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Malmquist Productivity Index for Container Terminal

Kasypi Mokhtar[1] Muhammad Zaly Shah[2]

1. Department of Maritime Management, Faculty of Maritime Studies and Marine Science
   Universiti Malaysia Terengganu, Malaysia Email: m.kasypi@yahoo.com
2. Department of Urban and Regional Planning, Faculty of Built Environment
   Universiti Teknologi Malaysia Email: zaly@live.utm.my

Abstract

The current decade sees significant growth in worldwide seaborne container transportation and with it an essential need for optimization of its productivity. Container ports and their terminals are required to remain competitive and able to handle the anticipated growth as there are huge challenges to increase its productivity, to reduce the spatial pressure and terminal congestion. The paper aims to analyse and measure the productivity of major container ports in Peninsular Malaysia. A non-parametric technique is employed to analyse and measure Malmquist productivity in estimating the utmost productive container terminals. The malmquist productivity results replicate the actual container ports productivity in line with resources within container terminals and obtained throughput. It is prove that current container terminals expansion by port operators in line with future demand.

Keywords: Container terminal, DEA, Malmquist Productivity Index

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1. Introduction

Development of Seaports are derived from the need of economic community, as well as the nature of the shipping business. As seaport is interface between land and sea, it has to follow the trade needs of the region and the types of vessel it is designed to accommodate. Thus, seaport structure has changed over the decades to tap with the demand from clients. In order to cater these, high terminal productivity is essential in portraying excellent terminal. Technically, the complexity of seaport vast from operational (types of cargo handled, ships service, terminal managed, processes/systems operated, equipments, etc.) and its spatial (cluster, port, terminal, quay system, yard system, etc.). These complexities have created the confusion on what and how to measure with the technology advent and risk to be considered. The paper aims at analysing and measure Malmquist productivity index from the technological change. The change is based on the frontier movement period from 1 to 2 respectively.

The research covers 6 major container terminals in Peninsular Malaysia. The non parameter technique under frontier method is used to showcase result of window analysis and Malmquist Index (MI) from 2003 to 2010 data. The first section starts with introduction and follows with theoretical perspective on container terminal in section 2. Under section 3, the discussions on Malmquist index.Furthermore, the model applied for this research to analyse the panel data. Section 5 represents results and discussion on the analysis of Malmquist index. Section 6 represents conclusion of the research.

2. Theoretical Perspective: Container Terminal

2.1 Productivity Impact on Terminal Operation

Productivity is a summary measure of a quantity and quality work of performance with resource utilization considered. It involves doing a task or job in the best possible way and a criterion to be applied to individuals, groups and organizations. In order to achieve optimum productivity, it has to deal closely with performance where all the components must be applied especially effective and efficiency. Sumanth (1984) clarifies the meaning of productivity as a concern with the efficient utilization of resources (input) in producing goods and or services (output). Public likely confuse productivity with production terms, where the concerned is with the activity of producing goods and or services.

In shipping industry, port container terminal productivity can be measured in two types of operations. First is the vessel operation, which involves discharge and loading of container onto vessel. The other one is receiving and delivering operations, where containers transfer to and from outside trucks (Kim and Park, 2003). In addition, productivity in port container operation is key determinant for the cost of providing container stevedoring services. Meyrick and associates and Tasman Asia Pacific (1998) report, there are two partial productivity measures have been used in port productivity studies. First is annually lifts per employee (labor productivity), and it is defined as the number of container movements (container lifts) per terminal employee. The other is net crane rate (capital productivity), and it is defined as the number of container movements (container lifts) per net crane hour. This is the key word of an efficient container terminal to show to the stakeholders for high productivity.

Clark *et al*. (2004) elaborate further that port efficiency directly affects turnaround time for vessel in wharf and port efficiency varies widely from country to country and region to region. Singapore and Hong Kong have the most efficient ports in the world (Clark *et al*., 2004, and Gordan *et al*., 2005), whereas inefficient ports are located in Africa like Ethiopia, Nigeria and Malawi, or in South America like Colombia, Venezuela and Ecuador (Clark *et al*., 2004). Basically, to make sure that every port container terminals are having lesser vessel turnaround time, actually it is closely related with port efficiency. Port efficiency is highly correlated with handling cost. Therefore for countries with inefficient seaports they will have higher handling costs. In addition, for countries with good infrastructure actually they will have lower seaport costs. Tongzon (1994) studies that other determinant that will influence port users to select port container terminal as their port of call. Inevitably, these determinants are closely related with port productivity and performances. The other factors are frequency of vessel visit, which closely relates to turnaround time for vessel and port efficiency.

Kasypi and Shah (2012) establish the integration model of container terminal by applying IDEF0 with supply chain. The model integrates component at container terminal in enhancing the operational activity for high productivity. Figure 4 depicts the IDEF0 model for container terminal.

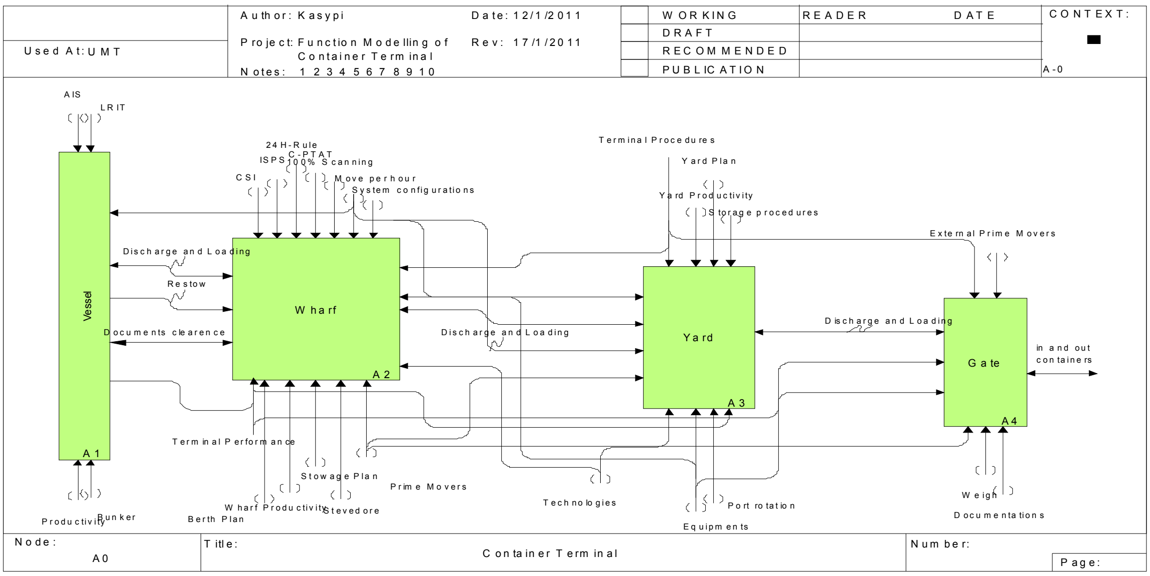

Figure 1. IDEF0 Model for Container Terminal (Kasypi and Shah, 2012)

3. Malmquist Index

3.1 Malmquist Index using Panel Data

Cooper et al (2007) express Malmquist index as an evaluate of productivity change of decision making unit (DMU) between two time periods and is an example in comparative statistic. Therefore, Malmquist index is defined into product of Catch-up and Frontier-shift terms. The terms explain catch-up (recovery) relates to the degree to which the DMU improves or worsens its efficiency. In addition, frontier-shift (innovation) reflects the change in the efficient frontiers between the two time periods.

3.2 The Model

For each time period, a set of n DMUs (x_j,y_j) $(j = 1,...,n)$ each having m inputs denoted by a vector $x_j \in R^m$ and q outputs denoted by a vector $x_j \in R^q$ over the period 1 and 2. In this case, assume that $x_j > 0$ and $y_j > 0$ $(\forall j)$. Therefore, the notations $(x_o, y_o)^1 = (x_o^1, y_0^1)$ and $(x_o, y_o)^2 = (x_o^2, y_0^2)$ are employed for designating DMU$_o$ $(o = 1,...,n)$ in period 1 and 2 respectively.

The production possibility set $(X,Y)^t$ $(t = 1$ and $2)$, its spanned by $(x_j, y_j)^t$ $(j = 1,...,n)$. It can be defined as follow

$$(X,Y)^t = \left\{ (x,y) \middle| x \geq \sum_{j=1}^{n} \lambda_j x_j^t, 0 \leq y \leq \sum_{j=1}^{n} \lambda_j y_j^t, L \leq e\lambda \leq U, \lambda \geq 0 \right\} \quad (1.0)$$

Where,
e vector = 1

$\lambda \in R^n$ intensity vector

L lower bound
U upper bound

$(L,U)=\{(0,\infty),(1,1),(1,\infty) \text{ and } (0,1)\}$ - correspond models;

Constant Returns to Scale (CCR)
Variable Returns to Scale (BCC)
Increasing Returns to Scale (IRS)
Decreasing Returns to Scale (DRS)

Cooper et al (2007) explain the production possibility set $(X,Y)^t$ is characterised by frontiers that are composed of $(x, y) \in (X,Y)^t$ that are not possible to improve any element of the x input or output y without worsening some other input or output. It is called as the frontier technology at period t. Under Malquist index analysis, the efficiencies of DMUs $(x_o, y_o)^1$ and $(x_o, y_o)^2$ are evaluated by frontier technologies 1 and 2 in several ways.

3.2.1 Catch-up Effect

In measuring catch-up effect, period 1 and 2 as frontier movement with following formula is used

$$\text{Catch-up} = \frac{\text{Efficiency of } (x_o, y_o)^2 \text{ with respect to period 2 frontier}}{\text{Efficiency of } (x_o, y_o)^1 \text{ with respect to period 1 frontier}} \qquad (1.1)$$

The (1.1) formula can be illustrated of catch-up effect as depict at Figure 1.0.

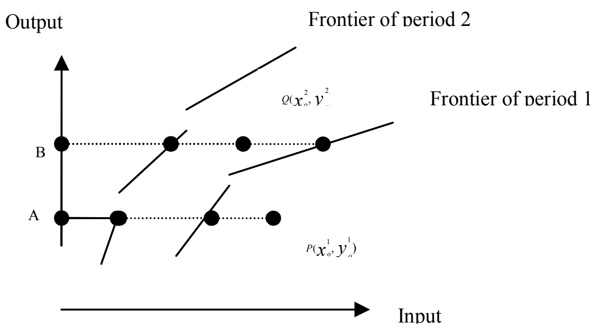

Figure 2 Catch-up

In addition, for computation reason the catch-up effect can be computed as follows

$$\text{Catch-up} = \frac{BD}{BQ} \Big/ \frac{AC}{AP} \qquad (1.2)$$

Derived from caomputation, result of catch-up is expressed as Catch-up > 1 shows the progess, = 1 and < 1 show no progress and regress inefficiency.

3.2.2 Frontier-shift Effect

As illustrated Figure 1, the expression of frontier-shift effect is the movement from reference point C of $(x_o, y_o)^1$ moved to E for the period 2. The frontier-shit effect at $(x_o, y_o)^1$ is evaluated as follows

$$\phi_1 = \frac{AC}{AE} \qquad (1.4)$$

The above equation technically is equivalent to

$$\phi_1 = \frac{\frac{AC}{AP}}{\frac{AE}{AP}} = \frac{\text{Efficiency of } (x_o, y_o)^1 \text{ wrt period 1 frontier}}{\text{Efficiency of } (x_o, y_o)^1 \text{ wrt period 2 frontier}} \qquad (1.5)$$

$$\phi_2 = \frac{\frac{BF}{BQ}}{\frac{BD}{BQ}} = \frac{\text{Efficiency of } (x_o, y_o)^2 \text{ wrt period 1 frontier}}{\text{Efficiency of } (x_o, y_o)^2 \text{ wrt period 2 frontier}} \qquad (1.6)$$

Therefore, by using ϕ_1 and ϕ_2, frontier-shift effect can be defined as

$$\text{Frontier-shift} = \phi = \sqrt{\phi_1 \phi_2} \qquad (1.7)$$

Where $\phi_1 \phi_2 = \frac{AC}{AE}\frac{BF}{BD}$

Frontier-shift > 1 shows the progress in frontier technology, whereby, = 1 and < 1 show the status quo and regress in frontier technology.

3.2.3 Malmquist Index (MI)

MI is computed as;

MI = (catch-up) x (frontier-shift) (1.8)

Therefore, from (1.5) and (1.6) with (1.2), the MI is expressed as

$$MI = \frac{AP}{BQ}\sqrt{\frac{BF}{AC}\frac{BD}{AE}}$$

In this case, mathematically efficiency score of DMU $(x_o, y_o)^{t_1}$ is measure by the frontier technology of t_2 and it has been derived as

$$\delta^{t_2}((x_o, y_o)^{t_1})(t_1 = 1,2 \text{ and } t_2 = 1,2) \quad (1.7)$$

Therefore, catch-up effect in (1.1) is mathematically expressed as

$$C = \frac{\delta^2((x_o, y_o)^2)}{\delta^1((x_o, y_o)^1)} \quad (1.8)$$

Where as the frontier-shift effect in (1.5) is mathematically expressed as

$$F = \left[\frac{\delta^1((x_o, y_o)^1)}{\delta^2((x_o, y_o)^1)} \text{x} \frac{\delta^1((x_o, y_o)^2}{\delta^2((x_o, y_o)^2}\right]^{1/2} \quad (1.9)$$

Therefore, MI is derived from the product of C and F above. MI is mathematically can be expressed asfollows

$$MI = \left[\frac{\delta^1((x_o, y_o)^2)}{\delta^1((x_o, y_o)^1)} \text{x} \frac{\delta^2((x_o, y_o)^2)}{\delta^2((x_o, y_o)^1)}\right]^{1/2} \quad (1.10)$$

4. Malmquist Productivty IndexUsing Data Envelopment Analysis

Data Envelopment Analysis (DEA), first introduced by Charnes, Cooper and Rhodes (CCR) in 1978 (Charnes et al, 1978), extended Farrell's (1957) idea of estimating technical efficiency with respect to a production frontier. The definition of efficiency is referred from the "Extended Pareto-Koopmans" and "Relative Efficiency" The CCR is able to calculate the relative technical efficiency of similar Decision Making Units (DMU) through the analysis, with the constant returns to scale basis. This is achieved by constructing the ratio of a weighted sum of outputs to a weighted sum of inputs, where the weights for both the inputs and outputs are selected so that the relative efficiencies of the DMUs are maximized with the constraint that no DMU can have a relative efficiency score greater than one. On the other hand, the DEA-BCC model (Banker et al., 1984) extend from DEA-CCR by assuming variable returns to scale where performance is bounded by a piecewise linear frontier. The BCC model relaxes the convexity constraint imposed in the CCR model which allows for the efficiency measurement of DMUs on a variable returns to scale basis. The BCC model results in an aggregate measure of technical and scale efficiency, the CCR model is only capable of measuring technical efficiency. This allows for the separation of the two efficiency measures.

A firm's productivity is usually measured by comparing its actual production volume with a production frontier. Wang et al. (2005), productivity measurement can be classified into using a parametric frontier approach or a non-parametric frontier approach. In the parametric frontier approach, the productivity frontier is estimated in a particular functional form with constant parameters. Liu (1995) uses a stochastic parametric frontier approach on 25 world ports, whereas Estache et al. (2001) studies 14 Mexican ports in order to investigate the efficiencies gained after port reform. Other studies on port performance with a stochastic parametric frontier approach are Tongzon and Heng (2005), Cullinane and Song (2003), Cullinane et al. (2002) and Notteboom et al. (2000). Besides this, Coto-Millan et al. (2000) uses a stochastic cost function approach on 27 Spanish ports. De and Ghosh (2002) examined 12 Indian ports using a time-varying production function approach. On the other hand, the non-parametric frontier approach assumes no particular functional form for the frontier.

There are numerous studies on port performance with DEA approach, some of them are Wang et al (2002), Tongzon (2001), Valentine and Gray (2001), Martinez-Budria et al. (1999), Roll and Hayuth (1993), Barros and Athanassiou (2004), Turner et al. (2004) and Cullinane et al. (2004, 2005). Recently, Wang and Cullinane (2006) apply DEA on 104 European ports across 29 countries. Besides this, Park and De (2004) introduced a four-stage alternative DEA approach on Korean ports.

4.1 Discussion of Input and Output

The research is using 6 container terminals in Peninsular Malaysia as DMU. The panel data used in this research is from year 2003 to 2010. The presentation of results is base on Malmquist index. The research is used DEA-Solver Pro 7 version for window analysis and Malmquist productivity index. The research is based on Cooper et al (2007) algorithm approach without adjustment. Golany and Roll (1989) highlight that the number of DMUs should be at least twice the number of inputs and outputs for the homogeneity reason.

5. Result and Discussion

5.1 Analysis Result and Discussion on Malmquist Index Constant Return to Scale and Variable Return to scale

The analysis of the research is using panel data from 2003 to 2010 of container terminals in Peninsular Malaysia. Table 5 represents the inputs target are TTA, MD, BL, QC, YS,Vand GL and Output target is T. The DMUs are AW, BN, CP, DJ, EPP and FK.

Figure 3 depicts result for Catch-up and Frontier-shift. The Catch-up shows that 2006=>2007 DMU for FK is the highest at 2.35, this represents good progress for efficiency. On the one hand, 2004=>2005 DMU for EPP is the most regress for catch-up (inefficient) regress at 0.58. On the other hand, yearly progress (23) for DMUs is greater than regress (19) from 2003 to 2010. On the Frontier-shift, the most progress year 2003=>2004 for DMU EPP at 1.27. In addition, 2006=>2007 for DMU FK is regress at o.41 and there is no status quo DMU from 2003 to 2010.

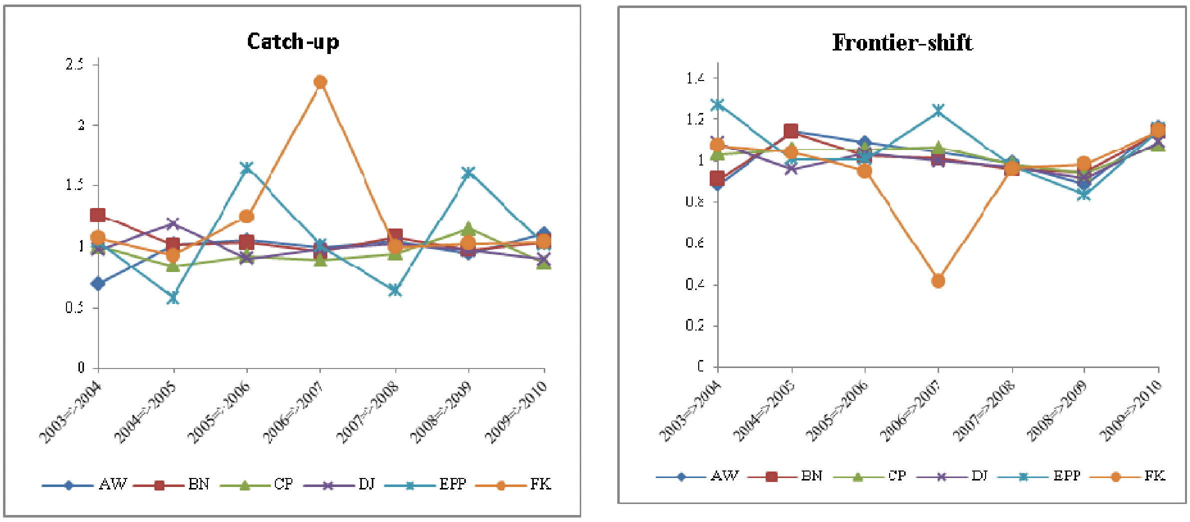

Figure 3 Catch-up and Frontier-shift for Constant Return to Scale

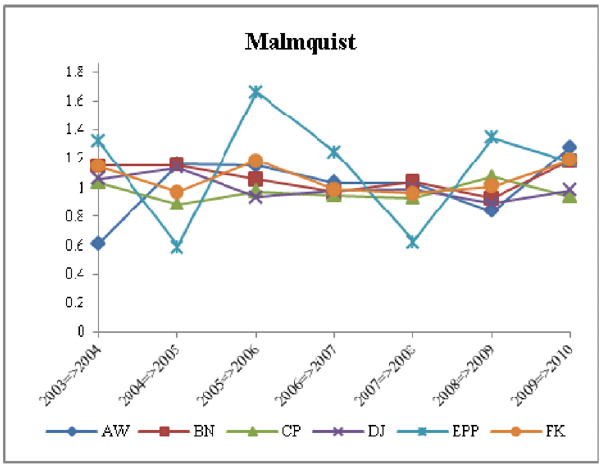

Figure 4 Malmquist Index for Constant Return to Scale

DMU EPP for 2005=>2006 shows the progress in productivity at 1.66, whereas 2004=>2005 DMU for EPP depicts detetoriation at 0.58 in productivity. Therefore, something has been done to increase the productivity for 2005=>2006 at 1.66. However, the management need to focus for DMU EPP where the pattern shows the index is not consistent from 2003 to 2010. The other DMUs depict consistent for the index from 2003 to 2010.

Table 2, 3 and 4 in the appendix represent summary for Catch-up, Frontier-shift and Malmquist index

In conjunction of constant return scale, Figure 5 depicts result for Catch-up and Frontier-shift for variable return to scale. The Catch-up shows that 2005=>2006 DMU FK is the highest at 1.23; this represents good progress for efficiency. On the one hand, DMU AW for 2003=>2004 is the most regress for catch-up (inefficient) at only 0.69. In addition, DMU CP represent no progress from 2003 to 2010 (=1).On the other hand, yearly progress (22) for DMUs are greater than regress (12) from 2003 to 2010. On the Frontier-shift, the most progress year 2004=>2005 at 1.14 for DMU AW. In addition, 2003=>2004 for DMU AW is regress at 0.88 and there is no status quo DMU from 2003 to 2010.

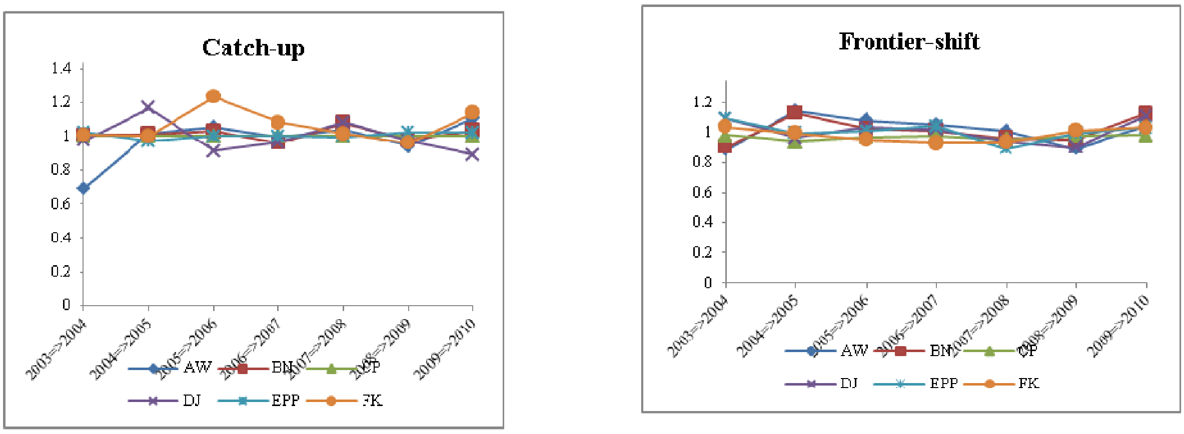

Figure 5 Catch-up and Frontier-shift for Variable Return to Scale

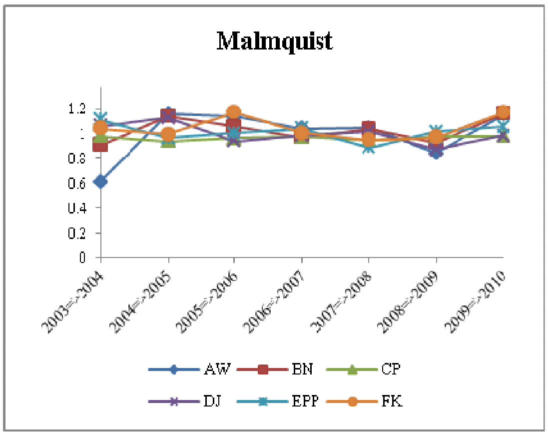

Figure 6 Malmquist Index for Variable Return to Scale

Malmquist index for variable return to scale, DMU FK for 2009=>2010 shows the progress in productivity at 1.17, whereas 2003=>2004 DMU for AW depicts detetoriation at 0.61 in productivity. The Malmquist index for variable return to scale slightly consistent from 2003 to 2010.

In the appendix, table 5, 6 and 7 represent summary for Malmquist index for variable return to scale.

6. Conclusion

The measuring technique by using Malmquist index for container terminal is able to express progress and regress terminals significantly. The research is selected Malmquist index for constant and variable return to scale to discuss result obtain. There are slightly different answer obtained from both approaches. By using variable return to scale, the Malmquist index is relatively consistent from 2003 to 2010. However, both approaches are applicable for discussion and impact similar value towards management. On the other hand, by using constant return to scale, EPP shows the most active DMU for Malmquist index if compared with other DMUs.

Therefore, by using constant return to scale, EPP is the most productive (1.66) and most regressive (0.58). On the other hand, by using variable return to scale, FK is the most productive (1.17) and AW is the most regressive (0.61) DMU. The results are significant for both approaches, and the management can choose preferable approach for their Malamquist index.

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Notes

Appendix A- Table(s)

Table 1. Input and Output

Input(s)	Output(s)
X1: Total Termianl Area in M^2 (TTA) X2: Maximum draft in meter (MD) X3: Berth length in meter (BL) X4: Quay crane index (QC) X5: Yard stacking index (YS) X6: Vehicles (V) X7: Number of gate lanes (GL)	Y1: Throughput (TEU: '000) (T)

Table 2. Summary of Catch-up for Constant Return to Scale

Catch-up	2003=>2004	2004=>2005	2005=>2006	2006=>2007	2007=>2008	2008=>2009	2009=>2010
Average	1.006825	0.928394	1.135426	1.197703	0.955283	1.112387	0.996431
Max	1.259826	1.185888	1.650492	2.3542	1.080758	1.60619	1.107319
Min	0.694515	0.58215	0.903859	0.890536	0.640315	0.944642	0.871402
SD	0.182896	0.204253	0.280228	0.568048	0.160716	0.252108	0.091158

Table 3. Summary of Frontier-shift for Constant Return to Scale

Frontier	2003=>2004	2004=>2005	2005=>2006	2006=>2007	2007=>2008	2008=>2009	2009=>2010
Average	1.043737	1.058689	1.027034	0.961915	0.973833	0.918032	1.128268
Max	1.271977	1.144081	1.090048	1.237106	0.991162	0.982968	1.158316
Min	0.886026	0.958615	0.950403	0.419023	0.96102	0.836856	1.076581
SD	0.139365	0.073274	0.04706	0.279659	0.011955	0.05112	0.03431

Table 4. Summary for Malmquist Index Constant Return to Scale

Malmquist	2003=>2004	2004=>2005	2005=>2006	2006=>2007	2007=>2008	2008=>2009	2009=>2010
Average	1.054841	0.983886	1.160982	1.027437	0.93011	1.013991	1.12677
Max	1.321551	1.1626	1.663735	1.244642	1.03863	1.344149	1.282626
Min	0.615358	0.587561	0.935782	0.949082	0.623645	0.837334	0.938135
SD	0.237481	0.224229	0.264308	0.110155	0.155612	0.182548	0.134689

Table 5. Summary of Catch-up for Variable Return to Scale

Catch-up	2003=>2004	2004=>2005	2005=>2006	2006=>2007	2007=>2008	2008=>2009	2009=>2010
Average	0.952101	1.029138	1.03886	1.000958	1.036828	0.980063	1.03308
Max	1.024001	1.168618	1.231905	1.08139	1.081363	1.022792	1.137574
Min	0.692149	0.972659	0.914163	0.962119	0.999402	0.944622	0.892128
SD	0.128295	0.070097	0.105894	0.042994	0.037543	0.027757	0.086667

Table 6. Summary of Frontier-shift for Variable Return to Scale

Frontier	2003=>2004	2004=>2005	2005=>2006	2006=>2007	2007=>2008	2008=>2009	2009=>2010
Average	0.996354	1.026668	1.008571	1.003804	0.948541	0.954853	1.051638
Max	1.088433	1.14121	1.076874	1.045585	1.006121	1.010547	1.12031
Min	0.886745	0.939876	0.951163	0.930264	0.894175	0.893496	0.980556
SD	0.088722	0.084852	0.045076	0.043502	0.036649	0.047628	0.052141

Table 7. Summary of Malmquist for Variable Return to Scale

Malmquist	2003=>2004	2004=>2005	2005=>2006	2006=>2007	2007=>2008	2008=>2009	2009=>2010
Average	0.954167	1.055562	1.045946	1.003617	0.983923	0.936434	1.085123
Max	1.112663	1.160014	1.171742	1.041721	1.048627	1.015129	1.173266
Min	0.613759	0.939876	0.94042	0.971085	0.89364	0.844016	0.980556
SD	0.180942	0.098163	0.092408	0.031353	0.060929	0.064956	0.088919