Research on Environmental Efficiency of China's Airlines under the Constraint of Carbon Emissions

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***Abstract*—Based on the consideration of airline carbon emissions, this paper uses SBM-DEA model to measure the environmental efficiency of 12 representative airlines in China from 2014 to 2017, and uses the Malmquist-Luenberger index to decompose airline environmental efficiency. The study found that the average environmental efficiency of private airlines continues to be lower than that of state-owned airlines, and there is room for improvement in environmental efficiency. The decline in the technical efficiency of state-controlled airlines has led to a downward trend in environmental efficiency, and the improvement in the technical efficiency of private airlines has led to a steady increase in environmental efficiency. In addition, the technological progress of private airlines has been relatively stagnant, hindering the further improvement of its environmental efficiency.**

Keywords—Airline, environmental efficiency, SBM-DEA model, Malmquist-Luenberger index

I. INTRODUCTION

In recent years, China's civil aviation transportation industry has entered a period of vigorous development. The total turnover of civil aviation transportation has increased at an annual rate of 12.07%, and the consumption of aviation kerosene has also increased sharply. The environmental problems brought about by carbon dioxide emissions will become more prominent. The international and domestic constraints on the environmental regulation of all walks of life are increasing. China's civil aviation transportation industry is no exception. The international competitiveness and development space of Chinese airlines are gradually restricted. Therefore, it is more urgent and important to study how to coordinate the rapid development of the civil aviation transportation industry and the growth of carbon emissions. The measurement of airline environmental efficiency is an important method to measure airline energy conservation and carbon emission reduction. Environmental efficiency is usually defined as "production efficiency with undesired output", which can fully reflect all input factors in the production system. The conversion relationship between expected output and undesired output [1]. Therefore, scientifically and accurately measure the environmental efficiency of airlines under the constraints of carbon emissions, and then explore the source of environmental efficiency changes, help airlines reduce carbon emissions, and better promote the sustainable development of civil aviation transportation industry.

Scientific measurement of environmental efficiency is the key to studying environmental efficiency issues. From the perspective of measurement methods, data envelopment analysis (DEA) is the mainstream tool for measuring environmental efficiency , and its various models are widely used in environmental efficiency measurement research [2,3, 4, 5]. There are few empirical studies on the environmental efficiency of civil aviation transportation enterprises in China, and there are many related literatures abroad, which can be divided into two categories from research methods. First, the traditional DEA model is used to study the environmental efficiency of airlines. Miyoshi et al. measured the carbon emissions efficiency and fuel efficiency of 14 European airlines from 1986 to 2007 based on the DEA model. The conclusions show that transportation distance, passenger utilization and fuel price have a significant impact on carbon emissions efficiency and fuel efficiency [6]. Zou et al. used the DEA model to measure the fuel efficiency of 15 US airlines in 2010. The conclusions show that the transportation distance and the number of passenger miles have a significant impact on fuel efficiency [7]. Second, the SBM-DEA model is used to study the environmental efficiency of airlines. Tone first built the SBM-DEA model to measure the environmental efficiency in 2003, and has received extensive attention from relevant scholars [8]. Cui et al. applied the weakly dispositionable network SBM-DEA model to measure the energy efficiency of the 22 international airlines in the operational phase and carbon emission reduction phase from 2008 to 2012. The conclusions indicate that European airlines have higher energy efficiency levels [9]. Chang et al measured the economic and environmental efficiency of 27 global airlines in 2010 based on the SBM-DEA model. The results show that Asian airlines are the most efficient, followed by European and American airlines [10].

In summary, at this stage, research on issues related to airline environmental efficiency has made some progress, but further exploration is still needed. First, there are shortcomings in the selection of input-output indicators. In the past, the number of aircraft selected as an important input index, and there is a big difference in the number of seats in different models. Therefore, the number of aircraft is selected as the input index. It is impossible to truly and effectively reflect the input of airline capacity, which will lead to measurement deviation of environmental efficiency. Second, the measurement of the environmental efficiency of airlines stays at a static measurement for a certain period, ignoring the dynamic process of environmental efficiency of airlines in different time spans. Therefore, this paper first uses the SBM-DEA environmental efficiency measurement model and introduces the SBM-DEA time window analysis method to dynamically measure the airline's environmental efficiency. In order to further reveal the reasons for the changes in the environmental efficiency trends of state-controlled airlines and private airlines, this paper uses the Malmquist-Luenberger index based on the SBM directional distance function to decompose the environmental efficiency.

II. RESEARCH METHOD

Compared with the traditional DEA model, the SBM-DEA model can effectively avoid the measurement deviation caused by angle selection and radial selection. At the same time, the slack variable is placed in the objective function, and the essence of environmental efficiency evaluation can be fully reflected unless the influence of efficiency factors is eliminated. Therefore, based on the SBM-DEA model and the SBM-DEA time window analysis, this paper constructs a measurement model suitable for airline environmental efficiency evaluation, and further decomposes the environmental efficiency based on the Malmquist-Luenberger index of the SBM directional distance function.

A. SBM-DEA model

Based on the modeling method of Tone [8], the basic form of the airline environmental efficiency SBM-DEA measurement model with the inputs, expected outputs and undesired outputs is as follows:

$$\min h_0 = \frac{1-\frac{1}{m}(\sum_{i=1}^{m}\frac{s_i^x}{x_{i0}})}{1+\frac{1}{s+k}(\sum_{r=1}^{s}\frac{s_r^y}{y_{r0}}+\sum_{p=1}^{k}\frac{s_p^z}{z_{p0}})} \quad (1)$$

$$\sum_{j=1}^{n}\lambda_j x_{ij} + s_i^x = x_{i0}, \forall i; i=1,2\cdots,m; \quad (2)$$

$$\sum_{j=1}^{n}\lambda_j y_{rj} - s_r^y = y_{r0}, \forall r; r=1,2\cdots,s; \quad (3)$$

$$\sum_{j=1}^{n}\lambda_j z_{pj} + s_p^z = z_{p0}, \forall p; p=1,2\cdots,k; \quad (4)$$

$$\lambda_j \geq 0, \forall j; s_i^x \geq 0, \forall i; s_r^y \geq 0, \forall r; s_p^z \geq 0, \forall p; j=1,2,\cdots,n;$$

The above model is an SBM-DEA model under the assumption of constant returns to scale, s_i^x, s_r^y, s_p^z representing the slack variables of inputs and outputs, respectively. When $s_i^x = s_r^y = s_p^z = 0$, it indicates that there is no redundancy in the input, there is no shortage of expected output, there is no redundancy in the undesired output, and there is no adjustable space for input and output. At this time, the optimal solution of the model is $h_0 = 1$, and s_i^x, s_r^y, s_p^z means that there is no efficiency loss in the decision-making unit, that is, the decision-making unit environmental efficiency level SBM-DEA is valid; when any slack variable in $0 < h_0 < 1$ is not zero, then E represents the decision-making unit. There is a loss of efficiency, that is, the decision unit environmental efficiency level SBM-DEA is invalid.

B. SBM-DEA time window analysis

The SBM-DEA time window analysis was first proposed by Charnes [11]. The method considers the same decision-making unit at different time points as different production units through panel data, and evaluates the efficiency of the decision-making unit by a method similar to moving average. The time period spanned by a production unit that is considered to be a different decision unit is the time window. The environmental efficiency of airlines depends to a large extent on the degree of technological innovation in the industry, and technological innovation is difficult to achieve in a short period of time. Therefore, the SBM-DEA time window is used for analysis, and the environmental efficiency measurement is performed in multiple time spans, and the overlapping of a series of time window measures can more accurately measure the environmental efficiency of the airline. Under the SBM-DEA time window analysis, there are A observations in each time window, starting from time B and the length of the time window is C. Charnes et al. believe that the time window span composed of 3 or 4 unit time can ensure the stability and timeliness of efficiency measurement [11]. In this paper, D is used to measure the environmental efficiency of airlines with 3 years as a time window.

C. Malmquist-Luenberger index based on SBM directional distance function

This paper draws on the method of Qi Qiying et al. citing the intertemporal dynamic concept [12], constructing the airline environmental efficiency index based on the SBM directional distance function from t to $t+1$, and defines it as:

$$ML(x_t, y_t, z_t, x_{t+1}, y_{t+1}, z_{t+1}) = \left[\frac{d_c^t(x_{t+1}, y_{t+1}, z_{t+1})}{d_c^t(x_t, y_t, z_t)} \times \frac{d_c^{t+1}(x_{t+1}, y_{t+1}, z_{t+1})}{d_c^{t+1}(x_t, y_t, z_t)}\right]^{0.5} \quad (5)$$

Among them, the SBM directional distance function $d_c^t(x_{t+1}, y_{t+1}, z_{t+1})$ represents the environmental efficiency value of the $t+1$ period of the production frontier measurement in the t period, $d_c^t(x_t, y_t, z_t)$ represents the total factor environmental efficiency index value of the current period of the t period, and $d_c^{t+1}(x_{t+1}, y_{t+1}, z_{t+1})$ represents the total factor environmental efficiency index value of the current period of the $t+1$ period.

$d_c^{t+1}(x_t, y_t, z_t)$ represents the total factor environmental efficiency index value of the t period of the production frontier measurement in the $t+1$ period. The ML index can be further decomposed into the technical efficiency $(MLeffch)$ and the technological progress $(MLtech)$ index under the assumption of the constant return of scale, which can be expressed as:

$$ML(x_t, y_t, z_t, x_{t+1}, y_{t+1}, z_{t+1}) = MLeffch^{t+1} \times MLtech^{t+1} \quad (6)$$

$$MLeffch^{t+1} = \frac{d_c^{t+1}(x_{t+1}, y_{t+1}, z_{t+1})}{d_c^t(x_t, y_t, z_t)} \quad (7)$$

$$MLtech^{t+1} = \left[\frac{d_c^t(x_{t+1}, y_{t+1}, z_{t+1})}{d_c^{t+1}(x_{t+1}, y_{t+1}, z_{t+1})} \times \frac{d_c^t(x_t, y_t, z_t)}{d_c^{t+1}(x_t, y_t, z_t)} \right]^{0.5} \quad (8)$$

Among them, $ML(x_t, y_t, z_t, x_{t+1}, y_{t+1}, z_{t+1}) > (=)(<)1$ respectively indicates that the total factor environmental efficiency index is improved (the total factor environmental efficiency index is unchanged) (the total factor environmental efficiency index is decreasing), and $MLeffch > (=)(<)1$ indicates that the technical efficiency is improved (the technical efficiency is unchanged) (the technical efficiency is deteriorated), and $MLtech > (=)(<)1$ indicates Technological advancement (technical stagnation) (technical retrogression).

III. Indicators and Data

A. Input-output indicator

Based on the selection of input and output indicators of Zhao Yuzhe, the improvement was made. This paper selects the number of employees, available tons of kilometers, and aviation kerosene consumption as input indicators [13]. Select the total turnover of the airline as the expected output indicator, and select the airline's carbon emissions as the non-expected output indicator.

- Number of employees: Regardless of the difference in employee positions, age, education and other factors, the airline's labor input is expressed by the number of airlines at the end of the year.
- Available ton-kilometer: This indicator refers to the product of the number of available seats of the airline and the total route mileage in a certain period of time, which can accurately express the actual capacity input of the airline.
- Aviation kerosene consumption: Airline kerosene consumption of airlines accounts for more than 90% of its energy input. Therefore, airlines' energy input is expressed by aviation kerosene consumption.
- Total turnover of transportation: This indicator refers to the product of the weight of the passengers and cargoes actually transported by the airline and the transportation distance within a certain period of time, which is the embodiment of the airline's production capacity. Therefore, the total turnover of transportation is used as the expected output indicator of the airline.
- Carbon emissions: The carbon dioxide emitted by airlines in the production process is the most important greenhouse gas and an important source of climate warming. Therefore, this paper selects carbon emissions as an indicator of undesired output. Calculated as follows:

$$C = V \times \beta \times \gamma \quad (9)$$

In equation (9), C is carbon emission, V is the aviation kerosene consumption of the airline, β is the conversion coefficient of the standard kerosene converted coal, and γ is the carbon emission coefficient of the standard coal.

B. Data

This paper selects 12 domestic airlines as the measure of environmental efficiency from 2014 to 2017, and divides 12 airlines into state-controlled airlines and private airlines according to the airline ownership structure. The total turnover of the 12 airlines accounts for about 70% of the total civil aviation transportation turnover, so its environmental efficiency status is representative of the industry. State-owned holding airlines including China International Airlines, Eastern Airlines, China Southern Airlines, Hainan Airlines, Sichuan Airlines, Chengdu Airlines, Shandong Airlines, Hebei Airlines accounted for 65% of the total civil aviation transportation turnover; private airlines including Spring Airlines, Shanghai Jixiang, Austria Kai Airlines and China Airlines accounted for 5% of the total civil aviation transportation turnover. Table I gives a statistical description of the inputs, expected outputs, and undesired output variables. This paper uses Matlab R2017a software for statistical analysis.

TABLE I. Statistical description of input and output variables of 12 Chinese airlines in 2014-2017

variable	***Minimum***	***Maximum***	***average***	***Standard deviation***
Number of employees	767	68317	13936	18770
Available tons of kilometers	7179	2684166	624649	817089
Aviation kerosene consumption	33376	5849704	1530267	1 910250
Total turnover	5470	1895021	457465	560319
Carbon dioxide emissions	105368	18467517	4831053	6030661

Note: The data comes from the China Civil Aviation Statistical Yearbook and the listed airline annual report.

IV. ANALYSIS

A. Analysis of environmental efficiency measurement results

The SBM-DEA model was programmed using Matlab R2017a to calculate the environmental efficiency of the selected 12 airlines in different time windows, and the environmental efficiency of the airline in a certain period was the average of the environmental efficiency in the overlapping time window. . Taking China International Airlines as an example, the calculation process and measurement results of environmental efficiency are listed in Table II. The calculation process of environmental efficiency of the remaining 11 airlines is similar, and will not be repeated. By calculating the two time windows that overlap in 2014-2017, the dynamic process of environmental efficiency of each airline can be described in detail. As can be seen from Table II, China International Airlines' environmental efficiency declined during 2014-2017, especially in 2014-2015, the environmental efficiency dropped significantly.

TABLE II. ENVIRONMENTAL EFFICIENCY VALUES OF TWO TIME WINDOWS OF AIR CHINA FROM 2014 TO 2017

window	*2014*	*2015*	*2016*	*2017*
1	1.000	0.886	0.878	
2		0.794	0.913	0.877
average value	1.000	0.840	0.895	0.877

Taking the China International Aviation Calculation Process in Table II as an example, the environmental efficiency values, historical averages and overall average values of each airline in different periods are calculated. Due to space limitations calculation results are not listed but are available for request. From the overall average of the environmental efficiency of airlines in different periods, the overall average environmental efficiency of China's airlines in 2014-2017 is 0.83, and the overall trend is decreasing year by year, which is in line with the energy consumption intensity of civil aviation transportation industry. The enhanced results are consistent. Specifically, the average annual environmental efficiency of China International, China Southern Airlines, Spring Airlines, Hainan Airlines, Sichuan Airlines and Shandong Airlines is greater than 0.90, and the environmental efficiency is at the highest level, which means that the growth of transportation turnover is in harmony with carbon emissions. Environmental efficiency is less likely to reduce carbon emissions. The average environmental efficiency of Eastern Airlines, Okay Airways and Lucky Airways is between 0.9 and 0.7, which means that the growth of transportation turnover is more coordinated with carbon emissions, and there is room for improvement in environmental efficiency. To some extent, environmental efficiency can be improved. Reduce carbon emissions. The average annual environmental efficiency of Hebei Airlines, Chengdu Airlines and China Airlines is lower than 0.7, which means that the growth of transportation turnover is not compatible with carbon emissions, and there is a lot of room for improvement in environmental efficiency. Has a prominent role. From the category of airlines, the overall environmental efficiency of state-owned airlines in 2014-2017 shows a downward trend, while the average environmental efficiency of private airlines shows a steady upward trend, but the state-owned holding airlines during the study period. The historical average of environmental efficiency is greater than that of private airlines.

B. Identify the Headings

Through the formulas (5)(6)(7)(8), the selected 12 airlines' total factor environmental efficiency index is calculated and decomposed, and the environmental efficiency of state-owned airlines is declining year by year and the environmental efficiency of The potential for the rising change. Due to space limitations, the specific factor environmental efficiency index and its decomposition data of specific airlines are not listed, but are available for request. Only the two-year airlines' Average annual total factor environmental efficiency index and its decomposition are listed in Table III.

TABLE III. THE ALL-ELEMENT ENVIRONMENTAL EFFICIENCY OF CHINA'S TWO TYPES OF AIRLINES AND ITS DECOMPOSITION IN 2014-2017

category	**years**	***ML***	***MLeffch***	***MLtech***
	2014-2015	1.04	1.03	1.01
State-owned	2015-2016	1.01	1.01	1.02
holding	2016-2017	0.94	0.95	0.98
	average	0.9967	0.9967	1.0033
	2014-2015	1.02	0.99	1.02
Private	2015-2016	1.06	1.05	1.01
aviation	2016-2017	1.23	1.34	0.96
	average	1.1033	1.1267	0.9967

It can be seen from Table III that the state-owned airlines have a total annual environmental efficiency of 0.33% at the rate of 0.33% in 2014-2017. As can be seen from Figure 1, the total factor environmental efficiency decline of China's state-controlled airlines is affected by technology. The impact of efficiency decline is relatively large, but it is less affected by technological progress; the technical efficiency index shows a downward trend, the technical level remains progressive in 2015-2017, and the technical level declines in 2016-2017. This is due to the fact that in recent years, the state has gradually tightened the restrictions on airline environmental regulations. State-owned airlines have allocated more resources in environmental governance, which has increased the operational burden and, to a certain extent, led to the transformation of state-owned airlines' technology from progress to decline. The technology advancement index showed an inverted V trend, in which the technological progress in 2016-2017 fell by 4%, accelerating the decline in the environmental efficiency of state-owned holding airlines.

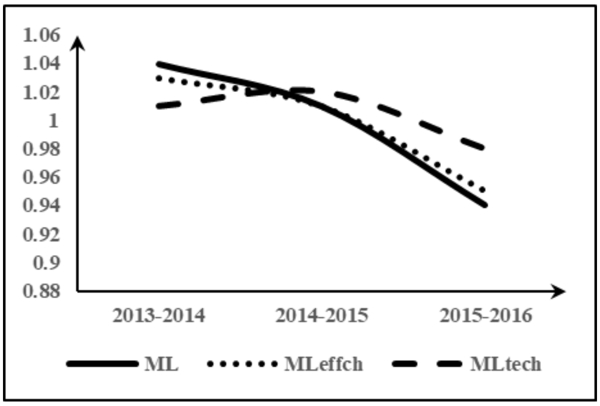

Fig. 1. The Total Factor Environmental Efficiency of State-owned Holding Airlines and Its Decomposition.

It can be seen from Table III that the total factor environmental efficiency of private airlines in 2014-2017 is increasing at an average annual rate of 10.30%; as can be seen from Figure 2, the efficiency of all-factor environmental efficiency of private airlines mainly comes from technical efficiency. Improvement, and the stagnation of technological progress has hindered the further improvement of its environmental efficiency. The technical efficiency index shows an upward trend year by year, which is improved by a 1% rate of decline and 34% speed, which greatly promotes the efficiency of the private aviation environment. This is because private airlines are more flexible and changeable in the face of environmental regulations, resulting in less burden on the company, resulting in a gradual improvement in their technical efficiency; and technological progress is declining year by year, resulting in The environmental efficiency of private airlines has slowed down. This is mainly influenced by China's mechanism and system. China's civil aviation transportation industry is still dominated by state-controlled aviation. Private aviation has a small market share and weak profitability. As a result, insufficient investment in R&D innovation has hindered technological progress to some extent.

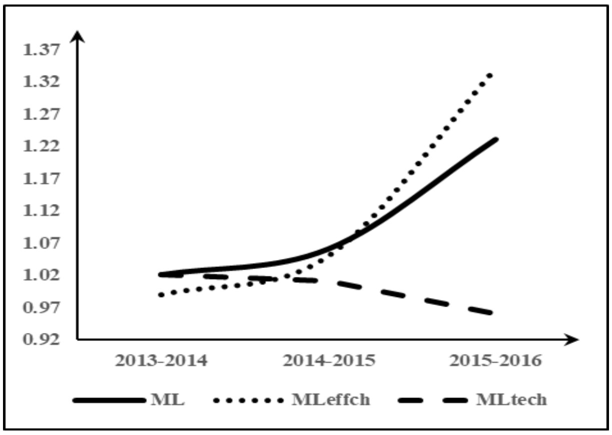

Fig. 2. The efficiency of the all-element environment of private airlines and its decomposition.

V. CONCLUSION

Based on the SBM-DEA model, this paper measures the environmental efficiency of 12 representative airlines in China from 2014 to 2017, and uses the Malmquist-Luenberger index to decompose the airline's environmental efficiency and explore the efficiency of its state-owned aviation and private aviation environment. The reasons for the trend change, the following conclusions are drawn:

(1) Compared with state-owned holding airlines, private airlines have much room for improvement in environmental efficiency. Therefore, private airlines should urgently take effective measures to speed up environmental efficiency and practice green development based on their own shortcomings.

(2) State-owned holding airlines are affected by the decline in technological efficiency, and environmental efficiency shows a downward trend. Therefore, state-owned holding airlines should pay attention to the improvement of independent innovation capability, increase research and development efforts, reserve innovative talents, and provide necessary prerequisites for promoting deepening reform within the enterprise to promote technological efficiency. At the same time, it will speed up the utilization of existing equipment and technology, improve the efficiency of resource utilization, and promote the improvement of the technical efficiency of state-controlled airlines, thereby improving environmental efficiency.

(3) The improvement of the efficiency of private aviation technology has led to an increasing trend of environmental efficiency. However, due to the small share of private aviation market and weak profitability, the investment in technology introduction and research and development funds is insufficient, resulting in technological progress. The stagnation has hindered the further improvement of environmental efficiency. Therefore, private airlines should pay attention to the improvement of technological progress, actively introduce advanced technology, strengthen cooperation with universities or scientific research institutions, enhance research and development capabilities and information application capabilities, enhance their own competitiveness through technological advancement, and promote environmental efficiency.

ACKNOWLEDGMENT

Thanks to the teachers and students who provided valuable comments on this article.

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