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Research on competition and cooperation in the two level multi agent supply chain of China's new energy vehicle industry based on differential game theory

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A B S T R A C T

Based on differential game theory, this article studies the competition and cooperation in the supply chain system of the new energy vehicle industry. It constructs profit functions for new energy vehicle manufacturers and core component suppliers in two different situations: competitive decision-making and cooperative decision-making. The optimal factor values and profit values of each subject are obtained, and case analysis is conducted. Research has found that: (1) Whether in competitive or cooperative decision-making situations, the optimal factor values of each subject are influenced by their respective costs and show an increasing trend. (2) By comparison, it is found that the optimal profit of new energy vehicle manufacturers under cooperative decision-making and the overall optimal profit of the new energy vehicle industry supply chain system are better than those under competitive decision-making. (3) The profit growth rate of core component suppliers of new energy vehicles and the supply chain system of the new energy vehicle industry under cooperative decision-making is significantly faster than that under competitive decision-making.

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1. Introduction

In recent years, driven by the dual goals of carbon neutrality and positive and negative subsidies, the development of the new energy vehicle industry has become increasingly rapid. However, the drawbacks of this expansive development have gradually become apparent, and the competition within the new energy vehicle industry has intensified (Huang & Deng, 2025). The Chinese government has proposed a series of measures to curb this competition. This internal competition also affects the healthy development of the upstream of the new energy vehicle industry. In the context of internal competition, is the supply chain of the new energy vehicle industry continuing to compete to gain market share or restraining internal competition through cooperation? This article will focus on the competition and cooperation in the supply chain of the new energy vehicle industry, in order to verify the breakthrough path of the new energy vehicle industry against internal competition.

Domestic and foreign scholars have conducted extensive research on industry competition and cooperation. From the perspective of industry chain competition, in recent years, international research has been conducted on the competition models of supply chains, such as scholars studying the supply chain competition between manufacturers and retailers upstream and downstream (Adida & DeMiguel, 2011), competition decision-making in green supply chains (Wang et al., 2024; Yan et al., 2025), and reverse supply chain competition design (Matsui, 2023). Domestic scholars have studied competition models for low-carbon supply chains, such as retail low-carbon supply chain competition (Huang et al., 2025); Competition in the carbon market among forestry enterprises (Chen et al., 2024); Consumer low-carbon behavior and competitive supply chain models for carbon quotas (Li et al., 2025; Zhang et al., 2023). Scholars have also studied competition in industrial chains from the perspective of government behavior (Hendalianpour, 2021; Huang et al., 2024; Pai & Hungund, 2025).

From the perspective of industrial chain cooperation decision-making, some scholars believe that industrial chain cooperation decision-making has a positive effect on industrial supply chains (Hacardiaux & Tancrez, 2022). Secondly, some scholars

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have studied supply chain cooperation models from the perspectives of green supply chains (Bashar et al., 2023), government intervention (Mahmoudi et al., 2021), and social issues (Manteghi et al., 2021). Domestic scholars have studied the cooperative decision-making of industrial chain and supply chain from various industries such as agriculture and battery recycling (Zhuo & Han, 2023; Shriharsha, 2025; Yang et al., 2025; Xiang et al., 2025). Scholars have also conducted research from the perspective of supply chain coordination (Hosseini-Motlagh, S. M., 2022; Zhou et al., 2025).

There is not much research on competition and cooperation decision-making in the new energy vehicle industry. Scholars have studied competition in the new energy vehicle industry from a policy and institutional perspective (Jones et al., 2023; Xu & Shi, 2023), while others have studied competition and supply chain cooperation in the new energy vehicle industry from a market driven perspective (Patchell et al., 2024; Fan et al., 2024; Han et al., 2022; Tang et al., 2024; Liu et al., 2021). Considering the bounded rationality of new energy decision-makers, many scholars have used differential games to solve decision-making problems in the new energy vehicle industry (Yuan et al., 2025). Our team's previous research results also include contract decision-making in the new energy vehicle industry (Hu & Wu, 2024, 2025).

The research conducted by domestic and foreign experts and scholars on industry competition and cooperation provides useful references for the study of competition and cooperation decisions in the new energy vehicle industry in this article. Previous researchers mainly studied the decision-making between the two-level dual subjects of new energy vehicles. Unlike previous studies, this article considers a two-level multi-agent model of the new energy vehicle industry supply chain to investigate its cooperation and competition decisions. Therefore, this article considers the competitive and cooperative decision-making scenarios of a two-level multi-agent supply chain for the new energy vehicle industry, and analyzes the impact of these two scenarios on the main body of the new energy vehicle industry supply chain.

2. Model Building

2.1 Assumptions

In recent years, the new energy vehicle industry market in China and even internationally has faced severe internal competition, which has led to a gradual decline in the overall vehicle prices of the new energy vehicle industry and seriously disrupted the virtuous cycle of the new energy vehicle industry supply chain. Therefore, this article studies the competition and cooperation in the supply chain of China's new energy vehicle industry, considering a two-level multi-agent supply chain system consisting of a single new energy vehicle core component supplier (G) and multiple new energy vehicle manufacturers (Z), and uses differential game theory to construct a competition and cooperation model for China's new energy vehicle industry supply chain. Based on the actual situation, the following assumptions are made:

Assumption 1: Sales price. New energy vehicle core component suppliers and new energy vehicle manufacturers need to set sales prices when selling core components and complete vehicles. This article uses W to represent the product prices of core component suppliers for new energy vehicles; Use P to represent the overall sales price of new energy vehicle manufacturers.

Assumption 2: Manufacturing cost. New energy vehicle core component suppliers need to pay production costs when producing with new energy vehicle manufacturers. Use C_g to represent the cost of producing core components for new energy vehicle suppliers; Use C_{Zi} to represent the production costs of the i -th new energy vehicle manufacturer, excluding core components, such as labor costs, final assembly costs, etc.

Assumption 3: Technological innovation. New energy vehicles require continuous updates and upgrades, with the most important being technological innovation in core components such as the three electric system and batteries. This article uses H to represent the level of technological innovation in new energy vehicles. According to previous research on innovation costs (Vivona et al., 2023; Zhang et al., 2015), the cost function of technological innovation for core components of new energy vehicles in this article is: $C(H)=\frac{1}{2}kH^2$, where k represents the innovation coefficient.

Assumption 4: Market size. Use α to represent the potential market demand for new energy vehicles. Due to the influence of price on market demand, use β to represent demand price elasticity. So the actual market demand is: $Q=\alpha-\beta P$. Using q_i to represent the total number of vehicles sold by the i -th new energy vehicle manufacturer, then $Q=\sum q_i$.

According to the above assumptions, $Q=\alpha-\beta P$ can be inferred that the total sales volume of all new energy vehicle manufacturers is $P=\frac{\alpha}{\beta}-\frac{Q}{\beta}$. Given $Q=\sum q_i$, then $P=\frac{\alpha}{\beta}-\frac{\sum q_i}{\beta}$.

Therefore, the profit function between the core component supplier of new energy vehicles and the i -th new energy vehicle manufacturer can be obtained as follows:

$$\Pi_G(W,q_i)=(W-C_g)\sum q_i-\frac{1}{2}kH^2$$

$$\Pi_Z(W,q_i)=(\frac{\alpha}{\beta}-\frac{\sum q_i}{\beta}-C_{Zi}-W)\sum q_i$$

2. Model Analysis

Based on the above basic assumptions, construct the competitive and cooperative decision-making scenarios for the supply chain of the new energy vehicle industry.

2.1 Competitive decision-making situation

Competitive decision-making refers to the competition among upstream new energy vehicle core component suppliers in the supply chain system of the new energy vehicle industry for upstream resources when facing multiple new energy vehicle manufacturers. Therefore, each new energy vehicle manufacturer will aim to optimize their own profits. Thus, the profit function between the core component supplier of new energy vehicles and the i -th new energy vehicle manufacturer can be constructed as follows:

$$\Pi_G(W,q_i)=(W-C_g)\sum q_i-\frac{1}{2}kH^2$$

$$\Pi_{Zi}(W,q_i)=(\frac{\alpha}{\beta}-\frac{\sum q_i}{\beta}-C_{Zi}-W)q_i$$

In the context of competitive decision-making, the new energy vehicle industry needs to first determine its own sales volume of new energy vehicles, and then the core component suppliers of new energy vehicles determine the price of core components. This article uses reverse induction to solve the optimal decision combination between new energy vehicle manufacturers and core component suppliers of new energy vehicles. The calculation process is as follows:

Step 1: Find the optimal sales volume for each new energy vehicle manufacturer. According to the profit function $\Pi_{Zi}(W,q_i)$ of each new energy vehicle manufacturer, solve the first-order and second-order derivative functions of the profit function of the i -th new energy vehicle manufacturer with respect to sales volume, which are:

$$\frac{\partial\Pi_{Zi}(W,q_i)}{\partial q_i}=(\frac{\alpha}{\beta}-\frac{\sum q_i}{\beta}-C_{Zi}-W)-\frac{q_i}{\beta}$$

$$\frac{\partial\Pi_{Zi}^2(W,q_i)}{\partial q_i^2}=-\frac{2}{\beta}$$

Obviously, the second-order derivative of the profit function of i -th new energy vehicle manufacturer with respect to sales volume is less than zero, i.e. $\frac{\partial\Pi_{Zi}^2(W,q_i)}{\partial q_i^2}<0$, indicating that the profit function of i -th new energy vehicle manufacturer is a concave function with respect to sales volume. Therefore, the first-order derivative function $\frac{\partial\Pi_{Zi}(W,q_i)}{\partial q_i}=0$ can be used to obtain:

$$q_i=\frac{(\alpha-\sum_{l\neq i}q_l-\beta C_{Zi}-\beta W)}{2}. \tag{1}$$

Similarly, we can obtain: $q_j=\frac{(\alpha-\sum_{l\neq j}q_l-\beta C_{Zj}-\beta W)}{2}$.

Let q_i-q_j obtain $q_j=q_i+\beta C_{Zi}-\beta C_{Zj}$, By substituting $j=1,2,3,\cdots,i-1,i+1,\cdots,n$ into function q_j, we can obtain:

$$\sum_{l\neq i}q_l=q_1+q_2+\cdots+q_{i-1}+q_{i+1}+\cdots+q_n=(n-1)(q_i+\beta C_{Zi})-\beta\sum_{l\neq i}C_{Zl}$$

By substituting the obtained $\sum_{l\neq i}q_l$ into Eq. (1), we can obtain:

$$q_i^*(W)=\frac{\alpha-(n+1)\beta C_{Zi}+\beta\sum_{i=1}C_{Zi}-\beta W}{n+1}.$$

Then:

$$\sum_{i=1}^{n}q_i^*(W)=\frac{n\alpha-\beta\sum_{i=1}C_{Zi}-n\beta W}{n+1}.$$

By inputting the obtained $\sum_{i=1}^{n}q_i^*(W)$ into the profit function $\Pi_G(W,q_i)$ of the new energy vehicle core component supplier, the profit function $\Pi_G(W,q_i)$ of the new energy vehicle core component supplier at this time can be obtained as:

$$\Pi_G(W,q_i^*(W))=(W-C_g)\frac{n\alpha-\beta\sum_{i=1}C_{Zi}-n\beta W}{n+1}-\frac{1}{2}kH^2$$

Step 2: Find the optimal component price for the core component supplier of new energy vehicles. Solve the first and second derivative functions of the profit function $\Pi_G(W,q_i^*(W))$ of the core component supplier of new energy vehicles with respect to component prices, which are:

$$\frac{\partial\Pi_G(W,q_i^*(W))}{\partial W}=\frac{n\alpha-\beta\sum_{i=1}C_{Zi}+n\beta C_g}{n+1}-\frac{2n\beta}{n+1}W$$

$$\frac{\partial\Pi_G^2(W,q_i^*(W))}{\partial W^2}=-\frac{2n\beta}{n+1}$$

Obviously, the second-order derivative of the profit function of the core component supplier of new energy vehicles with respect to component prices is less than zero, i.e. $\frac{\partial\Pi_G^2(W,q_i^*(W))}{\partial W^2}<0$, indicating that the profit function of the core component supplier of new energy vehicles is a concave function with respect to component prices. Therefore, the first-order derivative function $\frac{\partial\Pi_G(W,q_i^*(W))}{\partial W}=0$ can be obtained as follows:

$$W^*=\frac{n\alpha-\beta\sum_{i=1}C_{Zi}+n\beta C_g}{2n\beta}.$$

By substituting W^* into $q_i^*(W)$, the maximum sales volume of the i-th new energy vehicle manufacturer can be calculated as:

$$q_i^*(W)=\frac{\frac{\alpha}{2}-(n+1)\beta C_{Zi}+(\frac{2n+1}{2n})\beta\sum_{i=1}C_{Zi}-\frac{\beta}{2}C_g}{n+1}.$$

Then:

$$\sum_{i=1}^{n}q_i^*(W)=\frac{n\alpha-\beta\sum_{i=1}C_{Zi}-n\beta C_g}{2(n+1)}.$$

By substituting the obtained $\sum_{i=1}^{n}q_i^*(W)$, W^*, etc. into the profit function of the core component supplier of new energy vehicles and the i-th new energy vehicle manufacturer, we can obtain:

$$\Pi_G(W,q_i)^* = \frac{(n\alpha-\beta\sum_{i=1} C_{Zi}-n\beta C_g)^2}{4(n+1)n\beta}-\frac{1}{2}kH^2$$

$$\Pi_{Zi}(W,q_i)^* = \frac{1}{\beta}(\frac{\frac{\alpha}{2}-(n+1)\beta C_{Zi}+(\frac{2n+1}{2n})\beta\sum_{i=1} C_{Zi}-\frac{\beta}{2}C_g}{n+1})^2.$$

So the overall profit of the new energy vehicle industry supply chain system is:

$$\Pi = \sum\frac{1}{\beta}(\frac{\frac{\alpha}{2}-(n+1)\beta C_{Zi}+(\frac{2n+1}{2n})\beta\sum_{i=1} C_{Zi}-\frac{\beta}{2}C_g}{n+1})^2+\frac{(n\alpha-\beta\sum_{i=1} C_{Zi}-n\beta C_g)^2}{4(n+1)n\beta}-\frac{1}{2}kH^2.$$

2.1 Cooperative decision-making situation

The cooperative decision-making situation refers to the collaboration between upstream new energy vehicle core component suppliers and multiple new energy vehicle manufacturers in the supply chain system of the new energy vehicle industry, jointly coordinating with the new energy vehicle core components. Therefore, all new energy vehicle manufacturers will aim for overall profit optimization. Thus, the profit function between the core component suppliers of new energy vehicles and all new energy vehicle manufacturers can be constructed as follows:

$$\Pi_G(W,q_i) = (W-C_g)\sum q_i-\frac{1}{2}kH^2,$$

$$\Pi_Z(W,q_i) = \sum((\frac{\alpha}{\beta}-\frac{\sum q_i}{\beta}-C_{Zi}-W)q_i).$$

In the case of cooperative decision-making, all new energy vehicle manufacturers first need to determine the total sales quantity of new energy vehicles, and then the core component suppliers of new energy vehicles determine the price of core components. Using reverse induction method to solve the optimal decision combination of all new energy vehicle manufacturers and core component suppliers of new energy vehicles, the calculation process is as follows:

Step 1: Find the optimal sales volume for all new energy vehicle manufacturers. According to the total profit function $\Pi_Z(W,q_i)$ of all new energy vehicle manufacturers, solve the first-order and second-order derivative functions of the total profit function of all new energy vehicle manufacturers with respect to sales volume, which are:

$$\frac{\partial\Pi_Z(W,q_i)}{\partial q_i} = (\frac{\alpha}{\beta}-\frac{\sum q_i}{\beta}-C_{Zi}-W)-\frac{\sum q_i}{\beta},$$

$$\frac{\partial\Pi_z^2(W,q_i)}{\partial q_i^2} = -\frac{2}{\beta}.$$

Obviously, the second-order derivative of the total profit function of all new energy vehicle manufacturers with respect to sales volume is less than zero, i.e. $\frac{\partial\Pi_z^2(W,q_i)}{\partial q_i^2}<0,$ indicating that the total profit function of all new energy vehicle manufacturers is a concave function with respect to sales volume. Therefore, the first-order derivative function $\frac{\partial\Pi_Z(W,q_i)}{\partial q_i}=0$ can be used to obtain:

$$q_i = \frac{(\alpha-2\sum_{l\neq i} q_l-\beta C_{Zi}-\beta W)}{2}. \quad (2)$$

Similarly, we can obtain: $q_j = \frac{(\alpha-2\sum_{l\neq j} q_l-\beta C_{Zj}-\beta W)}{2}$.

If q_i-q_j, C_{Zj}=C_{Zi} can be obtained, then according to Eq. (2):

$$\sum_{i=1}^{n} q_i^*(W) = \frac{(\alpha-\beta C_{Zi}-\beta W)}{2}.$$

Then we can obtain:

$$q_i^*(W) = \frac{(\alpha - \beta C_{Zi} - \beta W)}{2n}.$$

By inputting the obtained $\sum_{i=1}^{n} q_i^*(W)$ into the profit function $\Pi_G(W, q_i)$ of the new energy vehicle core component supplier, the profit function $\Pi_G(W, q_i)$ of the new energy vehicle core component supplier at this time can be obtained as:

$$\Pi_G(W, q_i^*(W)) = (W - C_g)\frac{(\alpha - \beta C_{Zi} - \beta W)}{2} - \frac{1}{2}kH^2.$$

Step 2: Find the optimal component price for the core component supplier of new energy vehicles. Solve the first and second derivative functions of the profit function $\Pi_G(W, q_i^*(W))$ of the core component supplier of new energy vehicles with respect to component prices, which are:

$$\frac{\partial \Pi_G(W, q_i^*(W))}{\partial W} = \frac{\alpha - \beta C_{Zi} + \beta C_g}{2} - \beta W,$$
$$\frac{\partial \Pi_G^2(W, q_i^*(W))}{\partial W^2} = -\beta.$$

Obviously, $\frac{\partial \Pi_G^2(W, q_i^*(W))}{\partial W^2} < 0$, it can be inferred that the profit function of core component suppliers for new energy vehicles is a concave function with respect to component prices. Therefore, the first-order derivative function $\frac{\partial \Pi_G(W, q_i^*(W))}{\partial W} = 0$ can be obtained as follows:

$$W^* = \frac{\alpha - \beta C_{Zi} + \beta C_g}{2\beta}$$

By substituting W^* into $q_i^*(W),$, the maximum sales volume of the i-th new energy vehicle manufacturer can be calculated as:

$$q_i^*(W) = \frac{(\alpha - \beta C_{Zi} - \beta C_g)}{4n}.$$

Then:

$$\sum_{i=1}^{n} q_i^*(W) = \frac{(\alpha - \beta C_{Zi} - \beta C_g)}{4}.$$

By substituting the obtained values $\sum_{i=1}^{n} q_i^*(W)$, W^*, etc. into the total profit function of the core component suppliers of new energy vehicles and all new energy vehicle manufacturers, we can obtain:

$$\Pi_G(W, q_i)^* = \frac{(\alpha - \beta C_{Zi} - \beta C_g)^2}{8\beta} - \frac{1}{2}kH^2,$$
$$\Pi_Z(W, q_i)^* = \frac{(\alpha - \beta C_{Zi} - \beta C_g)^2}{16\beta}.$$

So the overall profit of the new energy vehicle industry supply chain system is:

$$\Pi = \frac{3(\alpha - \beta C_{Zi} - \beta C_g)^2}{16\beta} - \frac{1}{2}kH^2.$$

3. Equilibrium analysis and comparison

Summarize the optimal factor values and optimal profit values of the supply chain entities in the new energy vehicle industry under competition and cooperation into a table, as shown in Table 1.

Table 1
Optimal Factor Values and Profit Values of Photovoltaic Industry Supply Chain under Competition and Cooperation Scenarios

parameter	Competitive decision-making situation*	Cooperative decision-making situation**
q_i	$\frac{\frac{\alpha}{2}-(n+1)\beta C_{Zi}+(\frac{2n+1}{2n})\beta\sum_{i=1}C_{Zi}-\frac{\beta}{2}C_g}{n+1}$	$\frac{(\alpha-\beta C_{Zi}-\beta C_g)}{4n}$
W	$\frac{n\alpha-\beta\sum_{i=1}C_{Zi}+n\beta C_g}{2n\beta}$	$\frac{\alpha-\beta C_{Zi}+\beta C_g}{2\beta}$
Π_G	$\frac{(n\alpha-\beta\sum_{i=1}C_{Zi}-n\beta C_g)^2}{4(n+1)n\beta}-\frac{1}{2}kH^2$	$\frac{(\alpha-\beta C_{Zi}-\beta C_g)^2}{8\beta}-\frac{1}{2}kH^2$
Π_Z	$\frac{1}{\beta}(\frac{\frac{\alpha}{2}-(n+1)\beta C_{Zi}+(\frac{2n+1}{2n})\beta\sum_{i=1}C_{Zi}-\frac{\beta}{2}C_g}{n+1})^2$	$\frac{(\alpha-\beta C_{Zi}-\beta C_g)^2}{16\beta}$
Π	$\sum\frac{1}{\beta}(\frac{\frac{\alpha}{2}-(n+1)\beta C_{Zi}+(\frac{2n+1}{2n})\beta\sum_{i=1}C_{Zi}-\frac{\beta}{2}C_g}{n+1})^2+\frac{(n\alpha-\beta\sum_{i=1}C_{Zi}-n\beta C_g)^2}{4(n+1)n\beta}-\frac{1}{2}kH^2$	$\frac{3(\alpha-\beta C_{Zi}-\beta C_g)^2}{16\beta}-\frac{1}{2}kH^2$

Property 1: Regardless of whether it is a competitive or cooperative decision-making situation, the optimal sales quantity of new energy vehicle manufacturers decreases with the increase of non raw material costs and core component supplier costs of new energy vehicle manufacturers.
Property 2: Under competitive circumstances, the sales price of core components for new energy vehicle suppliers increases with the rise of costs; Under cooperative circumstances, the sales prices of core components for new energy vehicle suppliers decrease as the non raw material costs of the vehicle rise.
Property 3: Whether in competitive or cooperative decision-making situations, the optimal profit of the supply chain entities in the new energy vehicle industry decreases as the cost of core components and non raw material costs of new energy vehicles increase.

3. Case Analysis

This article selects BYD Auto as the benchmark enterprise for research, and based on relevant data from BYD's annual financial reports and other internal reports in recent years, analyzes and organizes the cost data of BYD Auto from 2020 to 2024 to calculate the cost of new energy vehicle batteries. The cost data of new energy batteries is set at 40% of the manufacturing cost of new energy vehicles. The detailed data table is shown in Table 2.

Table 2
Cost Data of BYD New Energy Vehicles and Sales Data of All Automotive Markets from 2020 to 2024

Parameter	2020	2021	2022	2023	2024
Cost of new energy batteries（YUAN）	48750	59100	90000	51825	30000
Manufacturing cost of new energy vehicles（YUAN）	121875	147750	225000	129562.5	75000
Total sales volume of all enterprise markets（Vehicle）	1367000	3545000	6887000	9495000	12866000

This article studies the supply chain ecosystem of the new energy vehicle industry. As the new energy vehicle industry is greatly affected by market price fluctuations, this article assumes a price demand elasticity coefficient of 2; The cost coefficient for technological innovation is set to 10000. For simplicity, this article takes the mileage of new energy vehicles as an innovation for core component suppliers of new energy vehicles. The normal mileage of new energy vehicles is set at 500 kilometers, which increases by 100 kilometers year by year due to technological innovation.

In the case study of this article, it is assumed that there are five new energy vehicle manufacturers, and their manufacturing costs for new energy vehicles are+-10000 and+-20000 of BYD's data values; The total market sales of the five new energy vehicle manufacturers are set at 60% of the total sales volume of all new energy vehicles. Based on this, the relevant data required for this article can be calculated as shown in Table 3.

Table 3
Supply Chain Data of New Energy Vehicle Industry from 2020 to 2024

parameter	2020	2021	2022	2023	2024
C_g	48750	59100	90000	51825	30000
C_{Z1}	101875	127750	205000	109562.5	55000
C_{Z2}	111875	137750	215000	119562.5	65000
C_{Z3}	121875	147750	225000	129562.5	75000
C_{Z4}	131875	157750	235000	139562.5	85000
C_{Z5}	141875	167750	245000	149562.5	95000
α	820200	2127000	4132200	5697000	7719600
H	500	600	700	800	900

Note： $k=10000,\ \beta=2.$

According to the data in Table 3, the optimal parameter values and profit values of the new energy vehicle industry supply chain can be calculated for both competitive and cooperative decision-making scenarios. The results are shown in Tables 4 and 5.

Table 4
Optimal Parameters and Profit Statement of Supply Chain Entities in the New Energy Vehicle Industry under Competitive Decision Situations

Parameter	2020	2021	2022	2023	2024
q_1	5.99E+04	1.63E+05	3.12E+05	4.65E+05	6.46E+05
q_2	4.99E+04	1.53E+05	3.02E+05	4.55E+05	6.36E+05
q_3	3.99E+04	1.43E+05	2.92E+05	4.45E+05	6.26E+05
q_4	1.07E+04	1.11E+05	2.51E+05	4.14E+05	6.02E+05
q_5	1.99E+04	1.23E+05	2.72E+05	4.25E+05	6.06E+05
W^*	1.68E+05	4.87E+05	9.66E+05	1.39E+06	1.91E+06
Π_g	4.61E+10	3.94E+11	1.55E+12	3.20E+12	6.06E+12
Π_{Z1}	7.18E+09	5.30E+10	1.95E+11	4.32E+11	8.34E+11
Π_{Z2}	4.98E+09	4.67E+10	1.82E+11	4.13E+11	8.08E+11
Π_{Z3}	3.19E+09	4.08E+10	1.70E+11	3.95E+11	7.83E+11
Π_{Z4}	2.29E+08	2.44E+10	1.26E+11	3.43E+11	7.25E+11
Π_{Z5}	7.93E+08	3.01E+10	1.48E+11	3.60E+11	7.34E+11
Π	6.24E+10	5.89E+11	2.37E+12	5.14E+12	9.94E+12

From Table 4, it can be seen that the optimal sales quantity for new energy vehicle manufacturers has been increasing year by year, mainly due to the increasing sales volume caused by the decreasing manufacturing costs of new energy vehicles. From the comparison of five new energy vehicle manufacturers, it can also be seen that as manufacturing costs increase, the optimal sales quantity gradually decreases.

Table 5
Optimal Parameters and Profit Statement of New Energy Vehicle Industry Supply Chain Entities under Cooperative Decision Situation

Parameter	2020	2021	2022	2023	2024
q_1	2.49E+04	8.67E+04	1.76E+05	2.68E+05	3.76E+05
q_2	2.44E+04	8.62E+04	1.76E+05	2.67E+05	3.76E+05
q_3	2.39E+04	8.57E+04	1.75E+05	2.67E+05	3.75E+05
q_4	2.34E+04	8.52E+04	1.75E+05	2.66E+05	3.75E+05
q_5	2.29E+04	8.47E+04	1.74E+05	2.66E+05	3.74E+05
W^*	1.68E+05	4.87E+05	9.66E+05	1.39E+06	1.91E+06
Π_g	1.43E+10	1.86E+11	7.73E+11	1.79E+12	3.54E+12
Π_{Z1}	7.78E+09	9.39E+10	3.88E+11	8.96E+11	1.77E+12
Π_{Z2}	7.47E+09	9.28E+10	3.85E+11	8.93E+11	1.77E+12
Π_{Z3}	7.17E+09	9.17E+10	3.83E+11	8.89E+11	1.76E+12
Π_{Z4}	6.87E+09	9.07E+10	3.81E+11	8.86E+11	1.76E+12
Π_{Z5}	6.58E+09	8.96E+10	3.79E+11	8.83E+11	1.75E+12
Π	5.02E+10	6.45E+11	2.69E+12	6.23E+12	1.24E+13

The sales prices of core components of new energy vehicles are also increasing year by year, due to the rising cost of technological innovation, which has led to an increase in their prices. Secondly, from the perspective of the optimal profit of the supply chain entities in the new energy vehicle industry, the profits of core component suppliers and new energy vehicle manufacturers are both increasing year by year. The growth trend of the optimal values and optimal profit values of each element in Table 5 is similar to that in Table 4, that is, in the case of cooperative decision-making, the changes in the optimal element values of each new energy vehicle and the optimal element values of the core components of the new energy vehicle are similar to those in the competitive situation.

Comparing the competitive decision-making situation with the cooperative decision-making situation, it can be found that the profit of new energy vehicle manufacturers in the cooperative decision-making situation is significantly higher than the optimal profit in the competitive decision-making situation, and the overall profit of the new energy vehicle industry supply chain is also higher than the overall optimal profit in the competitive situation.

Summarize the optimal profit growth trends of new energy vehicle core component suppliers and industrial supply chain systems under competitive and cooperative decision-making scenarios, as shown in Fig. 1 and Fig. 2.

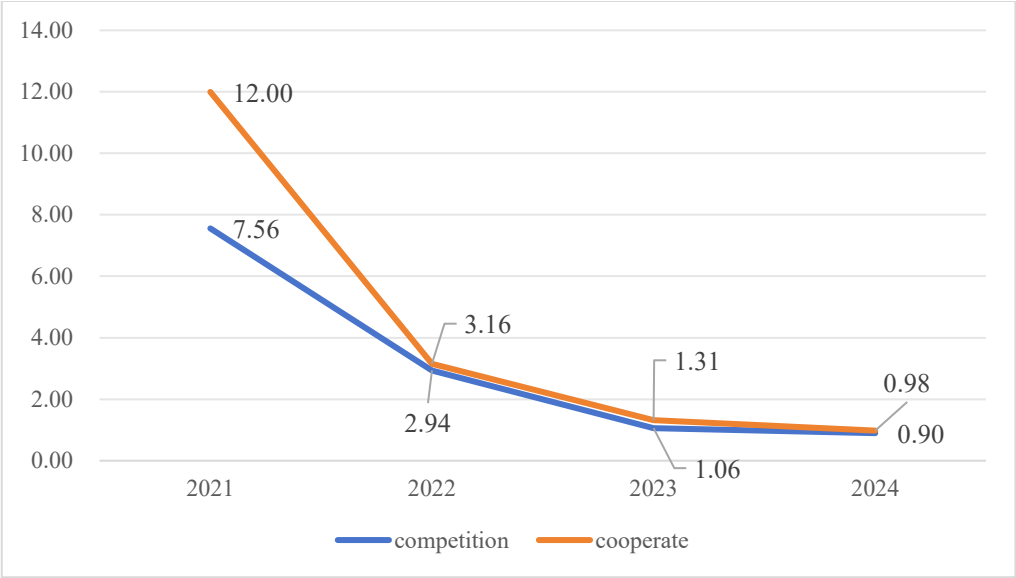

Fig. 1. Comparison of Profit Growth of New Energy Vehicle Core Component Suppliers under Competitive and Cooperative Decision Situations

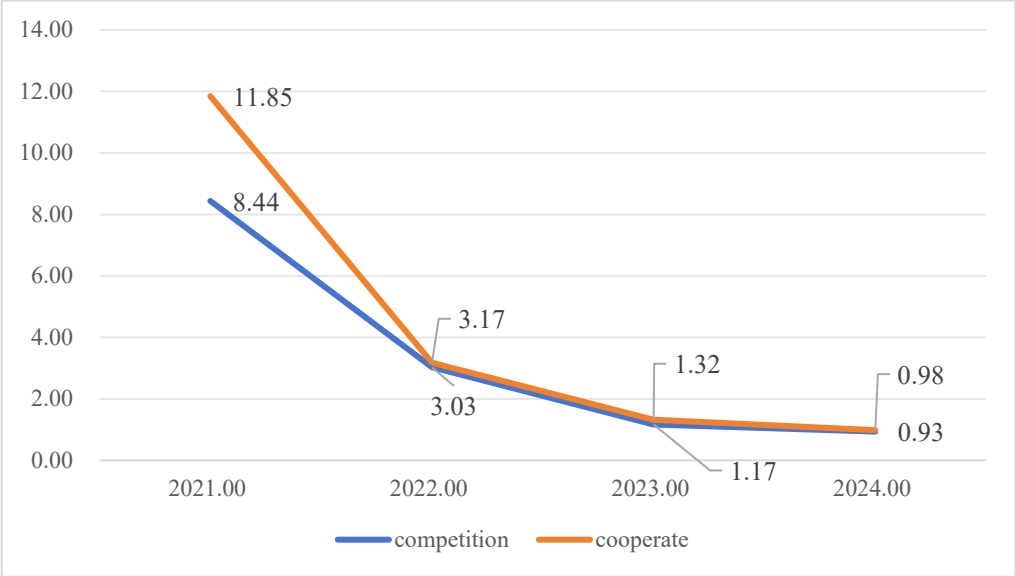

Fig. 2. Comparison of Profit Growth in the Supply Chain System of the New Energy Vehicle Industry under Competitive and Cooperative Decision Situations

From Fig. 1 and Fig. 2, it can be seen that the profits of the core component suppliers of new energy vehicles and the supply chain system of the new energy vehicle industry are increasing year by year (with a growth rate greater than zero), but the growth trend is decreasing year by year. Secondly, compared with the cooperative decision-making situation, it can be seen that the profit growth rate in the cooperative decision-making situation is significantly faster than that in the competitive decision-making situation.

4. Research Conclusion

This article constructs a two-level multi-agent supply chain model based on differential game theory, and studies the competition and cooperation of the supply chain system in the new energy vehicle industry. By constructing profit functions between new energy vehicle core component suppliers and new energy vehicle manufacturers under two different scenarios of competitive decision-making and cooperative decision-making, the optimal factor values and profit values of each are obtained, and empirical analysis is conducted through case studies. Research has found that:

(1) Whether in competitive or cooperative decision-making situations, the optimal factor values of each subject are influenced by their respective costs and show an increasing trend.
(2) By comparison, it is found that the optimal profit of new energy vehicle manufacturers under cooperative decision-making and the overall optimal profit of the new energy vehicle industry supply chain system are better than those under competitive decision-making.
(3) The profit growth rate of core component suppliers of new energy vehicles and the supply chain system of the new energy vehicle industry under cooperative decision-making is significantly faster than that under competitive decision-making.

Therefore, in the current situation of severe internal competition in the new energy vehicle industry in China and even globally, blindly competing in the industry cannot effectively obtain profits. At this time, new energy vehicle manufacturers can jointly tackle challenges and make cooperative decisions, which can quickly promote the healthy development of the industry. The government should also actively promote the integration of upstream and downstream industries, form industrial clusters, and better drive the coordinated development of the industrial chain.

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