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Analysis of Recycling Strategy of Waste Power Batteries Driven by Government Subsidies

Yanni Xiang

Chongqing University of Posts and Telecommunications, Chongqing, China

Abstract: Government subsidies play an important role in the government's effective regulation of the whole industry and in promoting better economic development. This paper introduces channel intrusion into reverse supply chain, applies it to closed-loop supply chain of power battery, and discusses the recycling strategy of waste power battery driven by government subsidy. Based on the key factors affecting power batteries, a tripartite game model of government, recyclers and consumers is constructed. There are government intervention modes such as supervision and subsidy in power battery recycling. Based on government supervision, this paper studies the influence of subsidy on decision-making of recyclers and consumers, so the government has two behavior modes: "subsidy" and "non-subsidy". The example analysis shows that the low amount of government subsidy has a strong incentive effect on improving the recovery rate of power batteries, but it has no obvious effect on increasing the sales of new energy vehicles. The high amount of government subsidies has obvious incentive effect on increasing the sales of new energy vehicles.

Keywords: Government subsidies, Waste power battery, Battery recovery.

1. Introduction

The recycling of waste power batteries has attracted the attention of China government. The recycling of waste power batteries of electric vehicles is an important part of the development of electric vehicle industry [1-3]. A large number of waste power batteries that cannot be disposed of pose a threat to the environment, and at the same time cause the waste of scarce metal resources such as cobalt [4]. This paper introduces channel intrusion into reverse supply chain and applies it to closed-loop supply chain of power batteries, discusses the recycling strategy of used power batteries driven by government subsidies, and compares and analyzes the changes of new energy vehicle sales with government subsidies.

2. Research Method

2.1. Problem description and hypothesis

Government subsidies play an important role in the government's effective regulation of the whole industry and in promoting better economic development. From the research purpose, most of the research is to use quantitative analysis and other methods to guide the optimization of government subsidies and the optimal decision-making of manufacturers, and only a small part focuses on the reuse of batteries [5-6]. This paper considers that manufacturers produce electric vehicles for the final consumers, the government provides subsidies for consumers to buy electric vehicles, and manufacturers are responsible for collecting and recycling used electric vehicle batteries to promote the sales of electric vehicles. In the process of power battery recycling, the government, recyclers and consumers get benefits and information according to their respective decisions, and constantly adjust their own strategies, so as to improve their own interests and make the government, recycling enterprises and consumers reach a balance in their respective decisions [7].

There are government intervention modes such as supervision and subsidy in power battery recycling. Based on government supervision, this paper studies the influence of subsidy on decision-making of recyclers and consumers, so the government has two behavior modes: "subsidy" and "non-subsidy". Different competing modes of new energy vehicle supply chain under government intervention are shown in Figure 1:

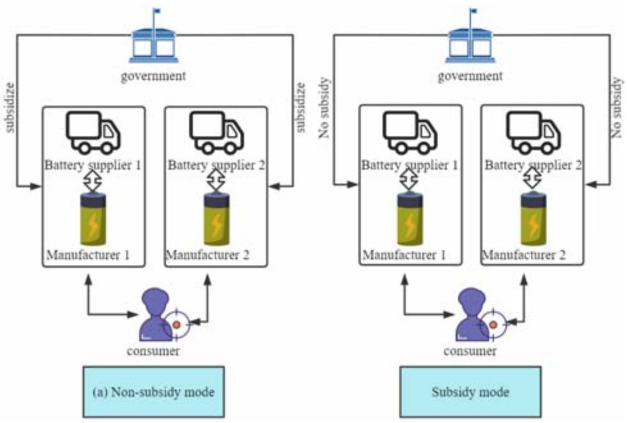

Figure 1. Different competing modes of new energy vehicle supply chain under government intervention

That is, the endurance of power battery of battery supplier 1 is an important factor to increase the demand of products in supply chain 1, and at the same time, it will cause the demand of supply chain 2 to decrease. Therefore, the market demand functions of products in supply chains 1 and 2 can be expressed as:

$$q_1 = (\alpha_0 + \lambda_1 r) - p_1 + b p_2 \tag{1}$$

$$q_2 = (\alpha_0 + \lambda_2 r) - p_2 + b p_1 \tag{2}$$

α_0 represents the potential market demand, b represents the cross-price impact between two products, and parameter λ_1, λ_2 represents the impact of the endurance of power battery of product 1 on the demand of products in supply chains 1 and 2 at the R&D level $\lambda_1 > \lambda_2$, respectively.

Assuming that when manufacturers recycle used batteries for different purposes, manufacturers can get benefits from battery recycling [8-9], the direct benefits that manufacturers get from battery recycling are:

$$A_r = r \cdot q \cdot \lambda \tag{3}$$

r is the average income of recycling a used battery. q is the market demand (sales volume) of electric vehicles; Y is the battery recovery rate, and $\lambda \in [0,1]$.

Assume that the demand function of power batteries produced by power battery manufacturers is definite and continuous, and assume that the price sensitive function is:

$$D_n = (\alpha_n - \beta(p + \gamma_3 T)) \tag{4}$$

D is the market demand of power batteries, and p is the sales price of each unit of new power batteries.

In addition, in order to explore whether the behavior characteristics have an impact on the production decision of electric vehicle manufacturers, this paper assumes that electric vehicle manufacturers have loss aversion behavior, and the following piecewise linear function table does not lose the aversion utility function:

$$U(\pi) = \begin{cases} \pi - \pi_0, & \pi \geq \pi_0 \\ \lambda(\pi - \pi_0), & \pi < \pi_0 \end{cases} \tag{5}$$

π represents the profit drawing number of electric vehicle manufacturers, π_0 represents the reference point, and λ represents the loss aversion coefficient.

2.2. Decision analysis

The principle of centralized decision-making is to maximize the profit of the system. During centralized decision-making, the power battery manufacturers, new energy vehicle manufacturers and new energy vehicle retailers in the supply chain system are regarded as a whole. By deriving the centralized decision-making model of the supply chain, the optimal power battery recovery rate, the selling price of new energy vehicles.

The centralized decision-making model of power battery recycling supply chain under non-subsidy mechanism is as follows:

$$\prod\nolimits_c^N = w_e \tau q + p \alpha q - c_b q - I \tag{6}$$

c_b represents the production cost of power battery pack; p represents the sales price of new energy vehicles; w_e represents the income obtained by the recycler from recycling unit waste power batteries; q represents the sales volume of new energy vehicles, and I represents the investment of recyclers in recycling waste power batteries.

The decision variable of the centralized decision model is p, τ, r, the profit is maximized by calculating the first derivative of the decision variable of formula (6), and then the Hesse matrix is obtained by calculating the second derivative. When Hesse matrix formula (7) is a negative definite matrix, formula (6) is a strictly concave function, and the optimal solution is obtained at the stationary point.

$$H_c^N = \begin{bmatrix} -2\alpha b_0 & -b_0 w_e & ag \\ -b_0 w_e & -2c_l & w_e g \\ ag & w_e g & -2\mu \end{bmatrix} \tag{7}$$

r represents the recycling reward paid by recyclers to consumers; c_l, μ is the conversion factor.

The quality of used power batteries varies, and electric vehicle manufacturers can choose their uses according to the quality of used power batteries. In reality, there are three common uses: one is to repair and manufacture, replace the damaged parts on the batteries, and re-manufacture the batteries and assemble them to electric vehicles; Second, changing the use, the battery is readjusted and assembled to the static energy storage device for non-vehicles; 3 is decomposition treatment [10].

Considering different incentive mechanisms of electric vehicles, that is, cost subsidy mechanism, electric vehicle manufacturers can get unit subsidy y when producing an electric vehicle. The manufacturer's goal is to determine the optimal output of electric vehicles by maximizing the benefits based on the recycling of used power batteries, government subsidies and loss aversion.

The manufacturer's revenue function can be described by the following expression:

$$\pi^M(Q, X = x) = \begin{cases} px + s(Q - x) - cQ + yQ + \Delta\tau Q - A\tau Q - B\tau^2, & x \leq Q \\ pQ - cQ + yQ + \Delta\tau Q - A\tau Q - B\tau^2, & x > Q \end{cases} \tag{8}$$

The demand of consumers in the market for remanufactured power batteries, that is, the recycling amount of used power batteries, is as follows:

$$q^{Y}=\frac{(1-f)\left[2-e^{2}(2-f)\right)\varphi+e(1-f)\varphi_{r}-2(1-f)\left(1-e^{2}\right)c-e(2-f)\left(1-e^{2}\right)[t-f]A\right]}{2\left[4(1-f)-e^{2}(2-f)^{2}\right]} \quad (9)$$

3. Example Analysis

Assuming that consumers buy cars from electric vehicle manufacturers with government subsidies, the numerical analysis uses the real data of Chinese government subsidies to buy electric vehicles and some existing literature data.The supply chain members can only maximize their own profits through decentralized decision-making.

Taking the relevant parameters of new energy vehicle as an example, the power battery used is a ternary lithium battery. The power battery recycler recycles a group of waste power batteries with a profit of $w_e = 140$ yuan. The production cost of the power battery for this vehicle is $c_b = 8*10^4$ yuan. The power battery cost accounts for 40%~60% of the value of the new energy vehicle, which is set as 50% in this example.

Under different recycling modes, when the government subsidy changes between [0,60000], the trend chart of the sales volume q of new energy vehicles with the government subsidy s is shown in Figure 2.

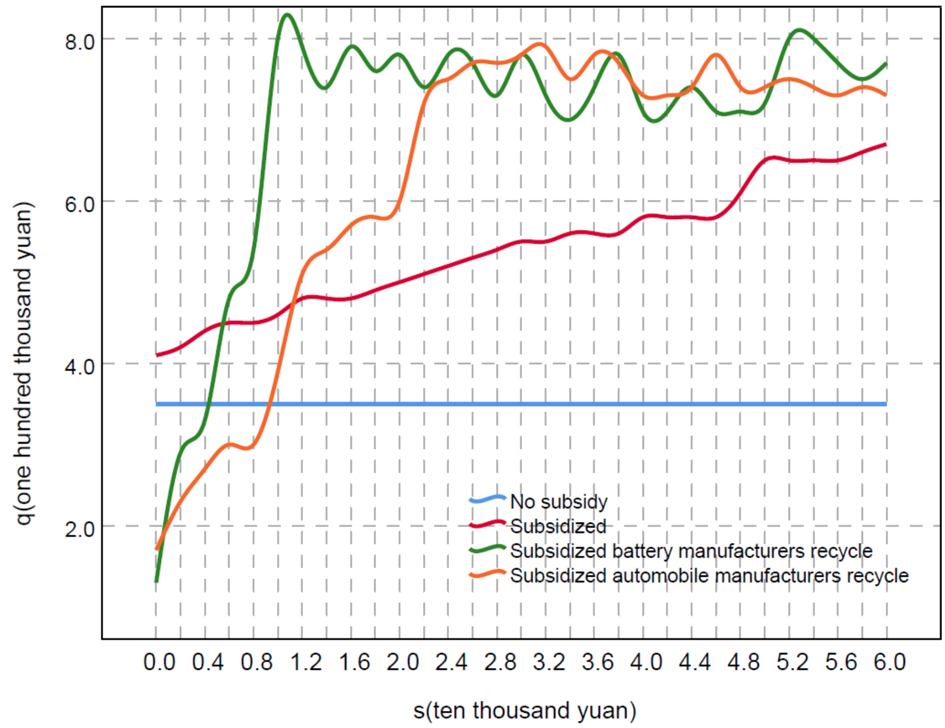

Figure 2. The relationship between s and q

When the members of the power battery recycling supply chain make decentralized decisions, the sales volume of new energy vehicles in the recycling mode of power battery manufacturers is the highest, with 76,802 vehicles; Therefore, under the non-subsidy mechanism, from the perspective of new energy vehicle sales, it is the best recycling channel strategy for power battery manufacturers to recycle used power batteries. The high amount of government subsidies has obvious incentive effect on increasing the sales of new energy vehicles.

4. Conclusions

The new energy industry is developing rapidly, and the amount of used power batteries continues to grow. At the same time, China's power battery recycling market has developed initially, and the recycling amount of power batteries is limited. A large number of waste power batteries that cannot be disposed of pose a threat to the environment, and at the same time cause the waste of scarce metal resources such as cobalt. Based on the key factors affecting power batteries, this paper constructs a tripartite game model of government, recyclers and consumers. Study the impact of subsidies on the decision-making of recyclers and consumers, so the government has two behavior modes: "subsidies" and "no subsidies". Assuming that consumers buy cars from electric vehicle manufacturers with government subsidies, the numerical analysis uses the real data of Chinese government subsidies to buy electric vehicles and some existing literature data. The example analysis shows that under the non-subsidy mechanism, from the sales volume of new energy vehicles, it is the best recycling channel strategy for power battery manufacturers to recycle used power batteries. The high amount of government subsidies has obvious incentive effect on increasing the sales of new energy vehicles.

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