Research on Cooperative Decision Making of New Energy Vehicle Supply Chain Technology R&D Investment in the Post subsidy Era

Yue Xin
Corresponding author.Email:roxy_xy@163.com

Beijing Technology and Business University, Beijing, China

Abstract. Based on the background of 'subsidy reduction policy', this paper mainly establishes a game model composed of a battery supplier, an automobile manufacturer and consumers in the post subsidy era for the technology R&D cooperation decisions between the battery supplier and the vehicle manufacturer in the new energy vehicle supply chain. This study analyzes the impact of enterprise technology R&D capabilities and consumer preferences on the decisions of battery suppliers and automobile manufacturers. The results show that: (1) Enterprise technology capability and consumer preference have interactive effects on enterprise technology investment level. (2) When consumer preference increases, the investment level in technology R&D of battery suppliers and vehicle manufacturers shows an increasing trend. (3) The cost sharing contract can coordinate the whole supply chain. This paper will be a reference for enterprises to make decisions on technology R&D cooperation.

Keywords: New energy vehicle (NEV); Research and development (R&D); Production decision; Supply chain coordination

1 Introduction

In recent years, the conflict between traditional energy and ecological environment has become increasingly prominent and developing new energy vehicles has become a world consensus. Since the 13th Five-Year Plan, China's new energy vehicle industry has made great achievements, but it also faces many problems. On the one hand, as the main power source of new energy vehicles, there is still a large improvement space in the technology of battery. On the other hand, since the subsidy amount of the new policy has been significantly reduced, the sales of new energy vehicles have begun to fall sharply. Although the new energy vehicle market in China has begun to take shape, how to attract consumers to buy new energy vehicles and expand the market scale without subsidies has become a problem that needs to be solved. Cooperation between battery suppliers and vehicle manufacturers is a common mode in the new energy vehicle industry, which is suitable for the development of the industry. It is necessary to study the technology R&D investment cooperation decision-making of new energy vehicle supply chain enterprises in the post subsidy era.

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2 Literature Review

In recent years, many of the scholars' research on the new energy vehicle supply chain considering the impact of subsidy policies, of which mainly discusses the impact of subsidy policies on the development of the new energy vehicles industry [1], the impact of subsidies on enterprise behavior [2, 3], the impact of subsidies on the green degree of the supply chain [4], etc. There are few literatures relating to technology research and development and consumer preferences in the new energy vehicle supply chain. Hou et al. [5] have built an innovation framework for the new energy vehicle industry based on the function theory of the innovation system. Chen et al. [6] analyzed the development of China's new energy vehicle industry from three aspects. In terms of quantitative research related to new energy vehicle supply chain. Wang [7] studied the resource investment strategy of the new energy vehicle supply chain. Xu et al. [8] studied the cooperative relationship of the vehicle supply chain. Yu et al. [9] considered the supply chain consisting of a vehicle manufacturer and a parts supplier, and considered the level of quality efforts and quality improvement. In the design of supply chain cooperation contracts, cost sharing and revenue sharing contracts are widely used. On the basis of existing research, this paper considers the technology R&D cooperation in the new energy vehicle supply chain, and analyzes the cooperation between the new energy supply chain enterprises when consumers have high mileage preferences in the post subsidy era.

3 Assumptions, Notations and Models

In order to simplify the problem, this paper takes the battery as the main research object and does not consider the cost of non-critical parts and assembly processing costs. This study constructs a game model including a battery supplier, a vehicle manufacturer and a market consists of many consumers. The order of the game is: firstly, the vehicle manufacturer provides incentive contracts to the battery supplier; Then the battery supplier decides the level of technology R&D investment by battery supplier and the selling price of the battery according to the incentive contract given by the vehicle manufacturer; Finally, the vehicle manufacturer decide the level of technology R&D investment by vehicle manufacture and the selling price of the whole vehicle.

Through cooperation, these two supply chain members jointly carry out technology R&D, so that the endurance mileage of the whole vehicle can be improved. What’s more, there is a market in which consumers prefer new energy vehicles with higher mileage. Assuming that the risk is neutral, the expected value of revenue or cost can be used as the target. The graphic abstract of the supply chain is as Figure 1.

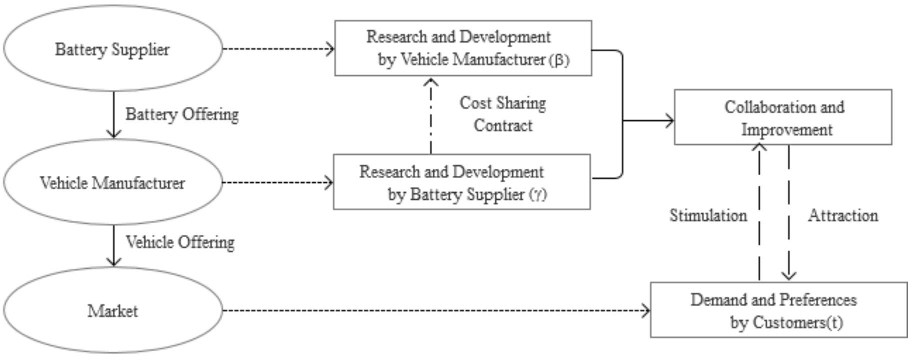

Fig. 1. Graphic Abstract of the Supply Chain. [Owner-draw]

4 Assumptions

Assumption 1. Both battery supplier and vehicle manufacturer invest in technology R&D, and the resulting costs refer to the research of GURNANI [10], in which the corresponding technology R&D investment costs of battery supplier and vehicle manufacturer are $\mathrm{T_b} = \frac{1}{2}\mathrm{m}\beta^2$,$\mathrm{T_v} = \frac{1}{2}\mathrm{n}\gamma^2$. Among them, the technology R&D cost coefficient by battery supplier and vehicle manufacture are m and n. The level of technology R&D investment by battery supplier and vehicle manufacture are β and γ,which reflects their behavior towards the technological improvement.

Assumption 2. Consumer awareness determines market demand, the market demand is $\mathrm{D} = \mathrm{a} - \mathrm{bp} + \mathrm{t}(\beta + \gamma)$, in which the original market size of new energy vehicle is a, selling price of the whole vehicle is p, the consumer price sensitivity coefficient is b, and the consumer preference coefficient for high mileage is t.

Assumption 3. Battery supplier invests in the battery technological R&D and supplies the battery to the vehicle manufacturer at the price of p_b and considering the production cost of the battery is p_c. The vehicle manufacturer sells the whole vehicle at the price of p. Considering that the production cost of the whole vehicle is $\mathrm{k}p_b$.The notations are provided in Table 1.

Table 1. Notations. [Owner-draw]

Parameters	Description
β	Level of technology R&D investment by battery supplier
γ	Level of technology R&D investment by vehicle manufacture
m	Technology R&D cost coefficient by battery supplier
n	Technology R&D cost coefficient by vehicle manufacture
a	Original market size of new energy vehicle
b	Consumer price sensitivity coefficient

p	Selling price of the whole vehicle
pb	Selling price of the battery
pc	Production cost of the battery
t	Consumer preference coefficient
ω	Proportion of cost-sharing by vehicle manufacture
1-ω	Proportion of cost-sharing by battery supplier
k	Reciprocal of the proportion of battery cost to whole vehicle production cost (k>1)

4.1 Decentralized Decision Model

Under decentralized decision model, when the two enterprises carry out technology R&D independently, they both make relevant decisions with the goal of maximizing their own profits. The profit functions of battery supplier and vehicle manufacturer are:

$$\pi_b^1 = (p_b - p_c)[a - bp + t(\beta + \gamma)] - \frac{1}{2}m\beta^2 \quad (1)$$

$$\pi_v^1 = (p - kp_b)[a - bp + t(\beta + \gamma)] - \frac{1}{2}n\gamma^2 \quad (2)$$

In this case, the order of the game between the battery supplier and the vehicle manufacturer is: firstly, the battery supplier decides its level of technology R&D investment β and the selling price of the battery p_b.Then the vehicle manufacturer, as the follower, decides its own level of technology R&D investment γ and the selling price of whole vehicle p according to the decision of battery supplier. Finally, the reverse solution method is used to solving the problem. The equilibrium solution is as shown in Table 2.

Table 2. Optimal values of the parameters in decentralized decision model. [Owner-draw]

Parameters	Values
p^*	$\frac{ka(m + bHm) - bkPc(bHkm - km + Ht2)}{b(2km - Ht^2)}$
γ^*	$\frac{Hkmt(a - bkp_c)}{n(2km - Ht^2)}$
${p_b}^*$	$p_c + \frac{m(a - bkp_c)}{b(2km - Ht^2)}$
β^*	$\frac{Ht(a - bkp_c)}{2km - Ht^2}$
π_b^1*	$\frac{Hm(a - bkPc)^2}{2(2km - Ht^2)}$

π_v^1*	$\frac{\mathrm{Hk^2m^2(a-bkPc)^2}}{\mathrm{2(2km-Ht^2)^2}}$
π_{sc}^1*	$\frac{\mathrm{m(a-bkPc)^2(2Hkm+Hk^2m-H^2t^2)}}{\mathrm{2(2km-Ht^2)^2}}$

4.2 Centralized Decision Model

Under centralized decision model, battery supplier and vehicle manufacturer are a whole, and they cooperate in technology R&D together.

$$\pi_{sc}=(p-kp_c)[a-bp+t(\beta+\gamma)]-\frac{1}{2}m\beta^2-\frac{1}{2}n\gamma^2 \quad (3)$$

Table 3. Optimal values of the parameters in centralized decision model. [Owner-draw]

Parameters	**Values**
p^{**}	$\mathrm{kp_c}+\frac{(\mathrm{a-bkp}_c)\mathrm{Hm}}{\mathrm{m-Ht^2}}$
γ^{**}	$\frac{\mathrm{m(a-bkp_c)(2bH-1)}}{\mathrm{t(m-Ht^2)}}$
β^{**}	$\frac{(\mathrm{a-bkp}_c)\mathrm{Ht}}{\mathrm{m-Ht^2}}$
π_{sc}^{**}	$\frac{\mathrm{(a-bkp_c)^2Hm}}{\mathrm{2(m-Ht^2)}}$

5 Comparative Analysis

Proposition 1. The impact of consumer preference t on level of technology R&D investment by battery supplier and vehicle manufacture and demand are as follows: $\frac{\partial\beta^*}{\partial t}>0$, $\frac{\partial\beta^{**}}{\partial t}>0$, $\frac{\partial\gamma^*}{\partial t}>0$, $\frac{\partial\gamma^{**}}{\partial t}>0$, $\frac{\partial D*}{\partial t}>0$, $\frac{\partial D**}{\partial t}>0$.According to proposition 1, both the level of technology R&D investment by battery supplier and vehicle manufacture increase following the increase of consumer preference coefficient. Meanwhile, the increase in demand of new energy vehicles is following the increase of consumer preference coefficient as well, which will promote the improvement of technology R&D.

Proposition 2. The impact of technology R&D cost coefficient m, n on level of technology R&D investment and demand are as follows:$\frac{\partial\beta^*}{\partial m}<0,\frac{\partial\gamma^*}{\partial m}<0,\frac{\partial D^*}{\partial m}<0$.According to proposition 2, the level of technology R&D investment and demand decreases with the increase of technology R&D cost coefficient. Strong technological innovation ability can bring higher market demand which can stimulate the innovation of technology R&D to meet consumers' needs, so as to expand the market.

Proposition 3.The impact of technology R&D cost coefficient m, n and consumer preference t on the profits are as follows: $\frac{\partial \pi_b^{1*}}{\partial t} > 0, \frac{\partial \pi_v^{1*}}{\partial t} > 0, \frac{\partial \pi_{sc}^{**}}{\partial t} > 0; \frac{\partial \pi_b^{1*}}{\partial m} < 0, \frac{\partial \pi_v^{1*}}{\partial m} < 0, \frac{\partial \pi_{sc}^{**}}{\partial m} < 0$.According to proposition 3, the profits of battery supplier and vehicle manufacturer increase with the increase of consumers' preference, and decrease with the increase of technology R&D cost coefficient. It shows that the increased investment in technology R&D can meet consumer demand and bring positive effects to the industrial chain.

6 Cost-sharing Contract

When making decentralized decisions, battery supplier and vehicle manufacturer only try to maximize their own interests, while the overall profit of the whole supply chain system is low, therefore it is necessary to formulate corresponding coordination mechanisms to maximize the interests of both sides. This paper adopts the cost-sharing contract to coordinate.

Cost sharing contract is a kind of prior contract due to the fact that batteries account for the largest proportion of the production cost of the whole vehicles, and batteries are also an important part of new energy vehicles. Under the cost-sharing contract, battery supplier and vehicle manufacturer jointly share the technology R&D investment costs of battery supplier. The proportion of cost-sharing by vehicle manufacture is $\omega\ (0 < \omega < 1)$ and the profit functions of battery supplier and vehicle manufacturer are:

$$\pi_b^3 = (p_b - p_c)[a - bp + t(\beta + \gamma)] - (1 - \omega)\frac{1}{2}m\beta^2 \quad (4)$$

$$\pi_v^3 = (p - kp_b)[a - bp + t(\beta + \gamma)] - -\frac{1}{2}n\gamma^2 - \omega\frac{1}{2}m\beta^2 \quad (5)$$

Under the cost-sharing contract, the decision-making order is as follows: firstly, the vehicle manufacturer provides the contract to the battery supplier, and the vehicle manufacturer decides the sharing proportion based on the principle of maximizing its own profits. Then the battery supplier decides the investment level of technology R&D and the selling price of battery according to the contract provided. The equilibrium solution is as shown in Table 4.

Table 4. Optimal values of the parameters in cost-sharing contract model. [Owner-draw]

Parameters	**Values**
p^{3*}	$\frac{ka(m + bHm)(\omega - 1) + bkp_c[Ht^2 - (bHkm - km)(\omega - 1)]}{b[2km(\omega - 1) + Ht^2]}$
γ^{3*}	$\frac{Hkmt(a - bkp_c)(\omega - 1)}{n[2km(\omega - 1) + Ht^2]}$

${p_b}^{3*}$	$\mathrm{p_c} + \frac{\mathrm{m(a - bkp_c)(\omega - 1)}}{\mathrm{b[2km(\omega - 1) + Ht^2]}}$
β^{3*}	$\frac{\mathrm{Ht(a - bkp_c)}}{\mathrm{2km - Ht^2 - 2km\omega}}$
π_b^3*	$\frac{\mathrm{Hm(a - bkPc)^2(\omega - 1)}}{\mathrm{2[2km(\omega - 1) + Ht^2]}}$
π_v^3*	$\frac{\mathrm{Hm(a - bkPc)^2[k^2m(\omega - 1)^2 - Ht^2\omega]}}{\mathrm{2[2km(\omega - 1) + Ht^2]^2}}$
π_{sc}^3*	$\frac{Hm(a - bkPc)^2[k^2m(\omega - 1)^2 + 2km(\omega - 1)^2 - Ht^2]}{2[2km(\omega - 1) + Ht^2]^2}$

We analyze the optimal values of cost-sharing contract model and some propositions are as follows.

Proposition 4. When the battery supplier's technology R&D cost coefficient meeting the condition $m > \frac{Ht^2}{2(1-k)}$, the cost-sharing proportion of vehicle manufacture is $\omega = \frac{-2km+2k^2m+Ht^2}{2m(k+k^2)}$ .According to proposition 4, when the technology R&D cost coefficient of the battery supplier is greater than a certain threshold, the vehicle manufacturer can share the technology R&D cost, and the sharing proportion is related to technology R&D cost coefficient of the battery supplier and the consumers' preferences.

7 Conclusions

Based on the background of 'declining subsidies policy', this paper mainly considers the technology research and development cooperation in the new energy vehicle supply chain, in which establishes a game model composed of a battery supplier, a vehicle manufacturer and consumers. This study analyzed the impact of enterprise technology R&D capabilities and consumer preferences on the decisions the supply chain.

The results show that: (1) The technological capabilities of enterprises and consumer preferences have an interactive impact on the level of technological investment. (2) When consumer preferences increase, the level of technology R&D investment an increasing trend. (3) Cost-sharing contract can realize the coordination of the whole supply chain. The proportion of cost sharing is affected by consumer preferences and the technological capabilities of enterprises. (4) With the increase of vehicle manufacturer's share proportion of battery supplier's technology R&D cost, it increases the respective profits of supply chain members.

The contribution of this paper is: the cooperation between upstream and downstream enterprises in the new energy vehicle supply chain is conducive to win-win, and it is the future development direction of the industrial chain. Cooperation in technology R&D can not only help improve the technology ability, but also improve the respective benefits of supply chain members. This incentive effect based on market guidance can promote the independent innovation of the industrial chain, so as to attract consumers, expand the market, and form a virtuous cycle of the industrial chain.

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