Advances in Engineering Research : Possibilities and Challenges
ISSN Print: 3079-5192
ISSN Online: 3079-5206
https://doi.org/10.63313/AERpc.9033

Influence of power battery improvement on the choice of competition and cooperation strategy of electric vehicle manufacturers

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How to cite this paper: Qin, Y. F., & Shi, J. N. (2025). Influence of power battery improvement on the choice of competition and cooperation strategy of electric vehicle manufacturers. Advances in Engineering Research: Possibilities and Challenges, 2(1), 16-25. ISSN Print: 3079-5192; ISSN Online: 3079-5206.
https://doi.org/10.63313/AERpc.9033
Published: 2025-07-11

Abstract

Under the background of process improvement of electric vehicle power bat-tery, this paper explores the impact of different competition and cooperation strategies of electric vehicle manufacturers on the pricing and profits of electric vehicle manufacturers. A system model including two electric vehicle manufac-turers (one with power battery technology and one without power battery technology) and a battery manufacturer with only power battery technology is constructed. The model is solved by using the inverse method, and the influence of factors such as power battery investment efficiency on the manufacturer's strategy selection is analyzed. The results show that: with the increase of in-vestment efficiency of suppliers, the investment effect of manufacturers with power battery technology decreases, regardless of the competition mode or the cooperation mode; Manufacturers with power battery technology usually have higher profits in the competition and cooperation mode than in the competition mode. The mode choice of manufacturers who lack power battery technology is affected by investment efficiency: when the investment efficiency is high, they tend to choose the competition and cooperation mode; When the investment efficiency is low, it tends to be competitive.

Keywords

game model; investment efficiency; coopetition strategy; profit maximization

1. Introduction

As "carbon neutrality" has become a global consensus, China has also incorporated it into the overall layout of ecological civilization. Vigorously developing electric vehicles is one of the core measures for China to implement the "double carbon" action . As the "heart" of electric vehicles, the cost of power batteries accounts for 40% to 60% of the total vehicle cost . Because of the high technical barriers, long research and development cycle and uncertainty of power batteries, many electric vehicle manufacturers have to give up the research and development of power batteries and choose to purchase batteries from power battery suppliers . Therefore, the procurement of power batteries has become an important challenge for electric vehicle manufacturers.

At the initial stage of the promotion of electric vehicles, the main theme of the supply and demand relationship in the power battery market is that car companies purchase power batteries from battery manufacturers . However, BYD relies on the advantages of self-developed batteries and vehicle manufacturing to compete with electric vehicle manufacturers and battery manufacturers. The power battery adopts the mode of self production and self marketing to maximize profits . As traditional and emerging car companies enter the electric vehicle market, some electric vehicle manufacturers choose to buy batteries from battery suppliers such as Ningde times and GuoXuan high tech, which has promoted the increase of market share of battery suppliers such as Ningde times. BYD electric vehicles' market share continues to decline due to the challenges of competitors, resulting in the revenue from battery business lagging behind competitors . Data show that in 2023, Ningde era's market share in the power lithium battery market was 42.7%, and BYD's market share was 30.1% . To improve this situation, BYD must change its battery supply strategy from self-produced and self sold to selling power batteries to competitors. In fact, BYD has implemented the external supply strategy in 2021, and quickly won the favor of other car companies in the market with high safety and high quality blade batteries . For example, FAW Hongqi, Chang'an, Jinkang and BAIC have been equipped with blade batteries ; Although the competition and cooperation strategy can improve the core competitiveness of car companies with power battery technology and other car companies. However, because the market demand is limited, the adoption of competition and cooperation strategy may also have a negative impact on vehicle enterprises with power battery technology and other vehicle enterprises. Therefore, whether to carry out the competition and cooperation mode based on the power battery has become a problem faced by electric vehicle manufacturers and other vehicle enterprises with power battery technology.

With the increasing competition in the power battery market, it is urgent for enterprises to improve their core competitiveness. Only by innovating and improving the power battery can enterprises occupy a higher market share and obtain more orders from electric vehicle enterprises, and even stand out in the increasingly competitive market [1]. Therefore, R&D and innovation of power battery suppliers has become an inevitable choice for them to enhance their competitiveness. When vehicle enterprises with power battery technology innovate and improve power batteries, it may improve the performance of power batteries and enable enterprises to obtain more orders for power batteries from vehicle enterprises; When battery suppliers with only power battery technology carry out innovation and improvement of power batteries, they may produce more power batteries and intensify the fierce competition of vehicle enterprises; Therefore, how the innovation and improvement of power battery affect the choice of competition and cooperation strategy of electric vehicle manufacturers is also of certain significance.

At present, scholars have conducted extensive research on the competition and cooperation relationship between enterprises. For example, some scholars pay attention to the competition and cooperation between OEM and its upstream and downstream enterprises in the process of product production. Wu et al. [2] examined the entry decisions of two competitive platform owners with differentiated R&D efficiency and the response strategies of original equipment manufacturers (OEMs) when choosing which platform to cooperate with, and analyzed the interaction between the entry decisions of platform owners and the response strategies of OEMs under the two cooperation modes. At the same time, scholars have also studied the competition and cooperation relationship among horizontal competitive enterprises. For example, Peng et al. [3] built a competitive game model between two manufacturing service integrators (MSI) on service price, service level and service innovation investment, and found that the cooperation between manufacturing service integrators and competitors in service innovation can provide higher quality services. Song and Yan [4] studied the optimal operation decision of the green supply chain of two manufacturers under different competition and cooperation relationships by comprehensively considering the influence of government subsidies, consumers' green preferences and green information trust.

At present, the research on supply chain technology innovation is relatively rich. For example, Du et al. [5] analyzed the importance of cooperative investment contracts between suppliers and manufacturers to sustainable innovation through the Stackelberg game model. Lu et al. [6] used the method of competition and cooperation to study the technological innovation decision of supply chain. Zhang et al. [7] proposed a reasonable income distribution system for supply chain collaborative innovation by using Shapley value method. Li and zhao[8] proved that without innovation and improvement, the cooperation between OEM and competitive suppliers does not exist. When suppliers innovate and improve, competitive suppliers tend to cooperate. Scholars' research on the technological innovation of automobile supply chain mostly focuses on the influencing factors and internal mechanism, mainly using the methods of system dynamics and game theory. For example, Li et al. [9] used the system dynamics method to analyze the influencing factors of the technological innovation ability of the automotive industry. Li et al. [10] used the three-stage dynamic game model to explore the relationship between technology diffusion, innovation performance and technology R&D in the automotive industry. Deng[11] used game theory to explore the internal mechanism of technological innovation in automotive industry clusters.

This paper constructs a game model under the competition and cooperation mode for the system composed of an electric vehicle manufacturer with power battery technology, an electric vehicle manufacturer without power battery technology and a manufacturer with only power battery technology. According to the two models, the model is built and the equilibrium solution is obtained. The impact of the degree of substitution of electric vehicles and the efficiency of power battery technology improvement on the pricing and profits of electric vehicles is analyzed. The impact of different competition and cooperation strategies on supply chain members is explored, so as to provide the best decision for them.

2. Problem Description and Model Assumptions

Considering the system composed of two competitive electric vehicle manufacturers and a battery manufacturer with only power battery technology, the electric vehicle manufacturer lacking power battery technology in the two competitive electric vehicle manufacturers is recorded as "electric vehicle manufacturer 1", the electric vehicle manufacturer with power battery technology is recorded as "electric vehicle manufacturer 2", and the battery manufacturer with only power battery technology is recorded as "battery manufacturer". The electric vehicle manufacturer 1 needs to purchase batteries from either the electric vehicle manufacturer 2 or the battery manufacturer to complete the manufacturing of electric vehicles, and it is assumed that the unit battery cost of the two battery suppliers is the same. Two modes are considered: (1) competition and cooperation mode: the electric vehicle manufacturer 1 purchases automotive batteries from the electric vehicle manufacturer 2, and the two manufacturers have a cooperative relationship in the form of wholesale price of power batteries in upstream activities. There is a competitive relationship in the electric vehicle market, that is, the electric vehicle manufacturer 1 purchases power batteries from the manufacturer 2 at the wholesale price w ($\mathrm{w} < c$), and the manufacturer 2 produces power batteries at the cost C. the two manufacturers choose their vehicle output respectively. (2) Competition mode: there is only competition between the two electric vehicle manufacturers in the electric vehicle market, in which the electric vehicle manufacturer 1 purchases batteries from non competitive battery manufacturers at the wholesale price W, the battery manufacturer produces power batteries at the cost C, and the two manufacturers choose their vehicle production respectively.

In this paper, the electric vehicles produced by manufacturer 1 and manufacturer 2 are substitutes for each other, so it is assumed that manufacturer 1 and manufacturer 2 conduct Cournot competition based on the output of electric vehicles, and their vehicle prices are jointly determined by their output of electric vehicles. According to the literature, the following anti demand function based on horizontal product differences is used:

$$p_i = -\beta q_j + \alpha - q_i, i, j = o, m, i \neq j \tag{1}$$

In this paper, electric vehicle manufacturer 2 and battery manufacturer invest in battery technology to reduce the unit production cost and technology improvement of power battery. By using x_m and x_n to represent the cost reduction and technical improvement effect achieved by manufacturer 2 and battery manufacturer respectively, according to the literature, the incremental function $kx_m^2/2$ and $kx_n^2/2$ can be used to model the implementation x_m and x_n, where $k>0$, represents the investment efficiency. The higher the investment efficiency, the lower the investment efficiency, which means that to achieve the same effect needs to pay more costs. k indicates the cost affecting the process improvement of the battery, and represents the R&D and production technology capacity of the battery. In order to avoid the results caused by different investment efficiency, it is assumed that two battery suppliers have the same cost parameters k. The symbols and definitions in the model are shown in Table 1

Table 1. Parameter symbols

symbols	definition
α	Maximum retail price of electric vehicles
β	Degree of substitution between two types of electric vehicles $\beta \in (0,1)$
c	Unit power battery production cost of manufacturer 2 and battery manufacturer
w^S	Manufacturer 1 wholesales the wholesale price of unit battery from manufacturer 2 or battery manufacturer respectively $S \in (C,N)$
p_i	Complete vehicle price of electric vehicle manufacturer 1 and manufacturer 2 $i \in (o,m)$
q_i	Vehicle market demand of electric vehicle manufacturer 1 and manufacturer 2 $i \in (o,m)$
k	Investment efficiency of electric vehicle battery
u	Proportion of government subsidies for technological innovation $(0<u<1)$
x_m	Manufacturer 2 realizes the effect of cost reduction and technical improvement
x_n	Battery manufacturers realize the effect of cost reduction and technical improvement
π_o^S	Profit of electric vehicle manufacturer 1 in competition and cooperation mode $S \in (C,N)$
π_{cs}^S	Profit of electric vehicle manufacturer 2 in competition and cooperation mode $S \in (C,N)$
π_{ns}^N	Profit of battery manufacturers in competitive mode

Superscript "C" stands for competition and cooperation mode, and superscript "N" stands for competition mode

3. Model Construction and Solution

3.1. Concurrence mode

In the competition cooperation mode, the decision sequence is: (1) electric vehicle manufacturer 1 (manufacturer 2) decides to purchase (sell) components from manufacturer 2 (manufacturer 1); (2) Manufacturer 2 determines the investment level of power battery according to the fierce competition in the electric market; (3) Manufacturer 2 determines the wholesale price of its power battery; (4) Electric vehicle manufacturer 1 and manufacturer 2 simultaneously determine the vehicle production q_o and q_m.

The profit function of manufacturer 1 is:

$$\pi_o^{C*} = \left(-\beta q_m^{C*} + \alpha - q_o^{C*} - w^{C*}\right) q_o^{C*} \tag{2}$$

The profit function of manufacturer 2 is:

$$\pi_{cs}^{C*} = \left(-\beta q_o^{C*} + \alpha - c - q_m^{C*} + x_m\right) q_m^{C*} + \left(w^{C*} - c + x_m\right) q_o^{C*} - \frac{(1-u) k x_m^2}{2} \tag{3}$$

3.2. Competitive model

In the competition mode, the decision sequence is: (1) the electric vehicle manufacturer 1 decides to purchase power batteries from the battery manufacturer; (2) Electric vehicle manufacturer 2 and battery manufacturer decide the investment level of power battery at the same time; (3) The battery manufacturer determines the wholesale price of its power battery; (4) Electric vehicle manufacturer 1 and manufacturer 2 simultaneously determine the vehicle production q_o and q_m.

The profit function of manufacturer 1 is:

$$\pi_o^{N*} = \left(-\beta q_m^{N*} + \alpha - q_o^{N*} - w^{N*}\right) q_o^{N*} \tag{4}$$

The profit function of manufacturer 2 is:

$$\pi_{cs}^{N*} = \left(w^{N*} - c + x_m^{N*}\right) q_o^{N*} - \frac{(1-u) k (x_m^{N*})^2}{2} \tag{5}$$

The profit function of the battery manufacturer is:

$$\pi_{ns}^{N*} = \left(w^{N*} - c + x_n^{N*}\right) q_o^{N*} - \frac{(1-u) k (x_n^{N*})^2}{2} \tag{6}$$

Profit letter of battery manufacturer in practice, in order to ensure that the cost reduced through technological innovation does not exceed the manufacturing cost of the original power battery, it is necessary to meet $k^C > \frac{(-6+\beta)(-2+\beta)}{2\left(3\beta^2 - 8\right)(-1+u)}$ in the concurrence mode and $k^N > \frac{\beta^2 - 8}{2(2+\beta)(-2+\beta)^2(-1+u)}$ in the competitive mode, $k > \underline{k} = \max\{k^C, k^N\}$.

The model is solved by using the inverse method, and the optimal decision of competition and cooperation mode is obtained.

The optimal battery improvement effect of electric vehicle manufacturer 2 in the competition and cooperation mode is:

$$\frac{(\beta-2)(\beta-6)(\alpha-c)}{6\beta^2 ku - 6\beta^2 k - \beta^2 - 16ku + 8\beta + 16k - 12} \tag{7}$$

The optimal battery improvement effect of electric vehicle manufacturer 2 in the competitive mode is:

$$-\frac{\left(\beta^2-8\right)\left(-2+(\beta+4)(\beta-2)(u-1)k\right)(\alpha-c)}{8(\beta-2)^2(\beta+2)^2(u-1)^2 k^2 + \left(\beta^4 - 24\beta^2 + 96\right)(u-1)k - 2\beta^2 + 16} \tag{8}$$

The optimal battery improvement effect of battery manufacturers in the competitive mode is:

$$-\frac{2\left(2(\beta+2)(\beta-2)^2(u-1)k-\beta^2+8\right)(\alpha-c)}{8(\beta-2)^2(\beta+2)^2(u-1)^2k^2+\left(\beta^4-24\beta^2+96\right)(u-1)k-2\beta^2+16} \tag{9}$$

The profit of electric vehicle manufacturer 1 under the competition and cooperation mode is:

$$\frac{16k^2(u-1)^2(\beta-1)^2(\alpha-c)^2}{\left(6\beta^2ku-6\beta^2k-\beta^2-16ku+8\beta+16k-12\right)^2} \tag{10}$$

The profit of electric vehicle manufacturer 1 in the competitive mode is:

$$\frac{4k^2(u-1)^2\left(2(\beta+2)(\beta-2)^2(u-1)k-\beta^2+8\right)^2(\alpha-c)^2}{\left(8(\beta-2)^2(\beta+2)^2(u-1)^2k^2+\left(\beta^4-24\beta^2+96\right)(u-1)k-2\beta^2+16\right)^2} \tag{11}$$

The profit of electric vehicle manufacturer 2 under the competition and cooperation mode is:

$$-\frac{k(u-1)(\alpha-c)^2(\beta-2)(\beta-6)}{2\left(6\beta^2ku-6\beta^2k-\beta^2-16ku+8\beta+16k-12\right)} \tag{12}$$

The profit of electric vehicle manufacturer 2 in the competitive mode is:

$$\frac{k(u-1)\left(-2+(\beta+4)(\beta-2)(u-1)k\right)^2(\alpha-c)^2\left(8(\beta-2)^2(\beta+2)^2(u-1)k+\beta^4-16\beta^2+64\right)}{2\left(8(\beta-2)^2(\beta+2)^2(u-1)^2k^2+\left(\beta^4-24\beta^2+96\right)(u-1)k-2\beta^2+16\right)^2} \tag{13}$$

3.3. Equilibrium analysis

Proposition1: (1) $\frac{dx_m^{C*}}{dk}<0$; $\frac{dx_m^{N*}}{dk}<0$; $k^N<k<k_1$, $\frac{dx_n^{N*}}{dk}>0$; (2) $\frac{dx_m^{C*}}{d\beta}<0$; $\frac{dx_n^{N*}}{d\beta}<0$; when $\beta\le\beta_1$ and $k^N<k<k_2$, $\frac{dx_m^{N*}}{d\beta}>0$,or when $\beta>\beta_1$, $\frac{dx_m^{N*}}{d\beta}>0$.

Proposition 1 (1) shows that the investment effect of manufacturer 2 decreases with the increase of supplier investment efficiency (k) in both competitive and cooperative modes. With the increase of investment efficiency (k), the innovation of power battery technology and the reduction of the same cost require greater investment effect of manufacturer 2. Therefore, when the investment efficiency (k) increases, manufacturer 2 will reduce the investment effect (x_m^{C*}). However, when the battery manufacturer k is small, the investment effect increases with the increase of k , and when k is greater than the critical value k_1 , the investment effect decreases with the increase of k . This is because when the investment efficiency is high in the competitive mode, manufacturer 2 and battery manufacturer have greater motivation to increase the investment level, and they form a fierce competitive relationship in the battery market. With the decrease of investment efficiency, the lower investment efficiency will reduce the competition intensity between manufacturer 2 and battery manufacturer. When the investment efficiency is greater than the critical value, battery manufacturer has the motivation to increase the battery investment effect with the decrease of investment efficiency, so that manufacturer 1 can occupy more market share, so as to increase the advantage of battery manufacturer in the market.

Proposition2: when $\beta > \beta_2$,if $\underline{k} < k \le k_3$,then $x_m^{N*} > x_m^{C*} > x_n^{N*}$; otherwise $x_m^{C*} > x_m^{N*} > x_n^{N*}$.

Proposition 2 shows that the battery improvement effect of electric vehicle manufacturer 2 in competition mode and cooperation mode is affected by the investment efficiency and the degree of electric vehicle substitution. When the degree of electric vehicle substitution and investment efficiency are large, the investment effect of electric vehicle manufacturer 2 in competition mode is higher than that in cooperation mode. The reason is that in the competition and cooperation mode, electric vehicle manufacturer 1 wholesales power batteries from manufacturer 2, and the sales of additional components with manufacturer 1 urge it to increase investment to improve production efficiency. At the same time, increasing investment enables manufacturer 1 to produce more electric vehicles at a lower cost, and forms a competitive relationship with manufacturer 2 in the electric vehicle market. When the degree of substitution of electric vehicles is greater and the investment efficiency of batteries is greater, the benefits brought by the increase of battery improvement effect are greater than the losses caused by fierce market competition. At this time, manufacturer 2 is willing to make more investment in the competition mode. When the battery investment efficiency is lower, the fierce competition and the difficulty of improving the battery effect increase, so that the income from manufacturer 2's investment is less than that from selling batteries to manufacturer 1. At this time, manufacturer 2 is more inclined to increase investment in the competition and cooperation mode.

4. Choice of competition and cooperation strategy

Proposition2: (1) $\pi_{cs}^{C*} > \pi_{cs}^{N*}$; (2)if $\underline{k} < k \le k_4$,then $\pi_o^{C*} > \pi_o^{N*}$; otherwise $\pi_o^{C*} < \pi_o^{N*}$.

Proposition 3 shows that manufacturer 2's profit in the competition mode is always less than that in the competition and cooperation mode, which means that suppliers prefer to choose the competition and cooperation mode when improving battery investment, and manufacturer 1 will also prefer the competition and cooperation mode when the investment efficiency is high. According to Proposition 2, the investment effect of electric vehicle manufacturer 2 is always higher than that of battery manufacturer. When the investment efficiency is high, manufacturer 2 is more likely to achieve a breakthrough in battery technology improvement. At this time, the profit of electric vehicle manufacturer 1 choosing the competition and cooperation mode is higher. Proposition 3 also shows that although manufacturer 1 will choose the competition and cooperation mode when the investment efficiency is high, it will still choose the competition mode in other cases. It is not difficult to understand that there is a competitive relationship between electric vehicle manufacturer 1 and manufacturer 2 in the automotive market, and choosing the competition and cooperation mode may help manufacturer 2 occupy more market shares, thus damaging its own profits.

Figure 1 shows the impact of power battery investment efficiency and electric vehicle replacement degree on the optimal strategy selection of electric vehicle manufacturer 1. Region I in Figure 1 shows that the total profit of manufacturer 1 in the competitive mode is greater than that in the competitive mode, and region 2 shows that the total profit of manufacturer 1 in the competitive mode is greater than that in the competitive mode. In other words, when the investment efficiency is high, if the degree of substitution of electric vehicles is low, the two manufacturers will choose the competition and cooperation strategy at the same time. If the degree of substitution of electric vehicles is high, manufacturer 1 may choose the competitive mode. Specifically, as the degree of substitution increases, the threshold gradually decreases, and the probability of manufacturer 1 choosing the competitive mode increases, while the probability of choosing the competitive mode decreases. This conclusion is consistent with the management practice in the electric vehicle industry. For example, Toyota focuses on hybrid technology, while sport utility vehicle is the professional field of Ssangyong. Compared with BYD in the field of pure electric vehicles, they are less replaceable. When the investment efficiency is not very high, BYD and Toyota and Ssangyong carry out the competition and cooperation mode. In contrast, Tesla focuses on the field of pure electric vehicles and is the main competitor of BYD. Therefore, BYD and Tesla carry out a competitive model.

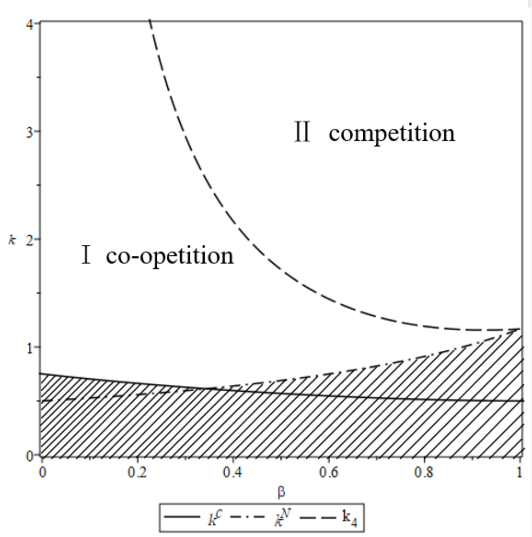

Figure 1. Electric vehicle manufacturer 1 strategy selection

5. Conclusion

This paper discusses the optimal strategy selection of electric vehicle manufacturers' competition and cooperation under the background of government subsidies for electric vehicle power battery process improvement. The study found that:

(1) The profit of electric vehicle manufacturer 2 in the competition and cooperation mode is still greater than that in the competition mode, but the mode choice of electric vehicle manufacturer 1 is affected by the investment efficiency. When the investment efficiency is high, electric vehicle manufacturer 1 will choose the competition and cooperation mode. If the investment efficiency is low, manufacturer 1 will also choose the competitive mode.
(2) The choice of the optimal strategy is determined by the degree of substitution of electric vehicles, the investment efficiency of power batteries and the proportion of government subsidies. Among them, power battery investment efficiency is the primary factor affecting the optimal strategy choice of electric vehicle manufacturers
This paper analyzes the strategic choice between two electric vehicle manufacturers and a battery manufacturer. It is assumed that the market demand for electric vehicles is deterministic, but the uncertainty in the market is also an important factor affecting the strategic choice.

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