Measurement of Innovation Efficiency of New Energy Automobile Companies in the Context of Digitalization

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Abstract. New energy automobile is an important manifestation of the transformation and upgrading of the automobile manufacturing industry in China's innovation system, and the innovation efficiency of new energy automobile companies is the key to their innovation and development. In view of this, this paper takes 22 new energy automobile companies in China as a sample, selects measurement indicators from the perspective of input and output, and uses government support, regional economic level, corporate age and equity concentration as environmental variables, and measures the comprehensive innovation efficiency, pure technical efficiency and scale efficiency of new energy automobile companies from 2010 to 2019 by using three-stage DEA model, compares and analyzes the calculation results before and after the adjustment. This research is expected to provide a rational decision-making theoretical basis for improving the innovation capabilities of new energy automobile companies.

Keywords: New energy automobiles; innovation efficiency; three-stage DEA; government subsidies; digital manufacturing

1 INTRODUCTION

As an important strategic engine to deal with energy crises and environmental issues, new energy automobiles have become an inevitable choice for the transformation and upgrading of the automobile manufacturing industry by virtue of its low energy consumption and low pollution. As early as the “Eighth Five-Year Plan” period, the key technologies of new energy vehicles were highlighted in key research projects; the “Three Vertical and Three Horizontal” strategies were proposed during the “Tenth Five-Year Plan” period, and the emerging strategic industries were determined in the “Twelfth Five-Year Plan” period. “Thirteenth Five-Year Plan” further instructions on the technological innovation of the new energy automobile industry, all highlight the great strategic significance of the development of new energy automobile enterprises and their technological innovation. Major auto companies are actively deploying new energy automobile products and are accelerating R&D and innovation of new energy automobiles through technologies such as assisted driving, Internet of automobiles, smart

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cockpits, and human-computer interaction, and promote coordinated development of automobiles and roads and digital iterative changes. However, limited to factors such as lack of innovative resources and immature technical conditions, it is difficult for the innovative development of China's new energy automobiles to achieve breakthrough results [1]. Therefore, in order to help new energy automobile companies comprehensively improve their innovation efficiency and achieve sustainable competition advantages, it is necessary to comprehensively and systematically measure the innovation efficiency of China's new energy automobile companies, and then provide a basis for exploring their innovation paths[2].

In recent years, domestic and foreign scholars have conducted extensive research on the efficiency of corporate innovation. Yan Junzhou [3], Liang Na [4] used the traditional DEA model to study the innovation efficiency of listed companies in China's strategic emerging industries and environmental protection industries. Furthermore, Wei Yongmei [5] measured the technical efficiency of 22 listed wind power companies based on the DEA-Tobit model, and analyzed its influencing factors at the same time; Feng Zhijun[6] constructed a two-stage DEA model, taking resource constraints as an entry point, focus on improving the traditional DEA model. However, despite its advantages, the two-stage DEA model cannot eliminate the influence of environmental and random factors, so the three-stage DEA model is widely used. Current research generally studies innovation efficiency from the perspective of industry (industry) and region (province), but lacks a measurement from the perspective of micro-enterprises; in addition, the selected efficiency measurement models are mostly based on traditional DEA models, ignoring environmental variables and randomness. Factors and other important influences on innovation efficiency, the measurement results lack objectivity and accuracy, and it is difficult to avoid systematic errors. In view of this, this article is based on a three-stage DEA model, combining traditional DEA and similar SFA, using the relevant data of 22 new energy automobile companies in China from 2010 to 2019 to measure the innovation efficiency of China’s new energy automobile companies, eliminating the impact of environmental variables, which makes the calculation result closer to the real level.

2 MATERIALS AND METHODS

2.1 Index system construction and sample selection

This article refers to the work of Li Shuang[7], selects new energy automobile companies as a sample to conduct research on their innovation efficiency.

1) Selection of input and output indicators: The innovation activities of new energy automobile companies are affected by a variety of factors such as innovation input and innovation output. Human, financial and material input play an important role as a typical factor of innovation input. At present, domestic scholars mostly select input indicators from the perspectives of capital and labor. This article is based on existing research. In consideration of aspects, the number of enterprise R&D personnel (X_1) and the enterprise R&D expenditure (X_2) the net fixed assets of the enterprise (X_3) are selected as the new energy automobile enterprises’ innovation investment indicators. For the output indicators, two parts of innovation achievement and innovation income are mainly considered. This article selects the number of patent applications of new energy automobile companies (Y_1) and the number of models selected by each company in the recommended model catalog (Y_2) as the output indicators of innovation and technology

achievements, and selects new energy automobiles enterprise operating income (Y_3) is used as an indicator of economic benefit output.

2) Environment variable selection: In the second stage of SFA-like regression analysis, in order to meet the “separation assumption”, it is necessary to eliminate relevant environmental variables, that is, factors that have an impact on the innovation efficiency of new energy automobile companies and are not controlled by the company. Therefore, in order to make the calculation results of the innovation efficiency of new energy automobile companies more comprehensive and accurate, it is necessary to comprehensively consider the environmental variables closely related to their innovation and development. This article summarizes the existing literature, combined with the characteristics of new energy automobile companies, and selects environmental variables as follows: Regional economic level (Z_1), the intensity of government subsidies (Z_2), the age of the enterprise (Z_3), and the concentration of corporate equity (Z_4).

Based on the above analysis, construct a new energy automobile enterprise innovation efficiency measurement index system, as shown in Table 1.

Table 1. New energy automobile enterprise innovation efficiency measurement index system.

Index category	Criterion layer	Index layer
Investment index(X)	Innovative manpower input	Number of enterprise R&D personnel （X_1）
	Innovation capital investment	Enterprise R&D expenditure （X_2）
		Net fixed assets of the enterprise （X_3）
Output indicators(Y)	Scientific and technological achievements output	Number of enterprise patent applications （Y_1）
		Recommended number of enterprise new energy automobiles （Y_2）
	Economic output	Main business income （Y_3）
Environment variable(Z)	Regional economic level （Z_1）	
	Government subsidies （Z_2）	
	Business age （Z_3）	
	Corporate equity concentration （Z_4）	

2.2 Research methods and model construction

1) The first stage of the traditional DEA model: On the basis of the first data envelopment analysis model (CCR model) proposed by Charnes, Banker et al. further proposed a DEA model with variable returns to scale, namely the BCC model, which decomposed the technical efficiency (TE) in the CCR model into pure technology. The product of efficiency (PTE) and scale efficiency (SE), see formula (1) for their relationship

$$TE = PTE \times SE \tag{1}$$

For any decision-making unit, the dual form of BCC model under input orientation can be expressed as formula (2):

$$\min \theta - (e^T S^- + e_1^T S^+)$$
$$s.t. \begin{cases} \sum_{i=1}^{19} X_i \lambda_i + S^- = \theta X_0 \\ \sum_{i=1}^{19} Y_i \lambda_i - S^+ = Y_0 \\ \lambda_i \geq 0, i = 1,2,\ldots,22 \\ S^-, S^+ \geq 0 \end{cases} \tag{2}$$

The second stage similar SFA model: In order to eliminate the influence of environmental variables and random errors on the efficiency measurement results, a similar SFA model is constructed as follows:

$$S_{ni} = f(z_i; \beta_n) + v_{ni} + \mu_{ni}; i = 1,2,\ldots,22; n = 1,2,3 \tag{3}$$

In order to put all new energy automobile companies under the same environment and luck level, the results of formula (3) are used to adjust the innovation input of each company, shown as formula (4)

$$\hat{x}_{ni} = x_{ni} + \left[\max_i \left\{z_i \hat{\beta}_n\right\} - z_i \hat{\beta}_n\right] + \left[\max_i \left\{\hat{v}_{ni}\right\} - \hat{v}_{ni}\right], i = 1,2,\ldots,19; n = 1,2,3 \tag{4}$$

The third stage DEA model: The input variables and original output variables adjusted by the second-stage similar SFA model are substituted into the BCC model again to calculate the innovation efficiency value of each new energy automobile company. The measurement results at this time have eliminated the influence of environmental variables and random factors. It can more truly reflect the innovation efficiency level of new energy automobile companies.

3 MATERIALS AND METHODS

3.1 Empirical results of the traditional DEA model in the first stage

Use DEAP2.1 software to conduct preliminary calculations on the innovation efficiency of 22 new energy automobile companies from 2010 to 2019, and obtain the innovation efficiency value based on the first stage of the traditional DEA model. Before adjusting through the second-stage SFA model, the comprehensive innovation efficiency value of China's new energy automobile companies fluctuated between 0.50 and 0.70 from 2010 to 2019, indicating that the innovation efficiency of China's new energy automobile companies is at a relatively low level and still needs to be improved. Among them, the comprehensive innovation efficiency value of ZGZQ and YZYX has always been maintained at 1.00, reaching the effective frontier of technological innovation, while the innovation efficiency of XKGF and CCQC has always been at a low level, and the difference in innovation efficiency between enterprises is relatively big.

Although preliminary calculations have been made on the innovation efficiency of new energy automobile companies, the innovation efficiency value obtained based on the first-stage DEA model is affected by environmental variables and random factors, and does not reflect the true level of innovation efficiency of new energy automobile companies, so it needs to be passed. In the second stage, SFA eliminates the corresponding external interference, so as to verify and adjust the results of the innovation efficiency calculation.

3.2 Regression results and analysis of similar SFA model in the second stage

The three innovation input variables obtained by the DEA model in the first stage are the slack variable of the number of enterprise R&D personnel (S_1), the slack variable of enterprise R&D expenditure (S_2), and the slack variable of enterprise net fixed assets (S_3) as the explained variables, and the government subsidy intensity, regional economic level, corporate age, and corporate equity concentration are the explanatory variables. The second-stage SFA model is established, and the FRONTIER4.1 software is used to investigate the impact of four environmental variables on the input slack variables. The regression results are shown in Table 2.

Table 2. SFA regression results of the second stage

	s_1	s_2	s_3
c	1705.279*** (1.000)	-95.115*** (1.000)	56.051*** (0.996)
z_1	-7.356* (4.523)	-0.592*** (0.057)	-0.285*** (0.020)
z_2	23.493*** (1.787)	0.419* (0.255)	1.413*** (0.039)
z_3	-223.32*** (0.967)	-5.161*** (0.563)	-4.891*** (0.400)
z_4	78.366*** (1.453)	0.243* (0.149)	0.264*** (0.090)
σ^2	9.87E+06	5.40E+02	1.79E+03
γ	0.999	0.999	0.999
Log likehood	-165.698	-73.284	-81.609
LR test of the one-side error	10.891**	9.263**	15.366***

Note: *, **, *** indicate the significance levels of 10%, 5% and 1% respectively; the corresponding standard deviations are in parentheses.

The above analysis shows that the impact of various environmental variables on the redundancy of new energy automobile enterprises' innovation investment varies in different directions and degrees, and the innovation efficiency is affected by random factors to a certain extent, so the innovation efficiency measured by the traditional DEA model in the first stage. The value may be distorted. Based on this, the second-stage SFA regression results should be used as the basis to adjust the innovation input of new energy automobile companies, and all companies should be placed under the same environment and luck level.

3.3 Empirical results of the adjusted DEA model in the third stage

In the third stage of DEA analysis, the Deap2.1 software was used to recalculate the innovation efficiency of new energy automobile companies, and the comprehensive efficiency, pure technical efficiency, and scale efficiency of the first and second stages of enterprise innovation were compared and analyzed. The results are as follows as shown in Table 3.

Table 3. The third stage of DEA: adjusted innovation efficiency of new energy automobile companies from 2010 to 2019

No.	Name	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	JLJT	0.41	0.76	0.50	0.35	0.34	0.35	0.34	0.27	0.37	0.32
2	YQJT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	ZTQC	0.86	1.00	0.11	0.39	0.51	0.48	0.51	0.24	0.32	0.08
4	BYD	1.00	1.00	0.92	0.74	0.66	0.94	0.66	1.00	1.00	0.76
5	DFQC	1.00	1.00	1.00	0.66	0.69	1.00	0.69	1.00	0.60	1.00
6	SQJT	0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	JHQC	0.47	0.49	0.38	0.60	1.00	1.00	1.00	1.00	1.00	0.34
8	XKGF	0.15	0.18	0.28	0.23	0.28	0.29	0.28	0.26	0.14	0.24
9	GQJT	1.00	0.29	1.00	1.00	0.56	0.39	0.56	0.39	1.00	0.41
10	CCQC	0.27	0.57	0.56	0.35	0.48	0.40	0.48	0.31	0.51	0.33
11	LFQC	0.18	0.35	0.33	0.30	0.29	0.38	0.29	0.18	0.15	0.20
12	HMQC	0.24	0.45	0.27	0.20	0.21	0.33	0.21	0.17	0.28	0.14
13	CAQC	1.00	0.48	0.34	0.25	0.39	0.44	0.39	0.37	0.64	0.30
14	AHAK	0.50	0.55	1.00	0.91	1.00	1.00	1.00	0.83	0.93	1.00
15	ZGZQ	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.60	1.00
16	ZTKC	0.86	0.35	0.45	0.48	0.46	0.80	0.46	0.66	0.77	0.61
17	ZZYT	1.00	1.00	0.48	0.63	0.46	0.82	0.46	0.78	1.00	0.57
18	BQFT	1.00	0.85	0.64	0.59	1.00	0.64	1.00	0.38	0.36	0.51
19	YZYX	0.67	0.49	0.72	0.24	0.70	1.00	0.70	1.00	0.35	1.00
20	SGGF	0.03	0.25	0.59	0.48	0.33	0.42	0.33	0.23	0.05	0.14
21	HLXM	1.00	0.51	0.77	0.53	0.51	0.38	0.51	0.37	1.00	0.74
22	XMJL	0.62	1.00	0.84	1.00	1.00	1.00	1.00	1.00	0.72	0.95
	Average	0.68	0.66	0.64	0.59	0.63	0.69	0.63	0.61	0.63	0.57

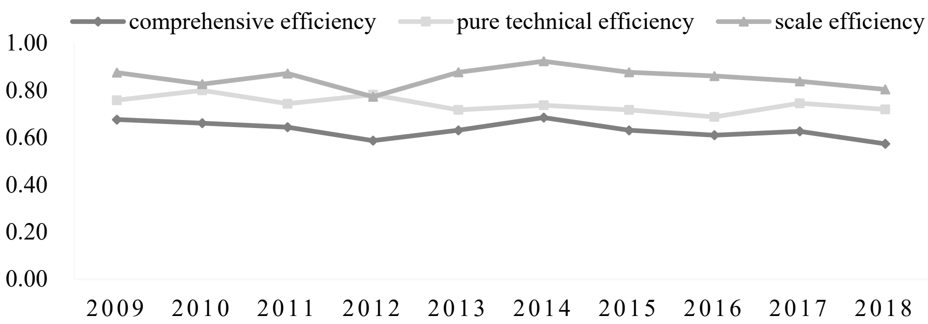

Figure 1. The third stage of DEA: the average change trend of innovation efficiency of new energy automobile companies.

From Table 3, it can be found that, except for 2017, the average innovation efficiency of new energy automobile companies after adjustment is significantly different from the unadjusted innovation efficiency in the first stage, indicating that the traditional DEA method does not consider environmental variables and random factors. As a result, the innovation efficiency of new energy automobile companies has become falsely high, which cannot reflect the true innovation efficiency level of each new energy automobile company.

From a horizontal perspective, in the first stage of DEA analysis results, ZGZQ and YZYX have always been at the forefront of innovation, while in the adjusted DEA analysis results, the above two companies have only 9 and 3 years respectively. Achieving effective innovation efficiency means that under the influence of environmental variables and random factors, some enterprises have falsely high innovation efficiency, which fails to reflect their true innovation level. At the same time, YQJT innovation efficiency value has always been maintained at the level of 1.00 after adjustment, reaching the effective frontier of technological innovation, indicating that the results of its first-stage DEA calculation have been affected by unfavorable environmental factors, and the innovation after removing relevant environmental variables. The efficiency value can better reflect its true level of innovation.

From a vertical point of view, the adjusted innovation efficiency of China's new energy automobile companies from 2010 to 2019 is still showing an upward trend and then a downward trend (as shown in Figure 1). Among them, the scale efficiency of new energy automobile companies is relatively high, which has become a driving force for new energy. An important factor in the innovation efficiency of auto companies. It shows that under the strong support of national policies, enterprises have vigorously promoted the large-scale development of enterprises by attracting large amounts of funds and gathering rich innovation resources, and the overall operating conditions are good; however, the pure technical efficiency of China's new energy automobile enterprises is low, indicating that the enterprise technology. The low level of innovation and management limits the improvement of the overall efficiency of corporate innovation. On the whole, the scale factor of China’s new energy automobile enterprises is stronger than the management and technical elements at this stage, and they have become the dominant force in promoting innovation and development. For the long-term development of this type of enterprise, it is still necessary to strengthen the rational allocation of innovative resources and effective. The ability to carry out technological transformation.

4 CONCLUSIONS AND SUGGESTIONS

4.1 Conclusions

Based on the three-stage DEA method that combines DEA and SFA, this paper estimates the innovation efficiency of 19 listed new energy automobile companies in my country. The main conclusions are as follows:

1) The difference in enterprise innovation efficiency calculated based on the traditional DEA model and the three-stage DEA model, shows that they are greatly affected by environmental factors (regional economic level, government subsidies, regional industrial policies and the degree of regional competition).

2) The adjusted average innovation efficiency of my country's new energy automobile companies from 2010 to 2019 shows a downward-rising-declining trend. The overall innovation efficiency value reached the highest value of 0.69 in 2015. After excluding environmental variables and random errors, the environment is favorable for the year. Innovation efficiency has decreased, and innovation efficiency has increased in unfavorable years.

3) The adjusted average pure technical efficiency of new energy automobile companies in our country from 2010 to 2019 fluctuates, and the pure technical efficiency value reached the highest value of 0.80 in 2011. Since 2013, the average pure technical efficiency value has basically maintained a downward trend.

4.2 Suggestions

1) Give full play to the regulatory role of government policies and provide strong environmental support. In view of the special impact of government subsidies on the innovation efficiency of new energy automobile companies, in order to promote the improvement of the innovation efficiency of new energy automobile companies, the government should implement differentiated support strategies and optimize the subsidy structure in a timely manner. On the other hand, the government should improve relevant legal mechanisms and implement supporting facilities. Policies and other measures guide new energy automobile companies to actively innovate. In addition, companies should build a moderate degree of equity concentration, and make rational use of regional economic advantages and government policy inclination to promote the steady improvement of corporate innovation efficiency.

2) Optimize the allocation of innovative resources and improve the level of pure technical efficiency. China's new energy automobile companies generally have problems such as low management efficiency and waste of innovation resources. Therefore, companies should focus on improving the efficiency of R&D talents and R&D funds, and continuously improve the internal innovation mechanism of enterprises, thereby improving the level of corporate innovation management; at the same time, new energy automobiles. Based on their own resources and conditions, enterprises should actively attract external innovation investment, consolidate the foundation of enterprise innovation, stimulate enterprise innovation vitality, and enhance the technological innovation capabilities of new energy automobile enterprises.

3) Increase investment in research and development and promote cooperation in innovation among enterprises. New energy automobile companies should appropriately expand the scale of innovation investment, increase innovation enthusiasm and initiative; and use modes such as "enterprise alliance" and "industry-university-research" cooperation to break the bottleneck of new energy automobile companies' innovation factors, strengthen the clustering effect between enterprises, and realize the enterprise Complementary resources, thereby improving the overall innovation efficiency of new energy automobile companies.

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