

Research Article

Research on the Technology Innovation Efficiency of China's Listed New Energy Vehicle Enterprises

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As a new industry, the healthy development of new energy vehicle industry is of great significance for effectively solving environmental problems and energy crises. The purpose of this study was to analyze the technological innovation process of China's new energy vehicle enterprises and construct the evaluation index system of technology innovation efficiency of China's new energy vehicle enterprises and SBM model-based network DEA model from the two aspects of technology research and development stage and achievement transformation stage. The overall technological innovation efficiency and staged efficiency of 16 listed new energy vehicle enterprises in China were measured and combined with the Malmquist Index Model. The technical change and efficiency change of 16 listed new energy vehicle enterprises in China, spanning from 2012 to 2018, were analyzed. The results show that the average overall efficiency of technological innovation of 16 new energy automobile companies is 0.5515, and the standard deviation is 0.2341. It reflects the low overall efficiency of technological innovation of Chinese new energy vehicle enterprises and the uneven development and the huge gap between different enterprises. From 2012 to 2018, the M index is less than 1, and the technical level change (TC) has a greater negative impact on the M index.

1. Introduction

With economic growth and social progress, environmental issues have raised more and more attention from people around the world. At the same time, the energy crisis is getting worse. Currently, China is highly dependent on oil imports. Data shows that China's automobile production and sales in 2009 have officially surpassed the United States and become the world's largest automobile market. It is still showing an upward trend. Therefore, it is necessary to promote the development of the new energy vehicle industry with the aim of solve environmental problems and energy crisis and drive industrial growth in China as well.

New energy vehicle industry, as a new industry, has been supported by relevant government policies. In 1992, the research and development of electric vehicles were designated as National High-tech R&D Program (863 Program) in China. It

was specifically pointed out in the Twelfth Five Year Plan on the Development of National Strategic Emerging Industries issued by the Chinese government in 2012, and new energy vehicle industry should serve as the locomotive of China's industry in 2020, propelling growth in the entire auto industry in China. With the strong support of the government, China's new energy vehicle market has made great progress. Data shows that new energy vehicle sales exceeded 1 million, reaching 1.256 million units in 2018, reflecting an increase of 61.6% compared with 2017. China's new energy vehicles are developing well and will reach 20% of total sales in 2025 (<https://www.reuters.com/article/us-china-autos-electric/new-energy-vehicles-to-make-up-20-of-chinas-new-car-sales-by-2025-idUKKBN27I0W9>) China's new energy vehicle companies led by BYD have made great progress in battery and vehicle manufacturing. China is currently the world's largest new energy vehicle market but is still lagging behind the

world's top level in terms of technology research and development. Therefore, to realize sustainable and healthy development, it is very important for China's new energy vehicle industry to improve the level of technology research and development and improve the efficiency of technological innovation.

This paper, taking China's new energy vehicle companies as the research subject, is an attempt to analyze the process of technological innovation of China's new energy vehicle companies, and construct the evaluation index system and evaluation model of technology innovation efficiency of China's new energy vehicle enterprises. It is of great significance for allocating innovation resources, improving the technological innovation efficiency of China's new energy vehicle enterprises, and realizing the sustainable development of China's new energy vehicle enterprises to scientifically evaluate and measure technical innovation efficiency of Chinese new energy vehicle enterprises and find out the key factors that affect the technological innovation efficiency of China's new energy automobile enterprises.

2. Literature Review

Evaluation and analysis of technological innovation efficiency mainly include data envelopment analysis (DEA), stochastic frontier analysis (SFA), Malmquist index, and other methods. Those classical evaluation methods are commonly used by scholars at home and abroad. Research on this issue mainly includes: Yacobucci [1] conducted comprehensive research and analysis on various types of new energy vehicles, such as electric vehicles, fuel cell vehicles, and hybrid electric vehicles. Raslavičius et al. [2] used the SWOT analysis method to study and analyze the new energy automobile industry in Lithuania and analyzed the advantages, disadvantages, opportunities, and threats involved. Papahristodoulou [3] conducted research and analysis on Korean auto companies and used DEA to evaluate the efficiency of technological innovation for all types of Korean auto companies. Mammadov and Abbasova [4] took many international companies such as the United States and Japan as the research object and used the measurement method of fuzzy theory to study their technological innovation efficiency. Fang and Sui [5] conducted in-depth research and analysis with the new energy automobile industry as the research body. Xiao et al. [6] selected Chinese industrial enterprises of different nature from 2005 to 2010 as the research objects and constructed a two-stage DEA model to comprehensively evaluate the technological innovation efficiency of different types of industrial enterprises in China. Wang and Chen [7] took the panel data of 66 military-civilian companies from 2008 to 2016 as the research object and used the stochastic frontier model to conduct an empirical analysis. Fan and Li [8] measured the overall efficiency and two-stage efficiency of technological innovation in the high-tech industries of 30 provinces in China from 2013 to 2015. Shao et al. evaluating the eco-

efficiency of China's industrial sectors by using a two-stage network data envelopment analysis [9]. Wang et al. study the impacts of the technological gap and scale economy on the low-carbon development of China's industries [10]. Ding et al. [11] took the panel data of military-civilian integration of electronic information manufacturing in 23 provinces in China from 2009 to 2016 as the main body of the research, using the two-stage DEA-Malmquist index method and panel model to conduct measurement and analysis of influencing factors. Li et al. [12] took China's high-tech industry as the main body of research and used the weight addition method to comprehensively measure its technological innovation efficiency. Li et al. [13] took China's integrated circuit industry as a research sample and used the three-stage DEA model to analyze and compare the technological innovation efficiency of the integrated circuit industry as a whole and each link of the industrial chain.

A large number of existing studies in the broader literature suggest that scholars from various countries have yielded fruitful results in the research of new energy vehicles. Research fields mainly focus on various key parts of new energy vehicles, such as power batteries, electronic control systems. Empirical research is also conducted on the relevant policies issued by governments to support the new energy automobile industry for giving valuable suggestions to foster the better and faster development of the new energy automobile industry. At the same time, scholars from home and abroad have made a lot of high-level academic achievements in the evaluation of technological innovation efficiency. They have conducted in-depth research and analysis of various industrial enterprises such as equipment manufacturing, pharmaceutical manufacturing, and military enterprises. However, there are few research results on the evaluation of technological innovation efficiency of energy automobile companies.

Among them, data envelopment analysis (DEA) is a very scientific evaluation tool for efficiency evaluation, but most scholars mainly use the traditional DEA model, which cannot yield more in-depth efficiency evaluation of each stage of technological innovation or adequately reflect the real situation. The problem with the stochastic frontier analysis (SFA) method is that it cannot handle multioutput situations. Besides, DEA is a nonparametric method, and there is no need to set a specific production function. SFA is a parametric method. It needs to set the production function. Since the new energy automobile industry is an emerging industry, its production function has not been thoroughly studied, so it is more suitable to use nonparametric methods. The SBM-based network DEA model can better overcome the shortcomings of the traditional DEA model, and its nonradial characteristics make the calculation of technological innovation efficiency in a more scientific and reasonable way and better reflect the real situation. However, few studies focus on the current two-stage network DEA using the SBM model. In this paper, we construct the SBM-based network DEA model and the Malmquist index method to study the technological innovation efficiency of Chinese new energy automobile companies.

3. Evaluation Principles and Model Construction

3.1. Enterprise Technology Innovation Process. In the 1820s, the well-known scholar Schumpeter first proposed the theory of innovation. He divided innovation into five levels: the development of new products, the application of new production methods, the opening of new markets, the selection of new sources of supply, and the establishment of new organizations. Over the years, all-round research on technological innovation has been conducted from different angles. This paper draws on the research method based on the perspective of the innovation value chain [14] and divides the enterprise technological innovation process into the upstream technology research and development stage and the downstream innovation achievement transformation stage. The technology research and development stage is the first stage in which the innovation entity conducts technological innovation activities. In this stage, the innovation subject needs to invest a large number of scientific researchers and related hardware equipment to make breakthroughs in core technologies. The results produced at this stage are more technological accumulation and theoretical enrichment, which is an important prerequisite for the subsequent transformation of scientific and technological achievements. It has a very important influence on the overall technological innovation activities of the innovation subject and is the original driving force for the innovation subject to carry out technological innovation activities. Although socially beneficial results will not be directly produced at the research and development stage, the breakthroughs in the core technology it brings are an important guarantee for promoting overall technological progress, thereby improving the overall technological innovation level. The achievement transformation stage is the process of transforming technological research and development achievements into economic benefits. In this stage, the enterprise transforms the technological research and development achievements such as invention patents obtained in the first stage of technological research and development into final products that can be applied to the market for sale. It is more market-oriented and an extension of the technology research and development stage. Its most important task is to maximize the social benefits of technology research and development results and meet the needs of consumers at different levels to the greatest extent. The achievement transformation stage is an important part of the technological innovation process, and the economic benefits it generates are the source of power for enterprises to carry out technological innovation. It is an important intermediate link between technological research and development results and the market, and the most important source of business benefits [6]. It transforms scientific and technological achievements into economic results and provides funding for the next cycle of technological research and development activities.

3.2. Network DEA Model Construction. Assume that there are a total of n DMUs in the model, and each DMU has 2 transition nodes, 1 intermediate output variable, 3 intermediate input variables, and 2 final output variables. The node is divided into two nodes, k_1 and k_2 , each node corresponds to m_k input variables, node k_1 corresponds to 2 input variables, and node k_2 corresponds to 4 input variables. We assume that x_{ij}^k is the actual input of the i th input variable of node k in DMU ($1 \leq j \leq n$) [15].

$x_j^k = (x_{1j}^k, \dots, x_{ij}^k)^T \in R^{m_k}$ ($1 \leq P_k \leq m_k$) is the actual input vector of the input variable of node k of DMU $_j$; y_j^2 is the actual output of the final output variable of DMU $_j$; z_j^2 is the intermediate output variable, λ_j^k is the intensity of node k , DMU in the case of VRS is as follows:

$$\begin{cases} x^k \geq \sum_{j=1}^n x_j^k \lambda_j^k, & (k = 1, 2), \\ y^2 \leq \sum_{j=1}^n y_j^2 \lambda_j^2, \\ z^{1,2} \sum_{j=1}^n z^{1,2} \lambda_j^1, \\ z^{1,2} \sum_{j=1}^n z^{1,2} \lambda_j^2, \\ \sum_{j=1}^n \lambda_j^k = 1, & (\forall k), \lambda_j^k \geq 0 (\forall j, k). \end{cases} \quad (1)$$

The above equation is transformed into linear programming:

$$\begin{aligned} \theta^* &= \min \sum_{k=1}^2 w^k \left[1 - mk^{-1} * \sum_{i=1}^{m_k} xi0^{-1} * si0^{k-} \right], \\ \text{s.t.} &\begin{cases} x0^k = x^k \lambda^k = s0^{k-}, & (k = 1, 2), \\ y0^2 = Y^2 \lambda^2 - s0^{2+}, \\ z^{12} \lambda^1 = z^{12} \lambda^2, \\ \sum_{j=1}^n \lambda_j^k = 1, & (k = 1, 2), \lambda_j^k \geq 0 (\forall j, k), \\ \sum_{k=1}^2 w^k = (\forall k), & w^k \geq 0 (\forall j, k). \end{cases} \end{aligned} \quad (2)$$

In the above equation, w^k is the weight of node k , $x_j^k = (x_{1j}^k, \dots, x_n^k) \in R^{m_k * n}$, $Y^2 = (y_1^2, \dots, y_n^2) \in R^{2 * n}$, $Z^{12} = (z^{12}, \dots, z_n^{12}) \in R_+^{12 * n}$, s_0^{k-} and s_0^{k+} are the slack variables adjusted by DMU $_0$ input and output variables, respectively.

3.3. SBM Model. Tone and Sahoo improved on the traditional DEA model in 2002 and proposed a nonradial SBM model [16]. It solves the shortcoming that the traditional DEA model cannot handle nonradial measurement, and the decision-making unit in the SBM model does not have to

follow the same proportion to change. The SBM model mainly includes three types: nonangle model, input-oriented model, and output-oriented model. Since the input factor is a graspable factor, in reality, most scholars and researchers adopt the input-oriented model. Therefore, this article adopts the input angle SBM model:

$$\begin{aligned} \min_{\lambda, s^-} \quad & \rho^* = 1 - m^{-1} * \sum_{i=1}^m \frac{s_i^-}{x_i^t}, \\ \text{s.t.} \quad & \begin{cases} x_0 = X\lambda + s^-, \\ y_0 \leq Y\lambda, \\ \lambda \geq 0, s^- \geq 0. \end{cases} \end{aligned} \quad (3)$$

3.4. Malmquist Index Model Construction. The M index model was first proposed by the Swedish economist Malmquist. It is also an important tool for measuring the total factor productivity index. The M index is a combination of changes in two aspects. It measures the change in technical efficiency (EC) and the change in technical level (TC) of DMUs between adjacent periods, which are numerically expressed as the product of the two. The M index represents the change in the productivity of a certain DMU from period t to period $t + 1$. If the value of the M index is greater than 1, it means that the productivity of the DMU is showing an upward trend. If the value of the M index is less than 1, it indicates that the productivity of the DMU is showing a downward trend. From the perspective of the decomposition item of the M index, the M index can be divided into technical efficiency change (EC) and technical level change (TC). Technical efficiency (EC) change indicates the degree of contribution of the DMU's technical efficiency change to the overall productivity change from t to $t + 1$. If the value of technical efficiency (EC) is greater than 1, it indicates that the technical efficiency level of the DMU has been improved within this time period. On the contrary, if the value of technical efficiency (EC) is less than 1, it means that the DMU has experienced a decline in technical efficiency during this time period. If the value of the technical level (TC) is greater than 1, it indicates that the technical level of the decision-making unit has an upward trend during the time period. On the contrary, the value of the technical level (TC) is less than 1, which indicates the technical level of the decision-making unit has shown a downward trend in the time period. If the values of technical efficiency (EC) and technical level (TC) are equal to 1, it indicates that the technical level and technical efficiency of the decision-making unit are fluctuating. The Malmquist productivity index based on output can be expressed as follows:

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \right) \left(\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)} \right) \right]^{(1/2)}. \quad (4)$$

If the M index is decomposed into technical efficiency change (EC) and technical level (TC):

$$\begin{aligned} M_o(x^{t+1}, y^{t+1}, x^t, y^t) &= \frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \\ &\quad \text{(efficiency change)} \\ &\times \underbrace{\left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \right) \left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)} \right) \right]^{(1/2)}}_{\text{(technical change)}}. \end{aligned} \quad (5)$$

4. Sample Data Source and Evaluation Index System

4.1. China's New Energy Vehicle Companies. This article takes China's new energy vehicle companies as the research object. The sample companies in this article are all new energy vehicle companies listed in the Energy Saving and New Energy Vehicle Yearbook from 2012 to 2018. After excluding samples whose main business is inconsistent with new energy vehicles or new energy vehicle projects which have been approved for less than five years, 16 new energy vehicle companies have been identified: BYD, Dongfeng Motor, Foton Motor, GAC, Haima Motor, JAC, Jiangling Automobile, King Long Automobile, Lifan, Weichai Power, FAW Car, Yutong Bus, Chang'an Automobile, Great Wall Automobile, Sinotruk, and Zhongtong Bus. The statistical data of the 16 companies selected in this article from 2012 to 2018 are all collected from the official statistical yearbooks and corporate annual reports published by China. The data on R&D investment, number of technical personnel, fixed assets, current assets, number of employees, main business income, and operating profit are all from the company's annual report. The data on the number of company patent applications come from the National Patent Office, and the rest of the relevant data comes from Shenwan industry in-depth research report and authoritative automobile website.

4.2. Evaluation Index System. Combining the characteristics of the technological innovation process of China's new energy automobile enterprises, this article will construct an evaluation index system for the technological innovation efficiency of China's new energy automobile enterprises from two aspects: the technological research and development stage and the achievement transformation stage in the technological innovation process of Chinese new energy automobile enterprises. In order to obtain a more objective and scientific evaluation result, we follow the principles of scientificity, comparability, systematization, and operability established by the technical innovation efficiency evaluation index system of China's listed new energy automobile companies, learn research results from Fang et al. [14] and Xiao et al. [6], Feng and Chen [15], Liu [17], and other scholars, and divide the criterion level in the two-stage evaluation index system of technological innovation efficiency of Chinese new energy automobile enterprises into four dimensions including initial input, intermediate output, intermediate input, and final output. A preliminary evaluation index system for the technical innovation efficiency of

China's new energy automobile companies is established, and key indicators in this system are identified by using group decision-making characteristic root methods. The technical innovation efficiency evaluation index system of China's new energy automobile enterprises is constructed as shown in Table 1.

5. Empirical Analysis on the Evaluation of Technological Innovation Efficiency of Chinese Listed New Energy Vehicle Companies

5.1. Analysis of Overall Technological Innovation Efficiency. After measuring the overall efficiency of the technological innovation of new energy automobile companies, the results obtained are shown in Table 2.

From the results in Table 2, it can be seen that from 2012 to 2018, the overall average efficiency of the technological innovation of 16 new energy automobile companies was 0.5515, and the standard deviation was 0.2341, which indicates that the overall technological innovation efficiency of the 16 new energy automobile companies was relatively low. And the development of technological innovation is relatively uneven. From the perspective of the comprehensive technological innovation efficiency value of enterprises, among the 16 new energy automobile enterprises, BYD, Foton Motor, Jianghuai Automobile, Lifan, Great Wall Motors, Sinotruk, and other 6 new energy automobile enterprises have technical innovation efficiency values above the average. It shows that the technological innovation efficiency of most new energy automobile companies is below the average level.

5.2. Substage Evaluation of Technological Innovation Efficiency of Chinese New Energy Automobile Enterprises

5.2.1. Technology Research and Development Stage. In order to analyze the two-stage technological innovation efficiency of new energy automobile companies in a more in-depth manner, this paper separately calculates the efficiency values of the substages of technology research and development and achievement transformation. The results of the sample technology research and development efficiency of 16 new energy automobile companies in China are shown in Table 3.

It can be seen from Table 3 that the overall level of technology R&D efficiency of 16 new energy vehicle companies in China is 0.4353, and the standard deviation is 0.3383, indicating that the overall level of technology R&D efficiency of the above-mentioned 16 new energy vehicle companies is low, and the efficiency difference between different companies is relatively big. It can be seen from Table 3 that the technical R&D efficiency of five companies including Sinotruk, Lifan, Jianghuai Automobile, Foton Motor, and BYD are above the average. Among them, Sinotruk's average technology research and development efficiency are the highest at 1.204. The main reason is that Sinotruk continued to increase its R&D investment during the seven years from 2012 to 2018, and its business revenue

has also increased year by year. Its strong profitability has provided a financial guarantee for its increase in technological research and development.

5.2.2. Achievement Transformation Stage. After measuring the efficiency of 16 Chinese new energy automobile companies in the transformation stage, this paper obtained the achievement transformation efficiency values in the following Table 4:

It can be seen from Table 4 that the average transformation efficiency of 16 Chinese new energy automobile companies from 2012 to 2018 was 0.7978, which is higher than the efficiency of the technology research and development stage, and the standard deviation is 0.1988, indicating a big difference in achievement transformation efficiency between different companies. Among them, the average achievement transformation efficiency value of 10 companies including Foton Motor, Haima Motor, JAC, Jiangling Motors, FAW Car, Yutong Bus, Changan Automobile, Great Wall Motor, Sinotruk, and Zhongtong Automobile is above the average level. The average technology research and development efficiency and achievement conversion efficiency of the new energy vehicle companies selected in this paper during the seven years from 2012 to 2018 are 0.4354 and 0.7978. According to the value of the technological innovation efficiency of each stage of the new energy automobile enterprises, the Chinese new energy automobile enterprises are divided into the following four types.

New energy automobile enterprise Type A features low technology R&D efficiency, low achievement transformation efficiency. New energy automobile companies represented by 4 companies including Dongfeng Motor, Guangzhou Automobile, King Long Motor, and Weichai Power belong to this type. Among them, Dongfeng Motor and Guangzhou Automobile belong to traditional automobile companies and have a very important position in the traditional automobile market. However, they are not sensitive to emerging markets such as new energy vehicles, so the technical innovation efficiency data is not eye-catching. However, these two companies have continuously increased their R&D investment in recent years, and their technological innovation efficiency values have also increased year by year, indicating that they have a good development foundation and broad market prospects. In addition, such companies, represented by King Long, face more severe problems, and their perennial technological innovation efficiency values are at a relatively low level. Their own technological innovation resources are relatively scarce, and their ability to integrate resources is relatively weak. On the one hand, they cannot effectively improve the efficiency of technological research and development, and on the other hand, they cannot produce effective market-oriented high-quality products.

New energy automobile enterprise Type B features low technology research and development efficiency and high achievement conversion efficiency. New energy automobile companies represented by seven companies, including Haima Motor, Jiangling Motors, FAW Car, Yutong Bus,

TABLE 1: Technical innovation efficiency evaluation index system of listed new energy vehicle companies in China.

Target layer	Criterion layer	Indicator layer
Evaluation index system of technological innovation efficiency of Chinese new energy automobile enterprises	Initial input	R&D investment (ten thousand yuan) X_1
		Full-time equivalent of R&D investment personnel (person-year) X_2
	Intermediate output	Number of patent applications (pieces) K_1
	Intermediate input	Fixed assets (ten thousand yuan) X_5
		Current assets (ten thousand yuan) X_6
	Final output	Number of employees (person) X_7
		Main business income (ten thousand yuan) Y_1
		Operating profit (ten thousand yuan) Y_2

TABLE 2: Technical innovation efficiency of 16 Chinese new energy automobile companies.

Enterprises	2012	2013	2014	2015	2016	2017	2018	Mean value
BYD	0.8800	0.6244	0.3409	0.4060	0.7666	0.5705	0.7099	0.6141
Dongfeng motor	0.6701	0.5400	0.4694	0.3532	0.4550	0.5785	0.4719	0.5054
Foton motor	0.9734	0.8937	0.9499	0.6051	0.5918	0.4415	0.3357	0.6844
GAC	0.1666	0.2633	0.2948	0.4451	0.5927	0.5444	0.4686	0.3965
Haima motor	0.3113	0.3400	0.3241	0.2992	0.3961	0.3874	0.4016	0.3514
JAC	0.7934	1.3093	0.9026	0.8839	0.8666	0.9318	0.9442	0.9474
Jiangling automobile	0.3494	0.3788	0.3420	0.3487	0.3263	0.3510	0.3440	0.3486
King long automobile	0.2937	0.3185	0.2972	0.3543	0.3232	0.2505	0.2229	0.2943
Lifan	0.6601	0.6272	0.5201	0.6394	0.5139	0.6133	0.6436	0.6025
Weichai power	0.2938	0.3266	0.3258	0.2770	0.4965	0.4806	0.5351	0.3908
FAW car	0.4431	0.4520	0.4770	0.6006	0.5897	0.6827	0.5656	0.5444
Yutong bus	0.3660	0.4210	0.4518	0.5100	0.4098	0.7567	0.5367	0.4931
Chang'an automobile	0.5517	0.5104	0.4976	0.4930	0.8623	0.5452	0.4559	0.5594
Great wall automobile	0.7864	0.7123	0.5322	0.4686	0.8245	0.4175	0.4420	0.5976
Sinotruk	1.7023	0.9478	0.8973	0.8808	0.9649	1.4482	1.5735	1.2021
Zhongtong bus	0.4397	0.4204	0.3643	0.1738	0.2290	0.2092	0.2033	0.2914
Mean value	0.6233	0.6574	0.6221	0.4322	0.5225	0.3619	0.3244	0.5515
Standard deviation	0.3659	0.2727	0.2152	0.1943	0.2162	0.2865	0.3171	0.2341
Minimum value	0.1666	0.2633	0.2948	0.1738	0.2290	0.2092	0.2033	0.2914
Maximum value	1.7023	1.3093	0.9499	0.8839	0.9649	1.4482	1.5735	1.2021

Chang'an Automobile, and Great Wall Motor, belong to this type. A common feature of this type of new energy automobile companies is that they have a strong ability to grasp the market. Although they do not have strong research and development capabilities, they have a relatively complete sales channel and system. Strong achievement transformation efficiency can maintain its long-term continuous investment in technological research and development. Although they currently have considerable achievement transformation efficiency values and low technological research, and development efficiency is still an important problem preventing them from achieving key technological breakthroughs.

New energy automobile enterprise Type C features high technology research and development efficiency, low achievement conversion efficiency. New energy automobile companies represented by BYD and Lifan belong to this type. This type of new energy vehicle companies features strong technology research and development capabilities, rich technology research and development hardware conditions and sufficient research and development human resources, and profound achievements in technology

research and development. However, the ability of such enterprises to transform scientific and technological achievements cannot effectively match their technological research and development capabilities, and they cannot efficiently transform their technological advantages accumulated in the process of technological research and development into market advantages. This shows that such enterprises' technological innovation achievements transformation mechanism and certain problems have appeared in the industrialization mechanism, and new products with strong market competitiveness cannot be mass-produced, which has caused a certain degree of waste of technical resources. The biggest problem they face is how to improve their ability to transform achievements and market sales.

New energy automobile enterprise Type D features high technology research and development efficiency, high achievement conversion efficiency. New energy automobile companies represented by three companies, including Jianghuai Automobile, Foton Motor and Sinotruk, belong to this type. Such enterprises feature sufficient technology research and development resources, strong new product production technology, and developed market sales network

TABLE 3: Technical R&D efficiency of 16 Chinese new energy automobile companies.

Enterprises	2012	2013	2014	2015	2016	2017	2018	Mean value
BYD	1.0000	0.5364	0.2041	0.2743	1.0000	0.7116	0.9089	0.6622
Dongfeng motor	0.7396	0.4779	0.4043	0.1987	0.2974	0.4040	0.3925	0.4164
Foton motor	1.0000	0.7981	0.9050	0.4996	0.4117	0.2186	0.1919	0.5750
GAC	0.0834	0.0740	0.1363	0.2332	0.3389	0.2579	0.1603	0.1834
Haima motor	0.1317	0.0871	0.0705	0.0689	0.0724	0.0638	0.0787	0.0819
JAC	0.6255	1.6969	1.0000	1.0000	1.0000	1.0000	1.0000	1.0461
Jiangling automobile	0.0599	0.0520	0.0399	0.0529	0.0716	0.1249	0.0868	0.0697
King long automobile	0.0530	0.0800	0.0680	0.0424	0.0632	0.0602	0.0609	0.0611
Lifan	0.9709	0.8109	0.6205	1.0000	0.6668	1.0000	1.0000	0.8670
Weichai power	0.1526	0.1830	0.1330	0.1182	0.4405	0.2272	0.2456	0.2143
FAW car	0.1287	0.1397	0.1708	0.3342	0.3190	0.4522	0.2862	0.2615
Yutong bus	0.0967	0.1019	0.1465	0.2128	0.0885	0.5661	0.3396	0.2217
Chang'an automobile	0.5728	0.3301	0.1969	0.1910	0.8480	0.3556	0.2682	0.3946
Great wall automobile	0.8785	0.4968	0.2417	0.1602	0.6773	0.2399	0.2091	0.4148
Sinotruk	2.3937	1.0000	1.0000	1.0000	0.9877	1.0434	1.0054	1.2043
Zhongtong bus	0.4396	0.4204	0.3643	0.1738	0.2290	0.2092	0.2033	0.2913
Mean value	0.5829	0.4553	0.3563	0.3475	0.4695	0.4334	0.4023	0.4353
Standard deviation	0.5887	0.4323	0.3264	0.3315	0.3367	0.3254	0.3441	0.3383
Minimum value	0.0530	0.0519	0.0399	0.0424	0.0632	0.0602	0.0609	0.0611
Maximum value	2.3937	1.6969	1.0000	1.0000	1.0000	1.0434	1.0054	1.2043

TABLE 4: Achievements transformation efficiency of 16 Chinese new energy automobile companies.

Enterprises	2012	2013	2014	2015	2016	2017	2018	Mean value
BYD	0.7736	0.7230	0.5126	0.5681	0.5820	0.4509	0.5484	0.5941
Dongfeng motor	0.6059	0.6075	0.5407	0.5530	0.6563	0.8024	0.5608	0.6181
Foton motor	0.9475	1.0000	0.9969	0.7265	0.8247	0.7642	0.5188	0.8255
GAC	0.2635	0.5336	0.5046	0.7449	0.9651	1.0000	1.0000	0.7160
Haima motor	0.5585	0.7461	0.7351	0.6561	1.0000	0.9937	1.0000	0.8128
JAC	1.0000	1.0191	0.8143	0.7805	0.7498	0.8680	0.8915	0.8748
Jiangling automobile	0.8565	1.0000	0.8914	0.8752	0.7397	0.6907	0.7605	0.8306
King long automobile	0.6770	0.6920	0.6517	0.9322	0.7516	0.5239	0.4431	0.6674
Lifan	0.4340	0.4773	0.4314	0.3890	0.3868	0.3518	0.3950	0.4093
Weichai power	0.4743	0.5098	0.5976	0.4882	0.5570	0.8656	1.0000	0.6418
FAW car	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Yutong bus	0.8103	1.0000	0.9784	1.0000	1.0000	1.0000	0.8015	0.9415
Chang'an automobile	0.5310	0.7470	1.0000	1.0000	0.8767	0.7964	0.7088	0.8086
Great wall automobile	0.7029	1.0000	1.0000	1.0000	1.0000	0.6545	0.7859	0.8776
Sinotruk	1.2450	0.8983	0.8046	0.7749	0.9427	2.0529	2.5905	1.3298
Zhongtong bus	0.8607	0.9893	1.0000	0.8364	1.0000	0.5587	0.4726	0.8168
Mean value	0.7338	0.8089	0.7787	0.7703	0.8145	0.8359	0.8423	0.7978
Standard deviation	0.2447	0.1956	0.2050	0.1906	0.1866	0.3714	0.4971	0.1988
Minimum value	0.2635	0.4773	0.4314	0.3890	0.3868	0.3518	0.3950	0.4093
Maximum value	1.2450	1.0191	1.0000	1.0000	1.0000	2.0529	2.5905	1.3298

in the technology research and development stage gives full play to its rich technological innovation resources to make breakthroughs in key technologies of new energy vehicles and continues to accumulate technological advantages; in the achievement transformation stage, it uses its own strong technological achievements to realize the ability to quickly transform the accumulated technological advantages into new products with market competitiveness and bring economic benefits to the company. Such enterprises have very broad development prospects.

5.3. Analysis of M Index of Technological Innovation Efficiency of Chinese New Energy Automobile Enterprises. In order to

analyze the changes in the technological innovation efficiency of China's 16 new energy vehicle companies from 2012 to 2018 in more depth, this paper uses the SBM network DEA-Malmquist index model to conduct an empirical analysis. The results are shown in Table 5:

It can be seen from Table 5 that the overall average value of the *M* index of technological innovation efficiency of China's 16 new energy vehicle companies is less than 1, indicating that the overall technological innovation efficiency of China's new energy vehicle companies is not in the rising stage. Among them, the average value of technical efficiency change (EC) in the seven years from 2012 to 2018 is 1.00575, indicating that technical efficiency is on the rise. The average value of the change in technology level (TC) in 7

TABLE 5: China's new energy vehicle companies' technological innovation efficiency M index and its decomposition items.

Year	Efficiency change (EC)	Technical change (TC)	M index (TFP)
2012-2013	0.999531	0.941569	0.941127
2013-2014	0.933166	1.01709	0.949114
2014-2015	0.973581	0.932154	0.907527
2015-2016	1.179937	0.797596	0.941113
2016-2017	1.024082	0.961613	0.984771
2017-2018	0.943233	1.051504	0.991813
Mean value	1.00575	0.946707	0.95215

years is 0.946707, indicating that the M index is more affected by the lower decomposition term of the change in technology level. The technical efficiency level of 2014-2015 and 2015-2016 was greater than 1, indicating that the technical efficiency of 16 new energy automobile companies has increased in the past two years, but the M index in the past two years was less than 1, which is mainly because the technical level of the past two years has shown a downward trend, which has caused a decline in the M index. The changes in the technical efficiency of new energy vehicle companies from 2012 to 2018 were generally stable and maintained an upward trend before 2017, while changes in the technical level (TC) were generally not stable, and there was a large decline in 2016-2017.

6. Results and Discussion

According to the conclusions above, the following countermeasures and suggestions are proposed:

- (1) Increase the R&D investment of China's new energy automobile companies. China's new energy automobile companies should deeply realize the importance of technological innovation, have a long-term strategic vision, actively increase investment in technology research and development, strengthen the emphasis on technological research and development activities and resource allocation, and improve the efficiency of technological innovation of new energy automobile companies. Produce more market-competitive new products, bring stable long-term income to enterprises, and truly promote the healthy development of China's new energy automobile enterprises.
- (2) Strengthen the construction of talent team of new energy automobile enterprises. Establish a sound talent introduction and training mechanism. China's new energy vehicle companies can strengthen the construction of their innovative talent team by attracting college professionals, traditional fuel vehicle professionals, and overseas high-level talents and establishing a good and inclusive corporate culture.
- (3) Reasonably allocate technological innovation resources. Companies should focus their development on core component technology research and development and independent innovation and use key technologies of new energy vehicles as a breakthrough point to drive the development of the overall

technical level of new energy vehicles; new energy vehicle companies should concentrate more on technological innovation funds in the technology research and development stage; more human and material resources will be invested in key breakthroughs in core components and core technologies, pushing China's new energy automobile industry into the world's most advanced level and achieving the largest output-to-input ratio in the process of technological innovation of new energy automobile enterprises. Improve the efficiency of technological innovation of new energy automobile enterprises.

- (4) Increase the innovation of industry-university-research cooperation among new energy automobile companies. Chinese new energy automobile companies should strengthen their ties with scientific research institutions and universities, give full play to their respective advantages, and learn from each other. The advantages and disadvantages of enterprises and universities and scientific research institutions complement each other. Enterprises provide R&D funds and projects for universities and scientific research institutions. Universities and scientific research institutions use their own scientific research personnel and scientific research equipment to carry out technological research and development, and the research and development results produced are handed over to new energy automobile companies to carry out new products and new processes to achieve a win-win situation.
- (5) Strengthen the collaboration and resource sharing of China's new energy automobile companies. Create a new energy automobile industry association with a sound system, strengthen the sharing of technological innovation resources and information exchanges among all new energy automobile companies, minimize technical thresholds, learn from each other's research results, and improve the overall level of technological innovation.
- (6) Sound government policies should be formulated. The government should improve policies to support new energy vehicles, striving for sustainable development at all stages of China's new energy auto industry. Incentive policies for key core technologies should be set up to motivate new energy vehicle enterprises to make technological innovations in key technologies. At the same time, the government's intermediary role should be brought into play to

introduce investment for new energy vehicle companies with average financial status to make continuous investment in technological research and development, improve the efficiency of technological innovation, and thereby improve the international competitiveness of China's new energy vehicle companies. In future research, the author intends to use the Global Malmquist Index to study the efficiency comparison of Chinese and foreign new energy vehicles industries.

Data Availability

The sample companies in this article are all new energy vehicle companies listed in the Energy Saving and New Energy Vehicle Yearbook from 2012 to 2018.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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