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A Predicating Analysis of New Energy Vehicles Development Based on Bass Model

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Abstract: *Predicting the development prospect of new energy vehicles (NEVs) in China is of great significance for the rational planning of industrial policies, the improvement of industrial structure and industrial layout, and achieving the orderly development of NEVs market. Based on the Toyota hybrid electric vehicles (HEVs) diffusion time series data of 20 years, the author establishes bass diffusion model, estimates the corresponding parameters combining with the characteristics of China's industrial policy, and predicts the development trend of the NEVs industry in China in the three scenarios of maintaining the existing policy strength, policy backslide, and increasing policy strength. The results show that the target of 5 million vehicles ownership will be difficult to achieve in the existing policy strength and the government should adjust the policy strength in various aspects including subsidies to achieve it.*

Keywords: *new energy vehicles; Bass model; predication; analogy method; scenario analysis*

1. Introduction

The development of the new energy vehicles (NEVs) industry is of great significance for achieving the strategic transition and upgrading of China's economic structure. China began to plan and promote NEVs in 2001, and over more than a decade of policy preparation and related technology research, there was an explosively increase in the NEVs in 2014 and 2015, becoming the fastest-growing country of NEVs in the world. According to the Energy Conservation and New Energy Vehicles Industry Development Plan (2012-2020) issued by the State Council, China's production capacity of NEVs will reach 2 million units by 2020, and the ownership will reach 5 million units. Whether the target can be achieved and what is the development trend of China's NEVs industry are issues that worth full concern under the existing technical conditions and policy system. At the same time, establishing a reasonable and effective NEVs ownership trend prediction model according to China's policy background and market environment conditions is of great practical significance to realize the orderly development and guide the layout of upstream and downstream reasonably of NEVs industry.

At present, the trend prediction of NEVs ownership is generally based on causality modeling, which mainly includes time series modeling prediction method (including curve trend extension method and grey model method based on grey theory), qualitative analysis method, logistic model, GDP growth scenario analysis method, Bass model, etc [1]. The predicting precision of the grey theoretical model is higher when the information or data on the predicted object is incomplete, but the predicting precision is not ideal when there are many factors affecting the variation of dependent variables and the grey scale of the model is large. When the logistic model is used to predict the ownership of NEVs, different goodness of curve fitting will be yielded by selecting different parameter K estimation values, and the best fitting curve can be obtained by sufficient data cycle, which is suitable for middle-long term predicating [2]. The scenario analysis methods such as elasticity coefficient method, vehicles ownership per thousand people method and proportional method all involve per capita GDP, as well as economic and regional population factors, which will be disturbed in the statistical quantity, making the data cannot really reflect the actual situation, indirectly resulting in affecting the ownership prediction of NEVs [3].

The NEVs are merely emerging, especially in China, where the number of NEVs ownership was about 5,000 in 2010 and break the barrier of 10,000 in 2011, and the ownership before that was very small and irregular, which did not have some reference value for modeling. The Bass diffusion model and its extension are usually used for an analysis tool to describe and predict the market

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purchase quantities of newly developed consumer durable goods. Early in the market assessment, it is often unnecessary to use complex market models. The Bass diffusion model is simple and suitable for research of the initial product market diffusion [4-5]. China's new energy market is still in its infancy, the available data is less, which makes the quantitative research is difficult. Based on the foreign studies on the NEVs ownership, domestic scholars have proposed a Bass model suitable for China's NEVs development and used it to analyze and predict. Zhang and Liao (2014) introduced the reference relationship among patents in the traditional Bass model to constructed an ownership prediction model of hybrid electric vehicles (HEVs) containing the factors contributed by technology diffusion [6]. Zeng et al. (2013) analogizes the parameters of other consumer durables to estimate each coefficient of the Bass model for China's NEVs ownership [7]. Liu et al. (2016). takes Toyota Prius' international data for reference and adjust the parameter estimation with Chinese market characteristics to build a Bass prediction model for China's new energy vehicle market sales, and to predict the overall trend of China's NEVs industry and the future market performance of typical models [8]. Ren et al. (2013) introduces infrastructure construction and price factors as decision variables into the Bass model, analogous to the US hybrid vehicle diffusion data, to study China's NEVs ownership [9].

In conclusion, scholars at home and abroad have obtained some achievements in the application of the Bass model to the prediction of the NEVs industry, but due to the limited historical data in China, the accuracy and precision of the model parameters need further improvement; besides, methods appeared in literatures assume that the maximum market potential of the model is unchanged, which is also the limitations of the Bass model. During the early stage of development of the NEVs market, i.e., the product introduction stage, policy support and guidance play a leading role in the product promotion and development, which makes the maximum market potential highly variable [10]. Therefore, this paper builds a Bass model based on the diffusional historical data of Toyota HEVs and observes the movement trend of the maximum market potential parameter values through error optimization processing, which serves as the basis for estimating the relevant parameters of China's NEVs diffusion model. Furthermore, this paper takes into account the changes of maximum market potential in combination with the changes of policy support and subsidies to construct a Bass model of China's NEVs ownership predication, and uses it to provide analysis data and policy support for the future development of China's NEVs industry.

2. Construction of NEVs diffusion model

The Bass model has been widely used in forecasting development in industries such as industrial technology, retail business, and consumer durables due to its advantage of taking into account all internal and external factors in predicting new product diffusion. The model is a non-parametric conditional likelihood model with three input variables, namely, maximum market potential, innovation coefficient (external influence coefficient) and imitation coefficient (internal influence coefficient). The external influence is mainly realized through mass media such as advertisements and promotions, while the internal influence is mainly realized through word-of-mouth communication from the buyers to the non-buyers about the convenience, reliability and durability of the product. Thus it can be seen the Bass model predicts the diffuse change degree of new products more accurately owing to both internal and external influencing factors are considered, but the Bass model has some shortcomings, including the model does not take into account the variability of the maximum market potential, supply constraints and repeated purchases, and ignores the randomness of the diffusion process [7] [11-13]. Although there are a couple of drawbacks, to a certain extent, it is also fit to predict market penetration of NEV products with network externality. The Bass model can be expressed as shown in Equation (1).

$$n(t) = \frac{dN(t)}{dt} = p \times \big(m - N(t)\big) + \frac{q}{m} \times N(t) \times \big(m - N(t)\big) \tag{1}$$

where $\mathrm{n(t)}$ refers the number of adopters at time t, $\mathrm{N(t)}$ refers the cumulative number of adopters at time 0 - t, p refers the innovation coefficient, q refers the imitation coefficient, m refers the maximum market potential of the first purchase, and $\mathrm{p \times \big(m - N(t)\big)}$ refers the number of adopters who bought the new product due to external influence, i.e., innovators. $\frac{\mathrm{q}}{\mathrm{m}} \times \mathrm{N(t)} \times \big(\mathrm{m - N(t)}\big)$ refers the number of adopters who purchased due to the influence of previous purchasers, i.e., imitators. When t = 0, n(0)=pm. Integral solution of equation (1) yields cumulative ownership equation (2).

$$N(t) = m \times \left[\frac{1 - e^{-(p+q)\times t}}{1 + \frac{q}{p} e^{-(p+q)\times t}}\right] \tag{2}$$

Because the promotion and development of NEVs in China have just begun, which are new technology products, the Bass model can be used to predict the ownership. However, due to the lack of

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historical data, it is impossible to obtain the parametric estimated values of Bass diffusion model directly. Therefore, this paper uses the analogy method to estimate the parameters, that is, the historical data of products with similar diffusion paths and market performance to China's NEVs market are selected to calculate the parameter values and then the parameters are substituted into the Bass diffusion model through estimating, so as to obtain the Bass model parameters of China's NEVs.

Since the introduction of PRIUS, the world's first mass-produced hybrid vehicle, in 1997, the cumulative sales of Toyota's HEVs have exceeded 10 million units by the end of January 2017, making Toyota the first company in the world to achieve mass production of NEVs, and the global market diffusion of Toyota HEV products is more representative than that of other NEVs. Therefore, this paper selects the global sales data of Toyota HEVs from 1997-2016, and given the sufficient amount of sample data, parameter estimation of these three parameters is carried out by nonlinear least squares method. Software EVIEWS was used to assist the data process. The specific results are shown in Table 1.

Tab.1 Parameter estimation results of Bass model for Toyota HEVs

Parameters	Estimated value	Standard error	P-value	R^2	Confidence level
m	1576.564	72.873	0.001	0.986	95%
p	0.000695	.000	0.000		
q	0.33460	.010	0.000		

The structure of the Bass model shows that the innovation coefficient is smaller than the imitation coefficient at the early stage of new product diffusion; for durable goods, the theoretical sum of innovation coefficient and imitation coefficient is around 0.3-0.5. It is generally believed that the average value of innovation coefficient is 0.03 and the average value of imitation coefficient is 0.38. From Table 1, we can see that the sum of p and q is about 0.3353, and the q value of 0.3346 is much larger than the p value of 0.000695. All the parameters pass the P test, which is statistically significant, and the coefficient of determination R2 is 0.986, which demonstrates that the simulation results is reasonable and accurate. Thus, the diffusion model can explain the market diffusion of Toyota HEVs commendably.

The parametric estimated values are brought into Equation (2) to calculate the predictive value of Toyota HEVs ownership over the years and compared it to the actual ownership values. The specific results are shown in Table 2.

Tab. 2 Comparison of predicted and actual values for Toyota HEVs based on Bass model

Year	Actual values/ten thousand	Predicted values/ ten thousand	Error	Predicted values after adjusting m value	Error after adjusting m value
1997	0.03	1.3	4233.33%	0.03	-3.72%
1998	1.79	3.12	74.30%	1.74	-2.80%
1999	3.31	5.65	70.69%	3.22	-2.57%
2000	5.2	9.18	76.54%	5.24	0.74%
2001	8.88	14.08	58.56%	8.93	0.59%
2002	13	20.89	60.69%	13.25	1.93%
2003	18.32	30.31	65.45%	19.23	4.96%
2004	31.78	43.3	36.25%	32.96	3.71%
2005	55.27	61.1	10.55%	54.26	-1.84%
2006	86.51	85.3	-1.40%	85.30	-1.40%
2007	129.44	117.88	-8.93%	117.88	-8.93%
2008	172.41	161.13	-6.54%	161.13	-6.54%
2009	225.41	217.47	-3.52%	217.47	-3.52%
2010	294.42	289.13	-1.80%	289.13	-1.80%
2011	357.31	377.53	5.66%	377.53	5.66%
2012	479.21	482.58	0.70%	482.58	0.70%
2013	607.21	601.98	-0.86%	601.98	-0.86%
2014	737.21	731.02	-0.84%	731.02	-0.84%
2015	857.21	863.12	0.69%	863.12	0.69%
2016	992.71	991.04	-0.17%	991.04	-0.17%

The comparison between the actual values and predicted values in Table 2 shows that the predicted error is large in the previous period, which is due to the failure to consider the changes in the maximum growth potential of the market, and early growth potential is overestimated. Now adjust the parameter

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values of the early maximum growth potential, control the error fluctuation of about 5% when measuring the m value, and observe the change trend of the m value, specifically as shown in Fig. 1. It can be seen that the maximum market potential of Toyota HEVs fluctuates greatly in the early stage of market diffusion, and it becomes stable in stages after 10 years of market introduction. In fact, along with changes in policy support, product technology innovation, price changes, market environment and consumer attitudes and other factors, the maximum market potential has a strong variability, especially in the early stage of product introduction, the consumption potential fluctuates greatly. China's NEVs market is at an early stage of development, and the variability of the maximum market potential should be fully taken into account when constructing models for it.

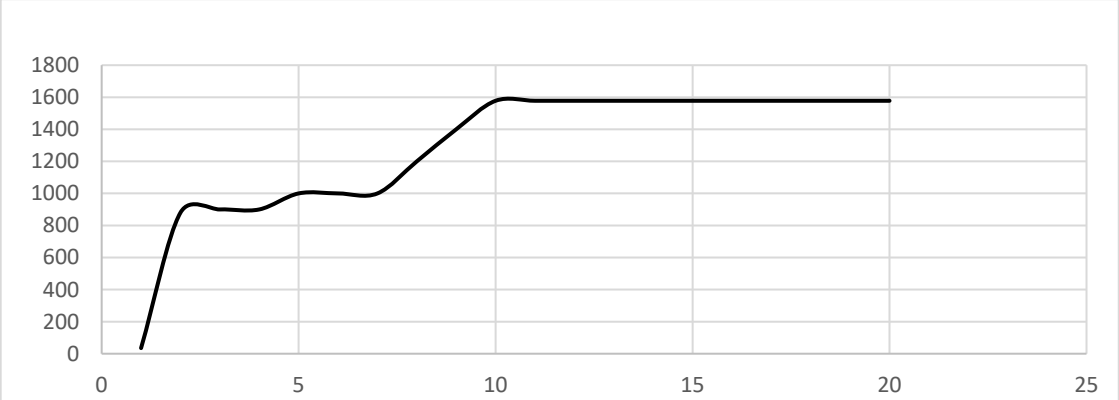

Fig. 1 Trend of m value for Toyota HEVs

3. The predictive trend of China NEVs Market

In 2001, the NEVs research project was included in the national "863" major scientific and technological projects during the 10th Five-Year Plan period. Since the 11th Five-Year Plan, China has proposed the strategy of "energy-saving and new energy vehicles", paying great attention to the research, development and industrialization of NEVs. With the pre-preparation and introduction of early policies, China started to enter the industrialization stage from 2011 to 2015, and NEVs were promoted in the whole society. After 10 years of the diffusion of Toyota HEVs, the value of m reaches about 1600. Considering that it has been 10 years since the introduction of new energy vehicles in China in 2012, the value of m is taken as 1600. Using the innovation coefficient and imitation coefficient obtained from the parameter estimation of the Bass diffusion model of Toyota HEVs, the formula for calculating the ownership of NEVs in China is as follows:

$$N(t) = 1600 \times \left[\frac{1-e^{-0.34155\times t}}{1+491.4388e^{-0.34155\times t}}\right] \quad (3)$$

In this paper, the year 2012 is taken as the base year for predicting the China NEVs ownership, and the predicted values in previous years can be obtained by applying the formula (3), and compared to the actual values. The specific results are shown in Table 3.

Tab. 3 Comparison of predicted and actual values for Toyota HEVs based on Bass model

Year	Actual values/ ten thousand	Predicted values/ ten thousand	Error	Predicted values after adjusting m value	Error after adjusting m value
2013	14.17	14.29	0.85%	14.29	0.85%
2014	21.64	21.20	-2.03%	21.20	-2.03%
2015	58.32	30.76	-47.25%	57.68	-1.10%
2016	109.02	43.94	-59.69%	109.86	0.77%
2017	153.01	62.01	-59.47%	155.02	1.32%

As shown in Table 3, the measurement error is small in 2013 and 2014, but large after 2015, which is due to the intensive introduction of various national policies in 2015, resulting in the rapid growth of China NEVs market in 2015 and 2016, thus causing a large deviation between the model's predicted values and the actual values. In order to predict the future market more accurately, we adjust the market potential values in 2015 and 2016 to control the error range, so that when the value of m in 2015 is 3000 and the value of m in 2016 and 2017 is 4000, the predicted values after adjusting m are shown in Table

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3.

Since China has been in the policy promotion period of NEVs industry before 2020, the change of policy intensity during the period plays a leading and decisive role in the market development direction, and even has a certain butterfly effect, the maximum potential value of the market fluctuates greatly. Therefore, this paper sets up three different scenarios to analyze the prediction of the ownership development trend of China's NEVs, which are to predict ownership of China's NEVs market from 2018 to 2030 in the scenarios of maintaining the existing policy strength, policy backslide, and increasing policy strength.

In the scenario of maintaining the existing policy strength, the government will continue to maintain the current level of support for the promotion of the new energy market; the infrastructure construction will be promoted steadily and the planning targets can be achieved; the technology will be improved steadily, but no breakthrough; the cost performance of NEVs will be steadily improved; the oil prices will be at low and medium level; and subsidies and incentives will be stable. Under this scenario, the maximum market potential value remains m = 4000.

In the scenario of policy backslide, infrastructure construction cannot meet expectations; No substantial progress in electric vehicle technology and no improvement in cost performance; long-term stability in oil prices; and gradual or even significant reductions in subsidies and incentives. According to the provisions of the actual policy backslide, the maximum market potential value m will be reduced by 10 percent per year from 2018 to 2020, with m values of 3,600, 3,240, 3,000 respectively, and will remain stable at 3,000 from 2020 to 2030.

In the scenario of increasing policy strength, infrastructure construction is accelerated and improved much more than expected; there is a breakthrough in technology, the cost performance ratio is greatly improved, and the oil price is at a stable and high level. Based on the existing policies, the government improves relevant policies and continuously increases subsidies and incentives. Now considering the change range of maximum market potential value with different degree of policy increase, the m value of maximum market potential value is assumed to increase by 5% per year from 2018 to 2020, with the m value being 4,200, 4,410, 4,630 respectively, and the m value is remaining stable at 4,630 from 2020 to 2030. It is also assumed that the m value of market maximum potential value increases by 10% per year from 2018 to 2020, with the m value being 4,400, 4,840, 5,320 respectively, and the m value is remaining stable at 5,320 from 2020 to 2030.

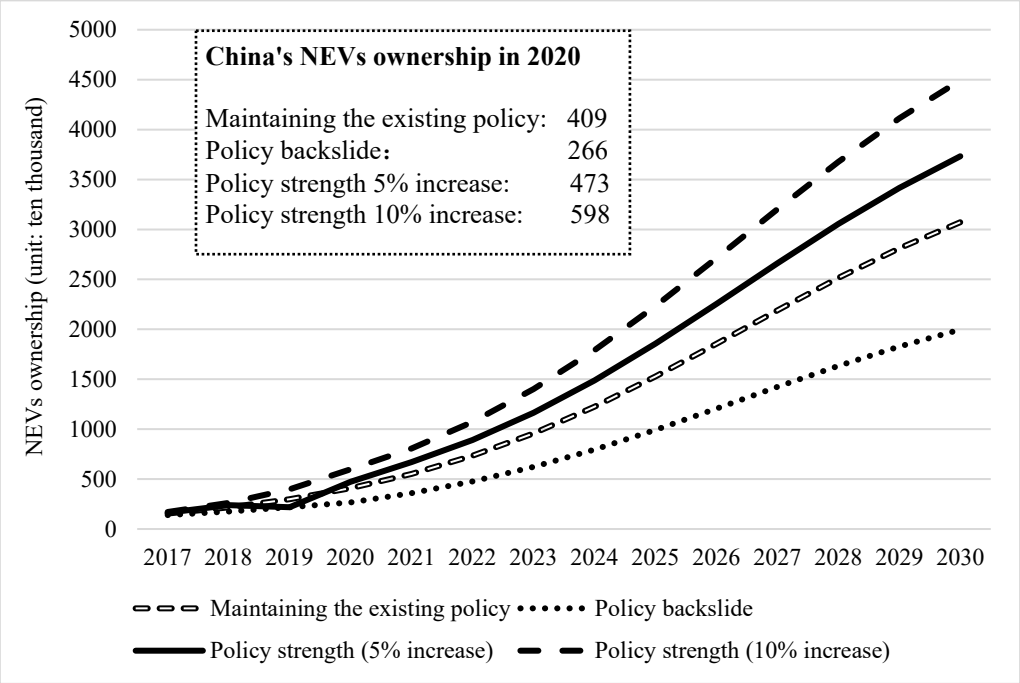

Fig. 2 The Trend prediction of China's NEVs ownership

By calculation the trend of China's NEVs ownership from 2017-2030 in three different scenarios is shown in Fig. 2 and Table 4. It can be seen that in terms of annual sales, the diffusion speed of NEVs in China is the fastest in the scenario of increasing strength, the sales have exceeded 1 million in 2019, and

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it still can exceed 1 million in 2020 in the existing policy scenario, while the annual sales in the policy backslide scenario is about half of the policy status quo, and it will exceed 1 million in 2022. Meanwhile, the sales of NEVs in China will peak around 2027. In terms of market ownership, only with the increase of policy strength, the NEVs ownership by 2020 will be 4.73 million (5% increase) and 5.44 million (10% increase), which can meet the national planning requirement of 10 million by 2022 and 30 million by 2028. In other scenarios, the planning objectives can't be achieved. In the scenario of maintaining the existing policy strength, the NEVs ownership will reach 4.09 million by 2020, which is 80% of the planned target, and will exceed 10 million by around 2024 and 30 million by 2030. However, the target year's ownership is 2.66 million vehicles in the scenario of policy backslide, which is only half of the planning target, the ownership will only exceed 10 million by around 2026 and 20 million by 2030.

Tab.4 The trend prediction of China's NEVs ownership in three different scenarios

Year	Maintaining the existing policy strength		Policy backslide		Increasing policy strength (5% increase)		Increasing policy strength (10% increase)	
	Sales/ 10000 vehicles	Ownership/ 10000 vehicles	Sales/ 10000 vehicles	Ownership/ 10000 vehicles	Sales/ 10000 vehicles	Ownership/ 10000 vehicles	Sales/ 10000 vehicles	Ownership/ 10000 vehicles
2018	61	216	36	175	72	227	83	238
2019	83	299	43	218	102	330	124	362
2020	110	409	48	266	143	473	182	544
2021	143	552	93	359	165	639	190	734
2022	182	734	118	477	210	849	242	976
2023	224	958	146	623	260	1109	298	1274
2024	267	1224	173	796	309	1417	354	1628
2025	303	1527	197	993	351	1768	403	2031
2026	327	1855	213	1206	379	2147	435	2467
2027	335	2190	218	1423	388	2535	446	2913
2028	325	2514	211	1634	376	2910	432	3344
2029	298	2812	194	1828	345	3255	396	3740
2030	260	3072	169	1997	301	3556	346	4086

4. Conclusions and Suggestions

This paper establishes a Bass diffusion model of China's NEVs ownership based on innovation diffusion theory and takes 20 years of sales data of Toyota HEVs for reference by analogy method, and predicts and analyzes the annual sales and ownership of China's NEVs market in 2018-2030 in three different scenarios, taking into account the changes of the market maximum potential in combination with the changes of China's policy support and subsidies. It is found that the innovation coefficient in the Bass diffusion model of NEVs is not high, but the imitation coefficient is high, which can ensure the rapid internal promotion and diffusion of NEVs among potential consumers once they are used first by some innovators. The predictive results show that if the current subsidy policy is maintained, the cost of NEVs is reduced and the infrastructure is implemented as planned, then the sales of NEVs will exceed 1 million in 2020, and the total ownership of NEVs will be 4.09 million by the end of 2020. If the policy backslide is taken into account, the sales of NEVs will exceed 1 million by 2022, and the total ownership will be 2.66 million. It can be seen that the target of 5 million will be difficult to achieve. The planning target can only be achieved with a sustained increase in policy strength.

The maximum market potential constrains the consumption of NEVs. If the technology of NEVs continues to progress, costs of vehicles cut down, cost performance increases, infrastructure such as charging piles is constantly improved, the cost of gasoline vehicles and other fuel vehicles is at a high level, and the government provides large preferential policies of subsidies for NEVs, then consumers are more willing to purchase NEVs, and the market potential of NEVs will be greater. Conversely, desire to buy NEVs is low and the maximum market potential is smaller. A series of incentive measures such as government subsidies are crucial in the overall development of China's NEVs, and the consistency between China's industrial policy and market performance in recent years demonstrates this. However, policy subsidies can't achieve the sustainability of the development of NEVs industry. China has implemented a gradual "backslide" measure on the subsidy for NEVs since 2016. Therefore, it is a strategic issue to be solved that how to adjust various kinds of policies including subsidy policy

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timely and appropriately so as to achieve the planning objectives of China's NEVs industry. Government departments will continue to research and improve relevant policies, increase policy guidance, strengthen the international introduction of battery technology, improve independent research and development abilities, implement various subsidies and incentive policies, speed up the construction of relevant infrastructure and supporting services, so as to promote the healthy and quick development of China's NEVs industry.

In addition, there are some limitations in this paper, such as only time series are considered in the process of establishing Bass model, but repeat purchase, competitive and other factors that influencing the development of NEVs are not taken into account. In the operation of actual market, both the government and the market are involved, and the sustainable development of the policy and the stability of the market environment provide a necessary condition to guarantee the prediction results. The predictions can be considered as extreme data of the ideal values and steady values in some extent, but large deviation will appear if the industrial policy and the market environment fluctuate greatly.

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