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# Measurement of Provincial Green Economic Efficiency -- Based on Three-stage DEA Model

Hao Chen[1,a,*], Xukai Wang[2,b]

[1]School of finance, Anhui University of Finance and Economics, Bengbu, China

[2]School of statistics and applied mathematics, Anhui University of Finance and Economics, Bengbu, China

[a,*] 1970673297@qq.com, [b]790728673@qq.com

## Abstract

**By analyzing the literature, this paper finds that the existing literature for measuring the efficiency of green economy does not consider the regional differences, and only analyzes the efficiency from the input and output, which has great limitations. Therefore, this paper adopts a Three-stage DEA model to revise the results of measuring the efficiency of green economy using the common DEA model from five aspects: science and technology culture, education, openness and economic structure, and obtains the Three-stage efficiency value of the efficiency of provincial green economy in China. A basic conclusion is that the efficiency of the revised green economy in western China is lower than that in other regions, while the efficiency of the revised green economy in eastern China is the highest.**

## Keywords

**Green Economy; Three-stage DEA; Comprehensive Assessment.**

## 1. Introduction

In the report of the 19th National Congress of the Communist Party of China, it is proposed to "speed up the reform of ecological civilization and physique", emphasizing that "green development" should be carried out. While developing the economy, we should not damage the ecological environment at the cost of improving the quality of economic development.What kind of economic development is of high quality? The high-quality development of economy requires at least coordinated development in innovation, coordination, green, openness and sharing. China's early crude economic development at the cost of damage to the ecological environment, although achieved a high GDP growth rate, but from the perspective of green environmental protection and coordinated development, the quality of economic development is not high.In recent years, the Chinese government has vigorously promoted environmental governance, energy conservation and emission reduction. The 13th five year plan clearly requires that China' s carbon emissions should be significantly reduced by at least 18% compared with 2015.This year is 2020, how about the quality of China's economic growth? This paper only studies from the perspective of green development, through measuring the efficiency of China' s provincial green economy, to quantitatively explain, and to make a horizontal comparison of the green economic efficiency of various provinces, municipalities and autonomous regions.

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## 2. Literature Review

In recent years, due to the importance of environmental issues, more and more studies have added environmental factors to economic efficiency. Hu Angang et al. (2008) used provincial panel data to rank the technical efficiency of each province based on various pollution conditions. Chen Shiyi (2009) introduced energy consumption and environmental pollution into industrial economic research to calculate industrial total factor productivity (TFP) and technical efficiency. Wang Bing et al. (2010) used SBM model and Luenberger productivity index to measure green economic efficiency. Kuang Yuanfeng and Peng Daiyan (2012) measured green production efficiency and total factor productivity from 1995 to 2009. Qian Zhengming and Liu Xiaochen (2013) measured the green efficiency of Eastern, central and Western China respectively, compared with the traditional economic efficiency, and analyzed the influencing factors of green economic efficiency with Tobit model. In the literature, DEA is the most used method to measure the efficiency, whether it is economic efficiency or green economic efficiency. For example, Yang Wenju (2011), Hu Angang (2008), etc., are summarized in the table below.

**Table 1.** Summary of literature methods on green economic efficiency

| method | literature |
|---|---|
| DEA method | (Hu Angang et al., 2008) |
| SBM directional distance function | (Wang Bing et al., 2010) |
| Non radial and non-angular SBM model | (Qian Zhengming and Liu Xiaochen, 2013) |
| Ml index and intertemporal DEA | (Yang Wenju, 2011) |
| Combination of GM index and stochastic frontier | (Kuang Yuanfeng and Peng Daiyan, 2012) |
| production function | (Chen Shiyi, 2009) |

Note: ML index refers to Malmquist Luenberger index, and GM index refers to generalized Malmquist index. In the table, abbreviations are adopted for beauty.

The common DEA models include CCR, BCC, SBM and so on. The earliest one is CCR model, which assumes that return to scale remains unchanged and has great limitations. BCC model relaxes this assumption. BCC model can be divided into IRS model and DRS model according to the increase and decrease of returns to scale.The SBM model is different from the former two models. It is a DEA model aiming at optimizing the relaxation variables.However, the above models are unified calculation for all decision-making units (DMUs), without considering their differences. For the measurement of provincial green economic growth efficiency, if it is determined that the level of culture, education, science and technology and development of all provinces, municipalities and autonomous regions are the same, it is obviously not in line with the actual situation, and the efficiency directly measured includes these differences, and the results are not accurate enough.In this paper, we consider using a Three-stage DEA method which can separate the differences.

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# 3. Theoretical Analysis

## 3.1. Principle and Steps of Three Stage DEA

Three stage DEA is different from traditional DEA. Through SFA regression of the relaxation value of input variables calculated by the first stage DEA, the input variables are adjusted by the regression results. At this time, the input is adjusted according to the culture, education, science and technology, and development level of each province, municipality directly under the central government and autonomous region .The results are more valuable for comparison.

### 3.1.1. The First Stage

In the first stage, the traditional BCC model is used to calculate the efficiency value and the relaxation value of input variables.

### 3.1.2. The Second Stage

The target variable is the slack value of the input variable in one stage, and the explanatory variable is the environmental variable. Refer to Fried (2002) for details. The main formula is as follows.

$$S_{ni} = \beta_i Z_i + \varepsilon_{ni} \tag{1}$$

$$\varepsilon_{ni} = V_{ni} + U_{ni}^{+} \tag{2}$$

Among them, $S_{ni}$ the relaxation value of the nth input DMU is expressed. $Z_i$ express the environment vector, $\beta_i$ the parameters of environment vector are generally assumed to be linear models, so they are directly multiplied. $\varepsilon_{ni}$ as a joint disturbance term, it is generally assumed that it is composed of a general disturbance term obeying normal distribution $V_{ni}$ the invalid rate term of kimono truncation normal distribution $U_{ni}^{+}$ and they are not related.The revised input is calculated according to the following formula:

$$X_{ni}^{*} = X_{ni} + [\max(\beta_i Z_i) - \beta_i Z_i] + [\max(V_{ni}) - V_{ni}] \tag{3}$$

Among them, $X_{ni}^{*}$ and $X_{ni}$ the distribution is modified input and modified input.max$(\beta_i Z_i)$ and max$(V_{ni})$ for extreme cases, through $[\max(\beta_i Z_i) - \beta_i Z_i] + [\max(V_{ni}) - V_{ni}]$ the actual investment can be revised to be the investment under extreme conditions.The difference between the original good situation and the maximum value is not far, and the adjustment is less; the original situation is poor and the maximum difference is far, more adjustment.

The key to the above formula lies in calculation $V_{ni}$ according to the method of Jondrow (1982), for random variables $V_{ni}$,using $E(V_{ni}|\varepsilon_{ni})$ as an estimator, it can be deduced that:

$$E(V_{ni}|\varepsilon_{ni}) = u^{*} + \sigma^{*} \frac{\phi(-u^{*}/\sigma^{*})}{\Phi(-\frac{u^{*}}{\sigma^{*}})} \tag{4}$$

Among them, $u^{*}$ and $\sigma^{*}$ it can be calculated according to the following formula:

$$-\frac{u^{*}}{\sigma^{*}} = \frac{\varepsilon\lambda}{\sigma} \tag{5}$$

$$\lambda = \frac{\sigma_u}{\sigma_v} \tag{6}$$

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Be $E(V_{ni}|\varepsilon_{ni})$ the formula can be changed as follows:

$$E(V_{ni}|\varepsilon_{ni}) = \sigma^*[\frac{\phi(\frac{\varepsilon\lambda}{\sigma})}{\Phi(-\frac{\varepsilon\lambda}{\sigma})} - \frac{\varepsilon\lambda}{\sigma}] \tag{7}$$

The result of the calculation is in the report $\gamma$ and $\sigma^2$ therefore, it can be converted according to the following formula:

$$\sigma_u^2 = \gamma\sigma^2 \tag{8}$$

$$\sigma_v^2 = (1-\gamma)\sigma^2 \tag{9}$$

$$\sigma^* = \frac{\sigma_u\sigma_v}{\sigma} \tag{10}$$

$$\varepsilon = \varepsilon_{ni} = S_{ni} - \beta_i Z \tag{11}$$

Among them,$\phi$ and $\Phi$ they are probability density function and cumulative density function of standard normal distribution,$\sigma_u^2$ and $\sigma_v^2$ they are the variance of invalid rate term and random disturbance term,$\sigma^2$ is the variance of joint disturbance term,$\gamma$ is the percentage of variance of invalid rate.

### 3.1.3. The Third Stage

The third stage is calculated from the second stage $X_{ni}^*$ as input, BCC model is used to calculate efficiency.

## 3.2. Index System

Based on the previous literature, this paper selects capital, labor and energy as input variables. The corresponding indicators are regional capital stock, number of employees and total energy consumption.In these three indicators, the number of employees and the total energy consumption can be found in the Yearbook, only the regional capital stock needs to be calculated.There are many related literatures on the calculation of regional capital stock, among which the representative ones are Zhang Junjian (1991), he juhuang (1992), Xie Qianli (1995), Zhang Jun (2004), etc. the early methods of calculating capital stock are different, but now the basic method of calculating capital stock is Gordon Smith(Goldsmith) created the perpetual inventory method in 1951.

$$K_t = K_{t-1}(1-\delta) + \frac{I_t}{p_t} \tag{12}$$

Among them,$k_t$ and $k_{t-1}$ represents the capital stock of T and T-1 respectively,$\delta$ represents the current depreciation rate,$I_t$ and $p_t$ they are the newly added investment and the investment reduction index in t period respectively. the new investment can be found in the statistical yearbook. According to the index in the references, this paper selects the total amount of fixed capital formation to represent the new investment.In the early stage, some literatures used the

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indexes calculated in the paper, but this method is too complicated and has no great help to the accuracy of calculation. In recent years, the investment price index is generally used to replace the investment price index in recent years. This paper also uses this method to represent the investment deflator index by using the investment price index.The depreciation rate is 9.6% estimated by Zhang Jun et al. (2004).As for the base period capital stock, it is generally believed that the earlier the base period is selected, the smaller the influence of the base period error on the follow-up. Zhang Jun et al. (2004) calculated the provincial capital stock of China from 1952 to 2000. The base period selected in this paper is very early and the calculation result is more accurate. Therefore, this paper uses its capital stock in 2000 as the base period capital stock.

In this paper, the expected output is selected as GDP and afforestation area as economic and environmental output respectively.There are several points to be explained about the unexpected output:

First, the early literature on DEA method has no unexpected output, but there is no undesirable output. In recent years, most of the literatures have added the index of unintended output, and this paper also adds the index of unintended output.

Secondly, as for the selection of unexpected output, a few literatures, such as Yang long and Hu Xiaozhen (2010), first used entropy method to conduct comprehensive evaluation on them, and then used the results of comprehensive evaluation as indicators of unintended output. However, most of the literatures chose the indicators before treatment as unintended output. This paper refers to the mainstream practice.The non expected output index selected in this paper is the total emission of industrial three wastes.

Thirdly, there are mainly three conversion methods for the treatment of unexpected output, i.e. taking negative, nonlinear transformation and linear transformation to convert non expected output into expected output (Bian Yiwen, 2006). The mainstream of the three methods is linear transformation and taking negative. Linear change has good properties. Taking negative is also a kind of linear transformation, which is the simplest transformation method. This paper uses the direct differentiation method.

Environmental variables are selected from six aspects: Science and technology culture, green endowment, culture, education, development degree and economic structure.Among them, the culture and education index is the result of comprehensive evaluation and calculation by using the entropy method. The import and export index is the ratio of the total regional import and export to the regional GDP, and the proportion of state-owned assets is the ratio of the total assets of the regional state-owned holding industrial enterprises to the total regional industrial assets. See the table below for all indicators.

## 4. Empirical Analysis

The data in this paper are mainly collected from the National Bureau of statistics in 2017. Deap is used in the first and third stages, and R language is used in the second stage. The regression results of the second stage are shown in Table 3. (The results of regression using forest coverage rate in the table are not significant, so the index of forest coverage is deleted.)

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**Table 2.** Index system

| Primary indicators | Secondary indicators | Third level index |
|---|---|---|
| Output indicators | Expected output | GDP |
| | | afforestation area |
| | Unexpected output | Total industrial wastewater discharge |
| | | Total industrial sulfur dioxide emissions |
| | | Total discharge of industrial solid waste |
| Input index | Capital investment | Regional capital stock |
| | Labor input | Number of Employed Persons |
| | Energy input | Total energy consumption |
| environment variable | science and technology culture | Number of valid invention patents |
| | Green endowment | forest coverage |
| | Culture | Cultural index |
| | education | Education index |
| | Development level | Import and export index |
| | economic structure | Proportion of state-owned capital assets |

**Table 3.** Regression results of SFA environmental variables

| index | Regional capital stock | Number of Employed Persons | Total energy consumption |
|---|---|---|---|
| (Intercept) | -24253 *** | -123.86 * | 460.44 |
| Number of valid invention patents | -0.097204 *** | -0.00039069 | -0.0028771 |
| Cultural index | 2824.6 *** | 479.9 *** | 87.917 |
| Education index | 24776 *** | -127.89. | 373.85 |
| Import and export index | -30119 *** | -33729 *** | -60230 *** |
| Proportion of state-owned capital assets | -7039.7 *** | -252.84 *** | -91.962 |
| Sigma2 | 69433000 *** | 107650 *** | 2463000 *** |
| gamma | 0.044758 | 0.0055739 | 0.0050134 |

Note: in the table, * *, *,. Are significant at the significance level of 0.1%, 1%, 5% and 10%.

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When the coefficient of SFA regression is positive, it means that the environmental variable has a positive effect on the input relaxation value, that is, increasing the input of the environmental variable will increase the input of the relaxation value, but the relaxation value is a negative indicator, which indicates the redundancy of input and the distance from the frontier.On the contrary, when the coefficient of SFA regression is negative, increasing the input of the environmental variable will reduce the input of relaxation value, and the input redundancy is smaller and the distance from the front is closer.

From the table, we can see that the import and export index and the proportion of state-owned assets have obvious negative effects on the regional capital stock, employment and energy. That is, the higher the proportion of state-owned assets and the higher the import and export index, the less redundant investment will be, and the higher the efficiency of green economy will be. This also shows that the pollution level of state-owned assets is low, compared with private assets, the impact of state-owned assets on investment is relatively low .The demand for interests is not so high, so the awareness of environmental protection is also high.The number of effective invention patents is also a negative effect, that is, the more patent inventions, the higher the investment efficiency, which is consistent with the fact.

Put the efficiency values calculated in the first and third stages into a table for comparative analysis, as shown in Table 4 below.

It can be seen from the above table that after the adjustment, the green economic efficiency of some regions has changed, such as Gansu Province, Guangxi Zhuang Autonomous Region and Shanghai city. The green economic efficiency in the first stage is 1, but it decreases slightly in the third stage. However, in Inner Mongolia, Hunan, Shandong, Jiangsu and Hebei, the green economic efficiency in the first stage is less than 1, but it reaches 1 in the third stage.( This paper uses comprehensive technical efficiency to represent green economic efficiency.)

On the whole, the provinces, municipalities and autonomous regions with high green economic efficiency include Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Liaoning, Jilin, Anhui, Jiangxi, Hunan, Shanxi, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Guangxi and Inner Mongolia. Their comprehensive technical efficiency is not less than 0.9, and the pure technical efficiency and scale efficiency are also very highHigh.The provinces, municipalities and autonomous regions with low green economic efficiency are mainly Hainan, Heilongjiang, Hubei, Ningxia and Xinjiang, whose comprehensive technical efficiency is lower than 0.9. Especially in Ningxia and Xinjiang, the comprehensive technical efficiency is far lower than that of other regions, and it is lower after correction.

From the regional perspective, the region with the highest green efficiency is the eastern region, including Beijing, Shanghai, Tianjin and other places. The average comprehensive technical efficiency of the third stage is as high as 0.95.The second is the central region, the average comprehensive technical efficiency is 0.94, which is also higher than the national average level.The area with the lowest green efficiency is the western region, and the average comprehensive technical efficiency is 0.89, which is lower than the average comprehensive calculation efficiency before correction.

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**Table 4.** Three stage efficiency comparison

| region | city | One stage | | | Three stages | | |
|---|---|---|---|---|---|---|---|
| | | Comprehensive technical efficiency | pure technical efficiency | Scale efficiency | Comprehensive technical efficiency | pure technical efficiency | Scale efficiency |
| Eastern Region | Beijing | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Tianjin | 0.92 | 1.00 | 0.92 | 0.90 | 1.00 | 0.90 |
| | Hebei | 0.89 | 1.00 | 0.89 | 1.00 | 1.00 | 1.00 |
| | Shanghai | 1.00 | 1.00 | 1.00 | 0.94 | 1.00 | 0.94 |
| | Jiangsu | 0.96 | 1.00 | 0.96 | 1.00 | 1.00 | 1.00 |
| | Zhejiang | 0.90 | 0.91 | 0.99 | 0.95 | 0.98 | 0.96 |
| | Fujian | 0.93 | 0.93 | 1.00 | 0.96 | 0.96 | 1.00 |
| | Shandong | 0.89 | 1.00 | 0.89 | 1.00 | 1.00 | 1.00 |
| | Guangdong | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Hainan | 0.78 | 1.00 | 0.78 | 0.71 | 1.00 | 0.71 |
| | average value | 0.93 | 0.98 | 0.94 | 0.95 | 0.99 | 0.95 |
| Three northeast provinces | Liaoning | 0.88 | 0.99 | 0.89 | 0.97 | 1.00 | 0.97 |
| | Jilin | 0.89 | 0.99 | 0.90 | 0.91 | 1.00 | 0.91 |
| | Heilongjiang | 0.90 | 0.91 | 0.99 | 0.84 | 0.92 | 0.91 |
| | average value | 0.89 | 0.97 | 0.92 | 0.91 | 0.97 | 0.93 |
| Central region | Anhui | 0.91 | 0.91 | 1.00 | 0.91 | 0.92 | 0.99 |
| | Jiangxi | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Henan | 0.83 | 0.91 | 0.91 | 0.89 | 0.93 | 0.95 |
| | Hubei | 0.83 | 0.83 | 1.00 | 0.87 | 0.88 | 0.99 |
| | Hunan | 0.97 | 0.99 | 0.98 | 1.00 | 1.00 | 1.00 |
| | Shanxi | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | average value | 0.92 | 0.94 | 0.98 | 0.94 | 0.96 | 0.99 |
| Western Region | Guizhou | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Yunnan | 0.96 | 1.00 | 0.96 | 0.96 | 1.00 | 0.96 |
| | Shaanxi | 0.85 | 0.86 | 0.99 | 0.91 | 0.94 | 0.96 |
| | Gansu | 1.00 | 1.00 | 1.00 | 0.99 | 1.00 | 0.99 |
| | Qinghai | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Ningxia | 0.73 | 1.00 | 0.73 | 0.56 | 1.00 | 0.56 |
| | Xinjiang | 0.71 | 0.73 | 0.97 | 0.65 | 0.76 | 0.86 |
| | Guangxi | 1.00 | 1.00 | 1.00 | 0.96 | 1.00 | 0.96 |
| | Inner Mongolia | 0.94 | 1.00 | 0.94 | 1.00 | 1.00 | 1.00 |
| | average value | 0.91 | 0.95 | 0.96 | 0.89 | 0.97 | 0.92 |
| whole country | average value | 0.92 | 0.96 | 0.95 | 0.92 | 0.98 | 0.95 |

Note: there are only 28 provinces, municipalities and autonomous regions in China, but Sichuan, Chongqing and Tibet are missing. A large number of data in Tibet are missing and cannot be calculated. However, when calculating the capital stock of Sichuan and Chongqing, the early literatures are all combined. The data of combined calculation will have a great impact on other data, and it is not easy to separate them in the later stage, so they are simply discarded.

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## 5. Conclusion and Suggestion

This paper revises the results of using the general DEA model from five aspects of science and technology culture, culture, education, openness and economic structure, and obtains the Three-stage efficiency values of China's provincial green economic efficiency, and compares the efficiency values of different regions

First, the average green economic efficiency of China's eastern, central and eastern provinces has been improved after correction, while the average green economic efficiency of Western China has declined.

Second, the average green efficiency of eastern China is the highest, and that of Western China is the lowest.This shows that there are indeed problems in the economic development of the western region, and the efficiency of economic development and ecological environment construction is not as good as that of other regions.

In view of the above conclusions, the following suggestions can be given:

First, the western region should focus on economic development at this stage, and then make efforts to optimize the ecological environment when the economy develops to a certain extent, so as to improve the current situation that the economic and environmental development efficiency is not high.

Second, the eastern region has a high degree of economic development and high efficiency. In order to improve the efficiency of green economy at this stage, it should be improved from the aspect of environmental optimization. Only focusing on the development of economic efficiency will not improve the efficiency of green economy, or even have a negative effect.

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