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Full Length Research Paper

Decomposing productivity growth in Malaysian food manufacturing industry

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In this study, a mathematical programming-based optimization technique known as data envelopment analysis, DEA is used to compute and analyze the decomposition of Malmquist index of total factor productivity, *TFP* into technological change, technical efficiency change and scale efficiency change by utilizing an output-oriented DEA model under the assumptions of constant and variable returns to scale. The methodology is applied to selected 5-digit Malaysian food manufacturing sub-industries using annual time-series data for the period 2002 to 2007. The results suggest that the *TFP* growth is largely due to positive technological change or frontier shift rather than technical efficiency change.

Key words: Data Envelopment Analysis, Malmquist productivity index, technological change, technical efficiency change.

INTRODUCTION

Decomposing productivity growth is important in identifying and understanding the sources of growth to aid and provide directions to decision makers in their policy making. Traditionally, productivity can be mathematically defined as the relationship between a set of input values and the output values. This gives rise to the concept of partial productivity which represents the change of output produced corresponding to each input used such as labour productivity and capital productivity. However, as technology progresses, it is observed that it is possible to produce more from less inputs by adopting better means and methods of production. It is therefore essential to conduct and analyze the productivity trends as well as the technological changes in order to understand the industrial situation and the productivity dynamics.

Output or productivity growth is therefore not attributed to growth in inputs only. Improvement in input qualities, efficient use of production processes, adoption of new technology and other non-physical factors do contribute to the dynamics of productivity growth. This non-physical contributor is known as total factor productivity, TFP. In short, TFP addresses any effect in total output not caused by inputs or economies of scale and is often found to be a found to be a significant contributor to output growth. Improvement in TFP will enable the industry to generate a larger output from the same resources, and hence shifting it to a higher frontier. The technological change component of productivity growth captures shift in the frontier technology and can be interpreted as providing a measure of innovation. Technical efficiency improvement or catching up effect, on the other hand, is measured by the difference between the frontier output and the realized output. Thus, the decomposition of TFP into technological change and technical efficiency change is therefore useful in distinguishing innovation or adoption of new technology by best practice firms from the diffusion of technology. The rest of the paper is organized as follows. The next section reviews selected literature in productivity performance analysis in the manufacturing sector. This is followed by definition of DEA output distance function for two time periods, the formulation and decomposition of Malmquist TFP growth index. The methodolody is applied to a set of 32 selected Malaysian food manufacturing sub-industries for the period 2002 to 2007. Results and findings are presented, followed by concluding remarks in the final section.

LITERATURE REVIEW

Various techniques have been used in the study of

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productivity growth. This includes the divisia index model (Brown and Greenberg, 1983; Kumbhakar, 2004; Star and Hall, 1976), growth accounting approach (Kumar et al., 2008; Iradian, 2007; Mongia and Sathaye, 1998; Sonobe and Otsuka, 2001; Zhi et al., 2003), aggregate or frontier production function estimates (Alvarez, 2007; Nishimizu and Page, 1982), stochastic varying coefficient approach (Karagiannis and Tzouvelekas, 2009; Gopalan and Shanmugam, 2010; Mahadevan, 2002) and the non-parametric DEA (Vahid and Sowlati, 2008; Hailu and Veeman, 2001; Jaforullah and Whiteman, 1999; Kirigia et al., 2007). An empirical analysis which focuses on the convergence hypothesis and scale effects in explaining different productivity growth rates within the manufacturing sectors of Canada and the United States is addressed by Mullen and Williams (1994). Fare et al. (2001) analyze productivity growth in 16 of Taiwan's manufacturing industries during the period 1978-1992 by utilizing the DEA approach to compute the Malmquist *TFP* index. Mahadevan and Kim (2003) examine the sources of output growth of four selected South Korean manufacturing industries from 1980 to 1994 using firm level data within each industry.

On the Malaysian scenario, Zulaifah and Maisom (2001) utilize the Dollar and Sokoloff model and an econometric approach to determine the intensity of use of factors of production in manufacturing industries. They obtained an estimated growth rate of 4.32% per annum for all industries for the period 1985-1998 with light and medium industries exhibiting the highest *TFP* growth rate of 17.3% per annum, followed by heavy industries at 11.7% per annum and resource based industries at 6.4% per annum. However, no analysis was conducted on the components or sources of *TFP* growth. A recent study by Ismail (2009) found that the technical efficiency change in food-based industry for the period 1985 to 2003 is low with a negative overall average of –0.976% per annum. Only twenty % of the twenty-five sub-industries investigated experience positive technical efficiency change. However, all the sub-industries experience positive technical or technological change with a mean value of 1.036 or 3.6% change. The *TFP* index exhibits positive growth with an overall mean of 1.011 (ranging from 0.949 to 1.073). In this study we utilize the concept of DEA Malmquist productivity index to decompose and analyze the *TFP* change into technical efficiency change and technology or frontier shift. The technical efficiency change will further be decomposed into pure technical efficiency change and scale efficiency change. The model is applied to thirty-two selected Malaysian food manufacturing sub-industries for the period 2002-2007.

DEA MALMQUIST INDEX

Fare et al. (1994) constructed the DEA-based Malmquist productivity index as the geometric mean of two Malmquist productivity indexes which are defined by a distance function relative to two different time periods.

Definition 1

Consider K decision making units (DMUs), each utilizing inputs $X_k^{(t)} \in \Re_+^N$ to produce outputs $Y_k^{(t)} \in \Re_+^M$, k = 1,2,…,K at time t. The output distance function for DMU-k with respect to two different time periods, $D_k^{(t)}(X_k^{(t+1)}, Y_k^{(t+1)})$ under the assumptions of constant returns to scale, CRS, is defined by an output oriented DEA linear programming problem such that,

$$\{D_k^{(t)}(X_k^{(t+1)}, Y_k^{(t+1)})\}^{-1} = Max \quad \Omega_k \tag{1}$$

$$s.t \quad \sum_{j=1}^{K} \lambda_j X_{j(n)}^{(t)} \le X_{k(n)}^{(t+1)}, \quad n = 1,2,3,...,N, \tag{2}$$

$$\sum_{j=1}^{K} \lambda_j Y_{j(m)}^{(t)} \ge \Omega_k Y_{k(m)}^{(t+1)}, \quad m = 1,2,3,...,M, \tag{3}$$

$$\lambda_j \ge 0, \quad j = 1,2,...,K. \tag{4}$$

A similar definition applies to $D_k^{(t)}(X_k^{(t)}, Y_k^{(t)})$, $D_k^{(t+1)}(X_k^{(t)}, Y_k^{(t)})$ and $D_k^{(t+1)}(X_k^{(t+1)}, Y_k^{(t+1)})$.

Definition 2

The Malmquist index of TFP for DMU-k, $M_k(X_k^{(t+1)}, Y_k^{(t+1)}, X_k^{(t)}, Y_k^{(t)})$ can be specified as the geometric mean of the productivity changes between two time periods such that,

$$M_k\left(X_k^{(t+1)}, Y_k^{(t+1)}, X_k^{(t)}, Y_k^{(t)}\right) = \left[\left(\frac{D_k^{(t)}\left(X_k^{(t+1)}, Y_k^{(t+1)}\right)}{D_k^{(t)}\left(X_k^{(t)}, Y_k^{(t)}\right)}\right)\left(\frac{D_k^{(t+1)}\left(X_k^{(t+1)}, Y_k^{(t+1)}\right)}{D_k^{(t+1)}\left(X_k^{(t)}, Y_k^{(t)}\right)}\right)\right]^{1/2} \tag{5}$$

A value of $M_k > 1$ indicates positive *TFP* growth or gain, $M_k < 1$ indicates *TFP* decline or loss, and $M_k = 1$ implies stagnation or no change in *TFP* for DMU-*k* from time *t* to *t*+1. Equation (5) can also be equivalently written as,

$$M_k(\ldots) = \left(\frac{D_k^{(t+1)}\left(X_k^{(t+1)}, Y_k^{(t+1)}\right)}{D_k^{(t)}\left(X_k^{(t)}, Y_k^{(t)}\right)}\right) \left[\left(\frac{D_k^{(t)}\left(X_k^{(t+1)}, Y_k^{(t+1)}\right)}{D_k^{(t+1)}\left(X_k^{(t+1)}, Y_k^{(t+1)}\right)}\right)\left(\frac{D_k^{(t)}\left(X_k^{(t)}, Y_k^{(t)}\right)}{D_k^{(t+1)}\left(X_k^{(t)}, Y_k^{(t)}\right)}\right)\right]^{1/2} \tag{6}$$

The first component,

$$TEC_k = \left(\frac{D_k^{(t+1)}(X_k^{(t+1)}, Y_k^{(t+1)})}{D_k^{(t)}(X_k^{(t)}, Y_k^{(t)})}\right), \tag{7}$$

measures the change in technical efficiency over the two periods, whether or not DMU-*k* is getting closer to its efficiency frontier over time. This term is normally referred to as the *catching up effect* since it measures the degree of catching up to the best-practice frontier over time. It is also a measure of diffusion of technology.The second component,

$$FS_k = \left[\left(\frac{D_k^{(t)}(X_k^{(t+1)}, Y_k^{(t+1)})}{D_k^{(t+1)}(X_k^{(t+1)}, Y_k^{(t+1)})}\right)\left(\frac{D_k^{(t)}(X_k^{(t)}, Y_k^{(t)})}{D_k^{(t+1)}(X_k^{(t)}, Y_k^{(t)})}\right)\right]^{1/2} \quad (8)$$

measures the technology change over the two periods, whether or not the frontier is shifting out over time. It can be viewed as a geometric mean of the change or shift in the frontier of technology or innovation experienced by DMU-*k* from time t to $t+1$. Hence, the Malmquist *TFP* index is simply the product of technical efficiency change and technological change. That is,

TFP growth = (*TEC*) . (*FS*) (9)

Fare et al. (1994) further proposed an *Enhanced Decomposition* of *TEC* (relative to CRS frontier) into a Pure Technical Efficiency Change, *PTEC* component (relative to a Variable Returns-to-Scale, VRS frontier), and a residual *Scale Efficiency Change*, *SEC* component which captures changes in the deviation between the VRS and CRS technology. That is,

TEC = (*PTEC*) . (*SEC*) (10)

The complete decomposition for DMU-*k* thus becomes,

$M_k(.)$ = (*TFP* growth)$_k$
= $(TEC)_k \,.\, (FS)_k$
= $(PTEC)_k.(SEC)_k.\ (FS)_k$, k=1,..,K. (11)

For evaluation under the assumption of VRS, an additional convexity constraint $\sum_{j=1}^{K} \lambda_j = 1,$ is imposed when solving the linear programming problem (1)-(4).

EMPIRICAL IMPLEMENTATION

Data source

The data used in the study are annual time-series data for 32 selected 5-digit Malaysian food manufacturing sub- industries for the period 2002 to 2007, compiled from the Annual Survey of Malaysian Manufacturing Industries, published by the Department of Statistics, Malaysia (various years). Table 1 lists these sub-industries and their 5-digit Malaysian Standard Industrial Code (MISC).

A single measure of output, value added deflated by the con-sumer price index for food, is used. Cost of inputs, total number of workers and total fixed assests constitute three measures of input. The cost of inputs and total fixed assets were deflated by producer price index for goods in the domestic economy for manufactured goods. Both de-flators with 2000 as the base year were obtained from the *Economic Report* published by the Ministry of Finance, Malaysia (various years). Next, we solve the DEA output-oriented model under the assumptions of CRS and VRS for each year. Results for the mean efficiency scores and returns to scale are summarized in Table 2.

RESULTS

Technical and scale efficiency

Out of the 32 sub-industries, only one sub-industry (15491 Manufacture of ice) obtains a scale efficiency score of 100%, implying that it is technically efficient in all years under evaluation and is operating on the frontier at the Most Productive Scale Size, *mpss*. Two other sub-industries (15420 Manufacture of sugar and 15496 Manufacture of sauces) are close to *mpss*. In fact, both sub-industries achieved scale efficiency score of 100% in five of the six years under consideration. The result also implies that, in general, more than 90% of the sub-industries were operating inefficiently and they need to increase their output (or reduce their inputs) to become efficient. The average *PTE* score was 80.93% during 2002 to 2007. This finding suggests that if these sub-industries were operating efficiently, they could have produced 19.07% more output. Nevertheless, more than 60% of the sub-indutries were more than 90.0% scale efficient.

Returns to scale

Apart from the inefficiency that could arise in the conversion process, another reason for the inefficiency of the inefficient units can be attributed to the scale of operations. DMUs that do not operate at the most efficient (or productive) scale size cannot be fully efficient. The inefficiency may arise because it is operating under decreasing returns to scale, *drs* or increasing returns to scale, *irs*. Whether a DMU is operating under *irs* or *drs* can be determined by observing its *TE* and *PTE* scores, such that

(i) if $TE = PTE$, CRS prevails
(ii) if $TE \neq PTE$, then

$$\begin{cases} \sum_{j=1}^{K} \lambda_j > 1 \rightarrow drs. \\ \sum_{j=1}^{K} \lambda_j < 1 \rightarrow irs, \end{cases}$$

The last column in Table 2 records the returns to scale based on the most frequent occurance observed during the years under consideration. As mentioned earlier, 3 (9.375%) sub-industries appeared to be operating at (or near) their *mpss*. 18 (56.250%) of sub-industries exhibited *drs*. These sub-industries should scale down their scale of operation if they were to operate on the frontier. The remainder 11 (34.375%) exhibited *irs*. These sub-industries should expand their scale of operation in order to become scale efficient. The average scale efficiency score in the sample for the period 2002 to 2007

Table 1. The Malaysian food manufacturing sub-industries.

5-Digit MSIC	Sub-industry
15111	Production of poultry and poultry products
15119	Production of meat and meat products
15120	Production of fish and fish products
15131	Pineapple canning
15139	Canning of other fruits and vegetables
15141	Manufacture of coconut oil
15142	Manufacture of crude palm oil
15143	Manufacture of refined palm oil
15144	Manufacture of palm kernel oil
15149	Manufacture of other oils and fats
15201	Manufacture of ice cream
15202	Manufacture of milk
15311	Rice milling
15312	Flour milling
15319	Manufacture of other mill products
15322	Manufacture of glucose and maltose
15323	Manufacture of sago and tapioca products
15330	Manufacture of animal feeds
15411	Manufacture of biscuits and cookies
15412	Manufacture of bakery products
15420	Manufacture of sugar
15431	Manufacture of cocoa products
15432	Manufacture of chocolate and sugar products
15440	Manufacture of macaroni and similar products
15491	Manufacture of ice (excluding dry ice)
15492	Manufacture of coffee
15493	Manufacture of tea
15494	Manufacture of spices and curry powder
15495	Manufacture of nut and nut products
15496	Manufacture of sauces
15497	Manufacture of snack (cracker/chips)
15499	Manufacture of other food products

period 2002 to 2007 was 88.48%, ranging from a minimum of 51.96% to a maximum of 100%.

Malmquist productivity change

Table 3 presents a summary of the annual geometric means of the Malmquist productivity index and its components. As can be observed, on average, the TFP for food manufacturing sub-industries showed a small increase of 0.30% per annum, ranging from -10.8 to 9.3%. The technological or frontier shift recorded a positive change for all sub-industries, implying that growth was largely attributable to innovation. The technological change (frontier shift or innovation) improved by 3.4% (ranging from 0.1 to 10.3%) per annum while technical efficiency regressed by 3.0 % (ranging from -15.3 to 5.4%) per annum. Hence catching up (that is diffusion of technology) is a problem facing most sub-indutries. Only 6 (18.75%) of the sub-industries showed improvement in all components. This includes two which exhibited *mpss*, three *drs* and one *irs*. 15 (46.87%) of the sub-industries showed positive TFP growth while another 17 (53.13%) recorded negative growth. The highest *TFP* growth comes from sub-industry 15493 manufacture of tea 15493 manufacture of tea (9.3% per annum) while the lowest is from sub-industry 15131 pineapple canning (-10.8% per annum).

Technological change (frontier shift)

All sub-industries, on average, experienced technological progress since the FS_k index attains a value greater than one for all k=1,...,32. The average score was 1.034, indicating a 3.4% technological progress per annum. The

Table 2. Mean efficiency scores from 2002 to 2007.

5-Digit MSIC	Technical efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
15111	0.5259	0.5823	0.9093	*drs*
15119	0.5299	0.5868	0.9242	*drs*
15120	0.6235	0.7749	0.8071	*drs*
15131	0.5327	0.6088	0.8853	*irs*
15139	0.7509	0.7706	0.9723	*irs*
15141	0.5172	0.9947	0.5196	*irs*
15142	0.5520	1.0000	0.5520	*drs*
15143	0.8482	0.9750	0.8671	*drs*
15144	0.7438	0.7615	0.9764	*irs*
15149	0.5668	0.6029	0.9296	*drs*
15201	0.7973	0.8200	0.9734	*irs*
15202	0.8931	1.0000	0.8931	*drs*
15311	0.3780	0.3978	0.9595	*drs*
15312	0.8299	0.8588	0.9607	*drs*
15319	0.7638	0.8517	0.9035	*irs*
15322	0.6287	1.0000	0.6287	*irs*
15323	0.6081	0.7035	0.8841	*irs*
15330	0.6026	0.7194	0.8360	*drs*
15411	0.6213	0.7376	0.8454	*drs*
15412	0.7194	0.9836	0.7326	*drs*
15420	0.9957	0.9986	0.9970	*mpss*
15431	0.6182	0.6525	0.9482	*irs*
15432	0.8817	0.9260	0.9503	*drs*
15440	0.6864	0.7458	0.9176	*drs*
15491	1.0000	1.0000	1.0000	*mpss*
15492	0.8174	0.8364	0.9797	*drs*
15493	0.5854	0.7295	0.7855	*irs*
15494	0.6568	0.6701	0.9800	*drs*
15495	0.8205	0.8930	0.9142	*irs*
15496	0.9415	0.9545	0.9837	*mpss*
15497	0.7156	0.7609	0.9379	*drs*
15499	0.9463	1.0000	0.9463	*drs*
Average	0.7093	0.8093	0.8844	
Std. dev	0.1577	0.1602	0.1223	
Maximum	1.0000	1.0000	1.0000	
Minimum	0.3780	0.3978	0.5196	

Note: *drs* and *irs* refer to decreasing and increasing returns to scale respectively.

highest technological progress of 10.3% per annum was achieved by sub-industry 15323 Manufacture of sago and tapioca products while the lowest innovative improvement of 0.1% per annum was recorded by sub-industry 15440 Manufacture of macaroni and similar products.

Technical Efficiency Change (catching up effect)

Only 7 (21.9%) showed improvement in technical efficiency with sub-industry 15493 Manufacture of tea attaining the highest score of 1.054 (catching up rate of 5.4% per annum). 25 (78.1%) sub-industries appeared to be lagging behind with sub-industry 15131 Pineapple canning recording the lowest score of 0.847 (a decline of -15.3% per annum). On average, the group was found to be staggering behind at -3.0% per annum. This indicates that technical efficiency is not improving in line with technological progress. In other words, the gap to the efficient frontier is widening.

Pure Technical Efficiency Chan*ge*

As mentioned earlier, *TEC* is the product of *PTEC* and *SEC*. 8 (25%) of the sub-industries indicated an increase

Table 3. Mean Malmquist productivity index change from 2002 to 2007.

5-Digit MSIC	$M_k(.)$ (TFP growth)	FS_k	TEC_k	$PTEC_k$	SEC_k
15111	1.015	1.009	1.006	0.986	1.021
15119	0.982	1.044	0.941	0.887	1.061
15120	0.980	1.024	0.957	0.944	1.014
15131	0.892	1.053	0.847	0.788	1.075
15139	1.029	1.043	0.987	0.973	1.014
15141	1.049	1.071	0.979	1.000	0.979
15142	1.027	1.016	1.011	1.000	1.011
15143	1.019	1.033	0.988	1.033	0.956
15144	0.984	1.041	0.946	0.959	0.986
15149	0.939	1.015	0.925	0.966	0.958
15201	1.091	1.097	0.995	1.004	0.991
15202	0.991	1.038	0.955	1.000	0.955
15311	1.013	1.036	0.977	0.963	1.015
15312	0.974	1.005	0.969	0.972	0.997
15319	0.999	1.010	0.989	0.997	0.992
15322	0.975	1.075	0.907	1.000	0.907
15323	1.086	1.103	0.985	0.915	1.076
15330	1.075	1.038	1.036	1.031	1.005
15411	1.009	1.012	0.996	1.024	0.973
15412	0.989	1.011	0.979	1.011	0.968
15420	1.046	1.041	1.005	1.002	1.003
15431	1.069	1.079	0.991	0.985	1.006
15432	0.976	1.054	0.926	0.946	0.979
15440	0.940	1.001	0.939	0.975	0.963
15491	1.041	1.041	1.000	1.000	1.000
15492	1.040	1.007	1.033	1.009	1.024
15493	1.093	1.037	1.054	1.003	1.051
15494	0.992	1.008	0.984	0.997	0.987
15495	0.932	1.022	0.912	0.935	0.975
15496	0.946	1.013	0.934	0.952	0.981
15497	0.923	1.016	0.909	0.934	0.973
15499	0.976	1.009	0.967	1.000	0.967
Average	1.003	1.034	0.970	0.975	0.996
Std.dev	0.051	0.027	0.043	0.048	0.036
Maximum	1.093	1.103	1.054	1.033	1.076
Minimum	0.892	1.001	0.847	0.788	0.907

Note: All Malmquist index averages are geometric means.

in pure technical efficiency with sub-industry 15143 Manufacture of refined palm oil taking the lead with improvement of 3.3% per annum. Eighteen (56.25%) indicated a decrease with sub-industry 15131 Pineapple canning retaining the lowest score of negative growth at -21.2% per annum. The remainder six (18.75%) sub-industries showed no change during the period under consideration as indicated by their *PTEC* score of unity.

Scale Efficiency Change

SEC of 14 (43.75%) of the sub-industries contributed positively to the productivity change since their scores exceed one. Sub-industry 15323 Manufacture of sago and tapioca products recorded the highest score of 1.076 (a change of 7.6% per annum), while sub-industry 15322 Manufacture of glucose and maltose recorded the lowest score of 0.907 (a change of -9.3% per annum). The average score for the group is 0.996 (a small decrease of 0.4% per annum).

DISCUSSION

From the results , we c an highlight a few observations thus:

(i) The Malmquist *TFP* index for Malaysian food manufacturing industry indicated only a small increase of 0.3% per annum.
(ii) The *TFP* growth is largely due to innovation (a positive shift in the frontier) rather than Technical Efficiency Change (catching up effect).
(iii) A decrease in *TEC* is attributable to both decrease in *PTEC* and *SEC.*
(iv) Sub-industry 15493 Manufacture of tea achieved the highest *TFP* growth with all components indicating positive changes.
(v) Sub-industry 15131 Pineapple canning recorded the lowest *TFP* growth with the lowest *TEC* score despite encouranging improvement in *FS* score (above group-average). The low *TEC* was due to the lowest *PTEC* despite a relatively high *SEC*.

POLICY IMPLICATION

The analysis provides some interesting policy implications. The study found that three sub-industries were operating at (or near) *mpss*. This should be sustained as long as possible since they were classified as achieving 100% efficient. 18 (56.25%) of the sub-industries were found to exhibit *drs*. This suggests an over-utilization of input resouces, both labour and capital. Thus scaling down their scale of operation is an appropiate action for these sub-industries if they were to be on the efficient frontier. Another 34.37% of the sub-industries were operating under *irs*. This suggests under-utilization of input resources, both in terms of quality and quantity, and provides potential for expansion. Thus expanding their scale of operation by injecting further investments in existing sub-industries and/or new investment in new establishments under these sub-industries seems the right move forward.

On the technology side, the adoption of new technology, although positive in all sub-industries, is relatively slow. The catching-up effect which indicates the gap to the efficient frontier, on the other hand is widening. Therefore, it seems that the choice of technology adopted is not in line with the skills available. Training should be provided by relevant parties such as government and employers for workers to acquire new and higher skills appropiate for the technology before adoption is made. Further, workers should be made more flexible and easily adaptable to new technology. Movements within sub-industries should be made easy, say from a sub-industry exhibing *drs* to a sub-industry exhibiting *irs*.

Conclusions

In this study, we have estimated the Malmquist *TFP* index and its decompositions using the output-oriented DEA distance functions for 32 Malaysian food manufacturing sub-industries for the period 2002 to 2007. The findings indicate that *TFP* only grew at a slow rate of 0.3% per annum despite an encouraging frontier shift or innovative improvement of 3.4% per annum. This is due to a decline in the catching up effect or *TEC* of -3.0% per annum which is further attributable to decrease in both *PTEC* and *SEC*. Only three sub-industries were found to be operating efficiently (exhibiting *mpss*) while twenty-nine exhibit variable returns to scale, indicating the needs for operation adjustments. The findings suggest that 18 and 11 of these sub-industries should scale down and expand their scale of operations respectively if they were to be operating on the efficient frontier.

The study is not without limitations. DEA is non-stochastic and does not capture random noise, thereby may have over estimated the magnitude of inefficiencies. The data utilized in the study are aggregated sub-industries data and not firm level data. This is because firm level data is not easily accessible. The study also assumes that all sub-industries under evaluation are fairly homogenous, utilizing similar set of inputs to produce identical outputs. This can only be achieved if we are evaluating a group of firms operating similar business activities such as banking or financial institutions, hospitals and others. The methodology can be revised, expanded and applied to other public and private organizations.

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