Radial Approach for Malmquist Productivity Index Measurement on Logistics Industry in Shandong Province

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Abstract. Data Envelopment Analysis (DEA), as a non-parametric linear programming technique, is a very useful tool to evaluate the efficiency of Decision Making Units (DMUs) where multiple inputs and outputs are involved. In this paper, the Malmquist Productivity Index (MPI) based on the radial DEA is used to measure the productivity changes of Shandong provincial logistics industry from 2012 to 2014. The analysis of the results indicates that there are large gaps in productivity development level among 17 cities in Shandong provincial logistics industry. Moreover, as a whole, the results also shows that the MPI of the Shandong provincial logistics industry experienced a continuous regress from 2012 to 2014. The empirical results analyses can provide decision makers of government and industry organizations significant suggestions in improving the productivity of the logistics industry and promoting the sustainable development of the logistics industry among different cities in Shandong province.

Introduction

During the past decade, the logistics industry played a more and more important role in the national economy and had become a pillar industry of national economy in China, and the same situation occurred in Shandong province. As an economically developed province, in 2014, the added value of the logistics industry was 385.2 billion yuan, accounting for 6.5% of GDP in Shandong province. However, the statistical data only describes an outline of the Shandong provincial logistics industry. In order to mine the more useful information about the development of Shandong provincial logistics industry from the statistical data, we need to evaluate the development level of Shandong provincial logistics industry, enhance through effective decision making and productivity improvement, therefore, it is necessary to dynamically and continuously analyze the productivity growth [1] of the logistics industry in Shandong province.

A large number of researches about the productivity changes in some industry are shown in the previous literature [7]-[13], which can provide an evaluation of economic prosperity and degree of competitiveness of some industry. And the analysis of the results can be used to support the design of strategies and government policies towards the improvement of industry productivity. In the paper, we will study the productivity changes of the logistics industry in Shandong province by means of Malmquist Productivity Index (MPI) based on the radial DEA model [1]-[5].

The structure of the paper is as follows. Section 2 describes the relative methodology about radial DEA model and MPI model. The empirical study about the productivity changes of logistics industry in Shandong province from 2012 to 2014 and the analyses of the empirical study results are
presented in Section 3. Eventually, the conclusions about the whole research is shown in the last section.

**Methodology**

Suppose that there are $N$ DMUs, and each DMU can produce $S$ outputs by using $M$ inputs. Let a $M \times N$ matrix $X$ stands for inputs matrix and a $S \times N$ matrix $Y$ stands for outputs matrix. Under the assumption of input-oriented Constant Returns to Scale (CRS) [2]-[5], the radial DEA model at the time $t$ can be formulated as follows:

$$
\theta_0(x'_t, y'_t) = \min \theta_0 \quad \sum_{k=1}^{N} x'_k \lambda_k \leq \theta_0 x'_0 \\
\text{s.t.} \sum_{k=1}^{N} y'_k \lambda_k \geq y'_0 \\
\lambda_k \geq 0, k = 1, 2, \ldots, N
$$

(1)

Where $x'_0$ and $y'_0$ are the input vector and the output vector of DMU$_0$ at the period $t$. The value of $\theta_0(x'_t, y'_t)$ means the technical efficiency of DMU$_0$ at the period $t$. If $\theta_0(x'_t, y'_t) < 1$, the observed production $(x'_t, y'_t)$ at time period $t$ is technical inefficient and interior to the Empirical Production Frontier (EPF) at the same period, and DMU$_0$ is technical inefficient at time period $t$. Otherwise, DMU$_0$ is technical efficient at time period $t$ if and only if $\theta_0(x'_t, y'_t) = 1$, and the observed production $(x'_t, y'_t)$ at time period $t$ is on the EPF at the same period.

From the time period $t$ to $t+1$, DMU$_0$’s technical efficiency may change or and EPF may shift. Based on the model (1), the MPI can be calculated via the following steps [5][7][12]:

1. Comparing $x'_t$ to the EPF at time $t$; namely, calculating $\theta_0(x'_t, y'_t)$;
2. Comparing $x'^{t+1}_t$ to the EPF at time $t+1$; namely, calculating $\theta_0^{t+1}(x'^{t+1}_t, y'^{t+1}_t)$;
3. Comparing $x'_t$ to the EPF at time $t+1$; namely, calculating $\theta_0^{t+1}(x'_t, y'_t)$ by following form:

$$
\theta_0^{t+1}(x'_t, y'_t) = \min \theta_0 \quad \sum_{k=1}^{N} x'_k \lambda_k \leq \theta_0 x'_t \\
\text{s.t.} \sum_{k=1}^{N} y'_k \lambda_k \geq y'_0 \\
\lambda_k \geq 0, k = 1, 2, \ldots, N
$$

(2)

4. Comparing $x'^{t+1}_t$ to the EPF at time $t$; namely, calculating $\theta_0^{t+1}(x'^{t+1}_t, y'^{t+1}_t)$ by following form:
\[
\theta^*_t \left( x^{i+1}_0, y^{i+1}_0 \right) = \min \theta_0 \\
\sum_{i=1}^N x_i \lambda_i \leq \theta_0 x_0^{i+1} \\
\text{s.t. } \sum_{i=1}^N y_i \lambda_i \geq y^{i+1}_0 \\
\lambda_i \geq 0, k = 1, 2, \ldots, N
\] 

(3)

The MPI is defined as:

\[
MPI = \left[ \frac{\theta_t^* (x^{i+1}_0, y^{i+1}_0)}{\theta_t^* (x^0_0, y^0_0)} \right]^{\frac{1}{2}} = \left[ \frac{\theta_t^* (x^{i+1}_0, y^{i+1}_0)}{\theta_0^* (x^{i+1}_0, y^{i+1}_0)} \right]^{\frac{1}{2}} \left[ \frac{\theta_t^* (x^{i+1}_0, y^{i+1}_0)}{\theta_t^* (x^0_0, y^0_0)} \right]^{\frac{1}{2}}
\] 

(4)

The MPI measures the productivity change between periods \( t \) and \( t+1 \). Productivity declines if \( MPI < 1 \), remains unchanged if \( MPI = 1 \), and improves if \( MPI > 1 \). In above Equation (4) the first component on the right hand side outside the brackets measures the change in technical efficiency (EFFCH) between periods \( t \) and \( t+1 \). And the second component on the right hand side measures the change in technology (TECHCH) between periods \( t \) and \( t+1 \). That is:

\[
EFFCH = \frac{\theta_t^* (x^{i+1}_0, y^{i+1}_0)}{\theta_t^* (x^0_0, y^0_0)}
\]

\[
TECHCH = \left[ \frac{\theta_0^* (x^{i+1}_0, y^{i+1}_0)}{\theta_t^* (x^{i+1}_0, y^{i+1}_0)} \right]^{\frac{1}{2}} \left[ \frac{\theta_t^* (x^{i+1}_0, y^{i+1}_0)}{\theta_0^* (x^0_0, y^0_0)} \right]^{\frac{1}{2}}
\]

Since MPI can be decomposed into the product of EFFCH and TECHCH. If \( TECHCH < 1 \), it means technical regress, if \( TECHCH > 1 \), it means technical progress, and there is no change in technology if and only if \( TECHCH = 1 \).

**Empirical Study and Results Analysis**

**Data and DMU Selection.** In the paper, we selected 17 cities in Shandong province as DMUs to measure the productivity changes of the Logistics industry in these cities from 2012 to 2014. When some rules of thumb [6] and data availability are taken into account, we selected three inputs (i.e., Logistics related industry total investment in fixed assets, Transportation, warehousing and postal service workers and Expressway and class I to IV Highways) and one output (Freight Turnover through highway). The data used in this empirical study came from Shandong Statistical Yearbook [14]-[16]. And the descriptive statistics of the data are shown in Table 1.

**Results analysis.** In the paper, with the help of Matlab software, Equation (4) is applied to calculated MPI and its components (EFFCH and TECHCH) for a sample of 17 cities in Shandong province over the period 2012 to 2014 using the panel data from Shandong Statistical Yearbook [14]-[16]. Table 2 shows us the results of MPI and its components.

It is easy to find out that from the results in Table 2, there are the same characteristics during the two period span, that is, the TECHCH of the logistics industry in all 17 cities of Shandong province experienced a continuous regress from 2012 to 2014. And there are four DMUs (2-Tsingtao, 5-Dongying, 6-Yantai and 8-Jining), the MPI values of them are large than 1, which means the improvement of productivity in time period 2012 to 2013, but the MPI values of them are less than 1,
which means the decline of productivity in time period 2013 to 2014. On the contrary, there are only two DMUs (1-Jinan and 15-Liaocheng), the MPI values of them are less than 1, which means

Table 1. The descriptive statistics of the Input and Output variables in 2012-2014.

<table>
<thead>
<tr>
<th>Year</th>
<th>Inputs/Outputs</th>
<th>Variables</th>
<th>Mean</th>
<th>Max</th>
<th>Min</th>
<th>Std.Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Inputs</td>
<td>$X_1$</td>
<td>169.3</td>
<td>401.7</td>
<td>24.5</td>
<td>100.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$X_2$</td>
<td>1.8</td>
<td>6.5</td>
<td>0.4</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$X_3$</td>
<td>14296.3</td>
<td>24456.1</td>
<td>3876.1</td>
<td>6294.4</td>
</tr>
<tr>
<td></td>
<td>Outputs</td>
<td>$Y$</td>
<td>41524.8</td>
<td>95844</td>
<td>5486</td>
<td>27017.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$X_1$</td>
<td>212.8</td>
<td>577.5</td>
<td>17.4</td>
<td>130</td>
</tr>
<tr>
<td>2013</td>
<td>Inputs</td>
<td>$X_2$</td>
<td>2.5</td>
<td>8.8</td>
<td>0.5</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$X_3$</td>
<td>14789.7</td>
<td>25558</td>
<td>4145.3</td>
<td>6473.9</td>
</tr>
<tr>
<td></td>
<td>Outputs</td>
<td>$Y$</td>
<td>44111.2</td>
<td>102885</td>
<td>5867</td>
<td>28014.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$X_1$</td>
<td>247</td>
<td>638.9</td>
<td>34.1</td>
<td>152.8</td>
</tr>
<tr>
<td>2014</td>
<td>Inputs</td>
<td>$X_2$</td>
<td>3.2</td>
<td>7.5</td>
<td>0.5</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$X_3$</td>
<td>15202.5</td>
<td>2677</td>
<td>9</td>
<td>4223</td>
</tr>
<tr>
<td></td>
<td>Outputs</td>
<td>$Y$</td>
<td>33596.2</td>
<td>118762</td>
<td>8852</td>
<td>6761.6</td>
</tr>
</tbody>
</table>

Note: $X_1$ - Logistics related industry total investment in fixed assets ($10^8$ yuan), $X_2$ - Transportation, warehousing and postal service workers ($10^4$ persons), $X_3$ - Expressway and class I to IV Highways (km), $Y$ - Freight Turnover through highway ($10^6$ ton-km).

Table 2. Radial MPIs and their components in 2012–2014.

<table>
<thead>
<tr>
<th>DMUS</th>
<th>EFFCH</th>
<th>TECHCH</th>
<th>MPI</th>
<th>EFFCH</th>
<th>TECHCH</th>
<th>MPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0345</td>
<td>0.9593</td>
<td>0.9924</td>
<td>1.8419</td>
<td>0.6090</td>
<td>1.1217</td>
</tr>
<tr>
<td>2</td>
<td>1.1177</td>
<td>0.9766</td>
<td>1.0916</td>
<td>1.7125</td>
<td>0.5199</td>
<td>0.8904</td>
</tr>
<tr>
<td>3</td>
<td>1.0000</td>
<td>0.9132</td>
<td>0.9132</td>
<td>0.8176</td>
<td>0.4388</td>
<td>0.3588</td>
</tr>
<tr>
<td>4</td>
<td>0.9832</td>
<td>0.9599</td>
<td>0.9437</td>
<td>0.6594</td>
<td>0.5414</td>
<td>0.3570</td>
</tr>
<tr>
<td>5</td>
<td>2.3734</td>
<td>0.8696</td>
<td>2.0639</td>
<td>1.6134</td>
<td>0.3928</td>
<td>0.6338</td>
</tr>
<tr>
<td>6</td>
<td>1.0312</td>
<td>0.9766</td>
<td>1.0071</td>
<td>1.2500</td>
<td>0.5199</td>
<td>0.6499</td>
</tr>
<tr>
<td>7</td>
<td>0.6481</td>
<td>0.8773</td>
<td>0.5685</td>
<td>0.6597</td>
<td>0.6698</td>
<td>0.4419</td>
</tr>
<tr>
<td>8</td>
<td>1.0848</td>
<td>0.9584</td>
<td>1.0397</td>
<td>1.2050</td>
<td>0.6189</td>
<td>0.7458</td>
</tr>
<tr>
<td>9</td>
<td>0.7965</td>
<td>0.8757</td>
<td>0.6975</td>
<td>1.5145</td>
<td>0.4519</td>
<td>0.6844</td>
</tr>
<tr>
<td>10</td>
<td>1.0938</td>
<td>0.9766</td>
<td>1.0683</td>
<td>2.8856</td>
<td>0.5199</td>
<td>1.5003</td>
</tr>
<tr>
<td>11</td>
<td>1.0128</td>
<td>0.9766</td>
<td>0.9891</td>
<td>0.9247</td>
<td>0.5199</td>
<td>0.4808</td>
</tr>
<tr>
<td>12</td>
<td>1.2586</td>
<td>0.9523</td>
<td>1.1985</td>
<td>1.6655</td>
<td>0.6575</td>
<td>1.0950</td>
</tr>
<tr>
<td>13</td>
<td>0.7775</td>
<td>0.8283</td>
<td>0.6440</td>
<td>1.2861</td>
<td>0.7752</td>
<td>0.9970</td>
</tr>
<tr>
<td>14</td>
<td>0.6520</td>
<td>0.8218</td>
<td>0.5358</td>
<td>0.7209</td>
<td>0.5854</td>
<td>0.4220</td>
</tr>
<tr>
<td>15</td>
<td>0.8811</td>
<td>0.9556</td>
<td>0.8419</td>
<td>2.0044</td>
<td>0.5394</td>
<td>1.0811</td>
</tr>
<tr>
<td>16</td>
<td>0.5836</td>
<td>0.7594</td>
<td>0.4432</td>
<td>1.5176</td>
<td>0.3984</td>
<td>0.6046</td>
</tr>
<tr>
<td>17</td>
<td>1.0000</td>
<td>0.8326</td>
<td>0.8326</td>
<td>0.6704</td>
<td>0.5722</td>
<td>0.3836</td>
</tr>
<tr>
<td>Geo. mean</td>
<td>0.9671</td>
<td>0.9074</td>
<td>0.8776</td>
<td>1.2320</td>
<td>0.5404</td>
<td>0.6657</td>
</tr>
</tbody>
</table>

Note: The number of DMUs Vs city is: 1-Jinan, 2-Tsingtao, 3-Zibo, 4-Zaozhuang, 5-Dongying, 6-Yantai, 7-Weifang, 8-Jining, 9-Taian, 10-Weihai, 11-Rizhao, 12-Laiwu, 13-Linyi, 14-Dezhou,
15-Liaocheng, 16-Binzhou, 17-Heze. Geo. mean is described as the abbreviations of Geometric mean.

The decline of productivity in time period 2012 to 2013, but the MPI values of them are large than 1, which means the improvement of productivity in time period 2013 to 2014. And it is amazing that there are only two DMUs (10-Weihai and 12-Laiwu) where the productivity of the logistics industry in these two cities experienced a continuous progress from 2012 to 2014. For the rest of the other 9 cities in Shandong province, the MPI of logistics industry in these cities experienced a continuous regress from 2012 to 2014. Especially, for all situations of the improvement of productivity, it is due to the changes in technology.

Although some cities gained the huge improvement of productivity, there are large gaps in productivity development level among 17 cities in the logistics industry of Shandong province, such as DMU5 (5-Dongying), productivity improved dramatically by 106.39% even the change in technology declined by 13.04%, it can be seen that this improvement was accompanied by a large technical efficiency progress by 137.34% from 2012 to 2013. Unfortunately, during the same time period, DUM16 (16-Binzhou), productivity declined dramatically by 55.68%. Particularly, as a whole, the results also show that the geometric mean MPI of the Shandong provincial logistics industry experienced a continuous regress from time period 2012 to 2014 by 12.24% and 33.43%, which is completely beyond our wildest expectation. Combining with the domestic and international economic development situation, we think that the main reasons may result from not only the economic has achieved a soft landing in China but also the speed of economic development slowing down all around the world during the same period.

**Conclusion**

It is well known that DEA approach is a non-parametric linear programming technique and a popular tool to measure the relative efficiency of DMUs. In the paper, MPI based on the DEA is used to measure the productivity changes of Shandong provincial logistics industry, the application focuses on panel data of the logistics industry in 17 cities of Shandong province from 2012 to 2014. The analysis of the empirical results indicates that there are large gaps in productivity development level among 17 cities in the logistics industry of Shandong province from 2012 to 2014. Moreover, as a whole, the MPI of the Shandong provincial logistics industry experienced a continuous regress from 2012 to 2014. The empirical results analyses can provide decision makers of government and industry organizations significant suggestions in improving the productivity of the logistics industry and promoting the sustainable development of the logistics industry among different cities in Shandong province.

**References**


