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Assessment of Port Efficiency in West Africa Using Data Envelopment Analysis

George Kobina van Dyck

School of Economics and Management, Shanghai Maritime University, Shanghai, China
Email: kobivandyck@yahoo.com

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Abstract

The aim of this paper is to apply the DEA method in assessing efficiencies of major ports in West Africa. Six ports were selected based on their container throughput levels, and the DEA model was used to determine their relative efficiencies and their efficiencies over time through window analysis. The DEA model was applied to a number of inputs of port production and a single output (container throughput). It was determined that the Port of Tema in Ghana was the most efficient West African port under study. Although Tema exhibited some inefficiency in its operations, the port was found to make good use of its resources for production. On the other extreme, the Port of Cotonou in Benin was found to be the least efficient port obtaining the lowest average efficiency rating over a seven year period. It was determined that the port exhibited a substantial waste in production. Generally, ports in West Africa could be said to exhibit high levels of efficiency considering that four out of six ports had an average efficiency score of 76% or higher for the period under study.

Keywords

DEA Analysis, Port Efficiency, West-Africa, Hub Port, Window Analysis

1. Introduction

Containerization and container transportation has led to increased competition between ports worldwide. Nowadays, hinterlands have become more shared due to better efficiency of ports and increased hinterland connectivity facilitated by containerization and multimodalism. The result of this intense inter-port competition in the container port sector is the interest in efficiency analysis by port operators [1] and port users. Efficiency analysis provides port operators/authorities with a means of making more informed decisions with regards to port planning or operations whiles it provides port users (especially shipping lines) with a means of assessing the relative

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competiveness of ports in order to make informed decisions on port utilization. Ports in Western-Europe, North-America and East-Asia have, for many years, utilized efficiency analysis to improve operations by minimizing the use of resources for production. This has fuelled port growth and massive investment in port related activities.

In West Africa (WA), the port industry has seen major growth in recent times. In the last twenty (20) years, a number of West African ports have undergone restructuring and reform processes. These processes have been mainly centered on allowing more private sector involvement in the port sector to generate investment for port development and to increase capacities and efficiencies of ports. More recently, port development in WA has been directed towards attaining hub port status [2]. Inter-port competition is at its highest level and private sector investment in port facilities continues to rise in the region. At present, ports that play a regional role in WA are generally viewed as the leading potential hub port contenders. They include ports in Ghana, Togo, Ivory Coast, Benin and Senegal, which provide transit services for landlocked countries in WA. Nigeria which is the largest economy in WA and which has some of the largest ports in the region however does not play a significant regional role as the distance between its ports and the landlocked countries in the region is great. In addition, in the past, Nigeria's large domestic demand has been the government's priority. Recently however, the Nigerian government is looking to play a more regional role in shipping and is directing its port development efforts to that effect.

There are several examples of port development projects in WA that have regional focus and are directed at attaining regional hub status. In Nigeria for example, the Lekki Port project seeks to create a multi-purpose deep water port in the Lagos free trade zone area with a projected capacity of 2.5 million TEU's (twenty-foot equivalent units) per annum. The port will include container, dry bulk and liquid bulk berths with a 14-metre draught and 670 metres turning cycle to accommodate larger ships [3]. Similarly, the Ghana Ports and Harbours Authority (GPHA) has secured $1.5 billion for expansion of the Port of Tema. The project involves the construction of four (4) deep water berths and an access channel to accommodate larger vessels with high capacity equipment. The aim of the project is to create the largest cargo port in West Africa with a capacity of 3.5 million TEU per annum once complete in 2018 [4]. The Port of Lomé has constructed a $640 million berth in Togo. The new quay has double docking capacity and measures 450 metres able to accommodate vessels of more than 7000 TEU capacity [5]. Similar port development projects can be found in other West African countries as there is no exclusivity in the selection of a hub by shipping lines. The selection of a port to act as hub depends on a number of factors.

In a recent survey, major shipping lines calling at West African ports were required to rank factors influential to the selection of a hub for the region [2]. High port efficiency and performance were ranked first amongst a list of 20 factors. West African ports have been noted to be highly congested and inefficient [6] as compared with ports in Europe and Asia. However, to the author's knowledge, no empirical study has been undertaken to determine the relative efficiency of ports in the region. The aim of this paper therefore is to empirically assess the efficiencies of ports in WA utilizing the DEA method. Measurement and analysis of port efficiency in WA allow port users to make efficiency comparisons and provide regional and national port operators/regulators with an important management tool for making informed decisions on port planning and operations [1].

2. Literature Review

The productivity of a firm can be measured by comparing its actual production volume with a production frontier [7]. Two classifications of productivity measurement are notable; parametric frontier approach and non-parametric frontier approach [8]. In the parametric frontier approach, the productivity frontier is estimated in a particular functional form with constant parameters. On the other hand, the non-parametric frontier approach assumes no particular functional form for the frontier. The most commonly used non-parametric frontier technique is DEA [7].

The application of the DEA technique to the port industry is not new. Different variations of the DEA technique have been used to analyze port production in various regions worldwide. The advantage of DEA is that multiple inputs and outputs can be added to the model, and therefore has the capability of providing an overall evaluation of port performance [9] unlike the port performance indicators developed by [10].

Reference [11] examined the efficiency of 26 ports in Spain using DEA-BCC models. The authors found that high complexity ports are associated with high efficiency. Reference [12] analysed the efficiency of 4 Australian ports in addition to 12 other international container ports for the year 1996. The author utilized both DEA-CCR and DEA-Additive models in the analysis and the results showed that the most inefficient ports sampled included Melbourne, Rotterdam, Yokohama and Osaka. The author notes that areas of improvement exist with respect to container berths, terminal area and labour inputs. Similarly, in order to compare port efficiency with regards to a specific ownership type and organisational structure, [13] also applied the DEA-CCR model. Thirty-one (31) container ports out of the 100 top container ports in the world for 1998 were analyzed. The authors found that some structural forms could be related to estimated levels of efficiency. In addition, organisational structures could be identified by utilizing cluster analysis.

Reference [14] also suggested the DEA method for measuring lean port performance. DEA window analysis was applied to 8 Japanese ports for a 10-year period (1990-1999). During the period under study, Tokyo was found to be consistent in its efficiency. Yokohama, Kobe and Osaka were found to have low efficiency scores throughout the period under study [15]. The inefficiencies of Yokohama and Osaka confirm the results of an earlier study by [11].

In determining the relationship that existed between the governance structures for the Portuguese port sector, the incentive regulation under the structure and the impact on port efficiency, [16] applied the DEA model. The study covers the period 1999 and 2000, and the author found that incentive regulation had positive impacts on efficiency in the sector. The author however suggested improvements to efficiency that could be achieved by redefining the role of Portugal's maritime regulatory body.

In determining sources of inefficiency, [17] applied DEA to the Portuguese port industry again for the years 1990 and 2000. The author found that although Portuguese ports exhibited high levels of technical efficiency over the period under study, technological change had superseded any advancement in the ports sector in Portugal. The paper attributed greater efficiency in the port sector to financial aid from EU Single Market program. Additionally, Tobit regression analysis applied in the study found that multi-cargo ports were less efficient than container ports. Market share and efficiency were found to be positively related and the study found that ports with greater public sector involvement exhibited relatively lower levels of efficiency.

The DEA model was also applied to estimate the relative efficiency of Portuguese and Greek ports [18] in order to benchmark and compare management practices and strategies within these countries. The paper concluded that economic benefits could be identified and evaluated from this form of benchmarking study.

In another paper applied to Spanish ports, [19] utilized a DEA technique that accounts for inaccuracies in input and output data used in order to determine commodity traffic efficiency of 23 Spanish ports from 1995-1998. The difference between this study and previous studies already reviewed is that the analysis is applied to ports that handle a range of different cargoes as opposed to just containerized cargo (which is popular). Due to multi-colinearity between prospective input variables, a single input-infrastructure endowment is incorporated into the model. Incidence analysis is used to identify ports of most and least efficiency.

Reference [20] applied different DEA methods based on cross-sectional and panel data analysis to container ports. The authors found that container port or terminal efficiency can be monitored over time providing policy makers and managers with useful insights to aid decision-making.

Additionally, a four-stage method for DEA was advocated for by [21] who identified a number of limitations in assessing the port efficiency exclusively based on labour and capital inputs. The four-stage DEA method involved the disaggregation of the efficiency model into individual DEA components, in order to gain insight into actual sources of port inefficiency. The model therefore determined overall efficiency in addition to efficiency related to productivity, profitability and marketability. After applying the method to a sample of ports in South Korea, the authors concluded that South Korean ports should prioritize improving their marketability.

In order to determine changes in North American ports in terms of infrastructural productivity, [22] utilized the DEA for the period 1984-1997. The authors further applied a Tobit Regression model as in [17] by using the productivity scores in order to determine the causal factors of the scores derived. Conclusively, the authors found that at both port and terminal level in North America, there were significant economies of scale present. In terms of causal factors for productivity, the authors found that infrastructural productivity in North American ports is highly correlated to rail network access.

The DEA and SFA techniques were compared in their application to a sample of the world's largest ports [23]. The authors found that the efficiency estimates derived from the models applied were highly correlated. In their analysis, the authors found high levels of technical efficiency associated with scale of ports, greater levels of private-sector involvement and also with transshipment ports. The authors concluded by outlining significant shortcomings with cross-sectional data utilization in the port sector and also elaborated on some benefits of panel data application for analysis.

The same authors [24] in another paper used DEA to examine the relationship between privatization and relative efficiency for a sample of world leading container ports ranked in the top 30 (in 2001), in addition to five container ports in China. A total of 240 observations were yielded comprising the application of a variety of panel data configurations to annual data ranging from 1992 to 1999. The authors concluded that based on the results obtained, greater private sector participation in the container port sector does not necessarily lead to improved efficiency in ports, contradicting the findings of an earlier study (see [20]).

DEA window analysis model was used to evaluate changes in container terminal efficiency over a period of 4 years for 11 terminals [25]. The input data used included total quay length, the number of cranes, labour number, and storage size, in addition to cargo throughput as the output.

Reference [26] applied cross-sectional data in a DEA model to the compare relative efficiency for a sample of 69 European container terminals. Using data for the year 2002 from ports that met the criteria of annual throughput of over 10,000 twenty foot equivalent units (TEUs), the sample covered 24 European countries. The authors found that European container terminals were relatively inefficient and that large container terminals were more likely to be associated with higher efficiency scores. Furthermore, the authors found significant variations in the average efficiency of container terminals located in different European regions. Terminals in the British Isles were found to be the most efficient with those in Scandinavia and Eastern Europe least efficient.

Reference [27] analyzed the port productivity using the DEA method, aimed at maximizing output and minimizing inputs. The output identified, as in some previous studies, was container throughput with total quay length and the number of quay gantry cranes as inputs. Applying panel data for 1998-2003 for 25 ports, the authors determined an efficient frontier that could be targets for inefficient ports, in addition to determining the causal factors and extent of inefficiency in ports.

3. Methodology

This DEA model is a non-parametric method based on application of linear programming for measuring the efficiency of units, referred to Decision-Making Units (DMUs). Reference [28] developed an input-oriented DEA model, known today as DEA-CCR that assumes constant returns-to-scale. The DEA-BCC model fashioned after [29] assumes variable returns-to-scale. Both models have been widely applied in research applying DEA models to the port sector. For this study in particular, input-oriented productivity efficiency will be investigated. The principle of this non-parametric method is based on two important sets of multiple variables called inputs and outputs [30], which are used to derive an efficiency score (ratio) adjusted to a number less than or equal to 1 but greater than or equal to 0. The following model illustrates how the relative efficiency score of DMU is obtained, as proposed by [28]:

$$\max \frac{\sum_{k=1}^{s} u_k y_{kp}}{\sum_{j=1}^{m} v_i x_{ip}} \tag{1}$$

$$\text{S.t.} \frac{\sum_{k=1}^{s} u_k y_{ki}}{\sum_{j=1}^{m} v_j x_{ji}} \le 1 \quad \forall i, \text{ and } u_k v_j \ge 0 \quad \forall k, j \tag{2}$$

where:

y_{ki} = amount of output *k* produced by DMUi,

x_{ji} = amount of input *j* utilized by DMUi,

u_k = weight given to output *k*,

v_j = weight given to input *j*.

Converting the computations above to Linear Programming form:

$$\max \sum_{k=1}^{s} u_k y_{kp} = \theta_p \tag{3}$$

$$\text{Subject to } \sum_{j=1}^{m} v_j y_{jp} = 1 \tag{4}$$

$$\sum_{k=1}^{s} u_k y_{ki} - \sum_{j=1}^{m} v_j x_{ji} \le 0 \quad \forall i, \; u_k, v_j \ge 0 \quad \forall k, j. \tag{5}$$

The combination of the two models results in the DEA-CCR and DEA-BCC models as shown below:

CCR Model Max $\varnothing_k$

$$\text{S.t.} \sum_{j=1}^{n} \lambda_j x_{ij} \le \varnothing_r x_{ir} \quad i = 1, 2, \cdots, m; \tag{6}$$

$$\sum_{j=1}^{n} \lambda_j y_{rk} \quad r = 1, 2, \cdots, s; \tag{7}$$

$$\lambda_j \ge 0 \ \ \forall j$$

BCC Model

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{8}$$

where $\varnothing_k$ is the efficiency the k^{th} DMU.

In order to capture the variations in the performance of the West African ports under study over time, window analysis is adopted in this study. Window analysis is useful for detecting efficiency trends over time or offers the opportunity to assess how performance of firms evolve through a chain of overlapping windows by considering each port as a different entity in each period under analysis. The model is based on the assumption that what was viable in the past remains viable forever, and that the treatment of time in windows analysis is more in the nature of an averaging over the periods of time covered by the window [31]. An important advantage of window analysis is that its increases the number of units for evaluation and in effect the discriminatory power of the method [32]. In applying window analysis, DEA first evaluates the performance of all DMU's in the same window and the efficiency of each DMU will be entered into the right window position in the table. This procedure is repeated to obtain all efficiency values in every window [33].

There is little consensus on the choice of window width. Reference [34] advocates the width should be as small as possible to minimize unfair comparison over time, but still large enough to have a sufficient sample size. Alternatively, [35] who applied the window analysis technique on a quarterly data set found that window length of 3 or 4 tended to yield the best balance of quality of information and stability of the efficiency scores. For this study, the DEA Solver programme is used to run the models for analysis.

4. Data and Analysis

This paper studies the efficiency of 6 major ports (in terms of throughput) in West Africa. The ports were selected based on throughput discrimination, *i.e.*, ports with annual throughput of over 100,000 TEUs were selected from the population of 12 West African ports. In West Africa, most ports have both dedicated container berths/terminals (usually operated under concession) and multi-purpose berths. For this study, the dedicated container terminals were used for the analysis in order to have uniformity in comparison and analysis of data. Furthermore, the dedicated container terminals were the main terminals for the handling of containerized cargo at the ports. The ports analysed can be found in **Table 1**.

Container throughput trend for the period 2006-2012 can be found in **Figure 1**. It is quite clear that the Lagos port has the highest throughput, but suffers from throughput fluctuations which smooth in ascendency over time. Slight throughput fluctuations characterize all the other ports with exception of the port of Cotonou which shows an increasing trend since 2006.

The specific choice of input and output variables is critical to the analysis of efficiency of ports/container terminals. Ill-defined variables may lead to misleading conclusions about port efficiency [26]. The input and output variables should reflect container port production as much as possible [20]. The output data used in the efficiency analysis are container throughput which remains the primary basis upon which container ports are compared. As a container terminal/port depends on the efficient use of land, labour and capital (equipment), the input data used include the quay length (in metres), the terminal area (in hectares), the number of quayside cranes, the number of yard gantry cranes, and the number of reach stackers used in each port over the period under study.

The quay length is important in evaluating the efficiency of ports/container terminals. The quay length is one important indicator as to the turn-around time that can be achieved by ports, since it reflects the size of a ship that can be allocated a berth at a particular point in time. As a strategy, berth availability as a function of quay length can affect the efficiency of shipping lines. In addition, the number of quay-side cranes is an important measure of productivity. This input directly affects the speed with which container ships may be served (more

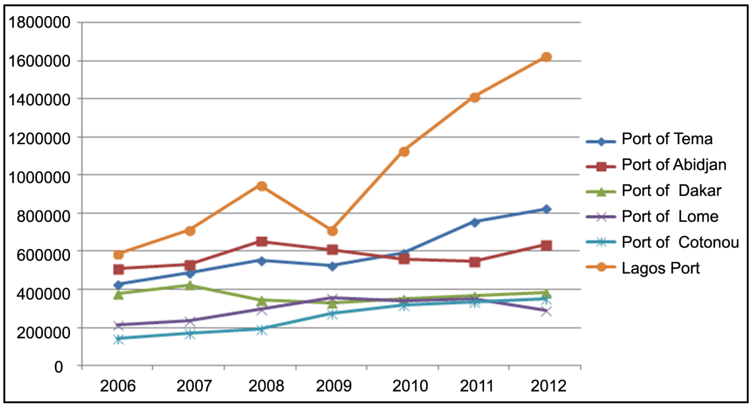

Figure 1. Container throughput trend 2006-2012.

Table 1. Container throughput for selected ports, 2006-2012 (source: [36] [37]).

Port	Terminal	Container Throughput (TEUs)						
		2006	2007	2008	2009	2010	2011	2012
Port of Tema	MPS Terminal	425,408	489,147	555,009	525,694	590,147	756,899	824,238
Port of Abidjan	SETV Terminal	507,100	531,809	652,358	610,185	561,535	546,417	633,917
Port of Dakar	DP World Terminal	375,876	424,457	347,483	331,076	349,231	369,137	383,903
Port of Lomé	Bollore Africa Logistics	215,892	237,891	296,109	354,480	339,853	352,695	288,481
Port of Cotonou	Bollore Africa Logistics	140,500	167,791	193,745	272,820	316,744	334,798	348,190
Lagos Port Complex	APM Terminals-Apapa	587,600	711,100	947,400	710,800	1,128,171	1,413,273	1,623,141

cranes may increase the number of containers handled per ship hour), and in effect, the turn-around time as well. The number of quay side cranes also increases the agility of the port by handling more vessels simultaneously [32]. The berth length and number of quay-side cranes therefore reflect the berth-side productivity of this analysis. Similarly, the terminal area, the number of yard gantry cranes, and the number of reach-stackers reflect yard-side productivity. In this study, the number of yard gantry cranes and reach stackers is used in the assessment because of their common use within terminal areas of the ports under study in particular. The input and output data have been compiled from [36]-[38]. Window analysis with panel data is utilized in order to assess port efficiency over time. This prevents conclusions being drawn based on seasonal irregularities in efficiency of ports that may arise from using cross-sectional data.

Table 2 shows the summary statistics of the data used (see **Table 3** for precise input and output data). The results of the window analysis can be found in **Table 4** and **Table 5**, and the trend in average efficiencies over time in **Figure 2**. The selected window length was 4 to account for the different changes in efficiency over time. Each port is representative of a different DMU with four windows per port in the analysis (the average port efficiency through each 4-year window can be found in **Table 6**).

The Port of Tema is found to be the most efficient West African port in its production over time and exhibits an average relative efficiency score of 91% for the period of analysis. Out of the seven years under review, the Port of Tema achieves efficiency in four. Tema however attains low efficiency scores in 2009 from the window analysis. This may have been due to a shortfall in output due to the impact of the world financial crisis on trade. After 2009, efficiency scores start to rise again and the port attains full efficiency by 2012. It must be noted that amongst the ports under study, the Port of Tema is one of the smallest ports in terms size (terminal area and berth length) but one of the largest in terms of throughput in West Africa.

On the other extreme, the Port of Cotonou is relatively the least efficient port amongst the sample with an efficiency score of 46% (which indicates the port could have achieved efficiency with 46% of its inputs). This means that the port has excessive capacity in relation to its inputs and therefore there exists a lot of waste in

Table 2. Summary statistics for sample West African ports.

	Container throughput (TEUs)	Total quay length (m)	Terminal area (ha)	Number of quayside cranes	Number of yard gantry cranes	Number of reach stackers
Mean	683645.00	701.50	27.67	5.17	8.67	20.33
Standard deviation	502677.21	244.54	17.07	2.40	5.75	6.02
Minimum	288481.00	430.00	10.00	4.00	0.00	15.00
Maximum	1623141.00	1005.00	55.00	10.00	16.00	31.00

Table 3. Input and output variables for various ports.

Port	Variables	2006	2007	2008	2009	2010	2011	2012
Port of Tema	Container throughput	425,408	489,147	555,009	525,694	590,147	756,899	824,238
	Total quay length (m)	574	574	574	574	574	574	574
	Terminal area (ha)	10	10	10	10	10	10	10
	number of quayside cranes	6	6	6	6	6	6	8
	number of yard gantry cranes	4	4	4	4	4	4	13
	number of reach stackers	0	4	4	10	10	10	23
Port of Abidjan	Container throughput	507,100	531,809	652,358	610,185	561,535	546,417	633,917
	Total quay length (m)	1000	1000	1000	1000	1000	1000	1000
	Terminal area (ha)	34	34	34	34	34	34	34
	number of quayside cranes	3	3	3	3	3	3	4
	number of yard gantry cranes	16	16	16	16	16	16	16
	number of Reach stackers	19	19	19	19	19	19	19
Port of Dakar	Container throughput	375,876	424,457	347,483	331,076	349,231	369,137	383,903
	Total quay length (m)	660	660	660	660	660	660	660
	Terminal area (ha)	35	35	35	35	35	35	35
	number of quayside cranes	4	4	4	4	4	4	4
	number of yard gantry cranes	8	8	8	8	10	10	10
	number of reach stackers	15	15	15	15	15	15	15
Port of Lomé	Container throughput	215,892	237,891	296,109	354,480	339,853	352,695	288,481
	Total quay length (m)	430	430	430	430	430	430	430
	Terminal area (ha)	12	12	12	12	12	12	12
	number of quayside cranes	4	4	4	4	4	4	6
	number of yard gantry cranes	0	0	0	0	0	0	0
	number of reach stackers	19	19	19	19	19	19	19
Port of Cotonou	Container throughput	140,500	167,791	193,745	272,820	316,744	334,798	348,190
	Total quay length (m)	540	540	540	540	540	540	540
	Terminal area (ha)	20	20	20	20	20	20	20
	number of quayside cranes	4	4	4	4	4	4	8
	number of yard gantry cranes	10	10	10	10	10	10	10
	number of reach stackers	15	15	15	15	15	15	15

Continued

Lagos Port Complex	Container throughput	587,600	711,100	947,400	710,800	1,128,171	1,413,273	1,623,141
	Total quay length (m)	1005	1005	1005	1005	1005	1005	1005
	Terminal area (ha)	55	55	55	55	55	55	55
	number of quayside cranes	10	10	10	10	10	10	10
	number of yard gantry cranes	12	12	12	12	12	12	12
	number of reach stackers	31	31	31	31	31	31	31

Table 4. Window analysis results.

Ports	2006	2007	2008	2009	2010	2011	2012	Average	C-Average
Port of Tema	1.00	0.88	1.00	0.95				0.96	0.91
		0.88	1.00	0.89	1.00			0.94	
			1.00	0.69	0.78	1.00		0.87	
				0.69	0.78	1.00	1.00	0.87	
Port of Abidjan	0.78	0.82	1.00	0.94				0.88	0.90
		0.82	1.00	0.94	0.86			0.90	
			1.00	0.94	0.86	0.84		0.91	
				1.00	0.92	0.90	0.86	0.92	
Port of Dakar	0.73	0.82	0.68	0.64				0.72	0.62
		0.79	0.65	0.62	0.65			0.68	
			0.56	0.53	0.56	0.59		0.56	
				0.49	0.51	0.54	0.56	0.53	
Port of Lomé	0.61	0.67	0.84	1.00				0.78	0.88
		0.67	0.84	1.00	0.96			0.87	
			0.84	1.00	0.96	0.99		0.95	
				1.00	0.96	0.99	0.81	0.94	
Port of Cotonou	0.31	0.37	0.43	0.60				0.43	0.46
		0.34	0.39	0.55	0.64			0.48	
			0.33	0.46	0.54	0.57		0.47	
				0.41	0.48	0.50	0.43	0.46	
Lagos Port Complex (Apapa)	0.62	0.75	1.00	0.75				0.78	0.76
		0.63	0.84	0.63	1.00			0.78	
			0.67	0.50	0.80	1.00		0.74	
				0.44	0.70	0.87	1.00	0.75	

Table 5. Port efficiency ranking for west africa.

Port	Average Score	Rank
Port of Tema	91%	1
Port of Abidjan	90%	2
Port of Lomé	88%	3
Lagos Port Complex (Apapa)	76%	4
Port of Dakar	62%	5
Port of Cotonou	46%	6

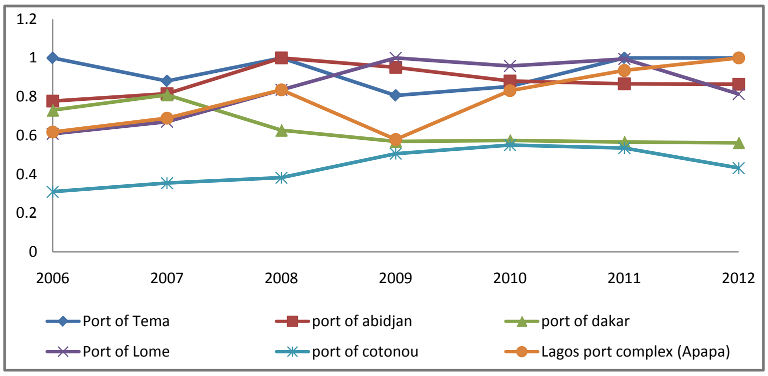

Figure 2. Port efficiency variation by term.

Table 6. Average port efficiency through window.

Ports	2006-2007-2008-2009	2007-2008-2009-2010	2008-2009-2010-2011	2009-2010-2011-2012
Port of Tema	0.96	0.94	0.87	0.87
Port of Abidjan	0.88	0.90	0.91	0.92
Port of Dakar	0.72	0.68	0.56	0.53
Port of Lomé	0.78	0.87	0.95	0.94
Port of Cotonou	0.43	0.48	0.47	0.46
Lagos Port Complex (Apapa)	0.78	0.78	0.74	0.75

production. In the window analysis, Cotonou never achieves efficiency levels higher than 64% throughout the period of study and can be said to be a serial under-achiever. In terms of size, Cotonou is similar in size to the Port of Tema but achieves significantly lower output than Tema. In order to increase its efficiency, the port may either have to put in measures to attract more containerized cargo or reduce its use of inputs.

The Ports of Abidjan and Lomé in Ivory Coast and Togo respectively also achieve quite high efficiency ratings. Abidjan achieves an average rating of 90% with of 78% being the lowest efficiency rating in the window analysis throughout the seven-year period. Abidjan's efficiency scores also exhibit slight fluctuations over time, as with its throughput. Lomé on the other hand exhibits low efficiency rating in the first two years under study, and then efficiency rises significantly from 2009 to 2011. Lomé's average efficiency score throughout the period under study is 88%.

Lagos Port Complex is the largest port in terms of size and throughput amongst the ports under study. The port is located in Nigeria, Africa's largest economy and most populous nation. From the analysis, the port achieves an average efficiency rating of 76%. Similar to Tema, Lagos Port Complex also achieves its lowest rating during 2009, presumably as a result of the effects of the world financial crisis on trade. The port, however, achieves some periods of efficiency in the last three windows as output increases significantly in that period.

The Port of Dakar exhibits quite an average performance throughout the period under study. The lowest efficiency score throughout the period was 49%, also in 2009 as with other ports in the sample. The port however only manages to achieve a high efficiency score of 82%, averaging 62% efficiency over the seven-year period under study. **Table 5** shows the ranking of West African ports according to their relative efficiency.

5. Conclusion

DEA is commonly used in port sector studies to measure efficiencies of ports and container terminals. Although it is a useful tool that can relate multiple inputs to outputs, it requires that data are accurate and DMUs are comparable. Out of a total number of 12 ports in West Africa, the present study measures the relative efficiency of 6 major West African ports looking to become regional hubs. Panel data from 2006-2012 are applied to the model to determine the relative efficiencies over time. Panel data are relevant in this study since cross-sectional data are susceptible to seasonal variations in efficiency and may lead to drawing misleading conclusions about the efficiency of the ports under study. Several input variables are selected for the study and they include the terminal area, berth length, the number of quay-side cranes, the number of yard gantry cranes and the number of reach stackers. A single output variable, container throughput, is also selected. Based on the results of the model, the Port of Tema in Ghana is the most efficient port amongst the sample with the Ports of Abidjan and Lomé closely following suit. On the other extreme, the study finds that the Port of Cotonou is least efficient and exhibited substantial waste in production throughout the period under study. The performance of the Lagos Port Complex adds to literature that casts doubt on the notion that larger ports are more efficient. The Lagos Port Complex, which is the largest amongst the sample in terms of size and throughput achieves an average efficiency score of 76% and therefore exhibits some inefficiencies in its operations. The results of the analysis also show that three neighboring ports, Tema, Abidjan and Lomé, who are the three largest providers of transit services to landlocked WA, have the highest efficiency ratings. Their efficiency scores may also be attributed to fierce competition between these ports for transit cargo meant for the Sahel region. For most of the ports, major inefficiencies in production occurred in 2009, presumably due to the world financial crisis and a reduction in output. Other conclusions are drawn as to the cause of inefficiencies which include a smaller customer base (and hence the lack of adequate output) relative to the inputs utilized in the ports operations. The implications of the study with respect to the selection of a potential hub port for WA are insightful. Amongst other requirements, shipping lines in WA require that a potential hub port exhibits high port efficiency and performance. Comparably, West African ports can be said to exhibit reasonable levels of efficiency given the resources available.

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