Research on the industry environmental total factor productivity in Jiangsu Province based on the SBM-SML

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Abstract. This paper uses the SBM-SML to measure the industry environmental total factor productivity in Jiangsu province of its 13 cities during 2005-2014 with SO₂ emissions as the undesirable output, and decomposes the total factor productivity into the pure technical efficiency, the scale efficiency change, the pure technical change and the scale technical change. The research shows that the overall trend of the industry environmental total factor productivity is increasing in Jiangsu province during 2005-2014, the technical change is a main reason pushing up growth rates of economy, and the pure technical change is the intrinsic motivation of the technical change.

1. Introduction

Since the reform and opening up, Jiangsu, as an economically developed province, has made tremendous contributions to the rapid development of China's economy, among which the vigorous industrial development of Jiangsu is outstanding. In 1979 to 2014, the average growth rate of industrial added value in Jiangsu was 13.9%, and industrial GDP accounted for 41.4% of the total GDP of Jiangsu in 2014. However, the excellent achievements made by industrial development are also accompanied with increasingly serious problems of environmental pollution. "Haze" has become a popular word in recent years. The large-scale haze in Jiangsu was obvious since 2011 and became more serious after 2012. The orange alerts of air quality have been issued in 13 cities repeatedly, and masks have become the essential goods. It was proposed in the Twelfth Five-Year Plan of Jiangsu that "environmental priorities should be insisted, and the ecological construction should be further promoted; to solve the problems threatening people's health and affecting sustainable development, effectively control the environmental pollution and ecological destruction, and fully complete the pollutant emission reduction task assigned by the country." Therefore, under the environmental factors, the study on the industry total factor productivity of Jiangsu is conducive to the comprehensive understanding of the changes in industrial economy in Jiangsu, and providing help for the government decision-making.

In terms of the research on environmental total factor productivity, domestic and foreign scholars tend to use the data envelopment analysis method with the environmental pollutants as non-expected output. Pittman (1983) treated the non-expected output as shadow price [1]; Fare (1989) proposed the weak disposability of input-output via the non-linear programming method[2]; Hailu et al. (2003) treated the non-expected output variable as input[3]; Scheel (2001) and Zhu (2003) took the reciprocal of non-
expected output as the input, and analyzed via the traditional DEA model[4][5]; Fare (2003) proposed a method of directional distance function[6]; in addition, Tone (2003) proposed a non-radial non-angular SBM model to solve the relaxation of input-output caused by the selection of angle and radial direction[7]. Since then, this method has been widely used in the study on environmental total factor productivity. The domestic studies based on this method included: Zhou et al. (2006) measured the environmental regulation and impact of carbon dioxide emissions of 30 organizations for economic cooperation in 1998-2002 using the SBM efficiency method[8]. Liu et al. (2009) selected SBM-NS environmental efficiency model to evaluate the environmental efficiency of 43 enterprises in Anhui in 2007, and proved the effectiveness of SBM model[9]; Tu Zhengge and Liu Leike (2011) analyzed China's industrial efficiency with energy and environmental factors based on the provincial data of SBM model[10]; Li Ling (2011) analyzed the green total factor productivity of pollution-intensive industries based on the empirical analysis of SBM model, and made a conclusion that environmental regulation did not really play a substantive role, and China’s pollution-intensive industries are still high-energy consumption and high-pollution[11]; Liu Hui and Li Zhicui (2013) compared the difference of industry environmental efficiency and economic efficiency in western China from the SBM model and the traditional CCR model and confirmed that the SBM model could avoid the choice problem of radial direction and angle, and better deal with the problem of non-expected output, which reflected the objective and real industry environmental efficiency[12]; Hu Biao et al. (2015) studied the urban ecological civilization construction efficiency based on the SBM model, illustrated by Tianjin, and made a conclusion that the fine overall efficiency of ecological civilization construction in Tianjin in the past 12 years and the irrational industrial structure are the root causes of ineffective comprehensive technical efficiency[13].

In conclusion, although the study on industry environmental total factor productivity based on SBM model has made a lot of achievements, there are few decomposition studies on the industry environmental total factor. Therefore, this paper analyzes the industry environmental efficiency of Jiangsu based on SBM-SML, and then analyzes it as four aspects, namely pure technical efficiency change, scale efficiency change, pure technical change and scale technical change, so as to better investigate the industrial economic development thoughts of Jiangsu and provide a theoretical basis for the common development of environment and economy.

2. Method

2.1. SBM model of non-expected output

Traditional CCR model does not consider the slack variable of input and output, and also ignores the inevitable non-expected output problems in production, so it overestimates the technical efficiency in the process of actual production with the distortion. But SBM model based on the non-expected output makes up the defects of the traditional model well.

Assuming that there are n DMUs with three factors for each: input, good output and bad output, presented as \( x \in R^n \), \( y^e \in R^m \) and \( y^b \in R^k \), respectively. In order to make the formula more concisely, it is expressed by matrix. \( x = [x_1, x_2, \ldots, x_n] \in R^{n\times n} \), \( Y^e = [y^e_1, y^e_2, \ldots, y^e_n] \in R^{n\times m} \), \( Y^b = [y^b_1, y^b_2, \ldots, y^b_n] \in R^{n\times k} \), and \( X > 0 \), \( Y^e > 0 \) and \( Y^b > 0 \). The production possibility set is presented as:

\[
P = \{(x, y^e, y^b) | x \geq X \lambda, y^e \leq Y^e \lambda, y^b \geq Y^b \lambda, \lambda \geq 0\}
\]

(1)

SBM model of non-expected output is obtained:
\[
\begin{align*}
\rho^* = \min & \left( 1 - \frac{1}{m} \sum_{i=1}^{m} s_i^r \right) \left[ 1 + \frac{1}{s_1 + s_2} \left( \sum_{i=1}^{m} s_i^r + \sum_{i=1}^{m} y_i^r \right) \right]^{-1} \\
\text{s.t.} & \quad x_0 = X \lambda + s^r \\
& \quad y_0^r = Y^r \lambda - s^r \\
& \quad y_0^b = Y^b \lambda + s^b \\
& \quad s^r \geq 0, s^b \geq 0, s^b \geq 0, \lambda \geq 0
\end{align*}
\]

In the formula (2), $s^r, s^b$ and $s^b$ is the input slack variable, expected output slack variable and non-
expected output slack variable, respectively; $\lambda$ is the weight vector, the objective function is strictly
decreased and the target value $\rho^* \in [0,1]$. When $\rho^* = 1$, $s^r, s^b$ and $s^b$ are 0, DMU is effective.

2.2. SML index and its decomposition

SML index (Sequential Malmquist) is based on DEA sequence; in other words, the reference set in each
phase contains all reference sets in previous periods, and the reference set in t phase is:

\[
s^{(t)} = s^1 \cup s^2 \cup \ldots \cup s^t = \left\{ (x_{1t}^j, y_{1t}^j) \right\} \cup \left\{ (x_{2t}^j, y_{2t}^j) \right\} \cup \ldots \cup \left\{ (x_{rt}^j, y_{rt}^j) \right\}
\]

So the technical regression or “sunken” status in production boundary can be avoided in the analysis.

The specific calculation method is as follows:

\[
MI(x^{t+1}, y^{t+1}, x', y') = \left( \frac{E^{(t)}(x_{1t}^{t+1}, y_{1t}^{t+1})}{E^{(t)}(x', y')} \right)^{1/2} \left( \frac{E^{(t+1)}(x_{1t}^{t+1}, y_{t+1}^{t+1})}{E^{(t+1)}(x', y')} \right)^{1/2}
\]

\[
EC = \frac{E^{(t+1)}(x_{1t}^{t+1}, y_{t+1}^{t+1})}{E^{(t)}(x', y')}
\]

\[
TC = \frac{E^{(t+1)}(x_{1t}^{t+1}, y_{t+1}^{t+1})}{E^{(t+1)}(x', y')}
\]

\[
MI = EC \times TC
\]

According to the decomposition method of Zofio, EC is broken down into PEC and SEC, TC is broken into
PTC and STC, namely

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

In the formula, EC is the technical efficiency change, TC is the technical change, PEC is the pure
technical efficiency change, SEC is the scale efficiency change, PTC is the pure technical change, and
STC is the scale technical change.

3. Data selection and processing

13 cities in Jiangsu Province in 2005-2014 were selected as the decision making units, and the input
and output data were obtained according to the Statistical Yearbook of Jiangsu, Statistical Yearbook of
China’s Regional Economic, China City Statistical Yearbook and statistical yearbooks in each city.

And according to related literature, as well as the availability and integrity of data, 2 input indexes, 1
expected output index and 1 non-expected output index were selected here.

Capital stock input index: the fixed capital investment of each city over the years were selected, and
the perpetual inventory method was used to calculate the capital stock of each city over the years.

Labor input index: the average number of employees in each industry was selected.

Expected output index: the industrial added value of each city over the years was selected, and made
into the constant price with the year 2005 as base year.

Non-expected output index: due to the increasingly serious haze, sulfur dioxide emission was selected
as the non-expected output.

The descriptive statistics of each index are as shown in Table 1.
### Table 1. Descriptive statistics of each index

| Index                   | Unit                  | Min.     | Max.     | Mean    | S.D.    |
|-------------------------|-----------------------|----------|----------|---------|---------|
| Capital stock           | Hundred million yuan  | 838.09   | 16346.52 | 4548.50 | 3522.32 |
| Labor                   | Ten thousand people   | 11.09    | 345.20   | 77.85   | 72.32   |
| Industrial added value  | Hundred million yuan  | 125.96   | 6516.82  | 1385.45 | 1246.83 |
| SO₂ emission            | Ton                   | 18251    | 242362   | 78923.46| 48695.52|

### 4. Empirical analysis

According to the panel data of 13 cities in Jiangsu Province, maxde6.8pro software was used to calculate the industry environmental total factor productivity index of each city based on SBM-SML, and it was decomposed into the pure technical progress, scale technical change, pure technical efficiency change and scale efficiency change. The industry environmental total factor productivity and internal factors of Jiangsu Province will be analyzed below from the whole industry and city.

#### 4.1. Change and decomposition analysis of industry environmental total factor productivity of Jiangsu Province

Table 2 shows the industry environmental total factor productivity and values of each decomposition index of Jiangsu Province in 2005-2014.

### Table 2. The industry environmental TFP and decomposition index of Jiangsu Province

| Year         | SMI       | EC        | PEC       | SEC       | TC        | PTC       | STC       |
|--------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 2005-2006    | 1.1107    | 1.0139    | 1.0242    | 0.9900    | 1.0955    | 1.0600    | 1.0335    |
| 2006-2007    | 1.1231    | 1.0061    | 1.0046    | 1.0015    | 1.1162    | 1.0795    | 1.0340    |
| 2007-2008    | 1.0022    | 0.9660    | 0.9664    | 0.9995    | 1.0375    | 1.0196    | 1.0176    |
| 2008-2009    | 1.1746    | 1.0061    | 1.0380    | 0.9692    | 1.1675    | 1.0909    | 1.0702    |
| 2009-2010    | 1.0943    | 1.0339    | 1.0056    | 1.0281    | 1.0584    | 1.0535    | 1.0046    |
| 2010-2011    | 1.2042    | 1.0214    | 1.0137    | 1.0075    | 1.1790    | 1.1104    | 1.0618    |
| 2011-2012    | 1.1560    | 1.0036    | 1.0081    | 0.9956    | 1.1518    | 1.0966    | 1.0504    |
| 2012-2013    | 1.1520    | 0.9926    | 0.9813    | 1.0116    | 1.1606    | 1.1197    | 1.0365    |
| 2013-2014    | 1.1447    | 1.0023    | 1.0042    | 0.9981    | 1.1421    | 1.1078    | 1.0309    |
| Geometric mean | 1.1277 | 1.0049 | 1.0049 | 1.0000 | 1.1222 | 1.0816 | 1.0375 |

According to Table 2, the variation trend map about the industry environmental total factor productivity and decomposition index of Jiangsu Province was drawn, as shown in Figure 1, Figure 2 and Figure 3.
The geometric mean of industry environmental total factor productivity of Jiangsu Province in 2005-2014 was 1.1277, indicating that the industry environmental total factor productivity of Jiangsu Province was on the rise in this decade. But it can be seen from Figure 1 that the growth rate of total factor productivity was not stable. In 2008, the global economic crisis leads to a decline in growth with the growth rate of 0.22%; subsequently, Jiangsu government conducted the large-scale government investment plans, and accelerated technological innovation, promoting the growth. However, Jiangsu Province was in the industrialization of heavy industry in the following years, so the sulfur dioxide emissions sharply rose in 2011 by 12.17% compared with that last year, sharply reducing the industrial total factor productivity growth included into the environmental impact. Figure 1 intuitively shows that the changing curve of SML index is consistent with that of technical progress, illustrating the technical progress change is the main factor of promoting the change in productivity growth.

Secondly, from the perspective of specific factor decomposition, in terms of the decomposition of technical efficiency change, Table 2 shows that the geometric mean of technical efficiency change in Jiangsu Province during the past decade was 1.0049, and that of the pure technical efficiency and scale efficiency change was 1.0049 and 1, suggesting that the pure technical efficiency change is the main...
internal factor of technical efficiency change. Technical efficiency change had the negative growth during 2007-2008 and 2012-2008, the former of which was because both pure technical efficiency and scale efficiency change were less than 1, and the latter of which was because the scale efficiency change growth was not enough to offset the negative growth of pure technical efficiency change. Combined with Figure 2, it can be seen that the scale efficiency change had negative growth many times, which shows that the industry in Jiangsu Province is optimized without blind pursuit of mass production. From the perspective of decomposition of technical changes, the geometric average of pure technical change was 1.0816, while the geometric average of scale technical change was 1.0375, so the pure technical change was the main internal cause of technical change. Combined with Figure 3, it can be seen that the fluctuations in the three curves are almost the same, a fluctuant increasing trend, showing that the industrial technology of Jiangsu Province was continuously improved.

4.2. Industry environmental total factor productivity and decomposition analysis of each city in Jiangsu Province

Table 3 shows the industry environmental total factor productivity and mean of each decomposition index of each city in Jiangsu Province in 2005-2014.

| DMU     | SML  | EC   | SEC   | PEC   | TC    | STC   | PTC   | Ranking |
|---------|------|------|-------|-------|-------|-------|-------|---------|
| Nanjing | 1.2597 | 1.0000 | 1.0000 | 1.0000 | 1.2597 | 1.0425 | 1.2083 | 1        |
| Changzhou | 1.2048 | 1.0398 | 1.0047 | 1.0350 | 1.1586 | 1.0390 | 1.1151 | 2        |
| Suzhou  | 1.1777 | 0.9984 | 0.9984 | 1.0000 | 1.1795 | 1.0495 | 1.1239 | 3        |
| Yangzhou | 1.1752 | 1.0323 | 1.0033 | 1.0289 | 1.1385 | 1.0496 | 1.0846 | 4        |
| Yancheng | 1.1334 | 1.0185 | 0.9918 | 1.0269 | 1.1128 | 1.0261 | 1.0845 | 5        |
| Zhenjiang | 1.1230 | 1.0000 | 1.0000 | 1.0000 | 1.1230 | 1.0521 | 1.0673 | 6        |
| Taizhou  | 1.1154 | 0.9819 | 0.9900 | 0.9917 | 1.1360 | 1.0790 | 1.0528 | 7        |
| Nantong  | 1.1114 | 1.0157 | 0.9931 | 1.0227 | 1.0943 | 1.0171 | 1.0759 | 8        |
| Wuxi     | 1.1060 | 1.0000 | 1.0000 | 1.0000 | 1.1060 | 1.0073 | 1.0979 | 9        |
| Xuzhou   | 1.0711 | 1.0029 | 1.0012 | 1.0018 | 1.0680 | 0.9987 | 1.0694 | 10       |
| Lianyungang | 1.0705 | 0.9917 | 1.0193 | 0.9730 | 1.0794 | 1.0318 | 1.0461 | 11       |
| Suqian   | 1.0673 | 0.9930 | 0.9930 | 1.0000 | 1.0748 | 1.0621 | 1.0119 | 12       |
| Huaian   | 1.0638 | 0.9918 | 1.0056 | 0.9862 | 1.0726 | 1.0360 | 1.0354 | 13       |

From the perspective of the ranking of environmental total factor productivity in each city, SML index of Nanjing was 1.2597, namely the growth rate of environmental total factor productivity of 25.97%, ranking in the first place. And Suzhou ranked in the third place with the growth rate of 2.71% lower than that of Changzhou, which was due to the negative growth of technical efficiency change, and caused by the scale efficiency change. But we can see that technical change growth in Suzhou was high, which was related to the continuous development of new technology and construction of high and new technology zones of Suzhou in recent years. The environmental total factor productivity of Huaian was the lowest, 1.0638, and it can be seen that the negative growth of pure technical efficiency change of Huaian was the chief culprit hindering the improvement of its total factor productivity, so Huaian should strengthen the effective utilization of resources, and speed up the optimization of resource allocation. Suqian was the last but one; although its technical efficiency change was the same as that in Huaian with a negative growth, the internal cause was different; the scale efficiency affected the growth of total factor productivity. Overall, the environmental total factor productivity in each city of Jiangsu Province increased in different degrees.
It can be seen from Figure 4 that the technical efficiency of 5 cities had a negative growth, among which the technical efficiency of Taizhou fell by 1.81% on average during the past decade. When it came to the reasons, the pure technical efficiency and scale efficiency had a negative growth at the same time. From the perspective of regional division, it can be found that Lianyungang and Huaian in north Jiangsu had the negative growth of high technical efficiency caused by the low resource utilization rate; Suzhou in south Jiangsu had the negative growth in technical efficiency because of the decreased scale efficiency. There were 5 cities whose mean technical efficiency was greater than 1, among which that of Changzhou was the highest with the growth of 3.98%, and large growth of pure technical efficiency and scale efficiency advantage were the intrinsic motivation.

It can be seen from Figure 5 that the technical change in Nanjing was the highest, 1.2597, and the pure technical change was the main factor of technical change compared with scale technique. The technical change in Xuzhou was the lowest, increasing by 6.8%. Overall, the pure technical change in each city was more stable, and the fluctuations in pure technical change and technical change tended to be consistent, suggesting that pure technical change was the main factor of technical change. From the perspective of regional division, it can be seen clearly that the average technical change in cities in south Jiangsu was significantly higher than that in middle Jiangsu, and that middle Jiangsu was also significantly higher than that in north Jiangsu. This is consistent with the reality, because there are many high-tech zones in south Jiangsu, such as Xinbei District in Changzhou, Jiangning District in Nanjing and Suzhou Industrial Park with strong technological innovation ability; but although north Jiangsu has rapidly developed in recent years, the industrial base is weak and the technology innovation ability is lagged compared to that of south Jiangsu.

5. Conclusions

Through the concrete analysis of the environmental total factor productivity and its internal factors from the perspective of Jiangsu Province and each city, the following conclusions can be made:

(1) During the study, the growth rate of industry environmental total factor productivity of Jiangsu Province was fluctuant, but it was on the rise with the average geometric growth rate of 12.77%, which made a great contribution to the industrial economic growth in Jiangsu, and was one of the important factors to promote economic development in Jiangsu. After decomposition, it was found that technical progress is the main factor relative to technical efficiency, and the pure technical efficiency, pure technical change and scale technical change were the intrinsic motivation of growth of industry environmental total factor productivity.
During the study, the industry environmental total factor productivity of each city in Jiangsu Province had the growth in different degrees, among which Nanjing and Changzhou ranked the first and second place, and Huai'an was the last one. From the perspective of decomposition, technical progress was the main factor of the growth of industry environmental total factor productivity, followed by technical efficiency.

From the perspective of administrative division of Jiangsu Province, the industry environmental total factor productivity in cities in south Jiangsu was generally higher than that in middle Jiangsu, and that in middle Jiangsu was generally higher than that in north Jiangsu. From the perspective of decomposition, technical progress was the reason why industry environmental total factor productivity was higher in cities in south Jiangsu than others, and the pure technical change was the main factor of technical progress. Pure technical efficiency of cities in north Jiangsu had a negative growth generally, hindering the improvement of industry environmental total factor productivity in each city.

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