J. COMBIN. MATH. COMBIN. COMPUT. 127a (2025) 6267--6277

Journal of Combinatorial Mathematics and Combinatorial Computing
www.combinatorialpress.com/jcmcc

Decision-making on price and after-sales service of new energy vehicle supply chain under different sales modes based on game theory models

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ABSTRACT

New energy vehicles have a broad market, and the pricing and after-sales service of new energy vehicle enterprises have become the effective competitiveness of new energy vehicle enterprises. Therefore, this paper studies the pricing and after-sales service decision-making of new energy vehicles on the basis of game theory, and the study first gives a brief overview of game theory. Then, in the context of new energy vehicle subsidies, the optimal pricing under different sales modes is studied using game theory models. It also studies the utility of service stores of the same level of new energy vehicles with the support of game theory, and finally puts forward service suggestions from four aspects: optimizing offline service stores, expanding online services, developing service projects, and developing personalized services. This study can also provide valuable references for the pricing and service marketing of new energy vehicle enterprises, improve the competitiveness of after-sales service at the same time, and also put forward feasible suggestions for the future after-sales marketing methods of new energy vehicle manufacturers.

Keywords: game theory, pricing strategy, after-sales service decision, new energy vehicles

1. Introduction

Although the emergence of automobile has greatly improved people's quality of life, it has also brought serious energy loss and environmental damage. With the continuous increase of automobile ownership, fuel consumption is also rising, which not only makes China's energy shortage problem more serious, but also makes the environmental pollution situation further aggravated [1-4]. With the development of society and people's awareness of environmental protection, new energy vehicles have gradually become the mainstream choice in the market. Compared with traditional fuel vehicles, the advantages of new energy vehicles lie in environmental protection and energy saving, but their after-

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Received 20 February 2024; Revised 25 April 2024; Accepted 20 November 2024; Published Online 15 April 2025.
DOI: 10.61091/jcmcc127a-345

sales service has also become the focus of consumers' attention [5-8].

After-sales service is an important service provided by automobile enterprises to consumers, and it is also an important index reflecting the strength of the enterprise and consumer satisfaction with the enterprise [9-10]. For new energy vehicles, after-sales service is even more important, because new energy vehicles are technically more complex than traditional models, and consumers have more doubts and needs about their performance and usage. However, the current after-sales service of new energy vehicles faces many problems [11-14]. First of all, the after-sales service system of new energy vehicles is not perfect compared with that of traditional fuel vehicles. Some new energy vehicle brands have a limited number of dealers and a narrow coverage of service outlets, which leads to low convenience for consumers in maintenance [15-18]. Secondly, compared with traditional models, new energy vehicles have higher technical requirements in terms of power systems and batteries, which require more professional technicians to provide maintenance services. However, there is a shortage of professional technicians for new energy vehicles in the market, and the maintenance technology of some dealers cannot meet the needs of consumers [19-22]. In addition, some spare parts of new energy vehicles need to be supplied directly by manufacturers, but the poor supply chain leads to insufficient supply of spare parts, which affects the efficiency of consumer maintenance [23-24].

Game theory is a common modeling method in the field of new energy automobile industry decision-making research, and this paper adopts Stackelberg game to simulate the price and after-sales service decision-making of new energy automobile. The study first analyzes the development trend of new energy vehicles and government subsidy policy. The two-stage game is used to simulate the demand and supply model under the tendency of manufacturers and consumers in the automobile market, and then the optimal production and price decisions under different sales strategies are simulated to arrive at a reasonable pricing. The utility decision of the same level of after-sales service stores is then studied, and suggestions are made for the after-sales service of new energy vehicles from four aspects in the light of the actual situation.

2. Game theory

2.1. Overview of game theory

Game theory refers to the participation of two or more people in decision making in an equal board, where each individual is making rational decisions to improve his or her strategy based on the behavior and decisions of the players in the game, and thus to win in this equal board. This game behavior is interactive, i.e., the behavior of one individual will affect the decisions of other players. Therefore, during the game each individual has to face different situations and respond with different strategies in order to win the game.

The four main elements of game theory are players, strategies, gains and losses, and equilibrium. In game theory, the players are the game participants who have the decision-making ability, and their decision-making power is the necessary condition to become the players. According to the difference in the number of players in the game, the classification of the game includes two-player game and multi-player game. Strategy is a complete action program that each player can choose in the game, and its role is to guide the global action of the game. At the end of the game, the outcome of each player is determined by the strategy he or she adopts, so the player's gain or loss is also a function of the strategy. Finite and infinite games refer to games in which the number of strategies is finite and infinite, respectively. Equilibrium, which refers to the steady state of the outcome of the game, can be derived from the general rules of the game. These four elements constitute the core content of the study of game theory, and through the analysis of these elements, the behavioral laws and action strategies of individuals in the game can be studied in depth, so as to predict the outcome of the game.

2.2. The Stackelberg game

Stackelberg game belongs to a kind of master-slave game, the participants in the game bureau are mainly divided into two categories, namely, the dominant player with a leading role and the follower with a following role. At the beginning of the game, the dominant player makes decisions based on his own decision-making goals. And the followers choose their own decisions based on the decisions made by the dominant player. The two parties are independent of each other and influence each other, and the optimal decision reached is acceptable to both. In the Stackelberg game, the dominant player and the follower have their own objective function and constraints. The dominant player's objective function and constraints are related to the optimal decision made by the follower in addition to his own decision variables, while the follower's optimal decision is influenced by the decision made by the dominant player.The basic mathematical model of the Stackelberg game problem is:

$$\begin{aligned} &\underset{x}{Max}\, F(x,y) \\ &s.t.(s,y)\in\Omega_1 \\ &\underset{y}{Max}\, G(x,y) \\ &s.t.(s,y)\in\Omega_2 \end{aligned} \tag{1}$$

where F, x, Ω_1 is the objective function, decision variables and constraints of the dominant, and G, y, Ω_2 is the objective function, decision variables and constraints of the follower, respectively.

3. New energy vehicle supply chain price based on game theory modeling

3.1. Research on the development trend of new energy vehicles

With the increasing degree of industrialization, China's economy has been developing rapidly, and the consumption of oil has been increasing. The excessive use of oil on the one hand increases air pollution and causes damage to the environment, and on the other hand makes China's national economy overly dependent on the price of oil, which is detrimental to the enhancement of China's international competitiveness. Accelerating the development of new energy vehicles can not only effectively alleviate China's oil pressure and environmental pollution problems, but also promote the upgrading of China's automobile industry and improve international competitiveness.

Since 2001, China has realized the importance of developing new energy vehicles, elevated the development of new energy vehicles to the level of national strategy, and successively introduced a series of initiatives to encourage the development of new energy vehicles, the government subsidizes new energy vehicles from the supply-side level, and invests a large amount of money into the subject of new energy vehicle technology research and development.

The development trend of new energy vehicles, as shown in Table 1, gradually expanding the scope of pilot cities to promote new energy vehicles in 2010, followed by the gradual establishment of new energy vehicles industrial development plan, from the central to local government multi-level subsidies, local protection, separate license, unlimited driving and other aspects of the joint promotion of the development of new energy vehicles. A variety of favorable factors make the rapid development of new energy vehicle market, according to the China Association of Automobile Manufacturers disclosed data show that in 2015, the sales of new energy vehicles exceeded 300,000, with an annual growth rate of 378.97%, and there is still a trend of continued growth.

Table 1. The development trend of new energy vehicles

Year	2010	2011	2012	2013	2014	2015
Electric car sales	3962	5585	11384	15368	45893	248952
Hybrid car sales	785	2589	1419	3546	23542	83623

New energy car sales	4747	8174	12803	18914	69435	332575
Annual increase	—	72.19%	56.63%	47.73%	267.11%	378.97%
Market share	0.025%	0.042%	0.065%	0.083%	0.322%	1.351%

3.2. *Analysis of New Energy Vehicle Subsidies*

The good development trend of new energy vehicles has brought a better market environment for new energy vehicles, and more automobile enterprises have joined the track of new energy vehicles, further accelerating the development of new energy vehicles. The decision on the supply chain pricing of new energy vehicles actually affects the sales of new energy as well as people's desire to buy, and is an important factor in the promotion and market development of new energy. Government policies and subsidies for new energy vehicles are one of the key factors affecting supply chain pricing. Therefore, combining the new energy vehicle enterprises listed on the stock market and the development of new energy vehicles in China, and referring to the sales volume of new energy vehicles, government subsidies, and the production characteristics of enterprises, we take 2014 as the demarcation line, and regard 2014 as the introduction period of the market, and 2014 as the rapid growth period. Growth period.

New energy vehicle sales and subsidy changes are shown in Figure 1, the sales of new energy vehicles from 2010 to 2020 have been showing an upward trend, and government subsidies are basically increasing, and by 2020 the sales of new energy vehicles exceeded 1 million, and the government subsidy range was also increased by 20% compared to 2019. The government's policies and subsidies allow consumers to more directly feel the government's support for the new energy vehicle industry and benefit from it.

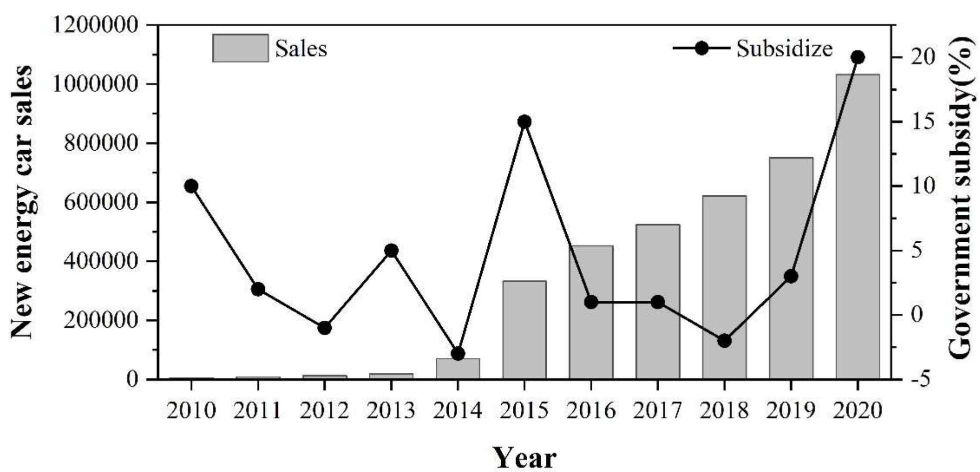

Fig. 1. New energy car sales and subsidy changes

3.3. *Price Decision Analysis Based on Game Theory Models*

The government's support policy aims to establish a long-term mechanism for the management of energy-saving and new energy vehicles and promote the healthy development of the automobile industry. In the context of new energy vehicle subsidies, price decision-making in the supply chain of new energy vehicles is a research topic of great value. This chapter uses the more mainstream stage game method, adding the game between consumers and car companies on the basis of the enterprise game, and conducts a more comprehensive simulation for the automobile market to analyze the impact of the policy and the new energy vehicle subsidy on the production, sales and pricing of automobiles in 2020-2021.

The sequential decision sequence is shown in Figure 2. In this chapter, considering that the duopoly model and the supply and demand model are only applicable to short-term decision-making, the game between automobile manufacturers and consumers is simplified into a two-stage dynamic game process. That is, considering only the game decision for a certain year, in the first stage of the game, the automaker first decides on the production model and production quantity. In the second stage of the game, the consumer decides on the model and quantity to purchase after observing the automaker's decision.

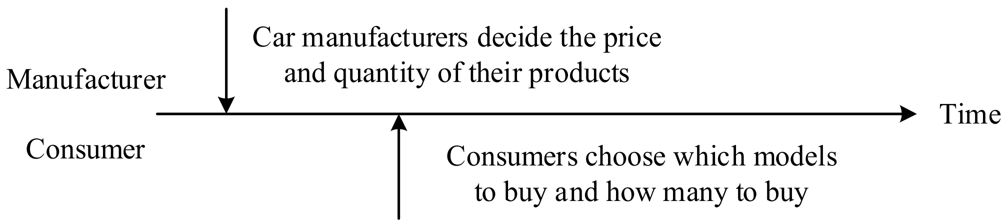

Fig. 2. Schematic diagram of sequential decision making

In this paper, a two-stage game is used to model the Nash equilibrium between manufacturers and consumers in the automobile market, and the duopoly model and the supply-demand model are used to model the decisions of manufacturers and consumers, respectively.

The utility function of the automobile manufacturer is expressed as follows:

$$\begin{cases} \pi_1 = (P_1 - K_1) \times Q_1 + (P_2 - K_2) \times Q_2 + P \times J_1 - G_1 \\ \pi_2 = (P_3 - K_3) \times Q_3 + (P_4 - K_4) \times Q_4 + P \times J_2 - G_2 \end{cases} \tag{2}$$

In the formula, π_i for the i nd car manufacturer's profits (million yuan), P_i for the i th product selling price (million yuan), K_i for the marginal cost of the product (million yuan), that is, increase the cost of a unit of product increases. In actual production, the marginal cost tends to change with the change in volume, this paper, in order to simplify the analysis, assuming that the marginal cost of automobile production is a fixed value, Q_i is the production of the i th product (10,000 units), G_i is the i th automaker's fixed costs (million yuan), does not change with the change in the number of products, including R & D investment, advertising investment, factory rent, etc.. J_i is the number of double points (10,000 points) of the i th automobile manufacturer, in order to simplify the analysis, according to the relevant provisions of the "double points" policy, NEV points can be traded between enterprises, here it is assumed that all NEV points generated in the automobile market have value (including points carried forward), and the market price of enterprises selling/buying points is P (10,000 yuan). J_i can be expressed as:

$$\begin{cases} J_1 = C_1 \times Q_1 - \beta \times Q_2 + \varphi \times T_2 \times Q_2 - \dfrac{F_2 \times Q_2}{Q_1 \times W + Q_2} \times (Q_1 + Q_2) \\ J_2 = C_3 \times Q_3 - \beta \times Q_4 + \varphi \times T_4 \times Q_4 - \dfrac{F_4 \times Q_4}{Q_3 \times W + Q_4} \times (Q_3 + Q_4) \end{cases} \tag{3}$$

All participants in the game are rational, i.e., maximize their own interests as the goal, and the consumer's decision Q_i^* is known, and the car manufacturer's optimal decision P_i^* can be obtained by the first-order optimality conditions:

$$\frac{\partial \pi_1}{\partial P_1} = 0, \frac{\partial \pi_1}{\partial P_2} = 0, \frac{\partial \pi_2}{\partial P_3} = 0, \frac{\partial \pi_2}{\partial P_4} = 0 \tag{4}$$

In order to validate the model, this paper government policy subsidies and the data in the Economic Operation of the Automobile Industry in December 2020, Economic Operation of the Automobile Industry in December 2021, and Evaluation Methods and Indicators for Passenger Vehicle Fuel

Consumption are used to validate the model.

The demand elasticity coefficient θ in the demand model is the main parameter to be fitted. In this paper, this model fitting is defined as a bounded constraint nonlinear least squares problem.

The objective function of this nonlinear least squares problem is shown in the following equation:

$$\sum_{i=1}^{2}\sum_{j=1}^{2}(Q_{ij}-Q_{ij}^{*})^2+\sum_{i=1}^{2}(S_i-S_i^{*})^2 \tag{5}$$

Where: $i=1$ represents new energy vehicles and $i=2$ represents fuel vehicles. $j=1$ represents the year 2020, and $j=2$ represents the year 2021.

In this paper, a data scaling method is used to eliminate the effect caused by the difference in the scale, and the problem is solved using the sequential least squares method (SLSQP). The objective function can be transformed into the following equation:

$$\sum_{i=1}^{2}\sum_{j=1}^{2}\left(\frac{Q_{ij}-Q_{ij}^{*}}{Q_{ij}}\right)^2+\sum_{i=1}^{2}\left(\frac{S_i-S_i^{*}}{S_i}\right)^2 \tag{6}$$

The predicted and true values of the fitted models under the corporate interest and consumer interest tendencies are shown in Table 2. The true value of the market demand under both models with consumer interest tendency is significantly higher than that of the corporate interest model. The true values of market demand under the corporate interest model in 2020 and 2021 are 1,406,000 and 1,314,000 units, respectively. None of the errors between the predicted and true values exceeded 5%. Overall, the results of the model forecasts are basically in line with the real data.

Table 2. The proposed model predictive value and true value

Year		Corporate interest		Consumer interest	
		Market demand	Government subsidy	Market demand	Government subsidy
2020	Fitting value	145.8	345.26	2434.2	761.91
	True value	140.6	330.45	2385.9	735.35
	Difference value	-5.2	-14.81	-48.3	-26.56
2021	Fitting value	133.85	335.78	2381.2	304.35
	True value	130.14	341.15	2254.5	317.5
	Difference value	-3.71	5.37	-126.7	13.15

Although the market demand for new energy vehicles is higher under the consumer interest tendency, when the comprehensive consideration of corporate profitability and social pressure level. Comprehensive M company situation, the optimal production and pricing of its four sales models (XS1~4) are solved under the new energy vehicle enterprise interest tendency. The optimal production and pricing results are shown in Table 3, where both XS2 and SX4 sales modes use lower prices and higher constants as the main competitive means, while XS1 and XS3 sales modes use high pricing and low generation to achieve the corporate revenue target. Depending on the different needs of the sales model, the pricing of the new energy vehicles is more reasonable between 150,000 and 210,000 yuan.

Table 3. Optimal yield and pricing results

Year	2020		2021	
	Automobile production	Car pricing	Automobile production	Car pricing
XS1	78.5	20.85	176.3	19.85

XS2	1275.3	16.14	1260.1	15.08
XS3	64.8	20.35	127.5	18.32
XS4	1157.6	16.22	1054.6	15.98

4. After-sales service decision-making based on game theory

4.1. After-sales service decision analysis

The after-sales service of new energy vehicles generally has multiple stores in the same level of area for after-sales service in order to satisfy the consumers' demand, therefore, this chapter will establish a game model of strategic behavior among multiple after-sales stores of the same level and conduct a brief analysis. For some kind of homogeneous after-sales service or some kind of preferential policies, each local store will always try to take effective strategies to fight for these resources or make full use of these preferential policies, in order to maximize the utility and service quality in the region. There is no affiliation between these same-level stores, and they will simultaneously and independently make decisions that are in their best interest. In the decision-making process, they will make the most advantageous decisions with the goal of maximizing utility based on the requirements of the firm and the store's own fundamentals, as well as judgments about the action strategies of the other participants.

Taking the problem of decision-making interaction between three local stores of the same level as an example, the situation of interaction between more than three stores is not fundamentally different from that of three stores, except that the number of possible situations grows exponentially, leading to a more complex and cumbersome analysis.

In order to describe a simple game model of the decision-making interaction between three local stores at the same level, imagine the case of the head office introducing an after-sales service project or system, considering the implementation cost, market demand and social benefits, assuming that if the plan is implemented by one store alone, the region can make a profit of M (100 million yuan). If two stores implement this program, they can make a profit of $m(0 < m < \frac{M}{2})$ (100 million yuan) per region. If these programs were implemented in three stores at the same time, the profit would be $n(0 < n < \frac{m}{3})$ (billion yuan) across all regions. If none of the three regions are implemented, then the profit for all regions is 0 yuan.

Three peer stores play a game on the service item problem, assuming that the profitability of the service item is the only utility of the game, then the three elements of the game are as follows:

1) Participants: three storefronts of the same level, i.e., A, B, and C.

2) Strategy set: the set of service strategies for all stores is (implement, do not implement).

3) Utility function: the situations and their corresponding utilities are shown in Table 4. The utility column ternary in the table represents (utility of A, utility of B, utility of C).

From the calculation, it can be known that the equilibrium situation (implementation, implementation, implementation) will be reached from any one situation, and the utility vector composed of the utility of each party is (n, n, n). For example, starting from the situation (no implementation, no implementation, no implementation), any store can improve its own utility by changing the strategy individually to "implementation". Without losing generality, if local store A first chooses "implement", the game situation becomes "(implement, not implement, do not implement)", that is, A implements, B and C do not implement, and the current utility vector is (M, 0, 0). Under this condition, B or C can also change their strategy to "implement" to improve its utility, if B chooses "implement", then the game situation becomes "(implement, implement, do not implement)", that is, A and B are implemented in two stores, C is not implemented, and the current utility vector is (m, m, 0). At this point, place C can also increase its utility to n by changing the strategy to "implement", so that the situation becomes (implement, implement, implement), and the corresponding utility vector of this situation is (n, n, n). At this point, neither side can gain more utility by changing their strategy alone. Therefore, the simultaneous implementation of three stores becomes the only equilibrium situation in this game. But this kind of equilibrium situation has a very obvious drawback, on the one hand, a simple calculation shows that the sum of the three utilities (i.e., profits) is $m = \frac{M}{2}$, which is less than half of the utility (expected utility of the project) that would be produced by a single storefront. On the other hand, in order to pursue the local interests of the present, the store leads to excessive implementation and duplicate implementation, which may have a negative impact on the future environment or other aspects such as implementation.

Table 4. The situation and its corresponding utility

The head office will not be in advance, and the local store a will be implemented			
B		Implementation strategy	Non-implementation strategy
C	Implementation strategy	n,n,n	m,0,m
	Non-implementation strategy	m,m,n	M,0,0
The head office is not pre-established, and the local store a does not implement the strategy			
B		Implementation strategy	Non-implementation strategy
C	Implementation strategy	0,m,m	0,0,M
	Non-implementation strategy	0,M,0	0,0,0

4.2. New Energy Vehicle After-sales Service Recommendations

Aiming at the above situation problems of after-sales service, this paper proposes the following strategies:

1) Optimize offline service stores. Most new energy automobile enterprises have built a number of special service stations across the country, but as can be seen in the previous analysis, there is strong competition and inhibition between the services of the same level of stores, so it is possible to carry out hierarchical management and cover customers in different regions by adding secondary service outlets. The second-level service network is constructed by the automobile first-level service station, and the form of construction includes the first-level service station funded self-built or cooperated with the local automobile repair service station. First of all, the location of the second-level network can be analyzed through the permanent residence of the retained customers, in the retained amount of more than 50 units can be set up when the second-level service outlets, the outlets should be selected in the more dense customer traffic in the door. Secondly, the secondary service outlets need to operate in accordance with the after-sales service management standard, set up automotive after-sales service standard door, configure lifter, automotive diagnostic instrument and other maintenance equipment, purchase automotive accessories, and provide customers with after-sales service in accordance with the standard process of automotive after-sales service.

2) Comprehensively optimize and expand online service products. For the basic service market, some common accessories and perishable accessories can be put into the online mall for sale, such as maintenance parts oil, machine filter, air filter, spark plugs, tires, batteries, brake pads and so on. For the value-added services market, you can develop automotive peripheral boutique products, such as vehicle-related vehicle retrofitting and modification of boutique products, and automotive life-related premium products. These products can be used as diversion products to attract customers into the store and increase customer stickiness. Secondly, we should expand the online service program. For the basic service market, you can target the customer distance, do not have time to enter the store repair and maintenance characteristics of the development of online booking door-to-door pick-up and delivery of cars, door-to-door service and other service projects. For the value-added services market, we can develop the mobility scooter borrowing, door-to-door car wash, accident agency, extended warranty service and other peace of mind services.

3) Development of customer life cycle service programs. As the quality of automobile products

improves, the vehicle failure rate decreases, and the frequency of customers coming to the station for maintenance decreases. If you want to maintain after-sales profitability, you need to develop service business in the whole life cycle of the car. The whole life cycle of the car includes vehicle licensing, insurance, repair and maintenance, annual inspection, refueling, parking, and used cars. Among them, automobile insurance and used car business is an indispensable part of the customer life cycle, which is also a new growth point for after-sales profit. If you want to keep customers from losing, you also need to layout on these two major areas. The first is auto insurance, which can develop one-click insurance service online, providing customers with convenient services through insurance expiration reminder, insurance trial calculation, insurance purchase, insurance claims, and one-click insurance renewal. The second is the used car replacement business, with the age of the car becomes longer and vehicle product replacement, more and more customers choose to replace the car, used car replacement has become a new profit growth point. F Auto can set up a used car zone on the mall to carry out used car transactions by collecting information on buying and selling customers and appraising used cars.

4) Develop personalized service products. With the promotion of the Internet plus car linkage technology, customer behavior can be recorded through in-vehicle data, and customer contacts can be recorded through APP. The in-vehicle data includes customer vehicle brand, model, purchase time and mileage, and the data recorded by APP mainly includes the number of customer vehicles and online behavior data related to offline services. These data record the customer's preferences and characteristics of car use and car maintenance in an all-round way, which will become the reference basis for the automotive after-sales service projects. Combined with the customer data information, it can intelligently recommend customers' favorite goods and services, provide customers with precise, personalized and intelligent travel solutions, and truly achieve the experience of service for thousands of people.

5. Conclusion

Considering the government's strong support for the new energy automobile industry, this paper then uses game theory to study the price and after-sales service decisions of new energy automobiles under the government's subsidy policy. This thesis firstly elaborates the game theory in detail, and studies the development trend of new energy vehicles and the subsidy situation. Among them, the sales volume of new energy vehicles exceeded 300,000 in 2015, with an annual growth rate of 378.97%, and there is still a trend of continued growth. By 2020, the sales of new energy vehicles exceeded 1 million, and the government subsidy range was also increased by 20% compared with 2019. It is self-evident that government policies and subsidies support and influence the new energy vehicle industry.

Based on game theory, the study simulated the game between automobile manufacturers and consumers, and analyzed the optimal results of automobile production, sales and pricing of different sales modes under the new energy vehicle subsidy from 2020 to 2021, and the pricing of the new energy vehicle from 2020 to 2021 is more reasonable between 150,000 and 210,000 yuan.

In the three same level of after-sales service store research species found that the simultaneous implementation of after-sales service becomes the only equilibrium situation of this game. However, the tripartite utility in this equilibrium situation is not as good as the utility generated by one store alone. For this reason, this paper puts forward relevant after-sales service optimization suggestions in terms of optimizing offline service stores, expanding online services, developing service projects and developing personalized services.

Acknowledgements

Fundamental Research Funds for the Central Universities (Grant Number: JUSRP122060); General Project for Philosophy and Social Science Research in Jiangsu Universities (Grant Numbers:

JUSRP123253).

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