ISSN: 2664-9640

Research on New Energy Vehicle Supply Chain Pricing Strategy Based on Game Theory And Particle swarm optimization

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Abstract

In the uncertain market environment, choosing the optimal strategy is the overall target of the new energy automobile supply chain, this paper compares and analyses the pricing strategy of supply Chain alliance under different environment. Firstly, the model of centralized decision and decentralized decision is an-alyzed by using Stackelberg game method. The optimal solution of the two is compared; secondly, a centralized and decentralized optimal supply chain model is constructed by using the method of operational research. Thirdly, the optimum solution of supply chain model is analyzed by particle swarm op-timization; Finally, the analysis results show that the supply chain alliance has the promotion goal to the benefit maximization to the members of the supply chain. The supply chain enterprises based on the cooperation help their own sustainable development.

Keywords

Stackelberg game; New Energy vehicle Supply chain; PSO.

1. Introduction

For the global automobile industry, energy saving and emission reduction has become an important task, and new energy vehicles have become a strategic trend. Due to the cost and market advantages, China has a leading position in the global new energy vehicle market. The State Council has also recognized the new energy vehicle industry as one of the three major industries of the seven strategic emerging industries in China, and has received financial and tax support policies. However, due to the major challenges of technology, industrial chain and social factors, the development space of new energy vehicles still needs to be further expanded [1]. Throughout the industrial chain of new energy vehicles, including raw material collection, automobile manufacturing, automobile sales and service and other links. From the perspective of the industrial value chain, it also needs the assistance of resources development and technological innovation. As the basis of supply chain research, we need to deeply analyze the value chain of new energy vehicles, which is conducive to enterprises to build a supply chain system suitable for the development of enterprises according to the value chain, so as to promote the development of new energy vehicle industry.

Scholars at home and abroad have done a lot of research on the supply chain, mainly focusing on the impact of government subsidies on the supply chain and the pricing strategy of the supply chain with the help of game theory, but few people use game theory combined with intelligent algorithm to analyze the optimal interests of the supply chain alliance. Starting from the game, Zhang Xuelong and Wang Junjin analyzed the decision selection of members in the supply chain of new energy vehicles, compared the decentralized and centralized decision models, and applied Shapley value method to effectively solve the problem of profit distribution of members in the supply chain [2]. Xiao Tianqi studied price subsidy from the perspective of supply chain, and studied the influence of subsidy objects on market sales volume and supply chain profit by building models under different decisions [3]. Based on the newsboy model, Zhen Peng analyzed the production strategy of new energy vehicles with subsidies and delayed delivery, and provided suggestions for stakeholders such as the government, new energy vehicle manufacturers and suppliers, as well as consumers [4]. Zhang Xiang has enriched the content on electric vehicle subsidies by combining consumer trade-offs and government subsidies to evaluate the relevant influence on the optimal electric vehicle production decision [5]. Qin Zhong et al. studied the pricing strategy in a two-level supply chain composed of one manufacturer and two retailers, with the manufacturer as the leader and the two retailers as the followers in the supply chain, and developed an expected value model to discuss the impact of pricing strategy and different competitive behaviors [6]. Saeed Alaei et al. studied the strategy of how manufacturers coordinate two same retailers to compete for local advertising investment, used Nash game and Stackelberg game to discuss the profit result of cooperation mode on supply chain, and proposed how members of supply chain should share profits under cooperation [7]. Xiaoyu Gu et al. proposed a new four-level supply chain model of the government, electric vehicle manufacturers, retailers and automobile users. Based on the concept of Steinberg's leader-follower, they considered the subsidies to automobile users and manufacturers, and provided the optimal pricing strategy for participants in the supply chain [8].

This article mainly from the perspective of supply chain (including value chain) to study the pricing problem of new energy automobile enterprises, analyses the evolution of the cooperative game process manufacturers and retailers, build cooperation mode optimization model, seeking to maximize profits by using particle swarm optimization (PSO) combined with the example simulation, puts forward new energy automobile manufacturer and retailer's pricing strategy, for the development of new energy vehicles to establish good cooperation between supply chain members to provide a new way of thinking.

2. New energy vehicle supply chain and value chain

According to the supply chain theory, all members of the supply chain are interdependent. If one party ignores this interdependent relationship and pays too much attention to its own development, then the overall efficiency of the supply chain will be affected. New energy vehicle supply chain is a chain involving upper, middle and downstream enterprises based on the supply of raw materials and parts. Supply chain members include raw materials, parts suppliers, new energy vehicle manufacturers, retailers and users. H.-O.Günther et al. believe that supply chain includes two basic processes: raw material extraction and product use. These processes do not have to be located in a certain manufacturing region, but are included in the global scope [9]. According to the previous research on the supply chain, we designed the supply chain structure of new energy vehicles, as shown in Figure 1.

As can be seen from the structure diagram of the supply chain, suppliers of raw materials are in the upstream of the supply chain, including enterprises with core parts of new energy vehicles, such as batteries and motors, etc., which will be affected by policies, foreign trade and technological level, etc. Manufacturers, retailers and consumers are in the middle and downstream of the supply chain respectively. Retailers will be affected by government subsidies and market orientation when selling to consumers. The forward selling process is accompanied by the flow of logistics and information. The reverse process is accompanied by the flow of money and information. Win-win cooperation as the mainstream of today's world, then the alliance between supply chain members reflects this trend. If there is an alliance among supply chain members, it will directly affect the benefit changes of the upper, middle and lower

ISSN: 2664-9640

reaches of the supply chain. Therefore, this paper studies the alliance of upstream, middle and downstream members of the supply chain, namely the alliance between raw material parts suppliers, new energy vehicle manufacturers and retailers, and considers the interest game between the alliance and non-alliance in the market environment with complete information, as well as the interest change of the alliance in the uncertain market environment. The particularity of new energy vehicles determines that the value creation space of sellers is limited, which is reflected in the following figure.

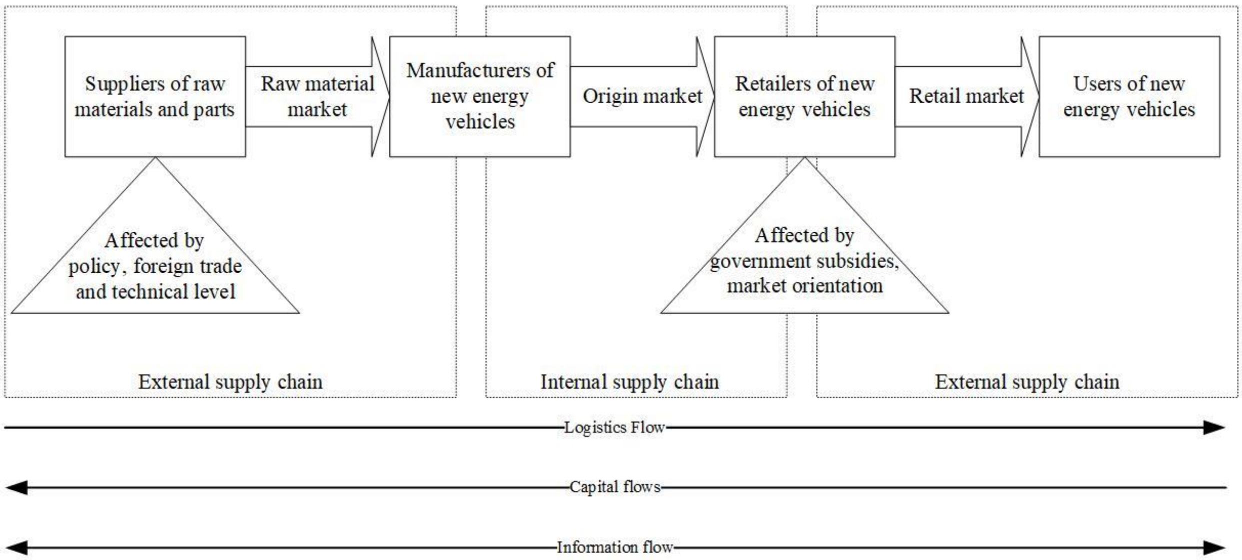

Figure 1. New energy vehicle supply chain structure diagram

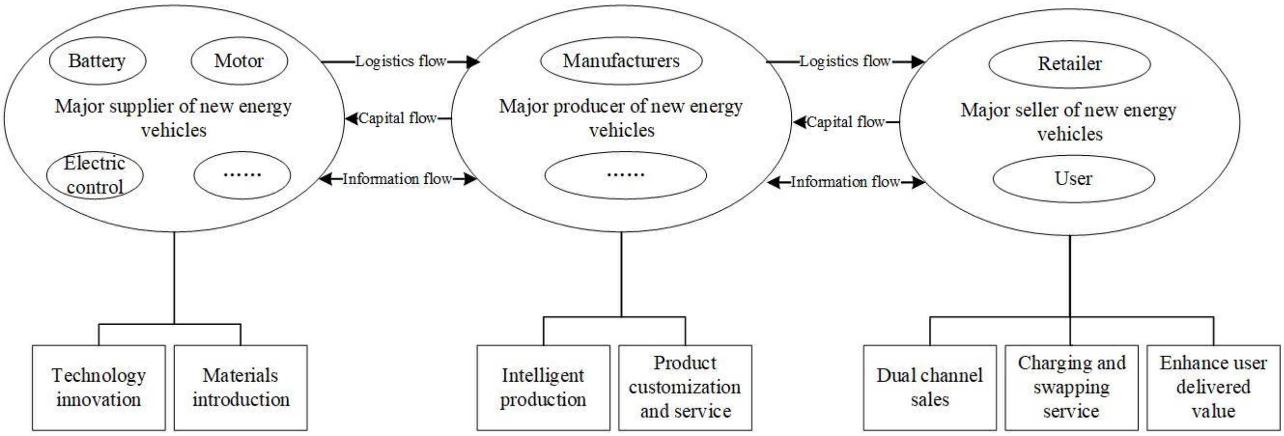

Figure 2. Value chain structure of new energy vehicles

According to the supply chain structure diagram in Figure 1, the value chain structure diagram is constructed accordingly, as shown in Figure 2. The value chain is the arrangement of activities required to deliver a product or service from conception and production to the final consumer. Regardless of the direction of the value chain, every link in the chain contributes to the increase of product value [10]. It can be seen from Figure 2 that there is a value creation process in the upstream, middle and downstream of the value chain. The upstream enterprises create value and innovate through technological innovation and intelligent production, while the midstream enterprises create value through customized products and services, enabling the downstream retailers to use dual channels to sell, which is conducive to improving user satisfaction and generating delivered value. In the value chain, enterprises have changed from cost orientation to value orientation, not only pursuing the lowest cost of enterprises, but also increasing profit income by achieving higher user satisfaction and income sources.

3. Model construction and analysis

In this paper, according to the division of supply, production and sales, only a single supplier, manufacturer and duopoly retailer are considered in the supply chain, and the manufacturer sells products to consumers through the retailer. Before building the model, there are the following assumptions:

The game between new energy vehicle manufacturers and retailers is carried out under the condition of complete information sharing.

New energy vehicle manufacturers and retailers are rational "economic men" whose goal is to maximize their utility.

The game model is a static game.

New energy vehicle manufacturers and retailers are faced with price-dependent demand at a time and must decide the optimal production quantity and the optimal selling price in order to maximize the total expected profit.

The parameters involved in the model are shown in Table 1.

Table 1. Model parameters and description

Parameters symbol	Description
D	Represents the maximum market demand of the retailer
Qi	Represents the demand of retailer i
αi	Sensitivity of Retailer i's quantity demanded to price change of Retailer j
P	Retail prices of new energy vehicles
β（0<β<1）	Degree of substitution among retailers
C	Production costs of new energy vehicle manufacturers
Pm	The wholesale price given by the manufacturer to the retailer
π_m	Manufacturer's profit
π_r	Retailer's profit

According to the introduction of the model parameter table, we can get the market demand function of new energy vehicles and the profit function of manufacturers and retailers:

$$Q_i = D_i - \alpha_i P_i + dP_j \tag{3-1}$$

$$\pi_m = (P_m - C)Q_i = (P_m - C)(D_i - \alpha_i P_i + \beta P_j) \tag{3-2}$$

$$\pi_i = (P_i - P_m)Q_i = (P_i - P_m)(D_i - \alpha_i P_i + \beta P_j) \tag{3-3}$$

Thus, the total profit function of the duopoly retailers can be obtained as follows:

$$\pi_r = P_1 D_1 + P_2 D_2 - \alpha_1 P_1^2 - \alpha_2 P_2^{\ 2} + 2\beta P_1 P_2 - P_m(D_1 + D_2) + \alpha_1 P_1\ P_m + \alpha_2 P_2 P_m - \beta(P_1 + P_2)P_m \tag{3-4}$$

In the following paper, we discuss profit changes under cooperative and non-cooperative modes in Stackelberg game to verify the necessity of supply chain alliance. In the Stackelberg model, the suppliers of raw materials and spare parts and manufacturers are alliances, and the manufacturer's cost is determined. We model the relationship between the participants and the manufacturer as a leader and the retailer as a follower. In the Stackelberg setup, duopoly retailers can follow Cournot model, which is divided into collusion and non collusion.

3.1. Stackelberg-Cournot model

In this case, duopoly retailers follow Cournot behavior, in which the manufacturer is the leader and the duopoly retailer is the follower, and there is no collusion between them. We use Stackelberg Cournot to propose the solution of this model. In this case, the retailer's profit function is $\pi_r = (P - P_m)Q = (P - P_m)(D - \alpha P + \beta P)$.

The optimal selling price of duopoly retailer are obtained: $P_1^* = \frac{D_1 + \beta P_2 + \alpha_1 P_m}{2\alpha_1}$

$P_2^* = \frac{D_2 + \beta P_1 + \alpha_2 P_m}{2\alpha_2}$

Then the equilibrium price which maximizes the profit of Two Oligarchic retailers are obtained:

$$P_1 = \frac{\alpha_2 D_1 - \alpha_1 D_2}{\alpha_1 \beta} + \frac{\alpha_2}{\alpha_1} P_2 \qquad P_2 = \frac{\alpha_1 D_2 - \alpha_2 D_1}{\alpha_2 \beta} + \frac{\alpha_1}{\alpha_2} P_1$$

The results show that the equilibrium sales of duopoly retailers are as follows:

$$Q_1 = D_1 + \frac{\alpha_1 D_2 - \alpha_2 D_1}{\alpha_2} + (\frac{\alpha_1 \beta}{\alpha_2} - \alpha_1) P_1 \qquad Q_2 = D_2 + \frac{\alpha_2 D_1 - \alpha_1 D_2}{\alpha_1} + (\frac{\alpha_2 \beta}{\alpha_1} - \alpha_2) P_2$$

The total profit function of duopoly retailer is obtained as follows: $\pi_r = (P_1 - P_m) Q_1 + (P_2 - P_m) Q_2$

The profit function of the manufacturer is $\pi = (P_1 - C) Q_1 + (P_2 - C) Q_2$

Therefore, the total profits of new energy vehicle manufacturers and retailers are

If oligarchs collude with each other in order to maximize the combined profit, then in terms of the demand function (3-1), the selling price and sales volume are $P = \frac{D + (\alpha - \beta) P_m}{2(\alpha - \beta)}$ and $Q = \frac{D - (\alpha - \beta) P_m}{2}$

$$\pi_m = (P_m - C) Q$$

So the total profit of the manufacturer is $\pi_i = (P_i - P_m) Q_i = (P_i - P_m)(D_i - \alpha_i P_i + \beta P_j)$

Then the price of the manufacturer is $P_m = \frac{D + (\alpha - \beta) C}{2(\alpha - \beta)}$

The total profit of oligopoly retailer and manufacturer are $\pi_m = \frac{[D - (\alpha - \beta) C]^2}{8(\alpha - \beta)}$

$$\pi_r = \frac{[D - (\alpha - \beta) P_m]^2}{4(\alpha - \beta)} = \frac{[D - (\alpha - \beta) C]^2}{16(\alpha - \beta)}$$

Finally, the total profit of the supply chain is $\pi = \pi_m + \pi_r = \frac{3[D - (\alpha - \beta) C]^2}{16(\alpha - \beta)}$

The price and profit of oligarchs in collusion are higher than those in non collusion, but the sales volume is lower than that in non collusion.

3.2. Cooperative game of supply chain members

In this case, the supply chain members cooperate with each other, and the wholesale price PM will not be considered, and the decision-making between manufacturers and retailers will no

ISSN: 2664-9640

longer be affected by each other, and the goal is to maximize the total profit of the supply chain.So the profit function becomes $\max \pi' = (P-C)(D-(\alpha-\beta)P)$.

According to the stagnation point theorem, the optimal retail price and market demand are obtained as follows: .

$$\mathrm{P}^* = \frac{D+(\alpha-\beta)C}{2(\alpha-\beta)} \qquad Q^* = \frac{D-(\alpha-\beta)C}{2} \qquad \pi^* = \frac{(D-(\alpha-\beta)C)^2}{4(\alpha-\beta)}$$

Finally, the overall profit of the supply chain alliance is .

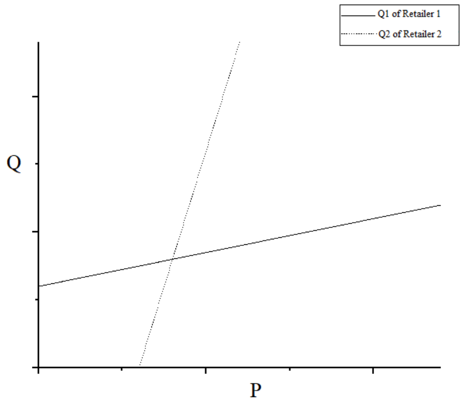

Figure 3. Non-cooperative model

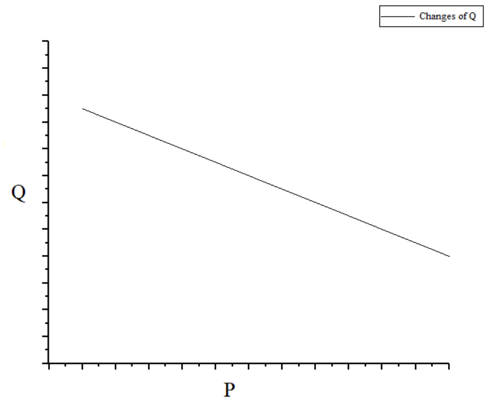

Figure 4. Collaboration model

In Figure 3, it can be seen that equilibrium price is the intersection point of two functions. In Figure 4, under the cooperation model, oligarchic retailers collude to set the same sales price. $\pi^* > \pi$ can be found by comparing cooperative and non-cooperative conditions.

Through the comparison of the two formulas, we can find that in the cooperative game between manufacturer and retailer, the overall profit of the supply chain alliance will be greater than that of each supply chain member in the non-cooperative game. Thus it can be seen that the establishment of an alliance between manufacturers and retailers not only meets the rational needs of individuals, but also the rational needs of the whole supply chain.

3.3. Comparative analysis of different decision models

The above two different decision models of the supply chain of new energy vehicles are discussed respectively, and the overall profit value of manufacturers, retailers and supply chain alliance under different decisions is obtained. The comparison results are shown in Table 2.

Table 2. Comparison of optimal solutions of supply chain models under cooperation and non cooperation

	Noncooperative game	Cooperative game
Sales price of new energy vehicles	$\frac{D+(\alpha-\beta)P_m}{2(\alpha-\beta)}$	$\frac{D+(\alpha-\beta)C}{2(\alpha-\beta)}$
Market demand for new energy vehicles	$\frac{D-(\alpha-\beta)P_m}{2}$	$\frac{D-(\alpha-\beta)C}{2}$
Overall profit value of supply chain	$\frac{3[D-(\alpha-\beta)C]^2}{16(\alpha-\beta)}$	$\frac{(D-(\alpha-\beta)C)^2}{4(\alpha-\beta)}$

Then, we compare and analyze the sales price and market demand under the two kinds of decisions through Table 2. The overall profit of supply chain under centralized decision making is higher than that under decentralized decision making. Then we get the low selling price and high market demand under the cooperation model. It shows that for consumers, they hope

ISSN: 2664-9640

manufacturers and retailers to cooperate. Low market price and high market demand are in line with the rational demand of the whole supply chain, which is more conducive to the promotion of new energy vehicles.

3.4. Optimization of supply chain model

The premise of the game based on Stackelberg principle is that the game is played under the condition of complete information, but the market environment is affected by multiple factors, so it is impossible to achieve complete information sharing. Therefore, it is assumed that the manufacturer is unable to formulate pricing strategy according to the market environment and the market demand is an uncertain factor. The cooperative model and non-cooperative model are constructed by using operations research method and solved by using particle swarm optimization algorithm.

3.4.1 Supply chain model under cooperation

In the cooperation between manufacturers and retailers, according to the analysis in Section3.3, we establish the following model to select the optimal demand of retailers.

$$\begin{cases} \max\limits_{Q} \pi \\ s.t. 0 \le Q \le l \end{cases} \quad (3\text{-}4)$$

Where l is the upper bound on the number of products ordered by the retailer. Since π is a continuous function about Q, there is an optimal solution for this model.

3.4.2 Supply chain model in non-cooperative case

In the case of non-cooperation, the manufacturer makes the decision first and sets the wholesale price for the retailer, and the retailer makes its own decision according to the wholesale price and finally obtains the optimal profit. Therefore, we build the following model to make the optimal decision.

$$\begin{cases} \max\limits_{P_m} \pi_m(P_m, Q^*) \\ s.t. P_m \le P \\ Q^* \text{is the solution to the following program} \\ \begin{cases} \max\limits_{Q} \pi \\ s.t. 0 \le Q \le l \end{cases} \end{cases} \quad (3\text{-}5)$$

The model makes the profit function πm an uncertain function because the market demand of the retailer when selling is an uncertain fuzzy variable.

3.4.3 Optimization algorithm based on PSO toolbox

Particle swarm optimization (PSO) is a stochastic optimization algorithm based on population. Its initial value is a group of random solutions, and the optimal solution is searched by iteration. In the process of the algorithm, each particle represents the possible solution in the model, and each particle is given position vector and velocity vector. The objective function of the model can be used as the fitness function of the algorithm. All particles fly at a certain speed in space, iteratively search the current optimal solution until the global optimal solution is found. [9] The PSO algorithm steps are as follows:

Step1 Initialize a particle swarm with the size of m, set the initial position and speed. During initialization,$[X_{\min}, X_{\max}]$ and $[V_{\min}, V_{\max}]$ should be set to represent the position range and velocity range of particles respectively. The initial value should be moderate and should not fall outside the feasible range.

Step2 The fitness of each particle is calculated.

Step3 The fitness value of each particle is compared with the one of the optimal position Q_i^{pbest} it has experienced. If it is better, it will be regarded as the current optimal position.

Step4 The fitness value of each particle is compared with that of the global optimal position Q_i^{gbest}. If it is better, it is regarded as the current global optimal position.

Step5 Update particle position and velocity.

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 (Q_i^{pbest} - Q_i^k) + c_2 r_2 (Q^{gbest} - Q_i^k) \tag{3-6}$$

$$Q_i^{k+1} = Q_i^k + V_i^{k+1} \tag{3-7}$$

Where $\omega = 1$ is the inertia weight, which is used to control the influence of the previous speed on the current speed. The former speed with larger ω has greater influence and stronger global search ability, and vice versa. We can jump out of the local optimal value by adjusting the size of ω. $c_1=c_2=2$ is acceleration factor, c1 is used to adjust the distance of particle flying to its own optimal position, and c2 is used to adjust the distance of particle flying to the global optimal position. r_1 and r_2 are random variables between [0,1]. When $V_i^k > V_{max}$, $V_i^k = V_{max}$ .When $V_i^k < V_{min}$, $V_i^k = V_{min}$.

Step6 Repeat step 5 until the maximum number of iterations is reached, which Q^{gbest} is the optimal solution.

Its algorithm flow is shown in Figure 5.

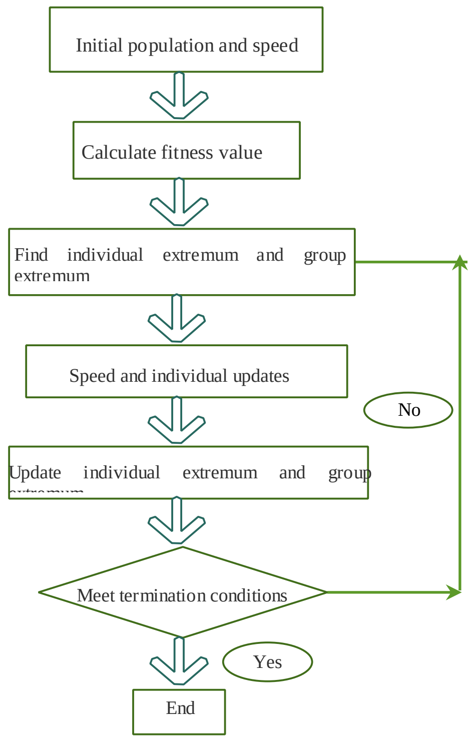

Figure 5. PSO algorithm flow

3.5. Numerical experiments

3.5.1 Optimization in complete information sharing environment

This section will be based on the previous theoretical analysis of the numerical test. Assuming that the new energy vehicle manufacturer is M, the retailer is R, the market demand in the complete information sharing environment is D=100000, $\alpha = 1$, $\beta = 0.5$, and the manufacturer's production cost C=30000. We compare the optimal solution of the supply chain model when cooperation and non cooperation, as shown in Table 1.

Table 3 Optimal solution of supply chain model under cooperation and non cooperation

	P*	Q*	π
Non cooperation	151,500	24,250	3,528,,375,000
Cooperation	103,000	48,500	4,704,500,000

According to the calculation results, we can find that in the market environment of complete information sharing, the price of cooperative model is lower than that of non cooperative model, which requires the government to set the maximum price of products. In terms of sales volume, the sales volume of cooperative model is higher than that of non cooperative model, so the government should encourage enterprises to cooperate with each other and promote consumption. The profit of the cooperative model is greater than that of the non cooperative model, so the alliance between manufacturer and retailer will increase the profit of the whole supply chain, which is in line with its rational demand.

3.5.2 Optimization in incomplete information sharing environment

Here, we only consider the supply chain model in the case of cooperation. According to the PSO algorithm, the model parameters are set as Section 3.5.1.

Matlab is used for arithmetic simulation, and the profit function curve is obtained. In the figure, x axis represents the retail price of new energy vehicles, y axis represents the automobile market demand in an uncertain environment, and the objective function is the profit function.

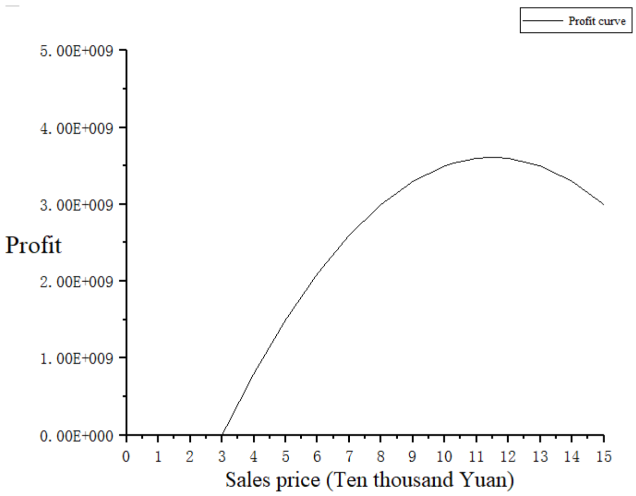

Figure. 6. Optimization diagram of objective function

The result is: P*=115,000, Q*=42,500 and π*=3,612,500,000.

We compared the optimization results under the two cooperation models, as shown in Table 3.

Table 4. Optimization results under the two cooperation models

	P*	Q*	π
Cooperation model based on Stackelberg-Cournot game	103,000	48,500	4,704,500,000
Cooperative model based on particle swarm optimization	115,000	42,500	3,612,500,000

We only consider the results of the alliance body model. The cooperation model based on Stackelberg game calculates the optimal results under the condition of complete information

ISSN: 2664-9640

sharing, while the cooperation model based on particle swarm optimization algorithm calculates the optimal results under the condition of incomplete information sharing. Through comparison, we find that due to the uncertainty of the market environment, the market retail price obtained by solving the model using particle swarm optimization algorithm is high, with low profit, but lower sales volume. Therefore, in the uncertain market environment, upper, middle and lower enterprises can establish alliances to maximize their benefits.

4. Conclusion

The cooperative relationship of supply chain has an impact on the cooperation of supply chain, and then affects the interests of supply chain members. As participants of supply chain alliance, raw material suppliers, new energy vehicle manufacturers and retailers can choose different pricing strategies to maximize their profits. Due to the uncertainty of market demand in the supply chain structure of new energy vehicles, the randomness of market demand is considered in this paper. The optimization model is constructed by using the method of operations research, and the optimal solution of supply chain is solved by particle swarm optimization algorithm. It can be seen from the analysis results that low price and high sales are conducive to the promotion of new energy vehicles, and the supply chain alliance can promote the members of the supply chain to achieve the goal of maximizing their interests. Supply chain enterprises based on cooperation are conducive to their own sustainable development.

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