistic benefits, research funds paid by enterprises to colleges and universities, increased government incentives, or reduced collaborative innovation costs can increase the probability of colleges and universities choosing collaborative innovation strategies.

### 3.3 Analysis of the Strategic Stability of Government Departments

The government chooses the expected returns of incentive supervision or non-incentive supervision $E_{G1}$, $E_{G2}$, and the average expected returns $\overline{E_G}$, respectively:

$$\begin{cases} E_{G1} = xy[R_3 + M - W - C_G] + x(1-y)[R_3 - \mu_A W - C_G] \\ \quad + (1-x)y[R_3 - C_G + 4S - \mu_B W] + (1-x)(1-y)[R_3 + 4S - C_G] \\ E_{G2} = xy[R_4 + M + S] + x(1-y)[R_4 + S] + (1-x)y[R_4 + 4S] \\ \quad + (1-x)(1-y)[R_4 + 4S] \\ \overline{E_G} = zE_{G1} + (1-z)E_{G2} \end{cases} \tag{9}$$

The dynamic replication equation selected by the government policy is:

$$\begin{aligned} F(z) &= dz/dt = z\left(E_{G1} - \overline{E_G}\right) \\ &= z(1-z)\left[x(-\mu_A W - S) - y\mu_B W + R_3 - R_4 - C_G\right] \end{aligned} \tag{10}$$

The first derivative of z and the set H(x) are, respectively:

$$\begin{aligned} \frac{d(F(z))}{dz} &= (1-2z)\left[x(-\mu_A W - S) - y\mu_B W + R_3 - R_4 - C_G\right] \\ H(x) &= x(-\mu_A W - S) - y\mu_B W + R_3 - R_4 - C_G \end{aligned} \tag{11}$$

According to the stability theorem of the differential equation, the probability that the government chooses the incentive supervision in a stable state must satisfy: $F(z) = 0$, $d(F(z))/dz < 0$. Because $\partial H(x)/\partial x < 0$, H(x) is the minus function to x.Therefore, $x = [R_3\text{-}R_4\text{-}C_G\text{-}y\mu_B W]/(\mu_A W + S) = x^*$, $H(x) = 0$, at this time, $d(F(z))/dz \equiv 0$, the government cannot decide on a stabilization strategy. Then $x < x^*$, $H(x) > 0$, at this time, $d(F(z))/dz|z = 1 < 0$, $z = 1$ is the government's ESS. Conversely, $x > x^*$, then $x = 0$ is ESS. The phase diagram of the government's strategy evolution is shown in Fig. 3.

Figure 3 shows that the volume $V_{A1}$ of the probability of the government's stable selection of the incentive supervision strategy is $A_1$, and the volume $V_{A2}$ of the associated

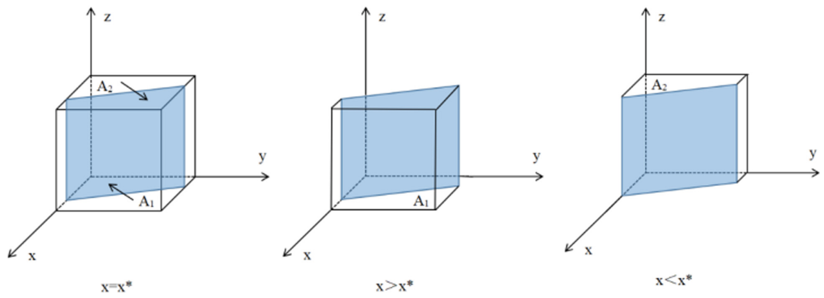


**Fig. 3.** Phase diagram of government strategy evolution

with of the government's regular section of the non-incentive supervision strategy is $A_2$, calculated as follows:

$$V_{A1} = \int_0^1 \int_0^1 \frac{R_3 - R_4 - C_G - y\mu_B W}{\mu_A W + S} dydz$$
$$V_{A2} = 1 - V_{A1} \tag{12}$$

Corollary 3 The probability of the government choosing incentive supervision is positively related to the income surplus obtained by the government choosing incentive supervision behavior and is related to the supervision cost, government incentive cost, and carbon tax burden.

According to the probability expression of the government's choice of incentive supervision VA1, the first partial derivatives of each element can be obtained: $\partial V_{A1}/\partial(R_3-R_4) > 0$, $\partial V_{A1}/\partial C_G < 0$, $\partial V_{A1}/\partial W < 0$, $\partial V_{A1}/\partial S < 0$. Therefore, if the government chooses incentive supervision, the income surplus will increase, or the supervision cost, government incentive cost, and the carbon tax will decrease, the probability of the government choosing incentive supervision will increase.

## 4 Simulation Analysis

In order to verify the effectiveness of the evolutionary stability analysis, the model was assigned numerical values combined with the actual situation, and the numerical simulation was carried out with Matlab. Array: $\gamma_A = 0.6$, $\gamma_B = 0.4$, $V = 7$, $K = 3$, $\mu_A = 0.6$, $\mu_B = 0.4$, $R_A = 4$, $C_A = 4$, $C_B = 3$, $R_3 = 20$, $R_4 = 9$, $C_G = 2$. Analyze the influence of x, y, z, W, S, and F on the process and result of the evolutionary game.

First, to analyze the influence of initial probabilities x, y, and z on the process and results of the evolutionary game, x, y and z are assigned as 0.1, 0.3, 0.5, 0.6, 0.8, 0.9. The simulation results of replicating the evolution of dynamic equations 50 times over time when the initial probabilities of the three parties change at the same time are shown in Fig. 4 and 5. When the initial likelihood of one party changes and the other two remain unchanged, the simulation results of the evolution of the equations are shown in Fig. 6, 7, and 8.

According to Figs. 4 and 5, when the initial values of x, y, and z are below 0.5, the slope of x is greater than that of z and more significant than that of y at the beginning. As

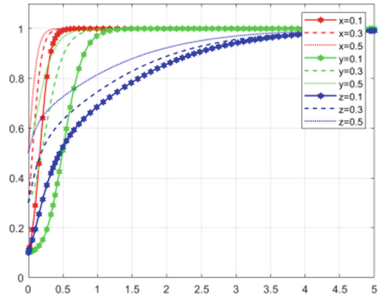


**Fig. 4.** Influence of Simultaneous change of initial probability on evolution result 1

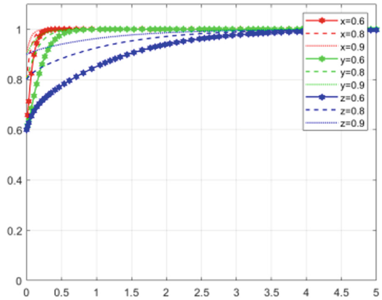


**Fig. 5.** Influence of simultaneous change of initial probability on evolution result 2

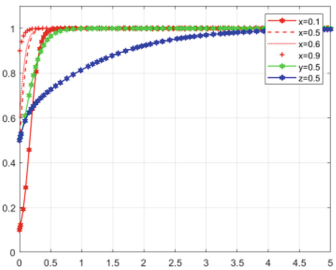


**Fig. 6.** Influence of initial probability x change on evolution results

the evolution progresses, the hill of z starts to be less than y. Eventually, x goes to "1" first, and y goes to "1" faster than z goes to "1". When the initial values of x, y, and z are 0.5 or above, the slope of x is always more significant than the slope of y is greater than the slope of z. The results show that when the initial probability of the three parties is low, the government will participate before the universities, and the government's policy encouragement will drive the universities to participate in collaborative innovation. When the participation probability of freight transport enterprises and universities is high, the government only needs to pay fewer incentive costs and supervision costs.

Figure 6 shows that when the initial probability of freight transport enterprise is not high, the probability y of university collaboration tends to be "1" faster than x. As

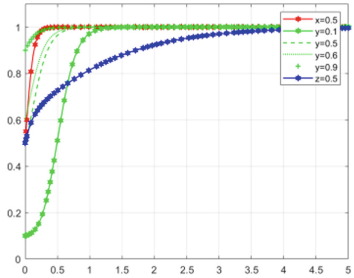


**Fig. 7.** Influence of initial probability y change on evolution results

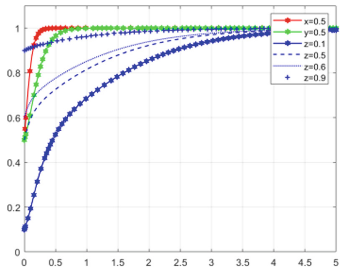


**Fig. 8.** The influence of the change of initial probability z on the evolution result

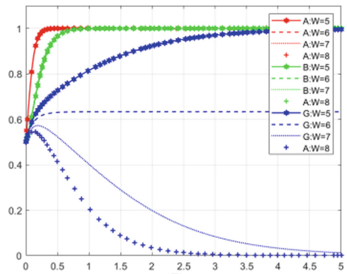


**Fig. 9.** The influence of the change of government incentive cost W on the evolution result

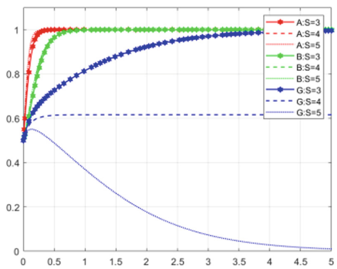


**Fig. 10.** Influence of changes in carbon tax S on evolutionary results

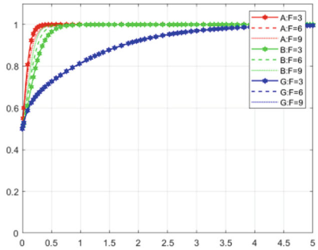


**Fig. 11.** Influence of changes in capital F paid by enterprises to universities on evolutionary results

x increases, the rate at which y and z approach "1" decreases. That is, the quarterly transportation probability of freight enterprises will increase with the rise in university collaborative innovation and government incentive and supervision probability. The growth rate is higher than universities because enterprises pay more attention to earnings than universities. Meanwhile, the likelihood of government incentive supervision will decrease with the increase of enterprise quarterly transportation and university collaborative innovation probability. Figure 7 shows that the probability of universities will increase with the likelihood of enterprises and governments, and the growth rate is always slower than that of enterprises. The probability of government is higher than that of universities in the early stage and decreases with the increase of the probability of universities and enterprises. Figure 8 shows that when the initial likelihood of universities and enterprises is not high, the probability of government grows faster, and the probability of government is higher than that of universities. As the initial likelihood of government increases, its growth rate gradually slows down, and the probability growth rate of enterprises and universities is higher than that of government.

Next, assign W = 5,6,7,8, respectively, and replicate the simulation results of the evolution of dynamic equations over time 50 times, as shown in Fig. 9. Assign S as S = 3, 4, and 5, respectively, and the simulation results are shown in Fig. 10. Given F = 3, 6, and 9, the simulation results evolving are shown in Fig. 11.

Figure 9 shows that when the threshold value of W is near 6, the probability of z no longer increases. When W is greater than 6, z begins to decline and gradually approaches 0, and with the increase of W, the speed of z comes 0 and becomes faster. Moreover, the rate at which x approaches "1" is always faster than at which y approaches "1". The cost of government incentives will affect the probability of government incentive behavior, and the unrealistic incentive reward will drive the government to give up participation. The influence of government incentives and supervision on enterprises is more significant than that on universities. The reason is that unrealistic government incentives will pressure the government financially, and enterprises value government incentives more than universities.

As seen in Fig. 10, the change amplitude of z affected by S change is greater than that of x affected by X. When S is 4, the slope of z growth is 0. When S is greater than the threshold value 4, z gradually approaches 0, and its growth skew is first negative and then zero. The results show that the carbon tax significantly influences the probability of government incentive supervision and has the most negligible impact on the likelihood of colleges and universities. Suppose the government's carbon tax subsidy to enterprises is too high. In that case, the government will give up the incentive behavior. At the same time, if the carbon tax is low, the non-low-carbon behavior of enterprises choosing off-seasonal transportation can be unrestricted. Therefore, the suitable formulation of carbon tax amount can not only effectively encourage enterprises to choose low-carbon transport modes but also increase the probability of the government choosing incentive behavior.

Figure 11 shows that with the increasing value of F, the speed of y approaching "1" considering moving the modifier increases, while the rate of x coming "1" considering moving the modifier decreases. When F exceeds the threshold of 9, y approaches "1" faster than x approaches "1". That is, the marginal benefit of the research funds paid by enterprises to universities decreases gradually. The increase in research funds affects the rise in university collaborative innovation probability, which is greater than the decrease in enterprise quarterly transportation probability. In general, the total revenue that enterprises can get from paying research funds to universities for collaborative innovation is far beyond the number of research funds paid. Therefore, research funds can be appropriately increased to promote university research and development and government-industry-academia collaborative innovation.

# 5 Conclusion and Prospect

## 5.1 Research Conclusions

1. The probability of seasonal transportation of freight enterprises converges to "1" faster than that of universities. Compared with universities, freight transport enterprises pay more attention to the economic benefits of collaborative innovation.
2. The cost of the government's incentive for quarterly transportation and collaborative innovation behavior of colleges and universities will affect the probability of the government's choice of incentive supervision behavior. High incentive costs will bring a financial burden to the government and drive the government to give up incentive behavior. However, the low incentive cost can not effectively promote the quarterly transportation of enterprises and collaborative innovation of universities. Therefore, the government should set a reasonable range of incentive costs.
3. The amount of carbon tax paid by freight transportation enterprises affects the probability of seasonal transportation and government incentive supervision behavior of freight transportation enterprises. When the carbon tax is low, the non-low-carbon transport behavior of freight enterprises can not be well constrained. When the carbon tax is too high, the tax allowance is too large, and the incentive payment will make the government give up the incentive behavior. Therefore, a reasonable carbon tax is essential to the government's work.
4. The research funds paid by freight transport enterprises to universities will affect the probability of strategic choice of enterprises and universities. Therefore, the enterprise should make a positive and reasonable fund plan to encourage colleges and universities to choose a collaborative innovation strategy and actively promote cooperation between government, industry, and universities.

### 5.2 Research Prospects

This paper only considers the low-carbon transformation of seasonal transportation of freight enterprises affected by extreme weather in northern China under the bounded rationality, and the low-carbon road transportation optimization scheme of freight enterprises in the southern region that battery activity is not affected by temperature is not considered, nor does it consider the influence of game order. Therefore, our subsequent research direction will be to reduce the consumption of fossil fuels in the transport industry and improve the whole industry's low-carbon transport system by considering influential factors such as southern multi-modal transport and regional business model.

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