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*Original Research*

# Environmental Efficiency and Regional Technology Gaps in China: A Metafrontier Non-Radial and Non-Oriental Malmquist Index Analysis

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**Abstract**

This paper proposes a metafrontier non-radial and non-oriental DEA to examine environmental efficiency in China. This approach takes the regional technology heterogeneity, non-radial slacks, and undesirable outputs into consideration simultaneously. The results show that undesirable output inefficiency largely contributes to environmental inefficiency. And under the metafrontier technology assumption, the technology gaps between three regions have been widened. Technology gap ratio, factor endowment level, and environmental governance capacity have a positive impact on TFEE, while industrial structure, foreign capital reliance, and energy consumption structure show the negative effect on it through two-stage regression analysis. This result suggests that emission reduction stress in China is greater than the energy savings stress in the future.

**Keywords:** environmental performance, metafrontier, non-radial and non-oriental DEA

## Introduction

With rapid economic growth in China over the past 30 years, the contradiction between economic growth and environmental protection is increasingly serious; so environmental performance gradually has become a focus of widespread concern. WHO (2006) [1] reported that 16 out of 20 of the world's most polluted cities are in China [2]. According to China's environmental accounting reports in 2009, China's economic loss caused by environmental pollution in 2009 was $203.5 billion, accounting for about 3.8% of GDP [3]. To solve these problems, the government has made great efforts, such as using regulations and developing a sustainable development strategy, but China is still in the mode of extensive economic growth.

Environmental efficiency is an economic value of products and services – to environmental load ratio. Evaluation on it started from the study of energy technology and $CO_2$ emissions in the production process [4, 5]; thereafter, many scholars started their research from reducing greenhouse gas emissions [6-8]. Recently, environmental efficiency studies mainly focus on the following two aspects: one is from the regional or national level [9-11] while the other is from the industrial level [12]. Although these studies put forward effective sustainable policies on energy savings and environmental protection from the regional or national or industrial levels, research on the determinants of environmental efficiency have not been paid attention to.

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Of the above literature, DEA is the leading approach to calculate efficiency. The DEA methods can be divided into two classes: radial and nonradial models. The radial and oriental method has its own drawbacks. When there is excessive input or insufficient output (i.e. input or output has a non-zero slack), radial DEA will overestimate the efficiency of decision making units (DMUs), while the oriental DEA can not satisfy both goals of input minimization and output maximization, which leads to the inaccuracy of the efficiency calculation. In order to overcome these two drawbacks, Fare [13] developed a more generalized nonradial and non-oriental (NRNO) DEA model based on the slack-based model (SBM) [14]. Thereafter, some scholars also have applied the method to calculate the environmental efficiency [15].

This paper contributes to the literature in several directions. First, the author proposes a metafrontier NRNO DEA to avoid the defect of radial or direction distance function. Secondly, environmental efficiency can be evaluated from regional to national and global levels.

The rest of this paper is organized as follows: Section 2 explains the methodology of this study. Section 3 presents the data that have been used and lists the results obtained. Section 4 is econometric analysis of influencing factors for TFEE, and Section 5 concludes.

## Methodology

### Non-Racial and Non-Oriential (NRNO) Model

Let every province as a DMU and each DMU uses N kinds of inputs $X = (x_1, x_2, ..., x_n) \in R_N^+$ to produce M kinds of desirable output $Y = (y_1, y_2, ..., y_m) \in R_M^+$ and L kinds of undesirable output $B = (b_1, b_2, ..., b_l) \in R_L^+$; the input and output value of the province k = (1, 2,..., $K$) is $(x_{k,t}, y_{k,t}, b_{k,t})$ (t = (1, 2,..., $T$), thus we define the NRNO model as:

$$S_v^t(x_{k'}^t, y_{k'}^t, b_{k'}^t) = \min$$

$$\rho = \frac{1 - \frac{1}{N}\sum_{n=1}^{N} s_n^- / x_{no}}{1 + \frac{1}{M+L}\left(\sum_{m=1}^{M} s_m^{y+} / y_{mo} + \sum_{l=1}^{L} s_l^{b+} / b_{lo}\right)} \quad (1)$$

$$\begin{aligned} S.t.\quad & x_{kn}^t - \sum_{k=1}^{K} z_k^t x_{kn}^t - s_n^{x-} = 0, \forall n; \\ & \sum_{k=1}^{K} z_k^t y_{km}^t - y_{km}^t - s_m^{y+} = 0, \forall m; \\ & \sum_{k=1}^{K} z_k^t b_{kl}^t - b_{kl}^t + s_m^{b-} = 0, \forall l; \\ & \sum_{k=1}^{K} z_k^t = 1 \\ & z_k^t \ge 0, s_n^{x-} \ge 0, s_m^{y+} \ge 0, s_m^{b-} \ge 0 \end{aligned} \quad (2)$$

...where $z_k^t$ represents the weight of cross-sectional value, $\rho$ is TFEE, $(x_{k'}^t, y_{k'}^t, b_{k'}^t)$ are the input and output vectors of province $k$, and $(s_n^{x-}, s_m^{y+}, s_l^{b+})$ represent the slack vectors of the input and output. Due to the linear program's constraint equation and different symbols in front of slack variables, when $(s_n^{x-}, s_m^{y+}, s_l^{b+})$ were greater than zero, the actual inputs and pollution are greater than the frontier input and output, but the actual output is less than the frontier output. Therefore, $(s_n^{x-}, s_m^{y+}, s_l^{b+})$ denote the quantity of the overused input, insufficient desirable output, and excessive emissions, respectively. When direction vector and slack vector in the same unit, the standardized slack ratio can be added.

### Environmental Performance Indices

In order to derive environmental efficiency indices, we first have to define the input and output variables explicitly. In this paper, the input vector $x$ contains capital (K), labor (L), and energy (E), the desirable output y refers to GDP in each province of China, and the undesirable output $b$ is contamination emission. Because there are three inputs and two outputs, the author assumes the same weight in inputs and outputs and sets the weight vectors as (1/6, 1/6, 1/6, 1/4, 1/4). Hence the author can define input inefficiency, desirable output inefficiency, and undesirable output inefficiency according to Cooper et al. [16], as follows:

Input inefficiency: $$IE_x = \frac{1}{2N}\sum_{n=1}^{N} s_n^{x-} / x_{no} \quad (3)$$

Desirable output inefficiency: $$IE_y = \frac{1}{2M}\sum_{m=1}^{M} s_m^{y+} / y_{mo} \quad (4)$$

Undesirable output inefficiency: $$IE_b = \frac{1}{2L}\sum_{l=1}^{L} s_l^{b-} / b_{lo} \quad (5)$$

Environmental inefficiency: $$IE = IE_x + IE_y + IE_b \quad (6)$$

...so $\frac{IE_x}{IE}, \frac{IE_y}{IE}, \frac{IE_b}{IE}$ are inefficiency contribution ratios of the input, desirable output, and undesirable output, respectively. $s_n^{x-}/x_{no}$, $s_m^{y+}/y_{mo}$, and $s_l^{b-}/b_{lo}$, are the percentages of improvements.

### Metafrontier and Group-Frontier Technologies

DMUs can be divided into J groups according to certain standards of classification, and DMUs of each group are assigned to the same technology set $T^j$:{$(x_t, y_t, b_t)$: $x_t$ *can produce* $y_t$ *and* $b_t$}, now, the production possibilities set can be defined as: $P_G^j(\mathrm{x}) = \{y_t:(x_t, y_t) \in T_G^j\}$, $P_G^j(\mathrm{x})$ is the group frontier, and $P_M$ is the metafrontier formed by all the $P_G^j(\mathrm{x})$.

From Oh and Lee's [17] point of view, the Malmquist index (MI) of the group frontier and metafrontier are, respectively, as follows [17]:

$$MI_G(x_t, y_t, x_{t+1}, y_{t+1}, b_t, b_{t+1}) = \frac{S_v^G(x^{t+1}, y^{t+1}, b^{t+1})}{S_v^G(x^t, y^t, b^t)} = \frac{TE_{t+1}}{TE_t} \times \frac{TP_{G,t+1}}{TP_{G,t}} = TEC \times TPC_G \quad (7)$$

Table 1. Definitions of variables.

| Variable | Data compilation |
|---|---|
| Capital stock (K) | Applies the perpetual inventory method to the formula, $K_t = K_{t-1}(1-\delta)$, where $K_t$, $K_{t-1}$ represent capital stocks in year $t$ and year $t$–1, respectively; δ is the depreciation rate of capital stock. |
| Labor force (L) | Uses effective labor force equal to the products of regional employment and employees' average education years*. |
| Energy consumption (E) | Involves the consumption of coal, petroleum, natural gas, and hydro-power, which are all converted into standard coal equivalent. |
| Desirable output (y) | Uses GDP calculated with a comparable price. |
| Undesirable output (b) | The emissions mainly include waste, waste gas, and waste water, which are all converted into standard weight units. |

*Calculated according to the following formula: average education years = proportion of primary school×6+the proportion of junior high school×9 + proportion of high school×12 + proportion of college×15 + proportion of undergraduate×16 + proportion of graduate×19.

$$MI_M(x_t, y_t, x_{t+1}, y_{t+1}, b_t, b_{t+1}) = \frac{S_v^M(x^{t+1}, y^{t+1}, b^{t+1})}{S_v^M(x^t, y^t, b^t)} = \frac{TE_{t+1}}{TE_t} \times \frac{TP_{G,t+1}}{TP_{G,t}} \times \frac{TGR_{t+1}}{TGR_t} = TEC \times TPC_G \times TGC \quad (8)$$

...where: *TE*, *TP*, *TEC*, *TPC* are denoted as technology efficiency, technology progress, and the change of *TE* and *TP*. *TGR* is the technology gap ratio, which is an efficiency ratio of the group frontier and metafrontier showing the deviation degree of the evaluation objects in different technology levels from the metafrontier technology; the bigger the value, the smaller the deviation degree. *TGC* is the technical gap change; if the value is greater than 1, it indicates the technology catch-up effect exists.

## Empirical Analysis

### Data

The author calculated the above indices for 30 provinces in China over 2000-10[1]. All data come from the respective years of the China Statistical Yearbook, China Labor Statistical Yearbook, and China Environment Statistical Yearbook. Table 1 provides detailed information on these five variables.

Characteristic description of the above five index data is shown in Table 2. It can be seen that the eastern region has the highest average rate of economic growth, accompanied by a high-speed labor growth rate and high emissions. The western region's economic growth rate is the lowest, but is accompanied by a high-speed capital investment growth rate, energy consumption growth rate and emissions growth rate, and this phenomenon is related to the strategy of western development since 2000. As for energy consumption per unit of GDP, three main regions take on a down trend, where eastern region drops fastest; from the emissions per unit of GDP, the west declines fastest.

### Empirical Results and Implications

*Total-Factor Environmental Efficiency (TFEE)*

Table 3 shows that China's TFEE has obvious regional differences, under the metafrontier and groupfrontier the mean value of China's TFEE is 0.604 and 0.875, respectively, which illustrates that cutting down the national inputs by 39.6% and 12.5%, China can still realize original output. Obviously TEFF of group frontier is higher than that of metafrontier, and the average gap between the two kinds of frontier reached 27.1%. For example, in the western region, under the group frontier, TFEE reached 93.8%, showing that in its technical level, there is only 6.2% growth space; while in the metafrontier, its efficiency would be only 51.9%, the potential increase rate is 48.1%, far higher than improvement under groupfrontier. As for three regions, under the

Table 2. Descriptive statistics for variables.

| Variables | East China | Central China | West China | Nationwide |
|---|---|---|---|---|
| Average growth rate of K | 13.28 | 14.09 | 14.743 | 14.038 |
| Average growth rate of L | 5.744 | 5.272 | 4.58 | 5.198 |
| Average growth rate of E | 9.764 | 9.713 | 11.556 | 10.344 |
| Average growth rate of y | 12.157 | 11.822 | 11.709 | 11.895 |
| Average growth rate of b | 1.775 | 0.861 | 3.852 | 2.163 |
| Share of energy use | 49.33 | 26.39 | 24.03 | 100 |
| Share of emissions | 51.66 | 25.71 | 22.14 | 100 |
| Average growth rate of energy consumption per unit GDP | -4.038 | -3.896 | -3.588 | -3.841 |
| Average growth rate emissions of per unit GDP | -6.748 | -7.217 | -7.277 | -7.081 |

[1]Because of data in different statistics caliber, we choose the period 2000-10.

Table 3. Comparison of TFEE under metafrontier and group-frontier technologies.

| Region | Groupfrontier | | | | Metafrontier | | | |
|---|---|---|---|---|---|---|---|---|
| | Average | Std. dev. | Max | Min | Average | Std. dev. | Max | Min |
| East China | 0.777 | 0.022 | 0.810 | 0.741 | 0.775 | 0.023 | 0.810 | 0.734 |
| Central China | 0.937 | 0.026 | 0.967 | 0.891 | 0.527 | 0.040 | 0.582 | 0.448 |
| West China | 0.938 | 0.017 | 0.971 | 0.919 | 0.519 | 0.024 | 0.552 | 0.470 |
| Nationwide | 0.875 | 0.016 | 0.899 | 0.846 | 0.604 | 0.026 | 0.635 | 0.547 |

Table 4. Metafrontier environmental performance and its decompositions.

| | MI | | TEC | |
|---|---|---|---|---|
| | Average | Standard deviation | Average | Standard deviation |
| East China | 1.055 | 0.113 | 0.996 | 0.097 |
| Central China | 1.021 | 0.057 | 1.006 | 0.106 |
| West China | 1.003 | 0.060 | 0.999 | 0.077 |
| Nationwide | 1.027 | 0.086 | 1.000 | 0.093 |
| | TPC | | TGC | |
| | Average | Standard deviation | Average | Standard deviation |
| East China | 1.058 | 0.149 | 1.003 | 0.191 |
| Central China | 1.021 | 0.124 | 0.994 | 0.164 |
| West China | 1.047 | 0.154 | 0.958 | 0.162 |
| Nationwide | 1.044 | 0.146 | 0.984 | 0.174 |

metafrontier, the highest TFEE is in the eastern region, followed by the central and western regions.

*Metafrontier Environmental Performance and Its Decompositions*

From Table 4, MI in China is increased by an average of 2.7% over 2000~10, which mainly comes from the contributions of technology progress, but contributions from technical efficiency and technology gap change are fairly small, or negative. From three regions, MI of the eastern, central, and western are 5.5%, 2.1%, and 0.3%, respectively; the TFEE growth rate in the western region is much lower. Disparity among three regions is subtle, technological progress growth rate in the central region is only 2.1%, far lower than the other two regions; for TGC, the catch-up effect does not exist in the central and western regions.

*Analyses of Regional Technology Gap*

Fig. 1 shows TGR in the eastern region is higher than the central and western regions, and has always been very close to the front boundary. The reason is the eastern region, including Beijing, Shanghai, Guangdong, Jiangsu, and Zhejiang, which are China's most prosperous provinces and that have accumulated abundant capital and technology advantage early in the rapid economic development, so the technical efficiency is greatly increased. And TGR in the central and western areas is on the decline, the disparity is widened compared with the eastern region. The average TGR of the central and western regions is 0.511 and 0.628, respectively, which illustrates the same input and output in the two regions only reached 51.1% and 62.8% of metafrontier production technology, respectively.

## Econometric Analysis of the Influencing Factors for TFEE

As can be seen from the above results, TFEEs vary in different regions and the cause of these differences is

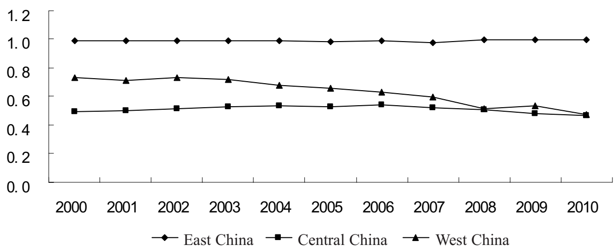


Fig. 1. Trends in TGR of three regions.

Table 5. Definitions of variables.

| Variable | Data compilation |
|---|---|
| Industrial structure (IS) | Uses the provincial secondary industry gross product share of GDP. |
| Foreign capital reliance (FCR) | The ratio of FDI and GDP |
| Energy consumption structure (ECS) | Uses the proportion of coal consumption which, converted to standard coal, accounted for energy consumption |
| Environmental governance capacity (EGC) | Uses industrial $SO_2$ removal rate (the reason for using this index is that the difference of $SO_2$ removal rate among the provinces is big but others are small). |
| Factor endowment level (FEL) | The logarithm of capital/labor ratio are used to indicate FEL |
| Technology gap ratio (TGR) | Uses the value obtained by formulas (8) |

Table 6. Parameter estimation of TFEE.

| Variable | Fixed effect | Random effect | Variable | Fixed effect | Random effect |
|---|---|---|---|---|---|
| α | 0.583*<br>(-5.75) | 0.557*<br>(-6.87) | EGC | 0.0026*<br>(-6.81) | 0.0025*<br>(-7.27) |
| IS | -0.0066*<br>(-4.68) | -0.0061*<br>(-4.84) | FEL | 0.0027*<br>(-6.94) | 0.0026*<br>(-7.86) |
| FCR | -0.0048<br>(-1.27) | -0.005<br>(-1.44) | TGR | 0.3271*<br>(-4.77) | 0.3019*<br>(-5.62) |
| ECS | -0.0041*<br>(-4.70) | -0.0037*<br>(-5.30) | LM test** | | 637.8 |

The values under the parentheses refer to T-values (under fixed effect model) and Z-values (under random effect model), respectively.
*Mean the significance level 1%.
**Breusch and Pagan Lagrangian multiplier test.

thought-provoking. Traditional DEA tends to emphasize the efficiency of DMUs, and ignored the effects of economic factors on production activities. In fact, the factors are various, such as the economic development level, factor endowment level, industrial structure, technical level, etc. This study selects the following six indicators as explanatory variables, as shown in Table 5.

## Results of Econometric Analysis

The model of this study has space and time dimensions, so the panel data regression model is adopted as follows:

$$TFEE_{k,t} = a + b_1 * IS_{k,t} + b_2 * FCR_{k,t} + b_3 * ECS_{k,t} + b_4 * EGC_{k,t} + b_5 * FEL_{k,t} + b_6 * TGR_{k,t} + \varepsilon_{k,t} \quad (9)$$

...where $k$ is province index and $\varepsilon_{k,t}$ is the disturbance term. The shape of the polynomial equation will expose the relationship between TFEE and explanatory variables.

Using Stata software to conduct parameter estimation of equation (9), the results are shown in Table 6.

First of all, from the LM test results, the regression model should choose random effects model. Secondly, TGR, FEL, EGC have a positive impact on TFEE and TGR makes the most impact. Narrowing the 1% technology gap, TFEE increases by 32.71%, which shows that the promotion of TFEE in China largely depends on the technology gap narrowing from both technology efficiency and technological progress. Thus for those provinces deviating from the metafrontier, increasing allocation efficiency of factors and the technical level is the most important. Secondly, FEL and EGC is positively related to TFEE. This has to do with China's strategy to promote new style industrialization, energetically develop an advanced manufacturing with low-energy consumption and high added value. Finally, IS, FCR, and ECS has a negative effect on TFEE, IS makes the largest negative influence, showing the more developed the second industry, the lower the TFEE; the negative influence of FCR on TFEE verified the "pollution haven" hypothesis, which suggests that foreign direct investment enterprises are mostly high energy consumption and high emissions industries; Energy consumption structure has certain negative influence on TFEE, which requires China to develop new energy sources and optimize the coal-based energy consumption structure to help energy savings and emissions reductions.

## Conclusions

This paper employs a metafrontier NRNO DEA model and takes regional technology heterogeneity, slack variables and undesirable outputs into consideration simultaneously. By using this approach, we develop several environmental inefficiency and performance indices. We calculate environmental inefficiency, TFEE index, TGR, MI indices, and analyze affecting factors of TFEE. The main conclusions are described below.

For TFEE, environmental efficiency under the groupfrontier is significantly higher than that under the metafrontier, the average gap between two kinds of frontier reached 27.1%. Under the metafrontier, TFEE is the highest in the eastern region, followed by central and western regions. From the analysis of MI index, MI mainly comes from the contribution of technological progress while the contribution from the technical efficiency and technology gap change is fairly small, or negative. From TGC, central and western regions did not have the catch-up effect, and their gap with the eastern region has widened. Through regression analysis, TGR, FEL, and EGC have a positive impact on TFEE, while IS, FCR, and ECS have a negative effect on it. The maximum positive impact is technology gap ratio, so China will improve the efficiency of the emissions reductions mainly through technological progress in the future.

According to the above conclusion, the work pressure of emissions reductions of future China is greater than energy savings. At first, the technology gap between the eastern, central, and western areas is larger, the two regions should take first priority on the promotion of technological progress. Secondly, promote new-style industrialization, energetically develop advanced manufacturing with low-energy consumption and high value-added; thirdly, in the introduction of foreign investment, we should avoid bringing the high-energy and high-pollution industry to China; finally, constantly optimize the coal-based energy consumption structure and promote the use of clean energy.

This study has some limitations. Firstly, the approach is a non-parametric and deterministic frontier analysis method with no specific function and non-statistical properties, so one does not have to consider the random factors. Secondly, this thesis only takes China's three regions as a group to study China's environmental efficiency and regional technology gap, but not incorporating China into the world background to study the technology gap, so future research needs to start from this aspect.

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## References

1. http://www.sznews.com/news/content/2006-10/08/content_415845.htm.
2. http://www.china.com.cn/news/txt/2006-10/08/content_7219756.htm.
3. http://zcj361.blog.163.com/blog/static/11101930520121385727312/.
4. EDMONDS J., REILLY J. A long-term global energy-economic model of carbon-dioxide release from fossil-fuel use. Energ. Econ. **5**, 74, **1983**.
5. GUSTAVSSON L., JOHANSSON B., BULOWHUBE H. An environmentally benign energy future for western scania, Sweden. Energy. **17**, 809, **1992**.
6. FARE R., GROSSKOPF S., TYTECA D. An activity analysis model of the environmental performance of firms – Application to fossil-fuel-fired electric utilities. Ecol. Econ. **18**, 161, **1996**.
7. ZAIM O., TASKIN F. Environmental efficiency in carbon dioxide emissions in the OECD: A non-parametric approach. J. Environ. Manage. **58**, 95, **2000**.
8. PASURKA C.A. Decomposing electric power plant emissions within a joint production framework. Energ. Econ. **28**, 26, **2006**.
9. DONG R.W., LI H.D. A Research on Regional Sustainable Development in China from the Aspect of Environmental Efficiency. Proceedings for the 4th Euro-Asia conference on environment and corporate social responsibility: tourism, mice and management technique session, PT **I**, 35, **2009**.
10. COLI M., NISSI E., RAPPOSELLI A. Monitoring environmental efficiency: An application to Italian provinces. Environ. Modell. Softw. **26**, 38, **2011**.
11. WANG L., CHEN Z., MA D., ZHAO P. Measuring Carbon Emissions Performance in 123 Countries: Application of Minimum Distance to the Strong Efficiency Frontier Analysis. Sustainability. **5**, 5319, **2013**.
12. LEE M., ZHANG N. Technical efficiency, shadow price of carbon dioxide emissions, and substitutability for energy in the Chinese manufacturing industries. Energ. Econ. **34**, 1492, **2012**.
13. FARE R., GROSSKOPF S. Directional distance functions and slacks-based measures of efficiency. Eur. J. Oper. Res. **200**, 320, **2010**.
14. TONE K. A slacks-based measure of efficiency in data envelopment analysis. Eur. J. Oper. Res. **130**, 498, **2001**.
15. CHOI Y., ZHANG N., ZHOU P. Efficiency and abatement costs of energy-related CO2 emissions in China: A slacks-based efficiency measure. Appl. Energ. **98**, 198, **2012**.
16. COOPER W.W., SEIFORD L.M., TONE K., ZHU J. Some models and measures for evaluating performances with DEA: past accomplishments and future prospects. J. Prod. Anal. **28**, 151, **2007**.
17. OH D.H., LEE J.D. A metafrontier approach for measuring Malmquist productivity index. Empirical Economics. **38**, 47, **2010**.