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

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Poor environmental performance of the manufacturing activities is said to be attributed to the 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 the manufacturing industries in Malaysia at the state level, for the period 2001 to 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 the technical efficiency were obtained, in which the eco-efficiency scores for the states under the Free Industrial Zone (FIZ) category were slightly higher than the Non-Free Industrial Zone (N-FIZ) category. This high eco-efficiency for the manufacturing sector demonstrates that environmental performance in Malaysia is not adversely affected with respect to industrial development in that Malaysia can be categorized as an eco-efficient country while simultaneously enabling firms to earn a profit.

1. Introduction

Essentially, performance measurement analyzes the success of work for various levels of activity 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 in that it allows a manager to identify the operating strength and weaknesses, target areas for improvement and recognize improvements, 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 determining the efficiency of their activities.

Koopmans (1957) definition of technical efficiency states that "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 based on the maximization of output or profit or minimization of cost (Thanassoulis 2001).

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Another performance measured is eco-efficiency. The concept of eco-efficiency can be described as a measurement of efficiency with the integration of undesirable outputs that contribute negatively to the environment (Dyckhoff & Allen 2001). In addition, Koskela and Vehmas (2012) reviewed the definition of eco-efficiency giving five variations: first, the numerous productions that have a limited amount of environmental impact, second, the relationship between environmental and economic performance, third, the ratio of economic performance to environmental influence, fourth, eco-efficiency as a management strategy, and fifth, 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 the 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). The productivity and efficiency of the manufacturing sector are especially crucial for the continuous growth and development of the economy. However, it would be inadequate to measure the efficiency of manufacturing activities without considering the elements of pollution, as these elements are regarded as undesirable outputs in efficiency measurement. Accordingly, 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 the last decade, many studies can be found in the literature that analyzes the technical efficiency of the manufacturing sector. For instance, Martin-Marcos and Suarez-Galvez (2000) examined the technical efficiency of Spanish manufacturing firms during the period 1990 to 1994. Hailu and Veeman (2000) measured technical efficiency in the Canadian pulp and paper industry from 1959 until 1994. Mini and Rodriguez (2000) measured the technical efficiency of manufacturing firms in the Philippine in 1994. Kaynak and Pagan (2003) estimated the technical efficiency for US manufacturing industries and Mokhtarul Wadud (2004) studied the efficiency in the Australian textile and clothing firms.

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 1980s increased gradually while the score decreased reversibly in the 1990s. A similar study by Jajri 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 1980s and decrease in the 1990s.

As for eco-efficiency studies, some examples are Boyd, Tolley and Pang (2002) who investigated the connection between productivity in the production of container glass and the emission of NO_x, a major pollutant released by glass production. Watanabe and Tanaka (2007) measured the eco-efficiency of the industrial sector in China. In 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, Oggioni and Toninelli (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 the productivity indicator. Ahmed (2007) further 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. In contrast to Ahmed (2006; 2007), this paper applies the non-parametric frontier approach called Directional Distance Function (DDF) to evaluate the eco-efficiency of the Malaysian manufacturing sector using a joint production framework involving both desirable and undesirable outputs, over a longer period of time. Therefore, this study fills the gap in the literature and conducts a two–pronged analysis, first using the DEA approach to evaluate technical efficiency and, second using the DDF approach to evaluate eco-efficiency of the manufacturing sector in Malaysia, at the state level, over the period 2001 to 2010.

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, Cooper and Rhodes (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.

$$S = \{(x,y) : x \text{ can produce } y\} \tag{1}$$

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:

$$\text{Max } \theta_m$$

Subject to

$$\sum_{n=1}^{N} z_n x_{in} \leq x_{im}; i = 1,2,..., I$$
$$\sum_{n=1}^{N} z_n y_{jn} \geq \theta_m y_{jm}; j = 1,2,..., J$$
$$z_n \geq 0; n = 1,2,..., N$$

(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 θ_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, Färe and Grosskopf (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.

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

(3)

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

$$\vec{D}_T(x, y, u; g_y, g_u) = Max\{\beta : (y + \beta g_y, u - \beta g_u \in T\}$$

(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 β seeks to increase the desirable outputs and reduce the undesirable outputs simultaneously. DDF model is formulated as below (see Chung, Färe and Grosskopf 1997):

$$
\begin{aligned}
&\text{Max } \beta_m \\
&\text{Subject to} \\
&\quad \sum_{n=1}^{N} z_n x_{in} \leq x_{im}; i = 1,2,...,I \\
&\quad \sum_{n=1}^{N} z_n y_{jn} \geq y_{jm} + \beta_m g_{y_j}; j = 1,2,...,J \\
&\quad \sum_{n=1}^{N} z_n u_{kn} = u_{km} - \beta_m g_{u_k}; k = 1,2,...,K \\
&\quad z_n \geq 0; n = 1,2,...,N
\end{aligned} \tag{5}
$$

Where z_n = intensity variables, x_{in} = i^{th} input of the n^{th} DMU, x_{im} = i^{th} input of the m^{th} DMU, y_{jn} = j^{th} desirable output of the n^{th} DMU, y_{jm} = j^{th} desirable output of the m^{th} DMU, u_{kn} = k^{th} undesirable output of the n^{th} DMU, u_{km} = k^{th} undesirable output of the m^{th} DMU, g_y = direction vector of desirable output and g_u = 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

Tables 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 – the Free Industrial Zone (FIZ) states consist of Johor, Melaka, Pulau Pinang, Perak and Selangor while the Non-Free Industrial Zone (N-FIZ) states consist of Kedah, Kelantan, Negeri Sembilan, Pahang, Perlis, Terengganu, Sabah, Sarawak and the Federal Territories of Kuala Lumpur and Labuan. The FIZ comprises 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 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 its sales in manufacturing by roughly 6.7% while maintaining the current inputs for the operating cost and capital.

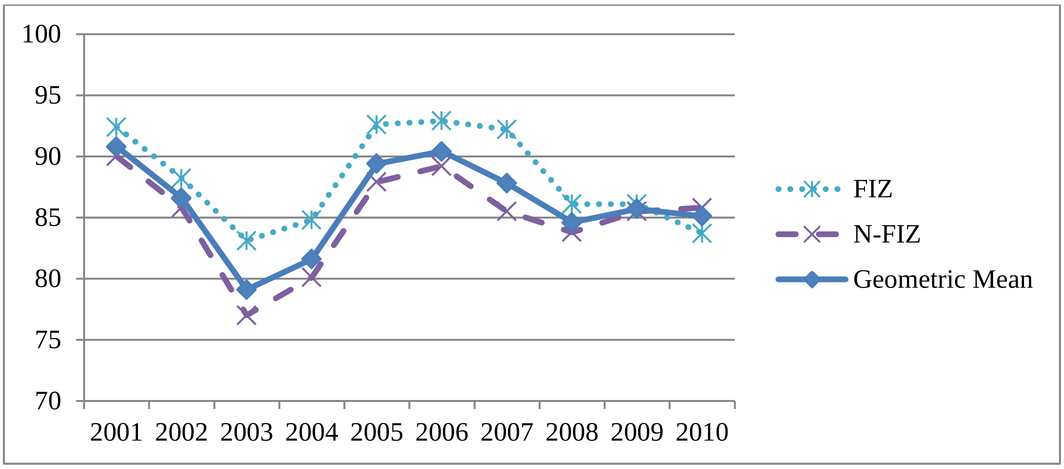
From the technical efficiency in this study, it can be observed that, the scores for the states under the FIZ category were slightly higher than that of the states under the N-FIZ category. This result implies that the manufacturing activities in Malaysia’s free industrial zones, which are categorized as industrial areas, perform better than the states in the N-FIZ areas. This result also indicates that the states under the FIZ category have efficiently allocated their resources while increasing the production of outputs.

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

State	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
FIZ	%	%	%	%	%	%	%	%	%	%
1. Johor	93.3	86.1	89.7	84.8	91.6	93.7	94.1	86.9	85.6	85.2
2. Melaka	87.3	86.8	81.7	90.1	100	100	100	95.7	90.4	91.9
3. Pulau Pinang	100	100	100	100	100	98.3	99.9	90.3	99.7	88.6
4. Perak	87.0	78.7	65.2	63.8	79.8	82.5	78.2	76.1	74.0	69.6
5. Selangor	94.6	89.4	79.0	85.4	91.4	90.0	89.0	81.7	80.8	83.2
Geometric mean	*92.4*	*88.2*	*83.1*	*84.8*	*92.6*	*92.9*	*92.2*	*86.1*	*86.1*	*83.7*
N-FIZ										
6. Kedah	96.5	80.2	62.9	69.3	83.0	81.8	76.1	71.4	74.2	71.9
7. Kelantan	93.3	93.4	95.6	90.6	91.3	96.5	86.4	100	81.4	90.1
8. Negeri Sembilan	87.0	80.6	71.4	81.4	93.1	93.5	93.5	90.7	97.9	94.1
9. Pahang	84.9	80.0	66.2	65.3	81.0	85.4	84.8	82.1	76.2	78.5
10. Perlis	90.2	80.0	69.8	67.7	84.2	78.8	73.4	70.9	72.4	65.0
11. Terengganu	72.1	73.1	67.9	66.6	65.8	70.9	66.5	68.4	69.5	71.3
12. Sabah	91.9	88.8	89.4	92.6	94.2	96.3	95.8	100	100	100
13. Sarawak	100	97.1	79.1	83.1	98.1	100	100	100	100	100
14. Kuala Lumpur	95.5	85.2	68.1	83.9	88.0	88.5	78.9	77.6	83.6	87.6
15. Labuan	88.9	100	100	100	100	100	100	77.3	100	99.6
Geometric mean	*90.0*	*85.8*	*77.0*	*80.1*	*87.9*	*89.2*	*85.5*	*83.8*	*85.5*	*85.8*
Total geometric mean	*90.8*	*86.6*	*79.1*	*81.6*	*89.4*	*90.4*	*87.8*	*84.6*	*85.7*	*85.1*
Number fully efficient	*2*	*2*	*2*	*2*	*3*	*3*	*3*	*3*	*3*	*2*

For the ten-year period of study, the majority of Malaysian states in respect of the manufacturing sector achieved high technical efficiency with an efficiency score of more than 75% for the geometric mean. This high technical efficiency by the manufacturing sector led to the Malaysian economy being among the national economies that recorded remarkable growth despite the uncertainties in the global environment arising from the September 11 incident in 2001, and the crude oil price upsurge in 2004 - 2005. The finding on high technical efficiency scores is similar to the results of the assessment for technical efficiency conducted by Mohamad and Said (2010). In their paper, they reported that the average technical efficiency in the food manufacturing sub-sector was about 71% between 2002 and 2007. In terms of trend, the FIZ and N-FIZ states both share a similar trend. Figure 1 clearly depicts graphically the trend of the technical efficiency score over the study period for the FIZ, N-FIZ and overall states.

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



However, the technical efficiency analysis above does not consider undesirable outputs, such as the production of pollutants from the manufacturing activities. It is worth noting that modeling the production process without undesirable outputs can provide misleading results and unfair assessments. Therefore, in this study, we further measure eco-efficiency using DDF in which both the economic efficiency as well as the ecological efficiency are assessed and the desirable and undesirable outputs are both taken into account 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 contracting its undesirable outputs by 6.3% to achieve full efficiency.

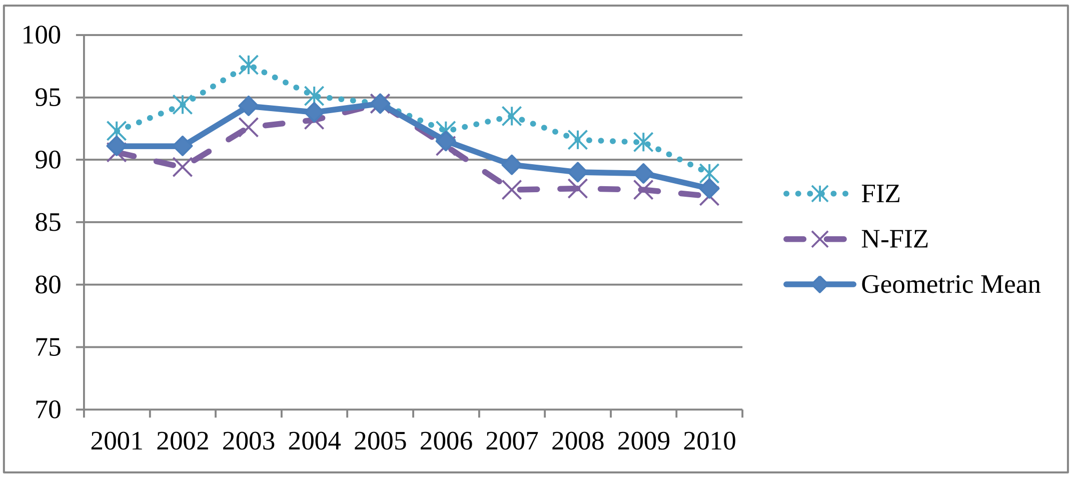
Looking at the overall picture of eco-efficiency, similar results to technical efficiency were obtained, where the eco-efficiency scores for the states under the FIZ category were slightly higher than the N-FIZ category during this ten-year period of study. This high eco-efficiency by the manufacturing sector demonstrates that environmental performance in Malaysia is not adversely affected in respect of industrial development, and that it can be categorized as an eco-efficient country while at the same time, firms can continue to earn profit. This indicates that the states have efficiently allocated their resources not only to increase the production of desirable outputs but also to reduce the production of undesirable outputs.

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

State	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
FIZ	%	%	%	%	%	%	%	%	%	%
1. Johor	93.7	92.7	100	96.5	94.2	93.3	98.7	93.9	89.8	89.1
2. Melaka	86.1	100	100	100	100	100	100	100	100	96.3
3. Pulau Pinang	100	100	100	100	100	100	100	100	100	94.6
4. Perak	86.7	80.0	88.1	80.8	84.2	78.8	78.6	74.2	79.2	72.2
5. Selangor	94.9	99.2	99.7	99.6	95.2	89.5	92.3	92.7	89.7	92.3
Geometric mean	*92.3*	*94.4*	*97.6*	*95.1*	*94.5*	*92.3*	*93.5*	*91.6*	*91.4*	*88.9*
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 confirm those of Watanabe and Tanaka (2007) who found that five coastal provinces/municipalities that have attracted a large amount of foreign direct investment managed to obtain a high score in efficiency when only desirable output was incorporated and also when both desirable and undesirable outputs were incorporated. These results exhibit that these five coastal provinces/municipalities are comparable with the states under the FIZ category in this study. The five coastal provinces/municipalities as well as the states under the FIZ category focus more on foreign direct investment activities. In addition, both manage to achieve high efficiency in terms of their economic efficiency and ecological efficiency.

Figure 2: The trend of the DDF eco-efficiency scores for FIZ, N-FIZ and Geometric mean



The trend of the eco-efficiency score for FIZ, N-FIZ and total geometric mean are incompatible with the trend for the technical efficiency where started at the 90's eco-efficiency score, the trend of eco-efficiency climbed gradually from 2001 until 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 not only in terms of economic efficiency but also eco-efficiency. Figure 2 clearly depicts graphically the trend of the eco-efficiency scores for FIZ, N-FIZ and total geometric mean between 2001 and 2010.

Comparing the technical efficiency with the 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. In addition, 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 modeling of the production process, which may provide false results when undesirable output is not considered.

The results of this study are different from those of Ahmed (2006; 2007), since he used a non-frontier approach for three periods of analysis, i.e. birth of Malaysia era, further diversification of the economy into industrial sectors and the development of the economy into more advanced industries. His study, which focuses on the impact of emission factors on productivity growth, found that industrial activities are related to the growth rate of emission factors generated by the manufacturing sector.

5. Conclusion

This study presents a comprehensive model that integrates the indicators between the environmental and industrial elements in the 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. Previous limited studies in the 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 the measurement of efficiency in the 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 conventional DEA model accounts for only two categories of variable, which are the input and the desirable output variables. When undesirable output is present, the model of DEA is no longer applicable. To handle the undesirable output, the Directional Distance Function (DDF) approach was employed which considered as a more appropriate eco-efficiency measurement approach for the manufacturing sector as industrial activities release pollutants. The reason why this model is considered as a more appropriate technique is because it allows one to expand the direction of desirable output while simultaneously contracting the direction of undesirable output by using a single scalar. This property is very useful in studying the input-output choices of polluting firms facing environmental regulation as firms attempt to reduce pollution and increase desirable output production simultaneously.

However, there is a limitation to the DDF approach. The direction vector for the production boundary is fixed arbitrarily, which means it may not provide the best efficiency measure. This is because a different direction vector may provide a different efficiency score. Indeed, there is still no consensus on what is the best direction vector to be employed in this model. Therefore, this provides the scope for future research.

Looking at the overall picture of eco-efficiency, similar results to technical efficiency were obtained, in that the eco-efficiency scores for the states under the Free Industrial Zone (FIZ) category were slightly higher than the 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 in respect of industrial development in that Malaysia can be categorized as an eco-efficient country while simultaneously enabling firms to earn a profit.

Finally, a future interesting area of study would be a cross sectional and longitudinal study of the Malaysian manufacturing subsectors since different subsectors may produce different pollutants thus offering interesting variations in the empirical literature.

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