Technical Efficiency and Eco-Efficiency in Manufacturing Industry: A Non-Parametric Frontier Approach

Noor Asiah Ramli¹ and Susila Munisamy²

Poor environmental performance of the manufacturing activities is said to be attributed to pollutants produced and emitted during the manufacturing process. These pollutants are regarded as undesirable output and cannot be ignored when measuring the efficiency of manufacturing activities. By applying Data Envelopment Analysis (DEA) and Directional Distance Function (DDF) approaches, this study evaluates the technical efficiency and eco-efficiency of manufacturing industries in Malaysia at the state level, over the period of 2001 until 2010. The evaluation is carried out through a joint production framework involving desirable and undesirable outputs. Looking at the overall picture of eco-efficiency, similar results to technical efficiency were obtained, where the eco-efficiency scores for the states under Free Industrial Zone (FIZ) category was slightly higher than Non-Free Industrial Zone (N-FIZ) category. This high eco-efficiency by the manufacturing sector demonstrates that environmental performance in Malaysia is not adversely affected with regards to industrial development and can be categorized as an eco-efficient country while obtaining the profits of the firms.

1. Introduction

Essentially, performance measurement analyzes the success of a work in various levels of activities such as group, program or organization by comparing data on what actually happened to what was planned or intended (Wholey & Hatry, 1992). Performance measurement evaluation is an important aspect that has been studied over the years. This evaluation is important since it may support a variety of management functions whereby it allow a manager to identify operating strength and weaknesses, target areas for improvement and recognize improvement when they occur. To evaluate the performance measurement, an appropriate quantitative approach can be applied. One of the approaches that can be considered to measure the performance is by determining the efficiency of their activities.

Koopmans (1951) provided a definition of technical efficiency whereby “A possible point in the commodity space is called efficient whenever an increase in one of its coordinates (the net output of one good) can be achieved only at the cost of a decrease in some other coordinate (the net output of another good).” Another basic description on the concept of estimating efficiency is by comparing the inputs and outputs of an entity with those of its best performing peers. These peers are measured with respect to an objective whereby it can be measured based on maximization of output or profit or minimization of cost (Thanassoulis, 2001).

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Another performance measured is an eco-efficiency. The concept of eco-efficiency can be described as a measurement of efficiency with the integration of undesirable outputs that contributes negatively to the environment (Dyckhoff & Allen, 2001). In addition, Koskela and Vesmas (2012) reviewed the definition of eco-efficiency in five variations. First definition is referring to the numerous productions with limited amount of environmental impact. Second definition is referring to the relationship between environmental and economic performance. Third definition is referring to the ratio of economic performance to environmental influence. Fourth definition is eco-efficiency as a management strategy and fifth is an adjustment to the management strategy definition.

This paper aims to evaluate the technical efficiency and eco-efficiency analysis of the manufacturing sector in Malaysia. The manufacturing sector has been chosen as a context of the study since this sector is the second largest contributor to the Gross Domestic Product (GDP) of Malaysia, and also one of the main contributors to environmental pollution (Department of Environment, 2008). Productivity and efficiency measurement of the manufacturing sector is especially crucial for the continuous growth and development of the economy. However, it would be incomplete to measure the efficiency of manufacturing activities without considering the elements of pollution as these elements are regarded as undesirable outputs in efficiency measurement. For that reason, this study demonstrates the Directional Distance Function (DDF) approach to measure efficiency incorporating both desirable and undesirable outputs within a Data Envelopment Analysis (DEA) framework.

The remainder of the paper is organized as follows: Section 2 reviews previous studies on technical efficiency and eco-efficiency. Section 3 discusses the DEA approach and the DDF model that are employed in this paper. Section 4 presents the results and provides some discussion from the analysis. Finally, Section 5 concludes the study.

2. Literature Review


In Malaysia, Mahadevan (2002) carried out a study on the manufacturing sector from 1981 to 1996 to investigate the technical efficiency. The results indicate that the technical efficiency score in the 80s increased gradually while the score decreased reversibly in the 90s. A similar study by Jají and Ismail (2007) using data from 1985 to 2000 shows that the food, wood, chemical and iron industries provide a higher efficiency score compared to other industries. Both studies show consistent results in terms of the trend in technical efficiency, i.e., increase in the 80’s and decrease in the 90s.

As for eco-efficiency study, some examples are Boyd et al. (2002) investigated the connection between productivity in the production of container glass and the emission of NOx, a major polluant released by glass production. Watanabe and Tanaka (2007) measured the eco-efficiency of the industrial sector in China. Another example, Zhang (2009) conducted a similar study to investigate the relationship between technical and environmental efficiencies in China’s industrial sector. Mandal and Madheswaran (2010) also studied the environmental efficiency of the Indian cement industry. More recently,
Riccardi et al. (2012) evaluated the impact of CO$_2$ emissions on the efficiency score of the world cement industry. The evaluation concludes that CO$_2$ emissions influence the efficiency score and the emissions need to be included when measuring the efficiency score in the cement sector.

With regard to eco-efficiency studies in the Malaysian context, the research done by Ahmed (2006; 2007) leads the way in the manufacturing sector. Employing the non-frontier Divisia Translog Index approach, he found that industrial activities contributed to the growth rate of carbon dioxide emissions and observed a slowdown in the productivity growth of the manufacturing sector when carbon dioxide is included in a productivity indicator. Ahmed (2007) demonstrated the negative impact of organic water pollutant biochemical oxygen demand (BOD) emissions on the productivity growth of the Malaysian manufacturing sector.

Studies analyzing the eco-efficiency of manufacturing firms are still very limited in Malaysia. Therefore, this study fills the gap to evaluate the technical efficiency and eco-efficiency of manufacturing sectors in Malaysia at state level over the period of 2001 until 2010. In contrast to the above Malaysian literatures, this study applies two models to measure efficiencies. First, the authors measure technical efficiency employing Data Envelopment Analysis (DEA) and next, the Directional Distance Function (DDF) approach has been used to measure eco-efficiency.

3. Methodology

Data Envelopment Analysis (DEA) is a linear programming technique for measuring the relative efficiency of a set of decision making units (DMUs) or units of assessment in the use of multiple inputs to produce multiple outputs. DEA identifies a subset of efficient ‘best practice’ DMUs and for the remaining DMUs, their efficiency level is derived by comparing them to a frontier constructed from the ‘best practice’ DMUs. This technique is originated from the seminal work by Charnes et al. (1978). To begin with this analysis, some notations have been made. Let $x \in R^I_+$ represents an input vector and $y \in R^J_+$ represents an output vector. Thus, $x_i$ represents the $i^{th}$ input, and $y_j$ represents the $j^{th}$ output of a DMU.

$$S = \{(x,y) : x \text{ can produce } y\}$$

The above expression defines production possibilities as the set of input-output vectors that are attainable given the production technology ($S$). The mathematical formulation in case of output oriented DEA - CRS model for DMU $m$ based on the given technology above is as follows:

Max $\theta_m$

Subject to

$$\sum_{n=1}^{N} z_n x_{im} \leq x_{im}; i = 1,2,\ldots,I$$

$$\sum_{n=1}^{N} z_n y_{jm} \geq \theta_m y_{jm}; j = 1,2,\ldots,J$$

$$z_n \geq 0; n = 1,2,\ldots,N$$

(2)
Where \( z_n \) = intensity variables, \( x_{in} = i^{th} \) input of the \( n^{th} \) DMU, \( y_{jn} = j^{th} \) desirable output of the \( n^{th} \) DMU, \( x_{im} = i^{th} \) input of the \( m^{th} \) DMU, \( y_{jm} = j^{th} \) desirable output of the \( m^{th} \) DMU and \( N = 1, 2, ..., N \) DMUs.

The DEA model seeks a set of \( z \) values which maximize the \( \theta_m \) and identifies a point within the production possibilities set whereby output levels of DMU \( m \) can be increased as high as possible proportion while input remain at current level. The efficiency scores of DMUs in this model are bounded between zero and one. The best performing DMUs are assigned an efficiency score of one while the performances of other DMUs that score less than one are inefficient.

Nevertheless this conventional DEA model accounts for only two categories of variable which are the input and the desirable output variables. When undesirable outputs are present, the model of DEA is no longer applicable. Therefore, another approach that treats the separation of undesirable outputs called Directional Distance Function (DDF) is discussed subsequently.

Chung et al. (1997) introduced an approach that incorporated the production of desirable and undesirable outputs in measuring the efficiency score. The DDF idea is to expand desirable outputs and reduce inputs and/or undesirable outputs simultaneously based on a given direction vector. The DDF approach is more appropriate than DEA approach when desirable and undesirable outputs are jointly produced.

To begin with this analysis, additional notations have been added to expression (1). To avoid confusion in the model development, the notations used in the DDF are similar to the ones used in previous DEA models. Let \( x \in R^I \) represents an input vector, \( y \in R^J \) represents a desirable output vector while \( u \in R^K \) represents an undesirable output vector. The above definition simply defines the “environmental output set” for production technology \( T \).

\[
T = \{(x, y, u) : x \text{ can produce } (y, u)\} \tag{3}
\]

The DDF on the technology \( T \), can be defined as below:

\[
\tilde{d}_g(x, y, u; g_y, g_u) = \text{Max} \{\beta : (y + \beta g_y, u - \beta g_u) \in T\} \tag{4}
\]

The distance function above tries to look for the extension of desirable outputs in the \( g_y \) direction and reduction of undesirable outputs in the \( g_u \) direction. In other words, proportion \( \beta \) seeks to increase the desirable outputs and reduce the undesirable outputs simultaneously. DDF model is formulated as below (see Chung et al., 1997):

\[
\begin{align*}
\text{Max } & \beta_m \\
\text{Subject to } & \\
\sum_{n=1}^{N} z_n x_{in} & \leq x_{im} ; i = 1, 2, ..., I \\
\sum_{n=1}^{N} z_n y_{jn} & \geq y_{jm} + \beta_m g_y ; j = 1, 2, ..., J \\
\sum_{n=1}^{N} z_n u_{kn} & = u_{km} - \beta_m g_u ; k = 1, 2, ..., K \\
z_n & \geq 0 ; n = 1, 2, ..., N
\end{align*} \tag{5}
\]
Where $z_n = \text{intensity variables}$, $x_{in} = i^{th} \text{ input of the } n^{th} \text{ DMU}$, $x_{in} = i^{th} \text{ input of the } n^{th} \text{ DMU}$, $y_{jn} = j^{th} \text{ desirable output of the } n^{th} \text{ DMU}$, $y_{jn} = j^{th} \text{ desirable output of the } n^{th} \text{ DMU}$, $u_{kn} = k^{th}$ undesirable output of the $n^{th}$ DMU, $u_{kn} = k^{th}$ undesirable output of the $n^{th}$ DMU, $g_y = \text{direction vector of desirable output}$ and $g_u = \text{direction vector of undesirable output}$.

In this study, the authors have computed the eco-efficiency analysis using the DDF method because it is simple, intuitive and can be easily put into practice. Furthermore, the DDF is flexible as it allows for the evaluation of efficiency using a single direction vector from the observed points.

This study considers the manufacturing sector in 15 states throughout Malaysia. The state level data for the observed period between 2001 and 2010 was obtained from the Department of Statistics, Malaysia. Two inputs and two outputs are employed. The inputs are operating expenditure and capital. In terms of the production outputs, they consist of one desirable and one undesirable output. The desirable output is sales in the manufacturing industry while the CO$_2$ emission factor has been included as an undesirable output.

4. Results and Discussion

Table 1 and 2 present the results of the technical efficiency and eco-efficiency analysis of the Malaysian manufacturing sector. The results are presented according to the industrial grouping of the states - Free Industrial Zone (FIZ) states consists of Johor, Melaka, Pulau Pinang, Perak and Selangor and Non-Free Industrial Zone (N-FIZ) states consists of Kedah, Kelantan, Negeri Sembilan, Pahang, Perlis, Terengganu, Sabah, Sarawak and the Federal Territories of Kuala Lumpur and Labuan. The FIZ comprise of a free zone for manufacturing companies that produce or assemble products mainly for export purposes.

The technical efficiency score in Table 1 indicates the presence of inefficient use of outputs and the extent of which the possibility for each state’s outputs to be increased while maintaining existing inputs. For example, in 2001, Johor was 93.3% technically efficient. This finding suggests that Johor could increase their sales in manufacturing roughly by 6.7% while maintaining the current inputs of operating cost and capital.

Table 1: Results of DEA technical efficiency score between 2001 and 2010

<table>
<thead>
<tr>
<th>State</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
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<td>FIZ</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1. Johor</td>
<td>93.3</td>
<td>86.1</td>
<td>89.7</td>
<td>84.8</td>
<td>91.6</td>
<td>93.7</td>
<td>94.1</td>
<td>86.9</td>
<td>85.6</td>
<td>85.2</td>
</tr>
<tr>
<td>2. Melaka</td>
<td>87.3</td>
<td>86.8</td>
<td>81.7</td>
<td>90.1</td>
<td>100</td>
<td>99.9</td>
<td>99.3</td>
<td>100</td>
<td>90.4</td>
<td>91.9</td>
</tr>
<tr>
<td>3. Pulau Pinang</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>98.3</td>
<td>99.9</td>
<td>99.3</td>
<td>99.7</td>
<td>88.6</td>
<td></td>
</tr>
<tr>
<td>4. Perak</td>
<td>87.0</td>
<td>78.7</td>
<td>65.2</td>
<td>63.8</td>
<td>79.8</td>
<td>82.5</td>
<td>78.2</td>
<td>76.1</td>
<td>74.0</td>
<td>69.6</td>
</tr>
<tr>
<td>5. Selangor</td>
<td>94.6</td>
<td>89.4</td>
<td>79.0</td>
<td>85.4</td>
<td>91.4</td>
<td>90.0</td>
<td>89.0</td>
<td>81.7</td>
<td>80.8</td>
<td>83.2</td>
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<tr>
<td>Geometric mean</td>
<td>92.4</td>
<td>88.2</td>
<td>83.1</td>
<td>84.8</td>
<td>92.6</td>
<td>92.9</td>
<td>92.2</td>
<td>86.1</td>
<td>86.1</td>
<td>83.7</td>
</tr>
<tr>
<td>N-FIZ</td>
<td></td>
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<tr>
<td>6. Kedah</td>
<td>96.5</td>
<td>90.2</td>
<td>62.9</td>
<td>69.3</td>
<td>83.0</td>
<td>81.8</td>
<td>76.1</td>
<td>71.4</td>
<td>74.2</td>
<td>71.9</td>
</tr>
<tr>
<td>7. Kelantan</td>
<td>93.3</td>
<td>93.4</td>
<td>95.6</td>
<td>90.6</td>
<td>91.3</td>
<td>96.5</td>
<td>86.4</td>
<td>100</td>
<td>81.4</td>
<td>90.1</td>
</tr>
<tr>
<td>8. Negeri Sembilan</td>
<td>87.0</td>
<td>80.6</td>
<td>71.4</td>
<td>81.4</td>
<td>93.1</td>
<td>93.5</td>
<td>93.5</td>
<td>90.7</td>
<td>97.9</td>
<td>94.1</td>
</tr>
<tr>
<td>9. Pahang</td>
<td>84.9</td>
<td>80.0</td>
<td>66.2</td>
<td>65.3</td>
<td>81.0</td>
<td>85.4</td>
<td>84.8</td>
<td>82.1</td>
<td>76.2</td>
<td>78.5</td>
</tr>
<tr>
<td>10. Perlis</td>
<td>90.2</td>
<td>80.0</td>
<td>69.8</td>
<td>67.7</td>
<td>84.2</td>
<td>78.8</td>
<td>73.4</td>
<td>70.9</td>
<td>72.4</td>
<td>65.0</td>
</tr>
<tr>
<td>11. Terengganu</td>
<td>72.1</td>
<td>73.1</td>
<td>67.9</td>
<td>66.6</td>
<td>65.8</td>
<td>70.9</td>
<td>66.5</td>
<td>68.4</td>
<td>69.5</td>
<td>71.3</td>
</tr>
<tr>
<td>12. Sabah</td>
<td>91.9</td>
<td>88.8</td>
<td>89.4</td>
<td>92.6</td>
<td>94.2</td>
<td>96.3</td>
<td>95.8</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>13. Sarawak</td>
<td>100</td>
<td>97.1</td>
<td>79.1</td>
<td>83.1</td>
<td>98.1</td>
<td>100</td>
<td>100</td>
<td>100</td>
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</tbody>
</table>
From the technical efficiency in this study, it can be observed that, the score for the states under FIZ category was slightly higher than that of the states under N-FIZ category. This result implies that the manufacturing activities in Malaysia’s free industrial zones, which are categorized as industrial areas, perform better than the states in the N-FIZ areas. This result also disclosed that the states under FIZ category have efficiently allocated their resources while increasing the production of outputs.

The majority of Malaysian states in the manufacturing sector experience high technical efficiency with more than 75% efficiency score in geometric mean during these 10 years period of study. This high technical efficiency by the manufacturing sector has made Malaysian economy one of the most remarkable growth recorded globally despite some uncertainties in the global environment arising from the September 11 incident in 2001 and crude oil price upsurge in 2004 - 2005. The finding on high technical efficiency scores approximately consistent with the results of the assessment on technical efficiency conducted by Mohamad and Said (2010). In the paper, they reported that the average technical efficiency in food manufacturing sub-sector is about 71% during 2002 to 2007. In terms of trend, the FIZ and N-FIZ states both share similar trend. Figure 1 clearly depicts graphically the trend of technical efficiency score over the study period for FIZ, N-FIZ and overall states.

Figure 1: The trend of technical efficiency scores for FIZ, N-FIZ and Geometric mean

However, the technical efficiency analysis above does not consider undesirable outputs such as production of pollutants from the manufacturing activities. It is worth noting that modelling the production process without undesirable outputs can provide misleading results and unfair assessments. Therefore in this study we further measure an eco-efficiency using DDF where both the economic efficiency as well as the ecological efficiency are assessed in which desirable and undesirable outputs are taken into account, as to avoid unfair assessment.

The eco-efficiency scores in Table 2 indicate the extent of desirable output expansion and undesirable output reduction. For instance, in 2001, Johor was 93.7% efficient. This result suggests that Johor could expand its desirable output by as much as 6.3% while concurrently contract its undesirable outputs by 6.3% to achieve full efficiency.
Looking at the overall picture of eco-efficiency, similar results to technical efficiency were obtained, where the eco-efficiency scores for the states under FIZ category was slightly higher than N-FIZ category during this 10 year period of study. This high eco-efficiency by the manufacturing sector demonstrates that environmental performance in Malaysia is not adversely affected with regards to industrial development and can be categorized as an eco-efficient country while obtaining the profits of the firms. This indicates that the states have efficiently allocated their resources not only to increase production of desirable outputs but also to reduce production of undesirable outputs.

Table 2: Results of DDF eco-efficiency score between 2001 and 2010

<table>
<thead>
<tr>
<th>State</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
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<tbody>
<tr>
<td>FIZ</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>1. Johor</td>
<td>93.7</td>
<td>92.7</td>
<td>100</td>
<td>96.5</td>
<td>94.2</td>
<td>93.3</td>
<td>98.7</td>
<td>93.9</td>
<td>89.8</td>
<td>89.1</td>
</tr>
<tr>
<td>2. Melaka</td>
<td>86.1</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>96.3</td>
</tr>
<tr>
<td>3. Pulau Pinang</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>94.6</td>
</tr>
<tr>
<td>4. Perak</td>
<td>86.7</td>
<td>80.0</td>
<td>88.1</td>
<td>80.8</td>
<td>84.2</td>
<td>78.8</td>
<td>78.6</td>
<td>74.2</td>
<td>79.2</td>
<td>72.2</td>
</tr>
<tr>
<td>5. Selangor</td>
<td>94.9</td>
<td>99.2</td>
<td>99.7</td>
<td>99.6</td>
<td>95.2</td>
<td>89.5</td>
<td>92.3</td>
<td>92.7</td>
<td>89.7</td>
<td>92.3</td>
</tr>
<tr>
<td>Geometric mean</td>
<td>92.3</td>
<td>94.4</td>
<td>97.6</td>
<td>95.1</td>
<td>94.5</td>
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<td>93.5</td>
<td>91.6</td>
<td>91.4</td>
<td>88.9</td>
</tr>
</tbody>
</table>

| N-FIZ       | %    | %    | %    | %    | %    | %    | %    | %    | %    | %    |
| 6. Kedah    | 96.5 | 92.6 | 88.3 | 92.9 | 96.8 | 85.0 | 86.4 | 87.0 | 87.6 | 76.6 |
| 7. Kelantan | 94.3 | 97.5 | 100  | 96.4 | 90.6 | 100  | 86.5 | 100  | 86.8 | 92.4 |
| 8. Negeri Sembilan | 86.9 | 86.9 | 90.6 | 92.9 | 96.5 | 92.9 | 100  | 99.7 | 100  | 100  |
| 9. Pahang   | 85.0 | 78.4 | 80.6 | 75.8 | 86.5 | 83.1 | 84.5 | 85.2 | 81.5 | 78.1 |
| 10. Perlis  | 91.5 | 78.5 | 89.7 | 81.9 | 83.2 | 63.3 | 71.1 | 73.4 | 73.3 | 56.7 |
| 11. Terengganu | 61.5 | 67.2 | 89.4 | 100  | 97.0 | 100  | 59.5 | 61.2 | 59.2 | 67.2 |
| 12. Sabah   | 93.7 | 93.3 | 94.9 | 96.4 | 100  | 97.3 | 100  | 100  | 100  | 100  |
| 13. Sarawak | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  |
| 14. Kuala Lumpur | 96.2 | 100  | 92.5 | 99.4 | 96.0 | 89.0 | 100  | 81.3 | 99.5 | 100  |
| 15. Labuan  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  |
| Geometric mean | 90.6 | 89.4 | 92.6 | 93.2 | 94.5 | 91.1 | 87.6 | 87.7 | 87.6 | 87.1 |
| Total geometric mean | 91.1 | 91.1 | 94.3 | 93.8 | 94.5 | 91.5 | 89.6 | 89.0 | 88.9 | 87.7 |
| Number fully efficient | 3   | 5   | 6   | 5   | 5   | 6   | 7   | 6   | 6   | 5   |

The technical efficiency and eco-efficiency results obtained in this study were confirmed by Watanabe and Tanaka (2007) where in their study they found that five coastal provinces/municipalities that have attracted a large amount of foreign direct investment are manage to obtain high score in efficiency when only desirable output incorporated and also when both desirable and undesirable outputs are incorporated. These results exhibit that these five coastal provinces/municipalities are comparable with the states under FIZ category in this study. Both the five coastal provinces/municipalities and the states under FIZ category focus more on foreign direct investment activities and both manage to achieve high efficient not only on their economic efficiency but also on their ecological efficiency.
The trend of eco-efficiency score for FIZ, N-FIZ and total geometric mean are incompatible with the trend of technical efficiency where started at the 90’s eco-efficiency score, the trend of eco-efficiency climbed gradually from 2001 up to 2003 but then fell slowly to less than 90% in 2010. If this trend is consistent, an investigation needs to be taken in order to monitor and evaluate firm performance which not only in terms of economic efficiency but also eco-efficiency. Figure 2 clearly depicts graphically the trend of eco-efficiency scores for FIZ, N-FIZ and total geometric mean between 2001 and 2010.

Comparing technical efficiency with eco-efficiency above, the results show some perturbations between both efficiency models. When the element of CO$_2$ is ignored in technical efficiency, only two or three states are 100% efficient. However, when the element of CO$_2$ is incorporated in eco-efficiency, there are three to seven states that are measured as 100% efficient. It is worth noting that as the number of variables increases (for example, with the inclusion of undesirable output in this case) the efficiency scores and the number of fully efficient states will increase. Apart from that, most of the total geometric means also exhibit lower eco-efficiency scores than technical efficiency scores. This indicates that when undesirable output is omitted in the efficiency analysis, the results can be misleading. The technical efficiency results could be a sign of erroneous modelling of the production process which may provide false results when undesirable output is not considered.

5. Conclusion

This study presents a comprehensive model that integrates the indicators between environmental and industrial elements in Malaysian context. The DEA and the DDF approaches have been deployed in this study to measure the technical efficiency and eco-efficiency of the Malaysian manufacturing sector. The previous limited studies in Malaysian manufacturing context neglected the incorporation of undesirable outputs in their framework and thus have no bearing on eco-efficiency. Therefore, this study provides another dimension concerning efficiency measurement in Malaysian context particularly in the manufacturing sector wherein both desirable and undesirable outputs are considered in the analysis.

From the analysis that has been carried out, it can be seen that the DDF model is an appropriate efficiency measurement approach for the manufacturing sector as industrial activities release pollutant. This model allows one to expand the desirable outputs while simultaneously contracting the undesirable outputs.
Looking at the overall picture of eco-efficiency, similar results to technical efficiency were obtained, where the eco-efficiency scores for the states under Free Industrial Zone (FIZ) category was slightly higher than Non-Free Industrial Zone (N-FIZ) category. This high eco-efficiency by the manufacturing sector demonstrates that environmental performance in Malaysia is not adversely affected with regards to industrial development and can be categorized as an eco-efficient country while obtaining the profits of the firms.

Finally, we would like to stress that in the future it could be interesting to study a cross sectional and longitudinal study of Malaysian manufacturing subsector since different subsector may produce different pollutions thus offer interesting variations in the empirical literature.

References


