Research on competition and investment strategy of electric vehicle charging and replacement mode

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Abstract. Based on consumers' different value preferences for EV charging and swapping battery, a tripartite game model is constructed from the perspective of EV manufacturers and swapping battery station builders to reveal the optimal decision under the competition between charging mode and swapping battery mode. By comparing the profit level and the number of swapping battery stations before and after the joining of swapping battery station builders, this paper explores the influence of swapping battery station hypothesis outsourcing on swapping battery vehicle manufacturers. The study found that although the construction of outlay swapping battery station can not increase the profits of swapping battery vehicle manufacturers, it can reduce the profits of charging vehicle manufacturers. When outsourcing, it is necessary to fully consider the appropriate dividend ratio to ensure the profit level of the swapping battery vehicle manufacturer.

Keywords: New energy vehicles, range anxiety, mode choice, swapping battery mode, game theory.

1 Introduction

The development of electric vehicles is an important measure to optimize the energy structure, improve the ecological environment, and help the sustainable development of cities. In the development of electric vehicles, how to supplement energy has always been a problem under discussion. At present, the charging mode dominates the market, and charging piles have been laid in most areas. However, it still has the problem of long charging time and range anxiety among consumers. In order to solve the above problems, the swapping battery model has developed under the support of national policies, and it has quickly seized a part of the market with the advantages of fast replenishment speed, showing great potential. Therefore, it is of great significance to study the operation and decision-making of the swapping battery mode to promote the development of China's electric vehicle industry and drive the sustainable development of society.

At present, domestic and foreign decision-making research on electric vehicles mainly focuses on two aspects: consumer choice and government subsidies. Lim et al.

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(2015)[1] considered resale anxiety and range anxiety, built a consumer utility model based on the heterogeneity of consumers, studied the impact of resale anxiety and range anxiety on the promotion of new energy electric vehicles, and proposed that the generation of anxiety would damage corporate profits, but could improve consumer surplus to a certain extent. Acvi (2012)[2] studied the impact of the emergence of power conversion mode in the market, from the perspective of the different impacts of the simultaneous emergence of fuel vehicles and charging mode or fuel vehicles and power conversion mode in the market, and compared the differences between the two business models. Schuitema et al. (2013)[3] studied the impact of consumers' perception of vehicle attributes on their willingness to use new energy vehicles, and believed that factors such as performance, driving pleasure and perception of symbolic meaning of new energy vehicles affected consumers' acceptance of new energy vehicles. Schneider et al. (2014)[4] analyzed the early user group data of new energy vehicles in Germany, and the research results showed that factors such as age, gender, living area and work type would affect consumers' purchase intention of new energy vehicles.

Gnann et al. (2015)[5] and Rijnsoevre et al. (2013)[6] respectively studied the impact of German policies and Dutch subsidy policies on the promotion, application and industrial development of new energy vehicles. Sakamot et al. (2016)[7]theoretically analyzed the impact of fiscal subsidies provided by the government on the adoption of new energy vehicles, and believed that fiscal subsidy policies were conducive to the popularization of new energy vehicles. Hao et al. (2014)[8] studied the issue of subsidies for new energy vehicles in China, proposed the basic principle of government subsidies in two stages, and estimated the impact of subsidy policies on the promotion of new energy vehicles.

Most of the above literatures take the charging mode as the research object, and rarely involve the swapping battery mode. It does not consider the operation strategy of the swapping battery mode under the competition of the charging mode. Based on the development status of electric vehicles, this paper constructs the Steinberg game model to simulate the competition between charging vehicle manufacturers and swapping battery vehicle manufacturers, and obtains the optimal pricing strategy of the two manufacturers.

2 Model

Consider a competitive market with charging vehicles manufacturers (firm A) and swapping battery vehicles manufacturers (firm B). The charging vehicles manufacturers only produce and sell charging vehicles, which will provide consumers with a basic functional value v. Because the charging infrastructure is now more complete, we do not consider the construction cost of its charging infrastructure. The swapping battery vehicle manufacturers only produce and sell swapping battery vehicles, which can not only provide functional value v to consumers, but also provide convenience to consumers by building switching power stations. The firm incurs a development cost $\frac{1}{2}km^2$ to increase the number of changing stations m The firm B does not necessarily need to undertake the construction of the swapping battery station itself. It can outsource the construction of the swapping battery station to a third-party swapping batter station construction company (firm C) and give it α percentage of profit.

Assuming that consumers are heterogeneous in functional value v, which follows a uniform distribution over [0,1].The utility of consumers buying a charging vehicles is $u_c^i = \delta v - p_c^i$.The top corner i indicates which mode you are in.Which p_c^i refers to the price of the charging vehicle, δ is the impact of range anxiety on the functional value v. The greater the range anxiety, the smaller the consumer's total valuation of the charging vehicles. The utility of consumers buying a swapping battery vehicle is$u_s^i = v - p_s^i + \beta m$, where p_s^i is the price of the electric replacement vehicle,β is the convenience factor of the power station, the more number of swapping battery station m, the more consumers feel the convenience of buying swapping battery vehicles.

In the model, the new energy vehicle enterprises all aim to maximize profits. In the competition without firm C, firm A, as the market leader, sets the price first, and the firm B then decides on the price of the swapping battery vehicles and the number of swapping battery stations at the same time. When firm C joins the competition, firm C decides the number of swapping battery stations to be built, and firm A and firm B decide the prices of charging vehicles and swapping battery vehicles at the same time. Therefore, this paper builds a Stackelberg game model to simulate the competition among new energy vehicle manufacturers.

2.1 No firm C

When firm C did not join the market, firm B independently undertook the construction of the swapping battery station to provide replacement service. when $u_s^1 > u_c^1, u_s^1 > 0$,consumers buy swapping battery cars,and v ∈ $[\frac{p_s^1 - p_c^1 - \beta m}{1-\delta}, 1]$.when $u_c^1 > u_s^1, u_c^1 > 0$,consumers buy charging vehicles,and v ∈ $[\frac{p_c^1}{\delta}, \frac{p_s^1 - p_c^1 - \beta m}{1-\delta}]$.So we can figure out that the number of the two models is:

$$d_s^1(p_s^1, p_c^1, m^1) = 1 - \frac{p_s^1 - p_c^1 - \beta m}{1-\delta} \tag{1}$$

$$d_c^1(p_s^1, p_c^1, m^1) = \frac{p_s^1 - p_c^1 - \beta m}{1-\delta} - \frac{p_c^1}{\delta} \tag{2}$$

Therefore, the profit of charging car manufacturers and switching car manufacturers is:

$$R_s^1 = p_s^1 d_s^1 - \frac{1}{2} k m^2 \tag{3}$$

$$R_c^1 = p_c^1 d_c^1 \tag{4}$$

In order to solve the Steinkolberg model, according to backward induction, the optimal pricing of firm A and firm B is solved at the same time, and then the optimal investment strategy of company B is solved. It can be seen through analysis, when $k > \frac{\beta^2}{1-\delta}$,The optimal pricing and the optimal number of swapping battery stations are

$$p_c^{1*} = \frac{\delta((\delta-1)k+\beta^2)}{(2\delta-4)k+2\beta^2} \tag{5}$$

$$p_s^{1*} = \frac{-k(\delta-1)(k(\delta^2-5\delta+4)+\beta^2(\delta-2))}{4(\delta-2)(\delta-1)k^2+\beta^2k(6\delta-8)k+2\beta^4} \tag{6}$$

$$m^{1*} = \frac{\beta((\delta^2-5\delta+4)k+\beta^2(\delta-2))}{4(\delta-2)(\delta-1)k^2+\beta^2k(6\delta-8)k+2\beta^4} \tag{7}$$

Substitute equations 5,6 and 7 into equations 3 and 4,the optimal profit available is:

$$R_c^{1*} = \frac{(k(\beta-1)+\beta^2)^2\delta}{4(4(\delta-2)k+\beta^2)(2k(\delta-1)+\beta^2)} \tag{8}$$

$$R_s^{1*} = \frac{-k(k(\delta^2-5\delta+4)+\beta^2(\delta-2))^2}{8(4(\delta-2)k+\beta^2)(2k(\delta-1)+\beta^2)} \tag{9}$$

2.2 Firm C's entry

Let's apply the sales function from the previous chapter. In this chapter, firm C will build the swapping battery station and share the profits of firm B. The profit function of the three companies is

$$R_s^2 = p_s^2 d_s^2 (1-\alpha) \tag{10}$$

$$R_c^2 = p_c^2 d_c^2 \tag{11}$$

$$R_b^2 = p_s^2 d_s^2 \alpha - \frac{1}{2} k m^2 \tag{12}$$

In order to solve the 3-level Stankelberg model, according to backward induction, the optimal investment strategy of firm C is solved first, and then the optimal pricing of firm A and company B is solved. It can be seen through analysis that when $k > \frac{2\alpha\beta^2(2-\delta)}{(4-\delta)(1-\delta)}$,the optimal pricing and the optimal number of swapping battery stations are

$$p_c^{2*} = \frac{\delta(\delta-1)(\delta(2\alpha\beta^2-5k)-4\alpha\beta^2+k(4+\delta^2))}{k\delta^2+\delta^2(2\alpha\beta^2-9k)+\delta(24k-8\alpha\beta^2)+8\alpha\beta^2-16k} \tag{13}$$

$$p_s^{2*} = \frac{2k(\delta-4)(\delta-1)^2}{k\delta^2+\delta^2(2\alpha\beta^2-9k)+\delta(24k-8\alpha\beta^2)+8\alpha\beta^2-16k} \tag{14}$$

$$m^{2*} = \frac{-4\alpha\beta(\delta-2)(\delta-1)}{k\delta^2+\delta^2(2\alpha\beta^2-9k)+\delta(24k-8\alpha\beta^2)+8\alpha\beta^2-16k} \tag{15}$$

Substitute the optimal solution into the profit function.

$$R_c^{2*} = \frac{\delta(1-\delta)(k(4+\delta^2)-4\alpha\beta^2+\delta(2\alpha\beta^2-5k))^2}{(k\delta^2+\delta^2(2\alpha\beta^2-9k)+\delta(24k-8\alpha\beta^2)+8\alpha\beta^2-16k)^2} \tag{16}$$

$$R_s^{2*} = \frac{4k^2(\alpha-1)(\delta-1)^3(\delta-4)^2}{(k\delta^2+\delta^2(2\alpha\beta^2-9k)+\delta(24k-8\alpha\beta^2)+8\alpha\beta^2-16k)^2} \tag{17}$$

$$R_b^{2*} = \frac{4k\alpha(1-\delta)^2}{k\delta^2+\delta^2(2\alpha\beta^2-9k)+\delta(24k-8\alpha\beta^2)+8\alpha\beta^2-16k} \tag{18}$$

3 Analysis

Proposition 1. The entry of firm c hurts the profits of firm b and increases the profits of firm A. Mathematically, we have $R_c^{1^*} > R_c^{2^*}$and.$R_s^{1^*} < R_s^{2^*}$.

The proposition shows that when the swapping battery vehicles manufacturer independently undertakes the construction of the swapping battery station, it can simultaneously decide the construction quantity of the swapping battery station and the price of the swapping battery vehicle, which can achieve the global optimal and maximize the total profit. This is in line with reality. In daily life, most of the manufacturers, such as NIO, choose to build their own swapping battery stations, and adjust the price of the vehicles through the construction cost of the swapping battery station, in order to obtain the maximum profit to offset the cost of operating the swapping battery station. The proposition also shows that the independent construction of the swapping battery station by the firm B can reduce the profits of competitors (firm A), so when the range anxiety is low and the competition is more intense, the strategy of independent construction of the firm B is more suitable.

Proposition 2 (i)When firm c does not enter, with the increase of the convenience coefficient of the swapping battery station, the profits of the firm B first decline and then increase. Mathematically, we have $\frac{\partial R_s^{2^*}}{\partial \beta} < 0$ when $\beta < \frac{\sqrt{(2-\delta)k(\delta^2-5\delta+4)}}{2-\delta}$ and $\frac{\partial R_s^{2^*}}{\partial \beta} > 0$when $\beta > \frac{\sqrt{(2-\delta)k(\delta^2-5\delta+4)}}{2-\delta}$.

(ii)when firm c enter, with the increase of the convenience coefficient of the swapping battery station, the profits of the firm B increase. Mathematically, we have $\frac{\partial R_s^{2^*}}{\partial \beta} > 0$.

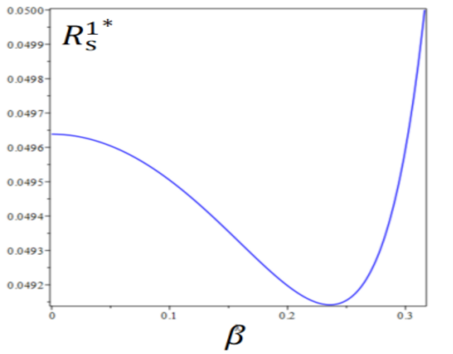

Fig. 1. The influence of convenience coefficient of swapping battery station on profit of Company B.

As shown in Fig.1, the proposition shows that when the firm C enters, the impact on the firm B is non-monotonic, showing a trend of first decreasing and then increasing. The larger β is, the greater the utility brought by the construction of each swapping battery station, the more people want to buy swapping battery vehicles, the price is relatively higher, and the profit should continue to grow. But β is at a younger age, the effect is just the opposite. This is mainly due to the existence of the construction cost of the swapping battery station. When β is less, the increase in profits brought by the increase in the number of swapping battery stations cannot make up for the cost brought by its construction, so only when it is larger can we see the positive effect on profits. Therefore, for the firm B that independently undertake the construction of the replacement power station, if the convenience coefficient of the swapping battery station is not high, the appropriate slowing down the construction demand of the swapping battery station is more in line with the interests of the firm B. When the convenience coefficient of the swapping battery station is high, the construction of the swapping battery station can be increased. At this time, the increase in the number of swapping battery stations can increase the profits of the firm B, and the investment is profitable.

When firm C enters, the impact of βis consistent with everyone's usual cognition, that is, consumers are more comfortable with the increase in the number of swapping battery stations, and the profits of the firm B should show an upward trend.Before and after the entry of firm C, the impact of β on the profit of the firm B is different, mainly because when firm C does not enter, firm B has to consider the cost of constructing the swapping battery station, which leads to the decline of profit when βis younger. When firm C enters, firm B only needs to consider the sale of cars, so the increase of B will directly lead to the increase of profits.

Proposition 3 When the profit distribution ratio is large, the number of swapping battery stations constructed by firm C is higher than that independently constructed by firm B. When the profit distribution ratio is small, the opposite is true. Mathematically ,we have $m^{1^*} > m^{2^*}$when α < α_x and $m^{1^*} < m^{2^*}$ when α > α_x .

Proof: We compare the number of swapping battery station under the two models. Defining$\Delta_1 = m^{1^*} - m^{2^*}$,we have $\frac{\partial \Delta_1}{\partial \alpha} < 0$.Setting $\Delta_1 = 0$,we have

$$\alpha_x = \frac{k(\delta-1)(\delta-4)^2(\delta\beta^2+k\delta^2-2\beta^2-5k\delta+4k)}{2(\delta-2)(\beta^4\delta^2+\beta^2\delta^2k+5k\delta^2\beta^2+8k^2\delta^2-14k\delta\beta^2-22k^2\delta^2+8k\beta^2+40\delta k^2-16k^2)}.$$

Proposition 3 shows that the number of swapping battery stations constructed by firm C is affected by the profit sharing ratio. When the profit sharing ratio given by firm B to firm C is too small (that is, the attraction to firm C is weak at the moment), the number of swapping battery stations constructed by firm C is too small. At this time, if firm B is selected to undertake the construction by itself, the number of swapping battery stations can be increased. When the profit sharing ratio of firm B to firm C is too large, resulting in the construction of too many swapping battery stations by firm C, there will be excessive investment, which will seriously affect the profits of firm B. When firm B considers whether to entrust firm C to undertake the construction of the swapping battery station, it should take into account the profit sharing ratio during the cooperation between the two parties and the current operating conditions. If it only pursues profit maximization, it can choose to undertake the construction by itself. When firm B is in the stage of high mileage anxiety, its profit is in the highest space, and it can promote the construction of the swapping battery station by increasing the profit sharing ratio. When the mileage anxiety is small and the profit of firm B is lower than that of firm B with high mileage anxiety, the competition among enterprises will become more intense, and the optimal decision can be reached by independently undertaking the construction of the changing power station by its own enterprise.

4 Conclusion

The main conclusions of this paper are as follows: 1 The participation of the third-party swapping battery station construction company will hurt the profits of the swapping battery vehicles manufacturers, but it can help to fight the charging vehicles manufacturers. 2 The influence of convenience coefficient of swapping battery station on the profits of swapping battery vehicles manufacturers is non-monotony. When the convenience coefficient of swapping battery station is small, they choose to outsource the construction of swapping battery station to other companies, and when the convenience coefficient of swapping battery station is high, they choose to undertake the construction by themselves. 3 swapping battery vehicles manufacturers can not blindly increase the dividend ratio, to consider their own business situation, too low dividend ratio will create a lack of swapping battery station, too high dividend ratio will damage their own profits.

References

1. Lim M K, Mak H-Y, Rong Y. Toward mass adoption of electric vehicles: Impact of the range and resale anxieties [J]. Manufacturing & Service Operations Management, 2015, 17(1): 101-19.
2. Avci B, Girotra K, Netessine S. Electric vehicles with a battery switching station: adoption and environmental impact[J]. Management Science, 2015, 61(4).
3. Schuitema G, Anable J, Skippon S, Kinnear N. The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles [J]. Transportation Research Part A: Policy and Practice, 2013, 48: 39-49.
4. Plötz P, Schneider U, Globisch J, Dütschke E. Who will buy electric vehicles? Identifying early adopters in germany [J]. Transportation Research Part A: Policy and Practice, 2014, 67: 96-109.
5. Gnann T, Plötz P, Kühn A, Wietschel M. Modelling market diffusion of electric vehicles with real world driving data – german market and policy options [J]. Transportation Research Part A: Policy and Practice, 2015, 77: 95-112.
6. van Rijnsoever F J, Welle L, Bakker S. Credibility and legitimacy in policy-driven innovation networks: Resource dependencies and expectations in dutch electric vehicle subsidies [J]. The Journal of Technology Transfer, 2013, 39(4): 635-61.
7. Sakamoto N, Niimura T, Ozawa K, Takamori H. Robust feedback control for the subsidy policy about plug-in electric vehicle using sliding mode control [J]. Electrical Engineering in Japan, 2016, 194(1): 10-7.
8. Hao H, Ou X, Du J, Wang H, Ouyang M. China’s electric vehicle subsidy scheme: Rationale and impacts [J]. Energy Policy, 2014, 73: 722-32.