

Research on Supply Chain Decision of Electric Vehicle with Double Integral Consideration Under R&D Subsidy

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Abstract:

In order to determine the impact of government subsidies and double credit policies on the pricing and endurance decisions of the battery swap vehicle supply chain, a supply chain composed of a new energy vehicle company, a battery swap operator and the government was studied. Considering the factors such as government R&D subsidy, credit accounting coefficient, credit price, battery leasing time and consumer range preference, this paper explores the optimal pricing and endurance decision of government R&D subsidy on supply chain members before and after the implementation of the double credit policy. The results show that when the market size is less than a certain threshold under the double credit policy, battery swap operators will reduce the battery rental price to attract consumers to extend the rental time and expand the consumer market. New energy vehicle companies will maintain their profits by raising the price of battery-swapped vehicles. When the market size exceeds this threshold, battery swap operators will gradually increase the battery rental price to obtain profits as the battery leasing time increases. New energy vehicle companies will promote the popularization and application of battery-swapped vehicles by reducing the price of battery-swapped vehicles. Increasing the R&D subsidy coefficient, credit accounting coefficient, credit price and consumer range preference are all conducive to reducing the price of new energy vehicles and improving battery life, but will push up the battery rental price. The increase in battery leasing time is conducive to improving battery life and reducing battery leasing prices, but it will bring about an increase in the price of new energy vehicles.

Keywords:

Government Subsidies and Double Points Policy, Automotive Supply Chain, Vehicle-Electricity Separation Mode, Pricing Decisions, Endurance Decisions

1. Introduction

Under the support of national strategy and policy, China's new energy automobile industry is developing vigorously. By June 2023, the number of new energy vehicles

in China has reached 16.2 million, accounting for 4.9% of the total number of vehicles; Among them, the number of pure electric vehicles is 12.594 million, accounting for 77.8% of the total number of new energy vehicles. However, overall, China's new energy vehicle market penetration rate is only 28.3%, and traditional fuel vehicles still occupy a dominant position in the automobile market. In order to meet the needs of the high-quality development of new energy vehicles in China, in June 2023, the Ministry of Industry and Information Technology, the Ministry of Finance and other five departments jointly announced the "Decision on revising the Average Fuel Consumption of Passenger Vehicle Enterprises and Parallel Management Measures for New Energy Credits". The revised double points policy further reduces the score value of new energy models, and the acquisition of new energy points by car enterprises is further tightened, and only the production of high-quality and high-life new energy vehicles can obtain the corresponding new energy points. Under the guidance of the dual integration policy, car companies are increasingly inclined to produce new energy vehicles with high endurance.

In order to further enhance the market competitiveness of new energy vehicles, new energy vehicle companies are actively exploring new business models. Among them, the vehicle-electric separation mode has two advantages: reducing the purchase cost and improving the replenishment efficiency. On the one hand, this model realizes the separation of battery assets and car body assets, that is, consumers obtain the right to use batteries by leasing after purchasing the car body, which effectively reduces the initial purchase cost of consumers. On the other hand, this mode makes it possible to quickly replenish energy, that is, after the battery runs out, the user can directly change electricity to the changing station for rapid energy replenishment, which greatly improves the replenishment efficiency of new energy vehicles. The specific forms of the car-electric separation model include: NIO's BaaS (Battery as a Service) model, and Nezha's "battery bank" program. In addition, major battery companies have launched replacement products, battery leasing programs, to change the power operator transformation, such as power battery giant Ningde times aggressively "into" the field of vehicle electric separation, not only launched for the realization of the model and the development of mass production of "chocolate power change block", but also released the power change service brand EVOGO "Lexin power change". Dual integration policy and vehicle-electric separation model are effectively promoting the development of China's new energy vehicle industry, and enterprises need to consider the influence of both when making pricing and endurance decisions.

In addition, in order to accelerate the research and industrialization of key technologies such as new system batteries and vehicle operating systems, help enterprises break through the key technologies of ultra-long life and high-safety batteries, and enhance the supply capacity of key parts and resource guarantee capacity, the government starts from the supply side and subsidize core parts enterprises of new energy vehicles. For example, in April 2023, Shandong Jinan Science and Technology Bureau issued the "Measures for the Implementation of Financial Subsidies for Enterprise Research and Development in Jinan City", which proposed that in order to encourage innovative subjects to continue to increase investment in research and development funds, the municipal finance will invest subsidies for qualified enterprises' research and development funds according to a certain proportion, and the maximum annual subsidy for a single enterprise is 3 million yuan. The key high-tech areas of subsidies include new power battery and energy storage battery technology, fuel cells, etc. Government support for battery

manufacturers is bound to affect their business management decisions. Therefore, it is of practical significance to study the influence of R&D subsidies implemented by the government under the dual integral policy on the pricing and endurance decision-making of the EV supply chain.

2. Review of Relevant Research Literature

Through literature review and development, the research closely related to this paper mainly focuses on three aspects: the impact of vehicle-electric separation mode on automobile supply chain, the impact of dual integration policy on automobile supply chain decision-making, and the impact of government subsidies on automobile supply chain decision-making.

The impact of government subsidies on automobile supply chain decision-making mainly involves (1) the impact of government subsidies on automobile supply chain pricing decision-making. By reviewing the effect of China's new energy vehicle subsidy policies, Dai Hui [1] found that new energy vehicle subsidies have a significant effect on new energy vehicles to obtain price competitiveness and promote the rapid growth of their production and sales. By comparing the impact of different government subsidies on the sales of new energy vehicles, Zhang Haibin et al. [2] found that when the government subsidizes consumers, it is conducive to expanding the market demand scale of new energy vehicles and thus promoting the reduction of prices of new energy vehicles. Similarly, Pan Jintao et al. [3] found that when the government does not subsidize or subsidize consumers, the price, demand, profit of supply chain members and social welfare of products in different channels continue to decrease with the increase of fairness concerns of retailers. Further considering consumer behavior, Shao Lulu et al. [4] found that with the increase in the residual value of old cars, new energy vehicle enterprises should increase replacement subsidies and increase the retail price of new energy vehicles. In order to determine the impact of different government subsidies on pricing decisions of new energy vehicle enterprises, Xiong Yongqing et al. [5] built an optimal pricing model for new energy vehicle enterprises and found that under different subsidy methods, new energy vehicle enterprises would adopt different pricing strategies according to changes in market competition environment and subsidy input. To further analyze the impact of intelligent manufacturing technology subsidies on the pricing decisions of new energy vehicle manufacturers, Chen Yujing and Sun Yanming [6] built a competitive pricing decision model between traditional and new energy vehicle enterprises, and found that government subsidies would intensify the market competition between traditional and new energy vehicle manufacturers and lower the prices of the two types of vehicles. In order to study the impact of government subsidies to different entities on automobile pricing decisions, Shen Chengran and Li Linzhi [7] established automobile supply chain decision-making models of direct subsidy manufacturers and direct subsidy sellers, respectively, and found that the difference in wholesale prices of new energy vehicles for manufacturers under the two subsidy modes was equal to the government subsidies for new energy vehicles. Wholesale prices for gas-powered cars are not affected by government subsidies. Similarly, Huang Hui et al. [8] found that when the government does not subsidize or subsidize vehicle manufacturers and retailers, both the wholesale and retail prices of automobiles are lower. Further considering the impact of government subsidies and the level of charging facilities construction on operators' pricing decisions, Peng Liagui and Li Ying [9] found that when the level of charging construction is lower

than a specific threshold, increasing operation subsidies is conducive to reducing operators' pricing, thus stimulating the proliferation of electric vehicles. Further considering the competition between new energy vehicles and traditional vehicles, Liu Jing et al. [10] analyzed the utility model and found that on the premise of ensuring the maximum social welfare, government subsidies would increase the price and market share of new energy vehicles, but reduce the price and market share of fuel vehicles. (2) The impact of government subsidies on vehicle supply chain endurance decisions. In order to reveal the impact of government subsidies on battery life and recycling strategies in the supply chain of new energy vehicles, Jia Junxiu and Zhao Kaike [11] established a Stackelberg game model with battery manufacturers as leaders and new energy vehicle manufacturers as followers, and studied the optimal decision-making problem of supply chain entities under different subsidy strategies. It is found that the subsidy strategy adopted by the government can effectively improve the battery life, the recovery rate of waste batteries and the profits of supply chain enterprises. By reviewing relevant literature and market analysis of market subsidies for new energy vehicles, Hardman et al. [12] believe that the sustainability of market subsidies is conducive to promoting the development of new energy vehicles, and consumers should be subsidized in the early stage of development of new energy vehicles, and new energy vehicles with strong endurance should be subsidized in the future. In order to explore the impact of R&D subsidies, market subsidies and mixed subsidies on the stability of the new energy vehicle market, Zhao Hua and Zheng Jichuan [13] built a dynamic game model and found that subsidies for the new energy vehicle industry played a positive role in expanding the market and accelerating industrial development, but excessive subsidies would hinder the development of enterprises. The average R&D investment and average profit of enterprises are lower than the equilibrium state. Considering government subsidies and consumers' environmental preferences, Xu Jing et al. [14] found that when the government subsidy threshold was too high, subsidy policies would not affect the research and development behavior of new energy vehicle enterprises. Based on the panel data analysis of listed companies, the impact of consumption upgrading and government support and their interaction items on the R&D efficiency of enterprises, Shen Junxi et al. [15] found that the government subsidy and R&D investment super-deduction policy have a significant promoting effect on the improvement of the R&D efficiency of China's new energy vehicle enterprises, and the interaction effect of R&D investment super-deduction is better than that of government subsidies. By introducing factors such as product recycling, energy conservation and emission reduction, and market competition, Zhang Heli et al. [16] established consumption subsidy and technology subsidy models and found that the implementation of consumption subsidy and technology subsidy was conducive to reducing the production cost and research and development cost of automobile manufacturers and improving the research and development level of new energy vehicles.

To sum up, the existing literature on the impact of the vehicle-electric separation mode on the automotive supply chain mainly focuses on the comparison of charging and replacing modes, battery reserve, operation optimization and factors affecting the battery rental price, etc., and rarely considers the impact of this mode on the product pricing and battery life of the new energy vehicle supply chain. Most studies on the impact of dual-integral policy on the automotive supply chain focus on the supply chain of new energy vehicles integrating fuel vehicles and vehicles and electric vehicles. There are few literatures on the impact of dual-integral policy on product pricing and endurance decision-making in the mode of vehicle and electric separation.

Research on the impact of government R&D subsidies on the automotive supply chain mainly focuses on the integrated model of vehicle and electricity, and discusses the impact of subsidies for new energy vehicle manufacturers, battery manufacturers or consumers on the product development and product price of the new energy vehicle supply chain, and rarely involves the impact of product pricing and endurance decisions in the separate model of vehicle and electricity.

Therefore, on the basis of the vehicle-electric separation model, this paper introduces factors such as double integral policy and R&D subsidy to explore the impact of double integral policy and R&D subsidy on the pricing and endurance decision-making of the EV supply chain. And use the integral calculation coefficient, integral trading price; Government subsidy amount and government subsidy rate reflect the influence of dual integral policy and government subsidy policy on supply chain decision-making, in order to obtain the optimal product pricing and endurance of electric vehicle supply chain and the optimal level of government subsidy, and optimize enterprise operation decision and government subsidy decision.

3. Problem Description and Hypothesis

The automobile supply chain in this paper consists of a new energy vehicle enterprise, a power exchange operator, the government and consumers. Under the model of vehicle-electric separation, the new energy vehicle enterprise is responsible for the production of pure electric models that support power replacement and energy replenishment, and the unit production cost is C_n , and the price is P_n sold to consumers; The replacement operator has the ownership of the battery, is responsible for daily operation management (energy replenishment and maintenance) and provides battery leasing and replacement services to consumers. The average annual operation management cost of each battery is C_1 , the annual depreciation cost is C_2 , and the residual value of the battery after retirement is S (step utilization + material recovery income). Its unit cost $C = C_1 + C_2$. After the completion of the purchase transaction, the consumer rents the battery from the replacement operator at the annual price P_b (including the replacement cost), and the average battery lease time of the consumer is N years. In addition, the revised double points policy stipulates that the standard points for each pure electric vehicle are, for the driving range of electric vehicles. The driving range of new energy vehicles ultimately depends on the battery life capacity. For the convenience of research, it is assumed that the driving capacity of new energy vehicles is equal to the battery life capacity, and the new energy credits obtained by each pure electric vehicle are $0.0034R + 0.2$, where R is the integral calculation coefficient set in the policy. In addition, in order to expand the battery rental market, power replacement operators improve battery life through battery life research and development, referring to the study of [4], the battery life research and development investment cost is, where is the R & D investment cost factor. In addition, in order to promote the high-quality development of the new energy industry, the government provides research and development subsidies for power replacement operators. With reference to the existing research and development subsidy policy that the government grants subsidies according to a certain proportion of the enterprise's research and development investment, it may be appropriate to set the government's subsidy rate for the battery life research and development investment of the replacement operator as g_2 . The supply chain system of EVs considering government subsidies is shown in Figure 1.

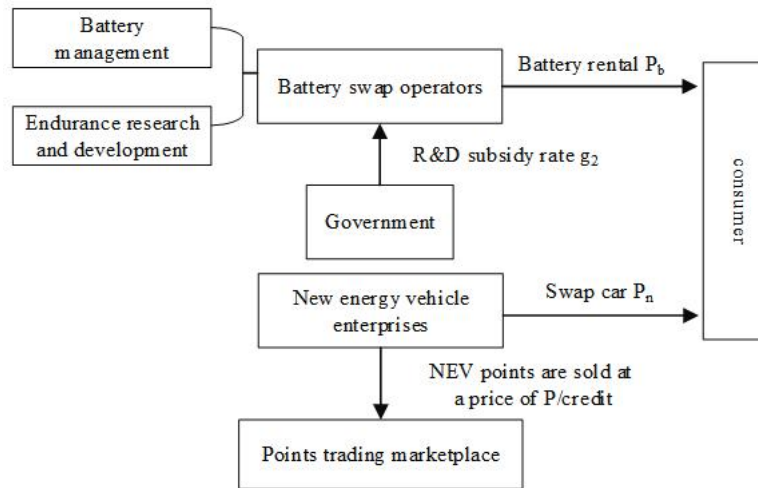


Figure 1. EV supply chain system considering R&D subsidies.

For the convenience of distinction and expression, this chapter will consider the case of government research and development subsidies without considering the double points policy as, and will consider the case of government research and development subsidies and double points policy as. The symbols and their meanings are shown in Table 1:

Table 1. Symbols and their meanings.

symbol	meaning	symbol	meaning
D	Demand for electric vehicles	C_2	Battery depreciation expense (per year)
α	Price sensitivity coefficient	S	Battery salvage value
β	Endurance preference coefficient	C_n	Unit production cost of electric vehicle replacement
e	Integral calculation coefficient	C_b	Unit battery production cost
P	Unit point selling price	P_n	The price of new energy vehicles without batteries
m	Potential market size of electric vehicles	P_b	Unit Battery Rental Price (per year)
k	Battery life research and development investment cost factor	R	Battery life
N	Battery rental Time (per year)	π_n	New energy vehicle enterprise profit
C_1	Replacement operating cost (per year)	π_b	Profit of switching operator
g_2	R&d subsidy rate	π_g	Social welfare

The decision order of this paper is as follows: First, the government, as the leader of the supply chain, aims to maximize social welfare, and first decides the optimal level of R&D subsidy; Second, replacement operators decide the level of battery life research and development and battery rental prices; Finally, new energy vehicle enterprises decide the price of electric vehicles. The decision goal of power replacement operators and new energy vehicle companies is to maximize profits.

4. Model Construction and Solution

4.1. Consider the case of double integration policy

In the context of only considering government R&D subsidies, the income of power replacement operators is battery leasing income, and the cost includes battery production cost, battery life R&D cost minus the remaining cost after government R&D subsidies, power replacement operating cost and battery depreciation cost. Its profit function is:

$$\pi_b^{XG_2} = [N(P_b - C) - C_b + S]D - (1 - g_2) \frac{1}{2} kR^2 \quad (1)$$

The income and cost composition of new energy vehicle enterprises are consistent with the situation, so the profit function in this situation is:

$$\pi_n^{XG_2} = (P_n - C_n)D \quad (2)$$

Under the government's production subsidy mechanism, the purpose of providing research and development subsidies is to improve the sustainable development and market competitiveness of battery enterprises, so as to better achieve the high-quality development goals of new energy vehicles. Therefore, the government income is defined as the sum of the profit of the EV supply chain system and the consumer surplus minus the government subsidy, specifically as follows:

$$\pi_g^{XG_2} = \pi_b^{XG_2} + \pi_n^{XG_2} + \frac{1}{2\alpha} D^2 - \frac{1}{2} g_2 kR^2 \quad (3)$$

Using the inverse induction solution method, the government can obtain the optimal unit production subsidy $g_2^{XG_2}$, the optimal battery life capacity of the power replacement operator R^{XG_2} , the battery leasing price $P_b^{XG_2}$, and the optimal pricing of new energy vehicle enterprises is $P_n^{XG_2}$. It can be concluded that the electric vehicle/battery rental market demand D^{XG_2} can be obtained, and the optimal profit $\pi_b^{XG_2}$ of electric vehicle replacement operators, the optimal profit $\pi_n^{XG_2}$ of new energy vehicle enterprises and the optimal social welfare $\pi_g^{XG_2}$ can be obtained.

4.2. Consider the case of double integration policy

Under the background of double integral policy and R&D subsidy, the profit function of the electricity changing operator is the same as that in the case, and its profit function is as follows.

$$\pi_b^{YG_2} = [N(P_b - C) - C_b + S]D - (1 - g_2) \frac{1}{2} kR^2 \quad (4)$$

On the basis of the revenue of new energy vehicle enterprises, there are more new energy integral sales revenue, and the cost composition is the same as in the case, so its profit function is:

$$\pi_n^{YG_2} = (P_n - C_n + eRP)D \quad (5)$$

The government income is still the sum of the profit of the EV supply chain system and the consumer surplus minus the government subsidy, specifically:

$$\pi_g^{YG_2} = \pi_b^{YG_2} + \pi_n^{YG_2} + \frac{1}{2\alpha} D^2 - \frac{1}{2} g_2 k R^2 \quad (6)$$

Using the inverse induction solution method, the government can obtain the optimal unit production subsidy $g_2^{YG_2}$, the optimal battery life capacity of the power replacement operator R^{YG_2} , the battery leasing price $P_b^{YG_2}$, and the optimal pricing of new energy vehicle enterprises is $P_n^{YG_2}$. It can be concluded that the electric vehicle/battery rental market demand D^{YG_2} can be obtained, and the optimal profit $\pi_b^{YG_2}$ of electric vehicle replacement operators, the optimal profit $\pi_n^{YG_2}$ of new energy vehicle enterprises and the optimal social welfare $\pi_g^{YG_2}$ can be obtained.

Theorem: The optimal decision results in the two cases are shown in Table 2.

Table 2. Optimal decision results in two cases.

variable	Scenario XG_2	Scenario YG_2
g_2	$\frac{H}{4N+H}$	$\frac{H}{4N+H}$
R^*	$\frac{\beta(NA - N\alpha C_n - \alpha B)(4N+H)}{N(4(2\alpha k + I) - H\beta^2)}$	$\frac{E(4N+H)(NA - N\alpha C_n - \alpha B)}{N(16\alpha k - E^2(4N+H))}$
P_b^*	$\frac{\left((4I - H\beta^2)(B + NC) \right) + 8Nk(m - \alpha C_n)}{N(4(2\alpha k + I) - H\beta^2)}$	$\frac{\left(8Nk(m - \alpha C_n) + (B + NC) \right) \left(8\alpha k - (4N+H)E^2 \right)}{N(16\alpha k - E^2(4N+H))}$
P_n^*	$\frac{4N(kA - I) - 4\alpha(B - N) + NH\beta^2}{N(4(2\alpha k + I) - H\beta^2)}$	$\frac{\left(4k(N(A + 3\alpha C_n) - B) - E \right) \left((4N+H)(ep(NA - B) + N\beta C_n) \right)}{N(16\alpha k - E^2(4N+H))}$
D^*	$\frac{NA - N\alpha C_n - \alpha B}{N(4(2\alpha k + I) - H\beta^2)}$	$\frac{4\alpha k(NA - N\alpha C_n - \alpha B)}{N(16\alpha k - E^2(4N+H))}$
π_n^*	$\frac{16\alpha k^2(NA - N\alpha C_n - \alpha B)^2}{N^2(4(2\alpha k + I) - H\beta^2)^2}$	$\frac{16\alpha k^2(NA - N\alpha C_n - \alpha B)^2}{N^2(16\alpha k - E^2(4N+H))^2}$
π_b^*	$\frac{2k(NA - N\alpha C_n - \alpha B)^2}{N(4(2\alpha k + I) - H\beta^2)}$	$\frac{2k(NA - N\alpha C_n - \alpha B)^2}{N(16\alpha k - E^2(4N+H))}$
π_g^*	$\frac{k(NA - N\alpha C_n - \alpha B)^2(4N+H)}{2N^2(4(2\alpha k + I) - H\beta^2)}$	$\frac{k(4N+H)(NA - N\alpha C_n - \alpha B)^2}{2N^2(16\alpha k - E^2(4N+H))}$

Here $A = m - \alpha C > 0$, $B = C_b - S > 0$, $E = \alpha eP + \beta > 0$, $H = \alpha + 2 > 0$, $I = 2\alpha k - N\beta^2 > 0$.

5. Model Comparison and Parameter Analysis

5.1. Comparison of decision variables in different situations

Corollary 1: There is the following relationship between the equilibrium results in the two cases where the double integral policy is not considered and the double

integral policy is considered: $g_2^{XG_2^*} = g_2^{YG_2^*}$ 、 $R^{XG_2^*} - R^{YG_2^*} < 0$ 、 $P_b^{XG_2^*} - P_b^{YG_2^*} > 0$ 、 $P_n^{XG_2^*} - P_n^{YG_2^*} > 0$ 、 $D^{XG_2^*} - D^{YG_2^*} < 0$ 、 $\pi_b^{XG_2^*} - \pi_b^{YG_2^*} < 0$ 、 $\pi_n^{XG_2^*} - \pi_n^{YG_2^*} < 0$ 、 $\pi_g^{XG_2^*} - \pi_g^{YG_2^*} < 0$ 。

Corollary 1 shows that the optimal government R & D subsidy rate is the same in the two cases, while the battery life, product demand, supply chain member profit and social welfare are higher in the case of dual integral policy, while the battery rental price and the price of electric vehicle replacement are lower than that in the case of R & D subsidy only. Regardless of whether the dual points policy is considered, the purpose of the government's R & D subsidies for power replacement operators is to stimulate them to improve the research and development level of battery life. By improving the research and development level of battery life, power replacement operators can expand the battery rental market and further obtain profits. Therefore, whether the government's double points policy is implemented or not will not affect the government's R&D subsidy rate.

5.2. Battery lease time coefficient analysis

Corollary 2: (1) $\frac{\partial g_2^{XG_2^*}}{\partial N} < 0$, $\frac{\partial R^{XG_2^*}}{\partial N} > 0$, $\frac{\partial P_b^{XG_2^*}}{\partial N} < 0$, $\frac{\partial P_n^{XG_2^*}}{\partial N} > 0$, $\frac{\partial D^{XG_2^*}}{\partial N} > 0$, $\frac{\partial \pi_b^{XG_2^*}}{\partial N} > 0$, $\frac{\partial \pi_n^{XG_2^*}}{\partial N} > 0$, $\frac{\partial \pi_g^{XG_2^*}}{\partial N} > 0$;

(2) $\frac{\partial g_2^{YG_2^*}}{\partial N} < 0$, $\frac{\partial R^{YG_2^*}}{\partial N} > 0$, $\frac{\partial D^{YG_2^*}}{\partial N} > 0$, $\frac{\partial \pi_b^{YG_2^*}}{\partial N} > 0$, $\frac{\partial \pi_n^{YG_2^*}}{\partial N} > 0$, $\frac{\partial \pi_g^{YG_2^*}}{\partial N} > 0$;

(3) When $m_0'' < m < m_1''$, $\frac{\partial P_n^{YG_2^*}}{\partial N} > 0$, $m_1'' < m$ 时, $\frac{\partial P_n^{XG_2^*}}{\partial N} < 0$;

(4) When $m_0'' < m < m_2''$, $\frac{\partial P_b^{YG_2^*}}{\partial N} < 0$, $m_2'' < m$, $\frac{\partial P_b^{XG_2^*}}{\partial N} > 0$.

Here, $m_0'' = \frac{(8\alpha k N C_n - (B - NC))}{8Nk}$, $m_1'' = \frac{\alpha \left((16\alpha k - NH E^2) (C + C_n) \right)}{N(16\alpha k - HE^2)}$,

$m_2'' = \frac{32\alpha k N^2 E^2 (C + C_n) - BE^2 \left(\frac{24\alpha k (H + 3N)}{(4N + H)^2 E^2} \right)}{N(16\alpha k - E^2 (4N + H))^2}$, and $m_0'' < m_1'' < m_2''$ 。

Corollary 2 shows that the R&D subsidy rate is inversely proportional to the battery lease time, while the product demand, supply chain member profits and social welfare are proportional to the battery lease time. When considering only the government R&D subsidy, the EV price and battery rental price are inversely proportional and proportional to the battery rental time respectively, while when considering the double integral policy and the government R&D subsidy at the same time, the relationship between the two and the battery rental time is different in stages, that is, when $m_0' < m < m_1'$ the EV price is positively correlated with the battery rental time,

otherwise it is negatively correlated. When $m'_0 < m < m'_2$, the battery lease price is negatively correlated with the battery lease time, and otherwise, it is positively correlated. With the increase of battery leasing time, the profit of power exchange operators continues to grow, providing financial guarantee for the improvement of battery life capacity, which is conducive to the power exchange operators to carry out battery life research and development, so the government research and development subsidies gradually decrease with the increase of battery leasing time.

5.3. Analysis of influencing factors of R&D subsidies and social welfare

$$\begin{aligned} \text{Corollary 3: (1)} \quad & \frac{\partial g_2^{XG_2^*}}{\partial \alpha} = \frac{\partial g_2^{YG_2^*}}{\partial \alpha} > 0; \quad \frac{\partial \pi_g^{XG_2^*}}{\partial \alpha} < 0, \quad \frac{\partial \pi_g^{YG_2^*}}{\partial \alpha} < 0; \\ (2) \quad & \frac{\partial g_2^{XG_2^*}}{\partial \beta} = \frac{\partial g_2^{YG_2^*}}{\partial \beta} = 0, \quad \frac{\partial \pi_g^{XG_2^*}}{\partial \beta} > 0, \quad \frac{\partial \pi_g^{YG_2^*}}{\partial \beta} > 0; \\ (3) \quad & \frac{\partial g_2^{XG_2^*}}{\partial S} = \frac{\partial g_2^{YG_2^*}}{\partial S} = 0; \quad \frac{\partial \pi_g^{XG_2^*}}{\partial S} > 0, \quad \frac{\partial \pi_g^{YG_2^*}}{\partial S} > 0; \\ (4) \quad & \frac{\partial g_2^{XG_2^*}}{\partial e} = 0, \quad \frac{\partial g_2^{YG_2^*}}{\partial P} = 0; \quad \frac{\partial \pi_g^{XG_2^*}}{\partial e} > 0, \quad \frac{\partial \pi_g^{YG_2^*}}{\partial P} > 0. \end{aligned}$$

Corollary 3 shows that: (1) With the increase of price sensitivity coefficient, the R & D subsidy rate of the government to the power switching operators will continue to increase, while the level of social welfare will continue to decrease. This is because, in order to avoid the high price of the products developed by the replacement operators, the market demand is small, the government will increase the research and development subsidy rate when the consumer is more sensitive to price. (2) In both cases, government R&D subsidies have nothing to do with consumer life preference, battery residual value, point accounting coefficient and point trading price, while social welfare increases with the increase of consumer life preference, battery residual value, point accounting coefficient and point trading price. Therefore, the government should focus on the impact of battery rental time and price sensitivity coefficient when determining the R&D subsidy rate.

6. Numerical Simulation Analysis

According to the revised dual points policy in June 2023, the standard points for a single pure electric vehicle is $0.0034R + 0.2$, where $e = 0.0034$. According to the “Annual Report on the Implementation of parallel Management of Passenger Vehicle Enterprise Average Fuel Consumption and new energy Vehicle Points (2023)” released by the Ministry of Industry and Information Technology in April 2023, the average unit price of new energy points trading orders in 2022 is 1128 yuan/point, which is taken here. In addition, according to the Provisions of the Standard for Compulsory Scrapping of Motor vehicles, the service life of small and micro rental passenger vehicles is 8 years, and the service life of the power battery is generally 5-8 years. In this paper, the average battery rental time limit is set to 8 years with reference to this provision. Considering that the probability of consumers changing cars within two years is low, this paper considers the lower limit of the battery lease time to be 2 years, that is $N \in [2, 8]$. In combination with the model assumptions and

references [13] and [14], here we make $m = 70000$, $C_n = 100000$, $C_b = 40000$, $C = 5000$, $k = 100$, $\alpha = 0.5$, $\beta = 0.3$, $S = 2000$. Substituting the above parameters into the equilibrium results of the XG_2 and YG_2 models (where N takes the mean value of 5), the equilibrium decision result of the EV supply chain can be obtained (because the R & D subsidy is proportional, the result is kept two decimal places, and other results are rounded to keep integers). The details are shown in Table 3.

Table 3. Equilibrium results for XG_2 and YG_2 models.

Equilibrium results	g_2	R	P_b	P_n	D	π_n	π_b	π_g
XG_2 model	0.11	116	26335	106867	3434	23580475	235207870	235207870
YG_2 model	0.11	992	28499	104146	3975	31597358	272270731	306304572

It can be seen from Table 3 that compared with only the government production subsidy scenario, the battery life, battery rental price, product demand, supply chain members' profits and social welfare level under the double credit policy and government production subsidy are higher, while the price of battery-swapped vehicles is lower, and the government R&D subsidy is the same in the two cases. Consistent with the conclusion of Corollary 1.

As can be seen from Figure 2, the level of government R&D subsidies and social welfare will be affected by the duration of battery leasing. Figure 2 shows that with the increase of battery leasing time, the level of government production subsidies and social welfare without considering/considering the double credit policy continues to increase, verifying Inference 2.

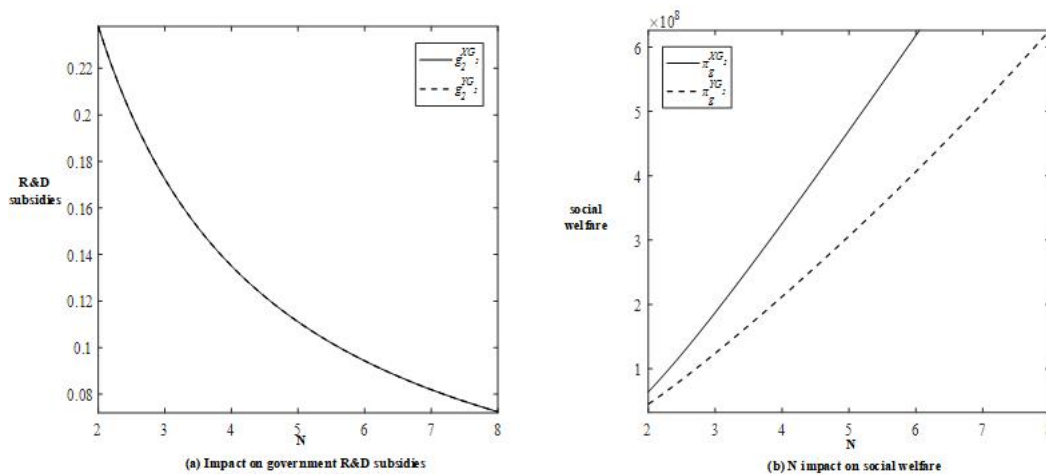


Figure 2. Impact of N on R&D subsidies and social welfare.

As can be seen from Figure 3, government R&D subsidies and social welfare levels are affected by price sensitivity coefficients. Figure 3 shows that with the increase of price sensitivity, the government production subsidy without considering/considering the double credit policy continues to increase, but the level of social welfare continues to decrease. As can be seen from Figure 3, when the consumer price sensitivity coefficient is too high, a large amount of R&D subsidies will not only not promote the improvement of social welfare level, but will reduce the level of social welfare, so the government should actively pay attention to consumer price sensitivity when making R&D subsidy decisions. Inference 3 was verified.

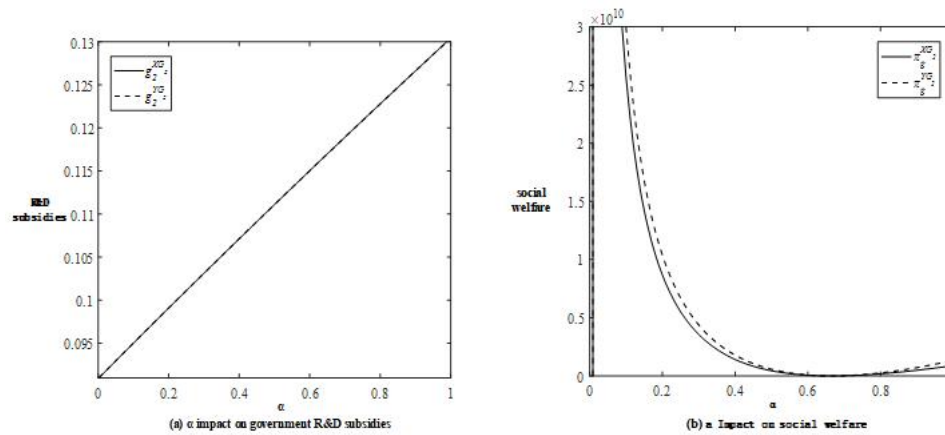


Figure 3. Impact of α on R&D subsidies and social welfare.

As can be seen from Figure 4, both the integral accounting coefficient and the integral transaction price affect the level of social welfare, that is, with the increase of the integral accounting coefficient or the integral transaction price, the level of government production subsidies and social welfare continues to rise. Inference 3 was verified.

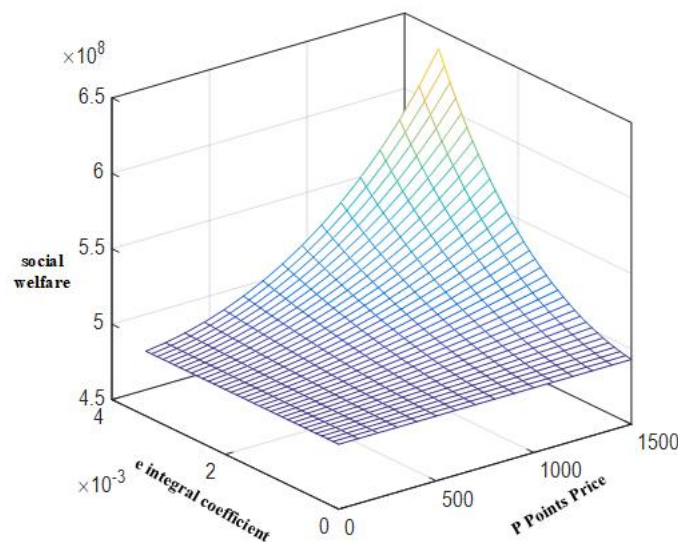


Figure 4. The impact of e and P on the level of social welfare.

7. Conclusions

Based on the characteristics of vehicle-electricity separation mode and government R&D subsidies, this paper establishes a decision-making model for the pricing and endurance of the battery swap vehicle supply chain without considering and considering the double credit policy, and obtains the following conclusions: (1) Increasing the credit accounting coefficient or credit price under the double credit policy is conducive to reducing the price of new energy vehicles and improving battery life, but it will push up the battery leasing price; (2) The enhancement of consumers' range preference is conducive to improving battery life, but it will lead to an increase in battery rental prices; The enhancement of consumers' range preference without considering the double credit policy will not affect the price of new energy vehicles, but it will bring about a decrease in the price of new energy vehicles when considering the double credit policy. (3) The increase of battery leasing time and

battery residual value is conducive to reducing battery leasing prices and improving battery life, but will lead to the increase in the price of new energy vehicles. (4) The implementation of the double credit policy does not affect the level of government R&D subsidies. (5) Government R&D subsidies are only affected by consumer price sensitivity coefficient and battery leasing time, and the level of R&D subsidies increases with the increase of price sensitivity coefficient, but decreases with the increase of battery leasing time.

Based on the above conclusions, the following recommendations are made:

(1) Improve the supervision system of points transactions and stabilize the price of points. Under the guidance of the double credit policy, more and more fuel car companies are transforming to new energy vehicle companies, and there will be too many new energy credits in the credit market, which will inevitably lead to a sharp decline in the price of new energy credits and dampen the enthusiasm of car companies to develop new energy vehicles. As the formulator of the points policy and the organizer of the points transaction, the government should strengthen the supervision of the points trading market, protect the legitimate rights and interests of all parties involved in the transaction, maintain the order of the points market, and stabilize the points transaction price.

(2) Grasp the policy orientation and plan the development of the enterprise. The revised double credit policy has further tightened the requirements for the acquisition of points for new energy vehicles, and put forward higher requirements for the innovation and development of new energy vehicles. Specifically, follow-up car companies need to focus on reducing the weight of the body and improving the efficiency of the three electric vehicles to improve the mileage of new energy vehicles. In addition, automakers should also pay close attention to government subsidy policies, and adjust their pricing strategies to maximize corporate profits.

(3) Lay out the battery recycling network and tap the residual value of retired batteries. Power battery recycling is the key to the sustainable supply of strategic mineral resources such as lithium, nickel and cobalt, and is also an important part of the sustainable development of the new energy industry. In the vehicle-electricity separation mode, the ownership of the battery belongs to the battery swapping operator, which helps to promote the 100% recycling of retired batteries. Therefore, battery swap operators should actively lay out the battery recycling network while providing battery leasing, and form a closed loop of business model through the cascade utilization of retired batteries and material recycling, so as to improve the economic benefits of retired batteries and promote the sustainable development of China's new energy industry.

(4) The government should provide production subsidies or R&D subsidies to members of the supply chain of battery-swapped vehicles under appropriate conditions, but it cannot blindly promote the development of the new energy vehicle industry by increasing financial subsidy expenditures, otherwise it will lead to low input and output. In addition, the government can also formulate relevant policies to guide members of the battery swap vehicle supply chain to actively lay out the battery recycling network, such as: setting up special subsidies for retired battery recycling, strengthening the promotion of retired battery recycling, and actively cultivating leading enterprises in retired battery recycling.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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