Research on Residual Value Evaluation of Battery Electric Vehicles Based on Replacement Cost Method

Hongwei Li*, Chuan Chen1
1China Automotive Technology & Research Center Co., Ltd., Tianjin, 300300, China
*Corresponding author’s e-mail: lihongwei@catarc.ac.cn

Abstract: Knowledge about the value of used battery electric vehicles (BEVs) is critical for potential BEV purchasers, corporations, and governments to consider the total cost of ownership for BEVs. This study introduces a new method to evaluate the residual value of BEVs in China and provides the evaluation results. We innovatively separate the power battery from the battery electric vehicle and apply big data analysis methods to research the residual value of these two parts. We find that with the improvement of the power batteries technology, the residual rate of power batteries is higher than that of vehicles. However, whether or not to get subsidies has a great impact on the value residual rate of vehicle, we also find that at present BEVs still cannot develop independently without subsidy in China, because the low value residual rate will affect consumers' purchase decision.

1. Introduction
As one of the seven strategic emerging industries in China, the NEV industry has developed rapidly in recent years. In 2009, China officially started the project of promoting and demonstrating 1,000 energy-saving and new energy vehicles in ten cities each year. By November 2018, China had promoted more than 2.8 million NEVs, accounting for more than 50% of the market volume of NEVs in the world.

Consumers are particularly worried about the rapid depreciation of BEVs, and the insurance industry is also troubled by the imperfection of commercial insurance for BEVs. In China, consumers also face the risk of quality or price fraud and illegal vehicle when buying used cars, and buyers and sellers have serious information asymmetry, which makes it difficult for them to guarantee the fairness of the evaluation results. There is no uniform standard for the evaluation of the residual value of BEVs. Several studies have examined the resale value of BEVs. Zhaomiao Guo[1] found the five-year residual rate of electric vehicles in the United States was lower than that of conventional vehicles. Jian Xun[2] constructed a residual value evaluation model for new energy vehicles, he used replacement cost method to evaluate the residual value of battery charging EV and battery swap modes EV, the results indicated that electric range and service life were two main factors that affected the residual value of new energy vehicles. Yan Zhou et al. (2016)[3] found that residual rate of PHEV was higher than ICE models in the first two years, the third-year residual rate was slightly lower than ICE. Tan ZP[4] constructed a residual value evaluation model for pure new energy vehicles, they found that the replacement cost of vehicles should be deducted from state subsidies and tax incentives, at the same time, electric range and vehicle status were the main factors that affect the residual rate. In addition, the using condition, vehicle condition and market value should be taken as the adjustment factor of residual rate. Brandon Schoettle [5] did some research in the new trend of residual rate of new energy vehicles and the impact of residual rate on consumers' purchase behavior, and found that the residual rate of BEV and PHEV was lower than ICE when the federal tax was not deducted; when deducting federal tax, the residual rate of PHEV
was comparable to ICE, and it has been found that consumers were most interested in price, fuel cost, and safety.

![Figure 1. Comparison of Residual Value Rate of Different Vehicle Types in the United States.](image1)

![Figure 2. Comparison of Residual Value Rate of Different Vehicle Types in China.](image2)

2. Material and Methods

This study chooses replacement cost method as the basis. The basic formula of replacement cost method is as follows:

\[
RV = P_0 \times R \times M
\]  

In the formula, \(P_0\) is the new car price after the current replacement cost; \(R\) is the basic residual rate; \(M\) is the residual rate correction factor.

2.1 Replacement Cost

The replacement cost of a BEV refers to the cost of re-purchasing the same or similar vehicle, involving the price of the new vehicle, purchase subsidy and purchase tax.

\[
P_0 = P - S + T
\]  

In the formula, \(P_0\) is the replacement cost; \(P\) stands for the guidance price provided by the manufacturer before deducting the subsidies; \(S\) stands for vehicle purchase subsidies, including state subsidies and local subsidies; \(T\) stands for vehicle purchase tax.

2.2 Basic Residual rate

As the power battery cost of BEVs accounts for a large proportion of the complete vehicle cost, batteries are significant to the residual rate of BEVs. Therefore, this study will discuss the residual rate of a complete vehicle from the perspectives of power battery system and other part.

\[
R = \alpha \times R_{\text{battery}} + \beta \times R_{\text{others}}
\]  

In the formula, \(R\) is the basic residual rate of BEVs; \(R_{\text{battery}}\) is the residual rate of power battery; \(R_{\text{others}}\) is the residual rate of other part except the power battery; \(\alpha\) is the weight of the residual rate of power battery; \(\beta\) is the weight of the residual rate of other part.

2.2.1 Residual rate of power battery. Depreciation of power batteries has a significant impact on the physical depreciation of BEVs. The reliability research of power battery involves state of charge (SOC) estimation and state of health (SOH) estimation. SOH is the ratio of the capacity discharged by the power battery at a certain rate from the fully charged state to the cut-off voltage to its corresponding nominal capacity under standard conditions, and it is the key to evaluate the health of the power battery. In this study, the residual rate of power battery is mainly characterized by SOH index, which is evaluated online based on monitoring data of BEVs and is characterized by the ratio of the driving range corresponding to the change of battery unit SOC to the driving range in the initial state.
In the formula, $R_t$ is the estimated driving range of the vehicle for the trip of No. $t$; $R_s$ is the estimated driving range of the vehicle when it is charged by the user for the first time; $R_0$ is the driving range that the vehicle can travel in the initial state; $R_{s1}$ is the accumulated driving range data of the vehicle at the beginning of the trip of No. $t$; $R_{se}$ is the accumulated driving range data of the vehicle at the end of the trip of No. $t$; $SOC_{s,t}$ is the SOC value of the power battery at the beginning of the trip of No. $t$; $SOC_{e,t}$ is the SOC value of the power battery at the end of the trip of No. $t$; $R_{s1}$ is the accumulated driving range data of the vehicle at the beginning of the first trip; $R_{e1}$ is the accumulated driving range data of the vehicle at the end of the first trip; $SOC_{s,1}$ is the SOC value of the power battery at the beginning of the first trip; $SOC_{e,1}$ is the SOC value of the power battery at the end of the first trip.

2.2.2 Residual rate of other part. According to the research results of scholars at home and abroad, the factors affecting the residual rate of conventional energy vehicles include vehicle age and driving range, which is similar to the other part of BEVs except power battery.

1) Vehicle age factor. The age of BEVs is one of the main factors affecting the residual rate of BEVs. See Formula (7) for the calculation method of the vehicle age-based residual rate generally accepted in the industry.

$$y_1 = \frac{N-t}{N} \quad (7)$$

In the formula, $y_1$ is the vehicle age-based residual rate; $N$ stands for the specified service life of the vehicle, the service life of non-operating vehicles is generally 15 years; $t$ stands for the service life of the vehicle.

2) Driving range. The driving range-based residual rate decreases with the increase of driving range. Zhiheng Chen and others[6] proposed a new method for calculating the driving range-based residual rate:

$$y_2 = 0.0001r^2 - 0.0331r + 0.991 \quad (8)$$

In the formula, $y_2$ is the driving range-based residual rate; $r$ stands for driving range.

3) Basic residual rate. The basic residual rate is the combination of the vehicle age-based residual rate and the driving range-based residual rate. Its formula is as follows:

$$R_0 = \alpha R_{battery} + \beta R_{others} = \alpha R_{battery} + \beta(y_1 \gamma + y_2 \delta) \quad (9)$$

In the formula, $\alpha + \beta = 1$ and $\gamma + \delta = 1$.

2.3 Residual rate correction factor

The factors that affect the correction factor of residual rate of BEVs include physical depreciation, functional depreciation and economic depreciation.

2.3.1 Physical depreciation. 1) Vehicle condition factor. The complete vehicle condition factor refers to the physical loss of vehicle components. Based on the evaluation specification of the conventional vehicle condition in GB/T 30323-2013[7] "Technical Specification for Used Car Appraisal Evaluation", in this study we appropriately revise and compile the vehicle condition evaluation form for BEVs, which can be used to evaluate the vehicle condition of BEVs. 2) Using purposes. Using purposes are also an important factor affecting the physical depreciation of BEVs. Different using purposes reflect the different use habit, intensity and environment of vehicles, and thus the corresponding score can be calculated. 3) Maintenance records. The maintenance records of BEVs are used to evaluate the maintenance level during the historical use of vehicles, which will affect the maintenance score. 4) Fault
records. The fault record of vehicles can be counted based on monitoring data and thus the fault record score can be calculated.

2.3.2 Functional depreciation. 1) One-time functional depreciation. One-time functional depreciation mainly refers to the depreciation caused by the upgrading of vehicles and the depreciation of functions resulted from the technical progress and labor productivity reduction. With the progress of science and technology, the application of new technology will inevitably lead to the depreciation of old technology, which is especially evident in strategic new industries including NEVs. Therefore, it is possible to score based on the application of key technologies on vehicles. 2) Operational functional depreciation. Operational functional depreciation mainly refers to the high operating cost in each coming year resulting from the high energy consumption level of BEVs due to low technical level. The corresponding score can be calculated through comparison of the energy consumption level of the evaluated vehicle type with the mainstream vehicle type of the same level. 3) Economic depreciation. First, brand reputation. Brand is the essence of enterprises and products for many years, serving as a key identity affecting consumers’ purchase in the fierce market competition. Brand also has a great impact on the value residual rate of automobile products. In this study, brands are included in the evaluation of residual rate correction factor, and reputation score in automobile websites are used as a measure of quantitative evaluation of brand reputation. Second, the strength of preferential policies. At present, in addition to subsidies and tax breaks in the purchase phase, BEVs also enjoy preferential policies in the use phase, such as not being restricted by the traffic control policy, and being exempted from parking fee/freeway fee/toll. These preferential measures promote the sale of BEVs and improve the value residual rate of BEVs to a certain extent. The comprehensive calculation formula is:

$$RV = P_0 \times R_0 \times M = (P - S + T) \times \left(\alpha \times R_{battery} + \beta \times R_{others}\right) \times \left(\varepsilon \times P_s + \epsilon \times P_f + \theta \times P_e\right)$$  \hspace{1cm} (10)

3. Results

3.1 Basic Information Acquisition
Based on the availability and implementability of data, this study selected a Haima@3 2017 comfort edition as the evaluation object. The specific parameters of the vehicle are as follows: The registration date of the car was in October 2017, and it had been used for rental purpose, and the evaluation time is in October 2018. The information obtained based on the monitoring system is as follows:

Table 1. Monitoring Data of the Evaluated Vehicle.

| Time            | Starting range | Starting SOC | End range | End SOC |
|-----------------|----------------|--------------|-----------|---------|
| October 2017    | 10.3           | 100%         | 63.7      | 58.7%   |
| September 2018  | 10,472         | 99%          | 10,504    | 74%     |

Fault condition 3 times of level 2 faults, and 15 times of level 3 faults

3.2 Weight of Residual rate Correction Factor
In this study, 5 used car evaluators were invited to score the weight of influencing factors.

Table 2. The weight of residual rate correction factor.

| Level 1 indicators   | Weight | Level 2 indicators                | Weight |
|----------------------|--------|-----------------------------------|--------|
| Physical depreciation | 0.6370 | Vehicle condition factor          | 0.3838 |
|                      |        | Using purposes                    | 0.1283 |
|                      |        | Maintenance records               | 0.0775 |
|                      |        | Fault records                     | 0.0473 |
| Functional depreciation | 0.2583 | One-time functional depreciation  | 0.1722 |
|                      |        | Operational functional depreciation| 0.0861 |
| Economic depreciation | 0.1047 | Brand reputation                  | 0.0698 |
|                      |        | The strength of preferential policies | 0.0349 |
3.3 Calculation Result of the Residual Value

As the model 2017 has been discontinued, according to the quotation for the model 2017 before the new model 2018 was launched, the price for a new vehicle of the model 2017 was RMB124,600 before it was subsidized by RMB54,000. The residual rate of power battery is calculated as follows:

\[
R_{\text{battery}} = \text{SOH} = \frac{R_t}{R_i} = \left( \frac{10504-10472}{99%-74%} / \frac{10504-9978}{100%-59.99%} \right) = 96.1\% 
\]  

(11)

The residual rate of other part is calculated as follows:

\[
R_{\text{others}} = y_1 \cdot \gamma + y_2 \cdot \delta = 94.5\% 
\]  

(12)

The residual rate correction factor:

\[
M = \epsilon \cdot P_s + \epsilon \cdot P_f + \theta \cdot P_e = 0.8441 
\]  

(13)

According to the above information, the basic residual rate is 95.2%, and the residual rate correction factor is 0.8441. The residual rate of the vehicle after corrected:

\[
R = R_0 \cdot M = 95.2\% \times 0.8441 = 80.36\% 
\]  

(14)

The replacement cost of a new vehicle of Haima@3EV 2017 comfortable edition is RMB70,600. The residual value (unit: RMB10,000) of the vehicle is:

\[
RV = P_0 \cdot R_0 \cdot M = 7.06 \times 95.2\% \times 0.8441 = 5.67 
\]  

(15)

Based on the residual value evaluation result of this Haima@3, compared with the 2017 manufacturer's guidance price of RMB149,800, the value residual rate of this vehicle is calculated as follows: 1) Without deduction of subsidies, the one-year value residual rate of the vehicle is only 37.85%, which is lower than the above-mentioned average level of the US market and is equivalent to the evaluation result of Auto Home. 2) If the subsidy is deducted, the one-year value residual rate of the vehicle is 59.19%, which is basically equivalent to that of the domestic conventional vehicles of the same class.

4. Discussion

In this study, we propose a residual value evaluation method for BEV for the first time, and residual value evaluation model for BEV is constructed, it has certain guiding significance for automobile enterprises and second-hand automobile evaluation institutions to carry out residual value evaluation of electric vehicles. The evaluation object is a rental electric car. Due to the large number of drivers and the relatively complex use environment of the vehicle, the physical depreciation coefficient of the electric vehicle is low. The rapid improvement of the technology is also the main reason for the rapid decline of the residual value of this research object.

At the same time, we also deeply feel that there are many limitations in the research. First, this study did not take into account factors such as brand difference and car parc, which also have a certain impact on vehicle residual value rate. These factors will be included in future studies. Second, there is only one car in the empirical part of this study, and the evaluation result is partly accidental.

5. Conclusion

According to the characteristics of BEVs, this study builds a residual value evaluation model based on the replacement cost method, and draws the following conclusions through the actual evaluation of the vehicle:

1) The technical improvement and cost reduction have significant impact on the residual value. It is found that in recent years, with the improvement of the technical level of complete vehicles and power batteries and the reduction of the cost, the replacement cost of the vehicle has dropped rapidly, so technical improvement and cost reduction have the greatest impact on the residual value of the BEV.

2) The residual rate of power battery is higher than that of vehicle. Some scholars' previous literature shows that the residual rate of power battery drops faster than that of vehicle. This study found that the one-year residual rate of power battery is higher than that of other part of the vehicle. Presumably, the reason may be that the power battery and control level in China have improved significantly in recent
years, reducing the depreciation rate of the power battery.

3) Whether or not to get subsidies has a great impact on the residual rate of vehicle. Through calculation, the residual rate with subsidy is higher than without it. It can be seen that at present BEVs still cannot develop independently without subsidy in China, because the low residual rate will affect consumers' purchase decision.

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