Study on Green Development Efficiency of Yangtze Economic Zone in China considering Resources and Environment

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Abstract: This paper evaluates the green development efficiency of 11 provinces and cities in the Yangtze River Economic Zone considering resources and environment. Input factors include assets, human resources and resources. Output takes into account GDP and major pollutants (as unexpected output). This paper makes a static analysis of the economic development efficiency of the provinces and municipalities in 2015. Considering the resource and environment constraints, the overall economic development efficiency is constrained to a certain extent. The Malmquist index model is used to calculate the changes of economic efficiency in 2005-2015, which is decomposed into pure technical efficiency, scale efficiency and technological progress index. Considering the impact of resources and environment, the overall economic efficiency of 11 provinces in the Yangtze River Economic Zone showed an upward trend in 11 years, with an average MI index of 1.014. Technological efficiency (EC) is declining as a whole. Pure technical efficiency (PEC) is the main factor that causes the decline of technical efficiency, while technological progress (TC) is an important factor to promote the increase of development efficiency during the research period. The results of regional analysis show that the decline of technological efficiency (EC) in Sichuan, Yunnan, Hubei and Anhui provinces is mainly affected by pure technological efficiency (PEC). The decline of technological efficiency (EC) in Guizhou, Jiangxi and Jiangsu provinces is mainly affected by scale efficiency (SEC).

1. Introduction
The Yangtze Economic Zone in China, with the Yangtze River Gold Waterway as its core, covers 11 development regions, including Shanghai, Jiangsu, Zhejiang, Guizhou, Sichuan and so on. The Yangtze Economic Zone covers an area of about 2.05 million square kilometers, accounting for 21% of China’s total area. The Yangtze Economic Zone is densely populated and economically active, with a total population and economy accounting for more than 40% of the national. At the same time, with the high-intensity development and construction, the Yangtze Economic Zone is facing the problems of resource shortage and ecological environment deterioration. It is urgent to change the traditional economic development model, systematically consider the resources and environmental constraints in the region, and create a green development path.

Data Envelopment Analysis (DEA) method was first proposed by Charnes, Cooper and Rhodes in 1978. It is a non-parametric technical efficiency analysis method based on the relative comparison among the evaluated objects. After years of development, DEA method has been continuously improved, and windows DEA and network DEA models have been developed. DEA can be used for efficiency analysis in the case of multi-input and multi-output. It has a wide range of applications and could also be used in combination with other methods. It has been applied in many fields such as...
as economy, taxation, agriculture, environment, resources, etc[5-8]. At present, there are many studies
on efficiency of resources, environment and economy with DEA model, but there are several problems.
One is that the influence of price is not taken into account in cross-time scale analysis. The other is
that the setting of input-output indicators is unreasonable. For example, pollutant discharge is regarded
as input. In fact, pollutant is not an input but an unexpected output.

2. Methodology

2.1. The basic principle of DEA method
The evaluated objects is called Decision Making Unit (DMU) in DEA method. DMUs need to be
comparable. Based on Constant Returns to Scale (CRS) model and Variable Returns to Scale (VRS)
model is the basic model of DEA. The technical efficiency calculated by CRS model includes scale
efficiency, which is often called "comprehensive technical efficiency". The technical efficiency
derived from VRS model excludes the impact of scale efficiency (SEC), and is called "pure technical
efficiency" (PEC), which indicates the change of efficiency caused by the improvement of
management. So the scale efficiency (SEC) can be calculated which represents a degree of proximity to
the optimal size. The improvement of efficiency can be solved by radial method, that is, the
improvement of efficiency is to reduce input or expand output with the same proportion, but there is a
problem of relaxation variables.

2.2. SBM Model
Tone Kaoru proposed the Slack Based Measure (SBM) model of DEA in 2001. SBM model is a
non-oriented model and can improve the relaxation of input and output. In addition, the model also
solves the problem of unexpected output.

\[
\begin{align*}
\min \rho &= \frac{1 - \frac{1}{m} \sum_{i=1}^{m} S_i / x_{ik}}{1 + \frac{1}{q} \sum_{r=1}^{q} S_r^+ / y_{rk}} \\
S_i X \lambda + s^- = x_k^t, Y - s^+ = y_k^t, \lambda, s^-, s^+ \geq 0
\end{align*}
\]

Where \( x_{ik} \) and \( y_{rk} \) indicate the input i and the output r of the DMU k. \( S_i^- \) and \( S_r^+ \) respectively indicate excess input and insufficient output. \( \lambda \) is a strength variable. \( \rho \) represents the efficiency of DMU k.

In static analysis with a fixed time, the efficiency of decision making unit is less than or equal to 1.
If the efficiency of decision making unit is 1, it is considered that it is in the production frontier and its
input-output efficiency is the best. If the efficiency value is less than 1, it is
considered that the efficiency is insufficient and there has a space for improvement.

2.3. Malmquist Index
The general DEA model is to evaluate the technical efficiency in a fixed time. When it is necessary to
evaluate the efficiency of multiple time points, the change of productivity includes the change of
technical efficiency and the technology change. In this case, the Malmquist Productivity Index (MI)
can be used for analysis. MI can be further decomposed into pure technical efficiency (PEC), scale
efficiency (SEC) and technological change (TC).

\[
MI = EC \times TC = PEC \times SEC \times TC
\]

MI is Malmquist Productivity Index. EC is technical efficiency which could be decomposed into
pure technical efficiency (PEC) and scale efficiency (SEC). technological change (TC) indicates
frontier movement effect. In the multi-time efficiency comparison, if TC is greater than 1, the
technology will be improved. If the efficiency value is less than 1, the technology will be backward.
The unexpected Malmquist Productivity Index is to apply the directional distance function including
the unexpected output to the Malmquist model. The distance function, such as radial and SBM can be
selected to combine with the Malmquist model.
In this paper, capital, labor and resource are taken as input items, gross product as expected output, pollutant discharge in production process as unexpected output, and the calculation of unexpected Malmquist Productivity Index is carried out by SBM method.

3. Data

3.1. Input data

3.1.1 Capital input. Capital input is mainly estimated by the Perpetual Inventory Method (PIM).

\[ K_t = I_t / P_t + (1 - \delta_t) K_{t-1} \]  

\( K_t \) is capital stock of year \( t \). \( I_t \) is new investment of year \( t \). According to the Capital Measurement Manual of OECD, it is represented by fixed capital accumulation of the year. \( P_t \) is fixed asset investment price index of year \( t \). \( \delta_t \) indicates capital depreciation of year \( t \). The fixed capital accumulation and fixed asset investment price index data comes from China Statistical Yearbook. The capital depreciation refer to Xu's research[9].

3.1.2 Labor input. The data of labor input are based on the total number of employees at the end of the year. And the data are from the regional statistical yearbook.

3.1.3 Resources input. The resources input is represented energy consumption (10,000 tons of standard coal). The data is from China Energy Statistics Yearbook.

3.1.4 Expected output. The expected output is indicated by Gross Regional Product(GRP) which is reduced at comparable prices in 2000. GRP and producer price index (PPI) are from China Statistical Yearbook.

3.1.5 Unexpected output. The unexpected output is the amount of pollutants produced in the production process. Three indicators, \( SO_2 \), COD and ammonia nitrogen (\( NH_3-N \)), are selected. The data are from China Environmental Statistics Yearbook. In order to reduce the number of input-output indicators in the model and improve the accuracy of the analysis results (Wang, 2015), the three indicators are synthetically calculated according to the pollutant equivalent proposed in the Environmental Protection Tax Law to form one unexpected output. The pollution degree of different pollutants with the same pollution equivalent is basically the same. \( SO_2 \) pollution equivalent is 0.95 kg, COD is 1 kg and ammonia nitrogen(\( NH_3-N \)) is 0.8 kg.

4. Result

4.1. The green development efficiency in 2015

MaxDEA software is used to calculate the production efficiency of 11 provinces in the Yangtze Economic Zone in 2015, which is divided into the situation without considering resources and environment and considering resources and environment constraints. The result is listed in table 1. Without considering the constraints of resources and environment, the average development efficiency (DE) of the provinces in the Yangtze Economic Zone in 2015 is 0.744, the pure technical efficiency (PEC) is 0.85, and the scale efficiency (SEC) is 0.833. Among them, Shanghai's production efficiency is the best, that is, the input-output ratio is at the optimal level. The pure technological efficiency (PEC) of Jiangsu, Chongqing and Guizhou are in the forefront, that is, technological progress plays a better role, but the scale efficiency (SEC) is insufficient. Sichuan, Yunnan, Hubei, Hunan and Anhui have high scale efficiency (SEC), close to the optimal production scale, but the pure technical efficiency (PEC) is insufficient.
Considering the constraints of resources and environment, the gap production efficiency between normal provinces and frontier provinces is further widened. The average green development efficiency (GDE) is 0.681. It shows that the green development efficiency of the Yangtze Economic Zone has 32% space for improvement. The average pure technical efficiency (PEC) is 0.838, and the average scale efficiency (SEC) is 0.831. In terms of pure technical efficiency (PEC), the provinces in front of production include Chongqing, Guizhou, Jiangxi, Jiangsu and Shanghai. It shows that the production technology level of these provinces is relatively high. In terms of scale efficiency (SEC), Sichuan, Hubei, Hunan, Anhui and Shanghai are all higher than 0.9. It shows that the proportion of investment in these provinces is reasonable.

Considering the impact of resources and environment, the efficiency of economic development has been reduced, which indicates that the constraints of resources and environment have resulted in a certain loss of economic growth efficiency. Among them, Shanghai is still at the production frontier, and its green production efficiency is the best in the Yangtze River economic belt. Chongqing, Sichuan and Anhui, the green efficiency loss is more than 12%. It indicates that these areas have not taken enough account of resources and environment in their development. And resources and environment are the shortcomings and important restrictive factors for their development. Yunnan is the only province which green development efficiency has been improved when considering the constraints of resources and environment. This shows that Yunnan Province has fully considered the use of resources and environmental protection in its development, and the clean development mode can play a reference for other regions.

| Region   | Regardless of resources and environment | Considering resources and environment |
|----------|-----------------------------------------|--------------------------------------|
|          | DE          | PEC          | SEC          | GDE          | PEC          | SEC          |
| Chongqing| 0.816       | 1.000        | 0.816        | 0.682        | 1.000        | 0.682        |
| Sichuan  | 0.745       | 0.773        | 0.964        | 0.646        | 0.668        | 0.967        |
| Guizhou  | 0.583       | 1.000        | 0.583        | 0.562        | 1.000        | 0.562        |
| Yunnan   | 0.509       | 0.553        | 0.922        | 0.545        | 0.623        | 0.876        |
| Jiangxi  | 0.645       | 0.816        | 0.790        | 0.596        | 1.000        | 0.596        |
| Hubei    | 0.746       | 0.778        | 0.959        | 0.660        | 0.690        | 0.956        |
| Hunan    | 0.678       | 0.694        | 0.976        | 0.618        | 0.632        | 0.978        |
| Anhui    | 0.766       | 0.820        | 0.934        | 0.653        | 0.723        | 0.904        |
| Jiangsu  | 0.864       | 1.000        | 0.864        | 0.767        | 1.000        | 0.767        |
| Shanghai | 0.830       | 0.916        | 0.906        | 0.758        | 0.887        | 0.855        |
| Chongqing| 1.000       | 1.000        | 1.000        | 1.000        | 1.000        | 1.000        |
| Average  | 0.744       | 0.850        | 0.883        | 0.681        | 0.838        | 0.831        |

4.2 The Malmquist Productivity Index
The Malmquist productivity index was calculated from a series of data of 11 provinces in the Yangtze Economic Zone from 2005 to 2015 considering the resources and environment. The Malmquist productivity index and the decompose results during the period are listed in table 2.
Figure 1. The MI and decomposition of Yangtze Economic Zone in 2006-2015

From the economic development of each province, the overall production efficiency showed an upward trend in the past 11 years, with an average MI index of 1.014. As far as the decomposition results, the technical efficiency (EC) is declining. Technology change (TC) shows an upward trend in each year, which indicates that technology is progressing continuously. From the perspective of technical efficiency (EC) decomposition, pure technical efficiency (PEC) is the main factor causing the decline of technical efficiency, which indicates that the input-output efficiency of the Yangtze Economic Zone is insufficient and needs to be improved through management measures. Scale efficiency shows a fluctuating state, and the allocation of input factors in 2006, 2007 and 2009 is not reasonable.

The average development efficiency of the provinces in the study period is shown in Table 2. According to the MI index of the provinces in the Yangtze Economic Zone, except Yunnan and Hunan, the economic development efficiency of other provinces has increased. Especially in Shanghai, the average MI index is 1.076, and the improvement of efficiency is mainly affected by technological progress. The technical efficiency (EC) of Sichuan, Yunnan, Hubei, Anhui is lower that mainly affected by pure technical efficiency (PEC). These areas need to increase management input and improve output efficiency. The technical efficiency (EC) of Guizhou, Jiangxi, Jiangsu is mainly affected by scale efficiency (SEC), indicating that these areas need to improve the input allocation of resources, capital, labor and so on.

Table 2. The regional average MI and decomposition of 2006-2015

|        | PEC | SEC | EC  | TC  | MI  |
|--------|-----|-----|-----|-----|-----|
| Chongqing | 1.000 | 0.999 | 0.999 | 1.024 | 1.023 |
| Sichuan  | 0.978 | 1.007 | 0.985 | 1.021 | 1.006 |
| Guizhou  | 1.000 | 0.989 | 0.989 | 1.013 | 1.002 |
| Yunnan   | 0.954 | 1.022 | 0.975 | 1.023 | 0.997 |
| Jiangxi  | 1.000 | 0.983 | 0.983 | 1.018 | 1.001 |
| Hubei    | 0.970 | 1.015 | 0.984 | 1.024 | 1.008 |
| Hunan    | 0.961 | 0.998 | 0.959 | 1.019 | 0.978 |
| Anhui    | 0.974 | 1.014 | 0.988 | 1.021 | 1.009 |
| Jiangsu  | 1.000 | 0.985 | 0.985 | 1.040 | 1.023 |
| Shanghai | 1.000 | 1.000 | 1.000 | 1.076 | 1.076 |

5. Conclusion and discussion

China has entered a transitional period of economic development, and high-quality economic
development is the direction of the future. More attention will be paid to the green development considering the restrict resources and environment. With the DEA method and Malmquist Productivity Index, the static green development efficiency of Yangtze Economic Zone provinces and cities in 2015 and the dynamic efficiency comparison between 2005 and 2015 are analyzed in the paper.

In the year of 2015, considering the constraints of resources and environment, the green development efficiency is constrained, and the average production efficiency is reduced from 0.833 to 0.681. It shows that resource and environment constraints have resulted in a certain loss of economic development efficiency. Shanghai is in the forefront of production and has the best efficiency. Other provinces and cities have certain optimization space in technology input, production input allocation, environmental protection and so on.

Considering the impact of resources and environment, the production efficiency of 11 provinces in the Yangtze Economic Zone showed an upward trend between 2005 and 2015, with an average MI index of 1.014. Technical efficiency (EC) is declining as a whole. Pure technical efficiency (PEC) is the main factor that causes the decline of technical efficiency, while technological progress is an important factor to promote the increase of production efficiency during the research period.

According to the MI index of the provinces in Yangtze Economic Zone, except Yunnan and Hunan, the green development efficiency of other provinces has increased, mainly affected by technological progress (TC). However, the technical efficiency (EC) generally shows a declining trend. The decline of technological efficiency (EC) in Sichuan, Yunnan, Hubei and Anhui provinces is mainly affected by pure technological efficiency (PEC), while that in Guizhou, Jiangxi and Jiangsu provinces is mainly affected by scale efficiency (SEC).

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