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Research on Influencing Factors and Trend Prediction of New Energy Second-hand Car Prices

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Abstract: With the advancement of technology, due to their lower cost and high performance than traditional fuel cars, new energy vehicles have been gradually occupying an increasingly important position in the economy and society for years. However, in addition to the continuous expansion of the industry, lots of consumers and dealers have turned their attention to the post production issues of new energy vehicles - the second-hand market. It's widely believed by the scholars that the resale value of new energy vehicles is influenced by a great many factors, mainly including the using time, mileage, policies and so on. This article used the Tesla model 3 as an example and established interpretative structural modeling (ISM) and ordinary least squares (OLS) models, in order to do factor analysis and trend prediction on the resale value of new energy vehicles. After containing quantities of results, the research ultimately found out the specific negative correlation between two major elements and the second-hand price of the new energy cars, together with simple point predictions through OLS models. In this condition, it is feasible for the dealer and costumers of the new energy vehicles market to get a standard in second-hand prices, while the theoretical field could also be partly extended in the aspect of mathematical statistics and economic analysis.

Keywords: mathematical statistics, factors analysis, trend prediction, social economic, new energy vehicles.

1. Introduction

As one of the main transportation facilities for people's daily travel, cars have played a crucial role in various countries and societies over the past century. In recent years, new energy vehicles, mainly based on pure electric and hybrid oil electric models, have been widely favored by the public due to their excellent performance and extremely affordable costs. At the same time, influenced by the cooperation of technologies such as AI and 5G network technology, as well as the government's various financial allowance and tax policy, the new energy vehicle industry has highly developed and expanded in recent years, becoming the main force of social economy [1,2].

Currently, more and more new energy vehicles are appearing on the roads in China. In the condition that new energy cars industry is already mature, people should start to focus more on the post-production issues. Xue believed that as the number of new energy vehicle increases, its second-hand market will gradually expand too [3]. In addition, many consumers chose to invest more attention in the second-hand market due to the lower resale value of new energy vehicles [4].

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Tao thought the second-hand price of new energy cars was often influenced by many professional concepts, and its determining factors included physical performance, price fluctuations, maintenance convenience, reliability, and so on [5]. It is notable that, as the main raw materials for batteries, price increases and production growths of lithium and cobalt could abstractly reflect the development of the electric vehicle industry [6], thus they also had a certain relationship with the fluctuation of vehicle prices. Furthermore, in recent years, price wars among enterprises have provided a significant impact on the preservation of value for new energy vehicles [7]. Additionally, the brand factor of new energy cars needs to be considered and systematically analyzed as well [8]. The last point is the government's policy and rules of car companies, including many preferential policies together with official second-hand car activities [9].

On the other hand, it is of great significance to have a deep understanding of the current situation and future plans of the new energy vehicle industry before the analysis and prediction of second-hand prices. Scholars have pointed out that there are problems with quality control and low resale value of new energy cars, while the degree and frequency of this phenomenon are generally related to the brand [10]. Therefore, when creating the model, the second-hand car prices of a single or two focus companies will be selected as a reference.

Finally, in terms of future prospects for the industry, new energy enterprises need to reduce quality control differences and improve core technologies as soon as possible [11]. The government should also continuously improve relevant policies, such as focusing on promoting technological innovation or appropriately reducing purchase subsidies [12].

According to the past researches, it’s not difficult to learn that the new energy vehicle industry is currently facing the challenge of overcoming the preservation rate in its rapid development under many helps from every part of the society. And, the most salient factors might include physical condition of the cars, brand impacts, price fluctuate of raw materials, policies and so on. However, although some reports and articles have focused specifically on this issue, relevant statistical and financial research is still very limited. Instead, this field is donated by the reviewer papers. What’s more, they majorly focused on the current phenomenon rather than what determines it.

Therefore, with the actuarial analysis of the prices of new energy used cars, this article is necessary and useful for both the industrial development and consumers’ options. Additionally, the paper could also expand the relevant research field in some degree just by the mathematic statistic and economic analysis. Due to the references, the topic of this article indeed provides a new way to learn about the development of new energy cars’ market, just by the statistical analysis and trend prediction which could be hardly seen among the previous researches. Besides, it is notable that this research used the ISM model to analyze the significance of potential factors, which is rarely applied in this topic. That’s also an innovation point in methods of this paper.

Figure 1 below shows the thought and structure of this research.

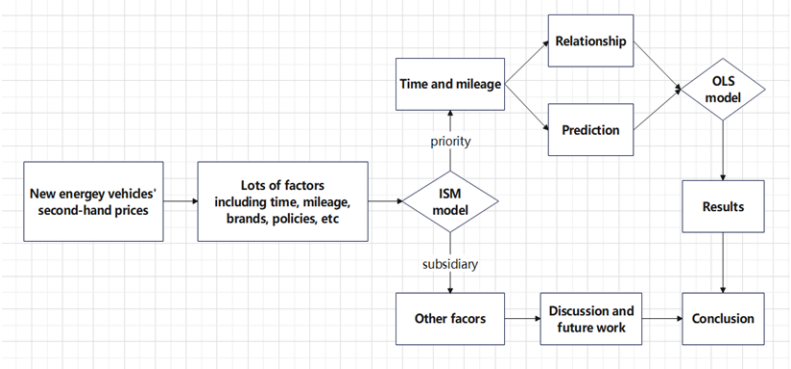

Figure 1: Thinking route and Framework construction process.

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The main body of this project is divided into four chapters, except Abstract and Reference listing the articles cited.

Firstly, Introduction leads to the question, while also introducing the background and motivation of the research. Several innovations are mentioned as well.

Secondly, in section Methods, the data sources and selection reasons for this study are presented. Overview of the statistical models and methods used is also introduced.

Subsequently, Results and Discussion shows the analysis process involved and results obtained. The specific relationships between crucial factors and the research object are determined based on this, together with the predictions. Ultimately, the research makes some simple explanation about the subsidiary features.

Finally, the project ends with Conclusion, summarizing the entire research and reflecting on some remaining issues.

2. Methods

2.1. Data Source

To start with, for some public and macro data in recent years, such as the annual production and sales of new energy vehicles in China and the per capita disposable income of Chinese citizens, the author chose the database Choice under East Money Information as the main source. These data, after extensive screening and organization, was presented in the form of charts in the text for analysis and comparison. For instance, here is Table 1 which shows the production and sales volume of different types of new energy cars from 2019 to 2022.

Then, this study mainly obtained the second-hand prices of many new energy vehicles with different brands and service lives through some famous online second-hand car trading markets in China, such as website like https://m.guazi.com and applications including DCar, etc. Data from them intuitively reflected the resale value of new energy vehicles under the influence of multiple factors, which is an important content of this research.

Table 1: Annual output and sales volume of new energy cars, from 2019 to 2022.

Data name	2019	2020	2021	2022
Production of plug-ins cars	22.3	26.1	59.8	158.1
Sales of plug-ins cars	35.9	25.3	60.5	151.7
Production of pure EV cars	102.3	108.3	294.0	545.6
Sales of pure EV cars	97.3	109.8	290.1	525.3
Production of new energy cars	124.6	134.3	353.2	704.0
Sales of new energy cars	133.1	135.1	350.6	687.3

The unit of the data inside the table: 10 thousand
Data source: *Choice*

2.2. Indicator Selection and Explanation

In this article, annual or quarterly data on the production and sales of new energy vehicles, the ownership of new energy vehicles, while the most significant data which shows the second-hand prices of Tesla Model 3 in different conditions including usage time and mileage.

The data on the number of new energy cars produced, sold, or owned is the most essential information to help us learn the condition of this industry. These data could clearly present the increasing demand and supply of new energy vehicles, which is the background of this research. For example, Figure 2 shows changes in the new energy cars ownership during these years.

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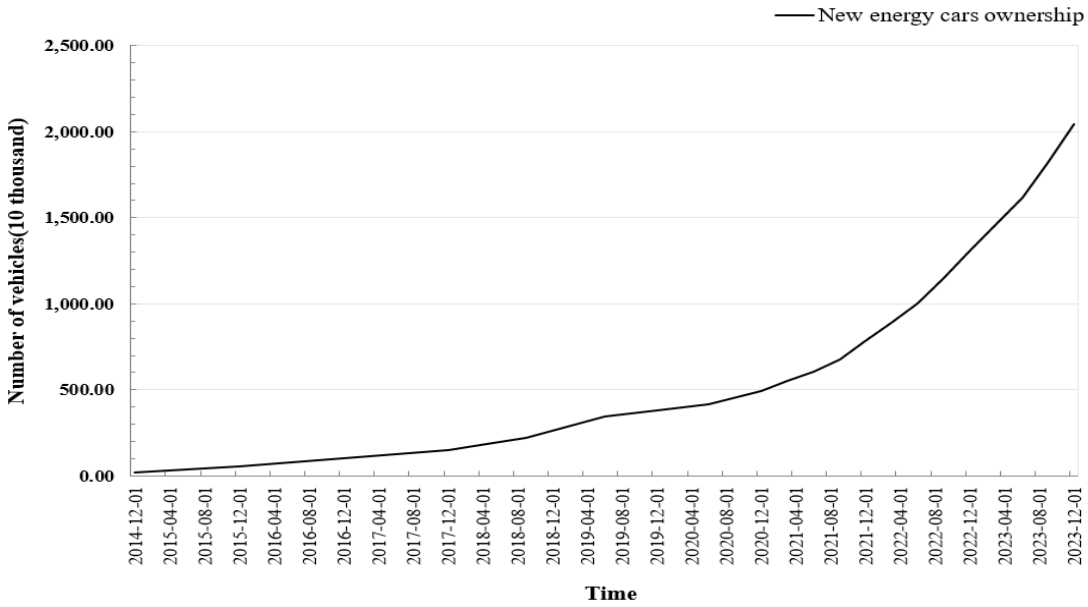

Figure 2: Changes in new energy cars ownership.

And then, data about second-hand prices for specific vehicle affected by several factors, such as time and mileage, is mainly used in the statistical models involved at the part 3 of the whole paper. Table 2 illustrated approximately 1/10 of data the author found from the online markets https://m.guazi.com, which was mainly about Tesla Model 3.

Table 2: Prices of second-hand Tesla Model 3 in different conditions.

Service life	Mileage	Transaction price	Original price*	Maintain value rate
0.8	1.35	17.78	23.19	76.67%
1.1	1.61	18.24	23.19	78.65%
1.8	4.16	16.38	23.19	70.63%
2.3	2.14	16.16	23.19	69.69%
2.8	8.76	13.88	25.17	55.15%
2.9	5.83	14.21	25.17	56.46%
3.0	4.49	15.50	25.17	61.58%
3.4	4.51	14.06	29.18	48.18%
3.8	10.73	11.98	29.18	41.06%
4.2	6.65	12.94	29.18	44.35%

*Changes in original prices happened because of variation in version every year.
The unit of the data: years, 10 thousand kilometers, 10 thousand yuan.
Data source: *https://m.guazi.com.*

2.3. Methods Overview

This research firstly used interpretative structural modeling (ISM) method to analyze the collection between various factors and changes in second-hand car prices, including the service life of cars, price of raw materials and so on. What's more, due to the rapid and significant fluctuations in the second-hand prices of new energy vehicles, it is particularly important to analyze and predict their future development. In this way, the article used specific data to establish ordinary least squares (OLS) models to make a prediction of the future price trends of used cars in individual new energy brand.

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3. Results and Discussion

3.1. Elements Screening

Due to the large number of factors mentioned, doing specific data analysis one by one was too complicated to achieve. Thus, this article firstly chose and applied Interpretative Structural Modeling Method to conduct a hierarchical and correlated analysis of them, in order to obtain the degree how different factors impact the second-hand price of new energy and focus on ones affecting the price most.

The ISM method is a widely used analysis method in modern systems engineering. It identifies the constituent factors of the problem through investigation or technical means, and then uses matrix models to analyze the relationships between each element, constructing a systematic and multi-level structural model, in order to clearly and directly display the operating mechanism of the problem.

This study summarized several known elements affecting the second-hand prices of new energy vehicles, set as $\alpha_n(n = 1, \cdots, 11)$, mainly including the service life of new energy vehicles (α_1), mileage condition of cars (α_2), guide price of new cars (α_3), public evaluation of types (α_4), brands' business condition (α_5), price and production of raw material (α_6), ownership of new energy vehicles (α_7), per capita disposable income (α_8), Gross Domestic Product (α_9), official second-hand business (α_{10}), intervention of government regulations (α_{11}).

To begin with, the author selected the 11 factors mentioned above to construct the ISM model. After extensive research and professional certification, the research has obtained a direct correlation between various factors and established an adjacency matrix set as A, of which the elements are all '0' or '1'.

The rule used to determine the number is as followed. If there's a clear direct relationship between α_i and α_j, this paper presented number '1' as the element a_{ij}, whereas '0' was the opposite. In this way, it could be obtained that

$$A = \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \end{bmatrix} \quad (1)$$

Then let matrix E be the identity matrix and perform repeatedly Boolean operations, shown below, together with the adjacency matrix A mentioned above,

$$(A + E)^{k-1} \neq (A + E)^k = (A + E)^{k+1} \quad (2)$$

so that this paper could get the accessibility matrix M after repeated calculations:

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$$M = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix} \quad (3)$$

Unlike the adjacency matrix that expresses the direct relationship between various factors, the accessibility matrix mainly displays the indirect impact relationship brought by the transmission between each element.

After several extractions, results of the ISM method are finally got, shown by Table 3.

Table 3: Stratification of factors affecting the resale value of new energy vehicles.

Hierarchy	Factors
1st layer	$\alpha_3,\ \alpha_5,\ \alpha_7,\ \alpha_9,\ \alpha_{10}$
2nd layer	$\alpha_4,\ \alpha_6,\ \alpha_8$
3rd layer	α_2
4th layer	α_1

Among all the influencing factors, the service life of new energy vehicles (α_1) and mileage condition of cars (α_2) are at the highest level. This indicated that they could most directly and effectively affect the price of used cars, while others interact and work together as indirect factors. Therefore, in the subsequent analysis, the service life and mileage of new energy cars were considered the main research objects by us. In contrast, other factors, due to the lack of specific data foundation or low hierarchy, need further correlation analysis and theoretical explanation which was presented later.

During the analysis process, the paper selected the second-hand price of Tesla Model 3 as the main research object, which is one of the most popular new energy cars around the world. As a result, data about it could give a more representative conclusion.

3.2. Models and Results

Using time and mileage, according to the ISM results, are the most direct and effective factors affecting the second-hand price of new energy vehicles. Hence, this article regarded them as important elements in linear regression to establish ordinary least squares (OLS) models for the resale value of Tesla Model 3.

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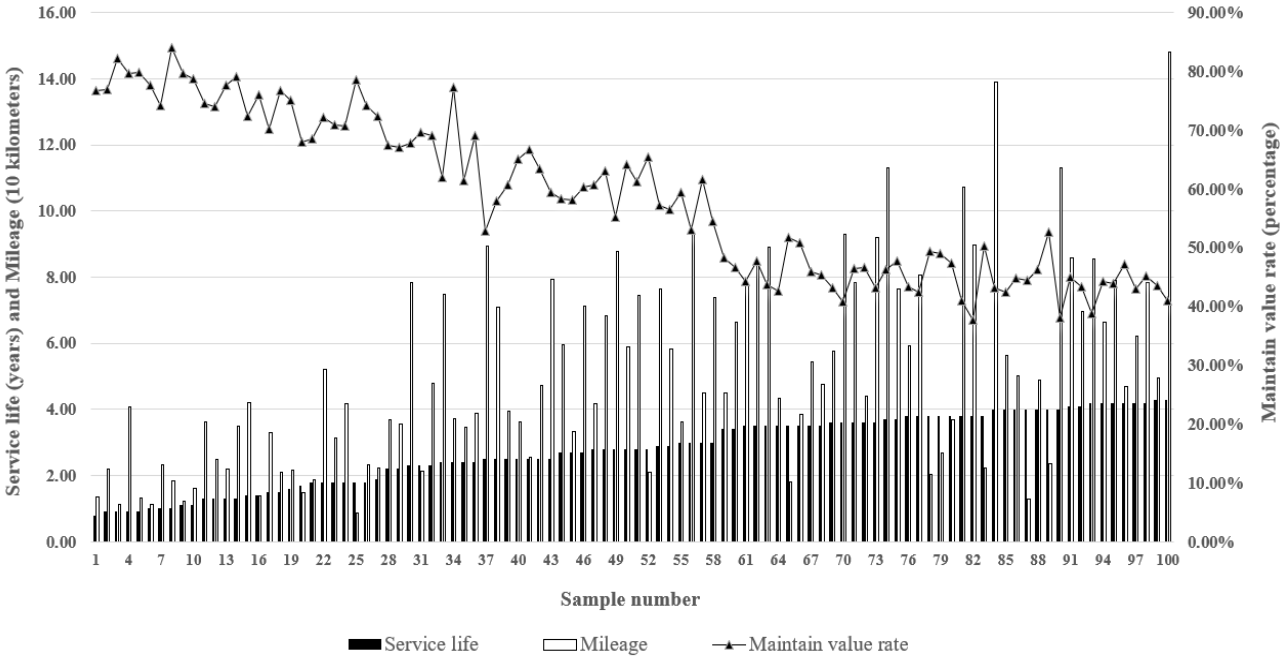

Figure 3: Remaining value of Tesla Model 3 in different conditions.

Figure 3 fully displayed the second-hand resale value of the brand's car under different service life and mileage conditions. Unit of service life is years while the mileage's is 10 thousand kilometers.

Linear regression is a statistical analysis method to determine the quantitative relationship between two or more variables that depend on each other. Ordinary least squares method is an essential channel in linear regression to find the best function matching for data by minimizing the sum of squared errors.

According to the results of the ISM model, this study firstly established an OLS model with only the service life of cars, which is in the highest level among all the factors. The dependent variable m was used to represent the maintain value ratio of new energy vehicles, while the independent variable n was used to represent the time vehicles were used in second-hand transactions. In addition, θ_0 and θ_1 represented constant terms and coefficients of n, respectively. So, the expression can be preliminarily determined as:

$$m = \theta_0 + \theta_1 n \tag{4}$$

The results of regression were obtained after calculating by SPSS and shown in Table 4. And the actual value and predictive value are presented in Figure 4.

It is clearly illustrated that the fitting degree of curvilinear regression was great, due to

$$R^2 = 0.909, Adjusted\ \ R^2 = 0.908. \tag{5}$$

In addition, the features showed that the Coef of elements were

$$\theta_0 = 0.923, \theta_1 = -0.121. \tag{6}$$

And the results of F-test, which expressed the significant differences, were

$$F = 979.172, P = 0.000^{***}. \tag{7}$$

The last point was that there were no collinearity or autocorrelation issues because

$$VIF = 1.00, D - W = 1.646. \tag{8}$$

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Finally, the function of this OLS model could be determined as

$$m = 0.923 - 0.121 * n. \quad (9)$$

Table 4: The first linear regression analysis results.

	$Coef$	$Std.Err$	t	P	95% CI
$Constant$	0.923***	0.012	80.018	0.000	0.901 ~ 0.946
$Service\ life$	-0.121***	0.004	-31.292	0.000	-0.129 ~ -0.114
R^2			0.909		
$Adjusted\ R^2$			0.908		
F			979.172		
VIF			1.00		
$D-W$			1.646		

***, * *, * represent significance levels of 1%, 5%, and 10%, respectively.

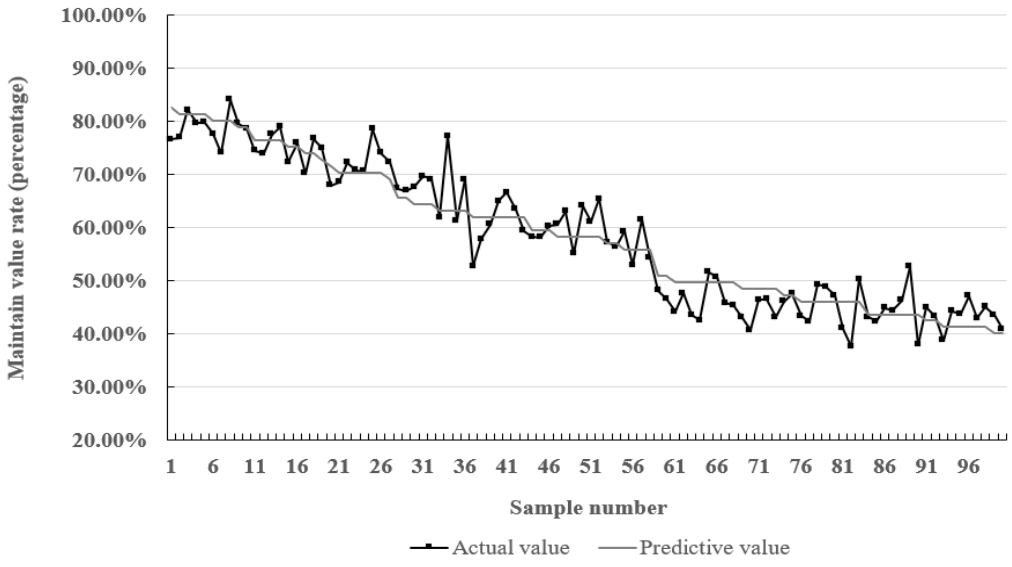

Figure 4: Actual and predictive value of research object in OLS model 1.

In summary, the second-hand price of new energy vehicles is negatively correlated with their service life. It means that the longer time cars are used for, the lower price they can be sold at for the second time.

However, from the ISM model, it's obtained that the mileage also plays an important role in affecting the maintain value rate of new energy vehicles. Hence, in order to make the results of analysis more accurate, this study also added the mileage as a new variable and established a second OLS model.

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In the second linear regression model, the dependent variable y was used to represent the value retention rate of the model in different situations, while the independent variables x_1 and x_2 were used to define the usage time and mileage of the vehicle when they were sold for the second time. Furthermore, β_1 and β_2 were regression coefficients respectively for x_1 and x_2, whereas β_0 was a constant. In this way, the final function that the model needed to obtain could be set as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2. \tag{10}$$

After OLS calculation, the results were shown in Table 5, together with the prediction compared to the true value shown in Figure 5.

From the various indices and specific numbers in the table, it could be concluded that the establishment of this model is successful and meaningful. Firstly, based on

$$R^2 = 0.925, Adjusted\ R^2 = 0.923. \tag{11}$$

this paper have determined that the curve fit of the model is extremely excellent. Secondly, based on the calculated $Coef$, it's feasible to get

$$\beta_0 = 0.926, \beta_1 = -0.110, \beta_2 = -0.007. \tag{12}$$

Finally, regarding the results of the F-test,

$$F = 594.467, P = 0.000^{***}. \tag{13}$$

It represented that it has passed and the results of this model had extremely significant differences. Additionally, from

$$VIF = 1.54, D - W = 1.631. \tag{14}$$

It can be determined that there were no collinearity or autocorrelation issues between the variables selected in the linear regression model.

Table 5: The second linear regression analysis results.

	$Coef$	$Std.Err$	t	P	95% CI
$Constant$	0.926***	0.011	87.530	0.000	0.906~0.947
$Service\ life$	-0.110***	0.004	-24.901	0.000	-0.118 ~-0.101
$Mileage$	-0.007***	0.002	-4.472	0.000	-0.010 ~ -0.004
R^2			0.925		
$Adjusted\ R^2$			0.923		
F			594.467		
VIF			1.54		
$D-W$			1.631		

***, * *, * represent significance levels of 1%, 5%, and 10%, respectively.

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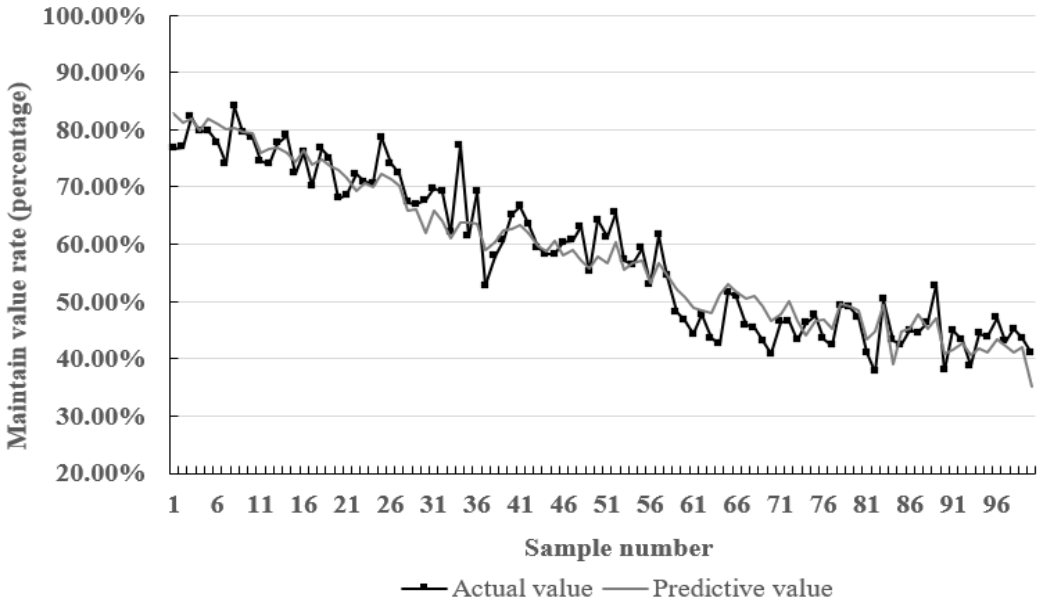

Figure 5: Actual and predictive value of research object in OLS model 2.

Overall, the regression coefficient value of service life was -0.110 and it shown a significance level of 0.01 (t=-24.901, p=0.000<0.01), indicating that this factor will have a significant negative impact on the maintain value rate of this type of cars. Mileage played a similar role in this model, whose regression coefficient was -0.007. Therefore, the residual value of Tesla Model 3 and other new energy vehicles would sensibly decrease with increasing service life and mileage, following this function:

$$y = 0.926 - 0.110 * x_1 - 0.007 * x_2. \quad (15)$$

It is possible to use point prediction to evaluate the resale value of Tesla Model 3 using a certain combination of time and mileage number, and then infer the second-hand price based on its original price. For example, a Tesla Model 3 in use for three years and ran 6.5 kilometers, with initial price of 231900 yuan, could be sold for nearly 127661 yuan in the second-hand market.

In addition, this study also conducted White-test and analysis of information criterion indicators on the two OLS models, and the results are shown in Table 6.

Table 6: Differences in results of White-test and other features.

	R^2	$Adjusted\ R^2$	X^2	p	AIC	BIC
OLS model 1	0.909	0.908	2.003	0.367	-3.548	-3.496
OLS model 2	0.925	0.923	2.650	0.754	-3.715	-3.637

From this table, it is saliently illustrated that the OLS model only about time factor has been more accurate and excellent after adding the second variable – mileage, due to the higher R^2, $Adjusted\ R^2$ and p, lower AIC and BIC.

Based on the above models and results, the paper found that the price of second-hand new energy vehicles is indeed closely related to time and mileage. Due to the ISM model, the author could take both two important factors into account, available for more accurate prediction and estimation of the remaining value.

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3.3. Discussion

According to the content of the introduction, many literatures and reports indicate that the resale value of new energy vehicles is influenced by many practical factors, including body condition, brand effect, policy support, etc. However, most of the previous researchers have focused on theoretical analysis and been lack of specific mathematical and statistical methods.

In this way, the article firstly established an ISM model, which graded and screened numerous factors. After three extractions, the research ultimately obtained 4 levels of factors. After this, this article focused on analyzing the two factors with the highest priority and strongest data support - vehicle usage time and mileage. This actually admits the theory given by Tao.

Based on the data of Tesla Model 3, the author established two OLS models, and subsequently obtained formulas for determining and predicting the maintain value rate of new energy vehicles. Notably, in the first OLS model with only one element, the R and $Adjusted\ R$ together showed that the fitting degree of curvilinear regression was extremely excellent, whose numbers, accounting for 0.908 and 0.909, are really infrequent in common analysis. Under the premise of using standard program calculations, this may be because the using time is indeed the most significant factor affecting second-hand car prices. Other features all presented the appropriate building of the model. And, in the second one with two elements, there was no problem in multicollinearity and insignificance as well. Here are the specific formulars.

$$m = 0.923 - 0.121 * n. \tag{16}$$

$$y = 0.926 - 0.110 * x_1 - 0.007 * x_2. \tag{17}$$

In this condition, it is feasible for the research to learn how much per time and per mileage negatively affect the second-price of new energy cars and make some simple point predictions through the functions. These results can rarely be found among the past review researches in new energy cars, and it's the value of this paper.

As for other factors, their main target objects are consumers and dealers in the second-hand market of new energy vehicles, which puts them in a lower priority. Meanwhile, these factors largely influence the subjective actions of both sides in the transaction, in hence it's difficult to analyze them using specific models.

To sum up, the results obtained in this article have identified specific relationships between some important factors and the research object, verified the rationality of previous research conclusions, and provided a certain degree of supplement in mathematical analysis for the study of this problem.

4. Conclusion

The study is to supplement the actuarial research on the influencing factors of the resale value of new energy vehicles, together with any predictions. First, this article screened a set of known elements through the ISM model, finally getting the most important elements which could also providing numerical data- time and mileage. Subsequently, taking Tesla Model 3 as an example, the paper quantitatively applied two mathematical and statistical models to derive the formulas for determining the resale value of new energy vehicles, which could make it more accurate to find the relationship and make predictions.

In summary, this research has displayed and graded many elements that affect the second-hand prices of new energy vehicles, and also predicted the maintain value rate of specific new energy vehicle models based on important and concrete factors, which is highly relevant to the theme. But there are still some issues haven't been addressed in this article, such as the difficulty in providing

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numerical values for statistical analysis of abstract factors like evaluation of cars after using. At the same time, how to solve the problem of low resale value of new energy vehicles is also waiting for the scholars in the future.

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