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Productivity and Efficiency of Nigeria's Seaports: A Production Frontier Analysis

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Abstract: Productivity and efficiency are key expectation of every production decision. Estimation of a port's production frontier is therefore critical in the assessment of port's productivity and efficiency. In this study, the production function of Nigeria's seaport is modeled using the Stochastic Frontier Framework. Panel data analyzed consists of records on eight coastal ports with details on output and multiple input variables covering a period of 22 years. The analysis reveals that total factor productivity of the ports averages >2.5 million ton per annum and 3 of them operate below frontier. In addition, capital inputs variables are found to significantly contribute to port productivity while labour input variable which represents manual cargo handling effort in the ports is found statistically insignificant. Thus, total mechanization of cargo handling operation, especially in developing and transition countries' ports to boost port infrastructure productivity and efficiency is again supported in the Nigeria's case.

Key words: Port infrastructure productivity, technical efficiency, total factor productivity, Stochastic Frontier Model, seaport, Nigeria

INTRODUCTION

The growths in ship's size, advent of containerization and advances in cargo handling methods have imposed considerable infrastructure requirements in seaports. In addition, the growing inability of government to finance state owned ports has led to deregulation and hence, removal of port financing and management functions from public to private sector. This shift in responsibility has called for muh emphasis on productivity and efficiency assessment in the management of seaports.

This is understandable given that the privatized ports face competition in the market place and must be both productive and efficient to remain viable. This is in fact the situation and challenge facing Nigerian seaports now under concession to private operators. Production function (or frontier) analyses are thus needed to understand the critical factors necessary for viability of these seaports. The major aim of this study is to assess the productivity and efficiency of Nigerian seaports. Specifically, the study evaluates the determinants of seaport infrastructure productivity, relative efficiencies of Nigerian ports and the total factor productivity of the entire coastal ports. The study findings are meant to address the following questions: Has there been significant port productivity following transfer of port infrastructure investment to private operators are the ports more efficient following transfer of management of ports to private operators and what variables drive port productivity and efficiency? Consequently, the following hypotheses are addressed in this study:

- The infrastructure productivity of Nigeria's ports is not significantly different from zero
- The relative efficiencies of Nigeria's seaports are not significantly different from zero
- The contribution of capital and labour inputs to seaport productivity is not significant

All hypotheses are tested at $\alpha = 0.05$ level of significance. Extant literature shows that researchers became increasingly interested in the study of port productivity and efficiency following the technological and structural reforms that have taken place in ports. These studies relied on partial indicators of productivity. For example, Talley (1994) and Tongzon (1995) use the indicators to compare different ports. The major limitation of partial indicators is that they do not assess the joint contribution of all inputs to production and cannot accommodate scenarios involving multi-output processes. This problem becomes particularly relevant in the port sector, since port products are very diverse and many different inputs are involved in their production. To overcome the limitations of the partial indicators approach, a new generation of studies based on formal efficiency measures-stemming from the research by Chang

(1978) developed. This study by Chang (1978) can be considered as the starting point in the estimation of a port production function and in a way, it led the way to the estimation of production frontiers. Since that first research, academic research on the topic has grown in various directions.

The methodologies used in the assessment of port efficiency are evenly distributed between Stochastic Frontiers and Data Envelopment Analysis (DEA) (Bonilla *et al*., 2002; Charnes *et al*., 1978, 1994; Cullinane *et al*., 2002; Estache *et al*., 2002; Martinez-Budria *et al*., 1999; Pestana, 2003; Roll and Hayuth, 1993; Tongzon, 2001; Valentine and Gray, 2001). Among the researchers relying on Stochastic Frontiers, four studies estimate a production frontier to calculate technical efficiency (Liu, 1995; Notteboom *et al*., 2000) and 3 others (Banos-Pino *et al*., 1999; Coto-Millan *et al*., 2000) quantify the economic efficiency through a cost frontier. The latter also estimates a distance function. The purposes of these research range from analyzing the relation existing between type of ownership and port efficiency (Cullinane *et al*., 2002, 2004; Valentine and Gray, 2001; Liu, 1995) to showing the effects of port reforms (Estache *et al*., 2002; Pestana, 2003) including international benchmarking of ports (Tongzon, 2001).

The diversity of port activities (which include not only complex activities such as loading and unloading the cargo but also simpler activities such as mooring of ships) entails that productivity analysis should centre on a particular activity. In this sense, the study presented here clearly determines the scope of research: productivity and efficiency analysis of infrastructure facilities in Nigerian port terminals. The approach to productivity in this study recognizes the multi-output nature of port products/services. For example, ports render services to both cargo and passengers. Cargoes exist in various forms and productivity can still be assessed while taking these forms into consideration.

However even though, the multi-output nature is well captured in the studies applying DEA, all the parametric applications use a simple measure of product. In this study, cargo throughput which is measure of tonnage of cargoes handled in a port per period is considered as representative of other output variables. Although, the present study builds on the attributes of production frontiers estimated so far in developed countries however, the work departs in context in that it contributes to literature on Stochastic Production Frontier estimation using data from ports in a developing country.

MATERIALS AND METHODS

The Nigerian Ports Authority (NPA) is the custodian of Nigeria's coastal ports. Established by the ports Acts of 1955, the authority was charged with the major responsibility of providing cargo handling and other ancillary services to cargo owners and ships that call at its terminals. The fiscal crises of the 1980s to the mid-1990 in most developing and transition countries affected government subsidy to most national ports (Estache *et al*., 2002). Thus, reduced and eventual absence of subsidy negatively affected investments in cargo handling facilities and port infrastructures and hence led to low port productivity.

The Nigerian government deregulated the ports to improve productivity through injection of private sectors resources in the management of ports. Specifically, it adopted the Landlord Port Model in which the port authority collects rents on existing infra and superstructure under concession to private operators while the concessionaires provide cargo handling and warehousing services to port users. Ancillary services like towage, pilotage and dredging are retained by the authority. However, where additional infrastructure is required, the private operator can access it through contract agreement (e.g., Build-Operate and Transfer (BOT)) with the port authority. Thus, while the concessionaires concentrate on cargo handling services, data collection and collation on vessel and cargo traffic is the responsibility of the ports' custodian authority; the NPA which generally oversees the activities of the private operators.

Data source and presentation: The data for this study sourced from NPA, consists of panel data on ship and cargo traffic from Nigeria's 8 coastal ports covering the period of 22 years (1987-2009). There are four variables considered for each port. These are cargo throughputs or totality of import and export cargo handled at each port, the number of berths, number of available equipment and stevedoring (labour) productivity at the various ports during the study period. Since, seaports essentially provide facilities for discharging and loading of vessels, cargo throughput represents a major output of a port. Cargo throughput is taken as the dependent variable in the production function empirical model while other

Table 1: Descriptive statistics of port metrics

	Port metrics (mean values)			
Ports	Thruputs[1] (m)	Berths	Equipment	Labour (ngh*)
Apapa	4,215.980	22	188	18.348
Cont_terminal	2,071.280	6	100	18.652
Tincan islnd	2,571.450	14	140	19.043
Roro	604.799	3	70	17.391
Warri	746.832	22	116	19.478
PHc	1,680.050	8	104	19.087
Onne	1,090.920	5	8	19.174
Calabar	203.643	14	74	17.783

[1]Thruputs (000), *ngh: net gang hour: Nigerian Ports Authority

variables which represent capital and labour inputs are considered as the independent variables. Table 1 shows the distribution of port metrics by respective ports for the study period.

In terms of throughputs, Apapa port tops the list; totaling >4 million metric ton of non-oil import and export cargoes during the study period. This is closely followed by Tincan island and Container terminal ports which average >2 million ton. These ports are situated in lagos area and are next to a very large market in Western Nigeria most cargo shippers are captive to lagos ports for the obvious reason. This may explain their relatively large shares of the national cargo throughputs. Port-Harcourt (PHC) port and onne port serve mostly the oil servicing sector in the niger delta region. The significant contribution of these ports (>1.5 million ton) in terms of cargo handled is hardly surprising in view of the fact that oil related business is the mainstay of Nigeria's economy. Ro-Ro port is a specialized port for handling Ro-Ro traffic. Ro-Ro traffic represents a relatively small portion of Nigeria's seaborne trade. Warri port is limited to handling of crude oil products; non-oil traffic represents a small share of its traditional traffic. Calabar port is faced with road access problem and less patronized by large cargo shippers. These reasons may explain their low share of throughputs.

The empirical model: The methodology adopted for testing the study hypotheses is a Parametric Model; the Stochastic Frontier Analysis Model (SFA). Stochastic Frontier Model considers production frontier as a random shock. Differently from a non-parametric method such as Data Envelopment Analysis (DEA) that assumes a deterministic frontier, the Stochastic Frontier allows for deviations from the frontier to represent both inefficiency and an inevitable statistic noise which tends to be a closer approach to reality given that observations normally involve a random walk. The models of Stochastic Production Frontier address technical efficiency and recognize the fact that random shocks beyond the control of producers may affect the production output. Therefore, in these models, the impact of random shocks (on labour or capital performance) on the products/services can be separated from the impact of technical efficiency variation. These models were simultaneously introduced by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977). This study will follow the dominant functional specification in literature based on the research by Bettese and Coelli (1992, 1995) in which it is formalized technical inefficiency in the production function of Stochastic Frontier for panel data. Suppose that a port has a production function:

$$y_{it} = f(X_{it}, \beta) \quad (1)$$

Where:

- F (.) = The identified functional form
- y_{it} = The output rate of the port i at time t. In this study, cargo throughputs handled at each port per annum represents the output rate
- X_{it} = The vector of corresponding level of inputs of port i at time t; these include berths, cargo handling equipment and dock labour
- β = The vector of parameters to be estimated

Ideally, without error or inefficiency in time t, the ith port would produce:

$$y_{it} = f(X_{it}, \beta) \quad (2)$$

However, the Stochastic Frontier assumes that each port potentially produces less than the output attainable because of inefficiency. Output is therefore:

$$y_{it} = f(X_{it}, \beta)\, \xi_{it} \quad (3)$$

Where, ξ_{it} the level of efficiency of port i at time t and $0 \le \xi_{it} \le 1$. If $\xi_{it} = 1$. The port utilizes its inputs optimally given its technology. However if $\xi_{it} < 1$, the port is not utilizing its production inputs given the technology of the production function. Output is also subject to random shocks, i.e:

$$y_{it} = f(X_{it}, \beta)\xi_{it} e^{v_{it}} \quad (4)$$

Taking the logs of both sides yields:

$$\text{In}\,(y_{it}) = \text{In}\,\{f(X_{it}, \beta)\} + \text{In}(\xi_{it}) + V_{it} \quad (5)$$

Assuming that there are k inputs and that the production function is linear in logs and defining, $U_{it} = -\text{In}\,(\xi_{it})$; the production function becomes:

$$\ln(y_{it}) = \beta_0 + \sum_{j=1}^{k} \beta_j \ln(X_{jit}) + V_{it} - U_{it} \quad (6)$$

The terms V_{it} and U_{it} are vectors representing decomposed error components. The first term refers to the random part of error or noise with normal distribution independent and identically distributed, i.e., $V_{it} \sim N(0, \sigma_v^2)$. The second term U_{it} is the non-negative technical inefficiency component; distributed identically and independently as truncated normal variable, i.e., $U_{it} = U_i$, $U_i \sim N^+(\mu, \sigma^2_u)$. It represents a deviation from the mean production function, constituting a deviation in relation to the production frontier. Thus, V_{it} and U_{it} terms are assumed to be distributed independently of each other and the covariates in the model. Based on the foregoing, the research model for this study is therefore specified as:

$$\ln(\text{Thruput}_{it}) = \beta_0 + \beta_1 \ln \text{Berths}_{it} + \beta_2 \ln \text{Equipment}_{it} + \beta_3 \ln \text{Labour}_{it} + \varepsilon_{it} \quad (7)$$

where, $\varepsilon_{it} = V_{it} - U_{it}$. Thus, the dependent and independent variables of the before research model can be defined in terms of output and input variables.

Output variable: Cargo throughput (Thruput) is defined as the totality of import and export cargo handled by utilizing port infrastructure and labour. It represents output that can be attained with efficient utilization of capital and labour resources. It is measured in metric tones.

Input variables: One of the input variables; the number of berths (Berths) gives a measure of vessel and cargo handling capacity of a port. The higher the number of available berths, the higher is the capacity of the port i, to accommodate vessels in demand of port service. Number of available equipment (Equipment) is a measure of available facilities; fixed or mobile for loading and discharging berthed vessels in the port. The labour input variable (Labour) measures the (in) efficiency of stevedoring operation in the port. Nigerian ports are not automated and hence, human labour (gang of men) is required to operate ship's derrick and shore based handling facilities.

Thus, the rate of discharge and/or loading of cargo using dock labour is an indication of the productivity of cargo handling activity. These inputs combine to determine infrastructure productivity of the port system.

RESULTS AND DISCUSSION

The result of data analysis employing inferential statistical procedures is discussed. In Table 2, estimates of coefficients are reported for two frontier models estimated; generalized least square model and the Time-Invariant specification based on truncated (half) normal distribution of error term U_{it} (the latter is the model adopted for hypothesis testing). In both models, all the production inputs except labour are significant at $\alpha = 0.05$. The coefficient of Berth (number of berths) is positive; implying that number of available berths at the port contributes significantly to its productivity.

Equipment variable is also significant but has a negative coefficient. Cargo handling in Nigeria's ports is not yet automated. These equipments are operated manually by dock labour. When more than required numbers of gangs are booked for stevedoring operation (i.e., at marginal productivity level); it may lead to negative productivity where the reverse is expected. This is in fact the case in Nigerian ports where more gangs than necessary are mandatorily booked for financial gains and to secure jobs for dock workers.

The coefficient of labour is also negative. This variable is measured by the tones produced per gang hour for any port. Labour gangs undertake the stevedoring operation at the quays. Low productivity of dock labour may explain the lack of significance of labour input in the port. Other model fitting information is also reported for the half-normal model: σ^2 is the variance of the likely-hood function and expressed in terms of variance parameters as:

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 = 19.354$$

where, $\gamma = \sigma^2_{v}/(\sigma^2_u + \sigma^2_u)$ is a measure of level of the inefficiency in the variance parameter. It has a value of 0.98 or 98%. This implies that 98% of the variation in port throughput is due to technical inefficiency and only 2% is due to stochastic random error. In Table 3, marginal values of the significant marginal products of capital inputs are 1.028 and -0.169. These values represent the proportions in which the inputs can be combined to produce total factor productivity. The total productivity

Table 2: Productivity frontier analysis results

	Least squares[a]				Half-normal model			
Coef.	Est.	SE	t	p>|t|	Est.	SE	t	p>|t|
β_{Berths}	1.076	0.234	4.600	0.000	1.028	0.152	6.760	0.000
$\beta_{Equipment}$	-0.184	0.071	-2.610	0.009	-0.169	0.072	-2.340	0.019
β_{Labour}	-0.203	0.169	-1.200	0.229	-0.212	0.167	-1.270	0.204
_Cons	12.581	0.878	14.330	0.000	13.588	0.639	21.260	0.000
σ^2	-	-	-	-	19.354	179.964	-	-
γ	-	-	-	-	0.982	0.165	-	-
σ_u^2	-	-	-	-	19.010	179.965	-	-
σ_v^2	-	-	-	-	0.344	0.039	-	-
Log L	-161.532	-	-	-	-163.987	-	-	-

[a]Generalized least squares. Dependent variable: ln (throughputs)

Table 3: Marginal effects and productivity of physical products

Variables	$\partial y/\partial x$	SE	T	p>|t|
Berths	1.028	0.152	6.760	0.000
Equipment	-0.169	0.072	-2.340	0.019

Marginal effects after xt frontier, y = Linear prediction, y = 2,473,134.667

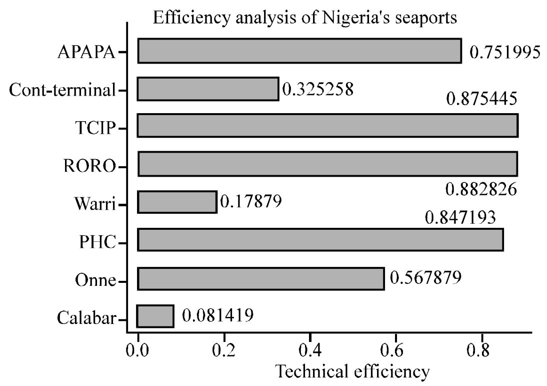

Fig. 1: Distibution of efficiency values by respective ports

(y) as shown in the footer of Table 3 is approximately 2.5 million metric ton annum^{-1}. This represents the total factor productivity of the Nigerian ports. It can be compared against industry standard to determine its optimality.

In Fig. 1, calculated efficiency values are plotted for each port. Height of bars indicates the level of efficiency. Bar results therefore show that Apapa, Tincan Island (TCIP), RoRo, Port-Harcourt (PHC) and Onne ports have Technical Efficiency (T.E.) values approximately 1.0. Container terminal, Warri and Calabar ports have efficiency values lying <1.0 and hence are considered technically inefficient. These ports may be productive but are not technically efficient. The broad objective of this study is to assess the productivity and technical efficiency of Nigerian ports using a stochastic production function framework.

The major findings are: total factor productivity of Nigerian ports is >2.5 million ton annum^{-1}; number of berths and cargo handling equipment are significant factors to achieving port productivity. Labour input is not a significant contributor suggesting the use of low productive dock labour in cargo handling operation. Among the ports under study, Apapa, Tincan Island, RoRo, Port-Harcourt and Onne ports are the ones found to be technically efficient. Container terminal, Warri and Calabar ports were found to be relatively inefficient in terms of infrastructure utilization. It may appear that cargo handling facilities are lacking in these ports. However, the major problem is under utilization caused by inaccessibility to these terminals. Calabar port for example, lacks good rail and road connections. Eastern port users, who ordinarily should be captive to Calabar or Warri ports, prefer other ports in the range owing to accessibility constraints. Poor port patronage lead to low throughputs handled and hence under utilization of cargo handling infrastructure.

Warri ports have low draughts and cannot handle large cargo vessels of drafts beyond 8 m. Thus, most shippers operating within Warri area divert their cargo to other ports for the obvious reason. Container terminal operate in the same range with Apapa, Tincan and may be having stiff competition for cargo from the bigger well equipped ports of Apapa Tincan and others.

CONCLUSION

Low efficiency recorded in these ports for the most part are due to under utilization of port infrastructure. The federal government has a role to play in improving road/ rail connections to calabar port and dredging of Warri port since, it retains the responsibility of providing ancillary services which dredging is part of. The low contribution of labour inputs to output of these ports suggests low mechanization of cargo handling in the Nigerian ports. Therefore, total mechanization in cargo handling should constitute a policy thrust. Benchmark analyses should also be conducted to determine if the empirical total productivity of Nigerian ports is below global port industry production frontier. Stochastic Frontier Model assumes that ports' output is a single measure; the Method of Data Envelopment Analysis (DEA) though non parametric can be applied to measure multiple output measures of seaports but has its limitations. Therefore, future research should consider improving on the methodology of this study by developing a hybrid model that incorporates the advantages of SFA and DEA Models.

REFERENCES

Aigner, D., C.A.K. Lovell and P. Schmidt, 1977. Formulation and estimation of stochastic frontier production models. J. Econ., 6: 21-37.

Banos-Pino, J., P. Coto-Millan and A. Rodriguez-Alvarez, 1999. Allocative efficiency and over-capitalization: An application. Int. J. Transp. Econ., 26: 181-199.

Battese, G.E. and T.J. Coelli, 1992. Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. J. Prod. Anal., 3: 153-169.

Battese, G.E. and T.J. Coelli, 1995. A Model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Econ., 20: 325-332.

Bonilla, M., A. Medal, T. Casasus and R. Sala, 2002. The traffic in spanish ports: An efficiency analysis. Int. J. Econ. Transp., 29: 215-230.

Chang, S., 1978. Production function and capacity utilization of the port of mobile. Maritime Policy Manage., 5: 297-305.

Charnes, A., W.W. Cooper and E. Rhodes, 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res., 2: 429-444.

Charnes, A., W.W. Cooper, A.Y. Lewin and L.M. Seiford, 1994. Data Envelopment Analysis: Theory Methodology and Application. Kluwer, Boston, ISBN: 0792394801.

Coto-Millan, P., J. Banos-Pino and A. Rodriguez-Alvarez, 2000. Economic efficiency in Spanish ports: Some empirical evidence. Maritime Policy Manage., 27: 169-174.

Cullinane, K., D.W. Song and R. Gray, 2002. A stochastic frontier model of the efficiency of major container terminals in Asia: Assessing the influence of administrative and ownership structures. Transp. Res. Part A, 36: 743-762.

Cullinane, K., D.W. Song, P. Ji and T.F. Wang, 2004. An application of DEA windows analysis to container port production efficiency. Rev. Network Econ., 3: 184-206.

Estache, A., M. Gonzalez and L. Trujillo, 2002. Efficiency gains from port reform and the potential for yardstick competition: Lessons from Mexico. World Dev., 30: 545-560.

Liu, Z., 1995. The comparative performance of public and private enterprise: The case of british ports. J. Transp. Econ. Policy, 29: 263-274.

Martinez-Budria, E., R. Diaz-Armas, M. Navarro-Ibanez and T. Ravelo-Mesa, 1999. A study of the efficiency of Spanish port authorities using data envelopment analysis. Int. J. Transp. Econ., 26: 237-253.

Meeusen, W. and J. van den Broeck, 1977. Efficiency estimation from Cobb-Douglas production functions with composed error. Int. Econ. Rev., 18: 435-444.

Notteboom, T.E., C. Coeck and J. van den Broeck, 2000. Measuring and explaining relative efficiency of container terminals by means of bayesian stochastic frontier models. Int. J. Maritime Econ., 2: 83-106.

Pestana, C., 2003. Incentive regulation and efficiency of portuguese port authorities. Maritime Econ. Logist., 5: 55-69.

Roll, Y. and Y. Hayuth, 1993. Port performance comparison applying Data Envelopment Analysis (DEA). Maritime Policy Manage., 20: 153-161.

Talley, W.K., 1994. Performance indicators and port performance evaluation. Logist. Transp. Rev., 30: 339-352.

Tongzon, J.L., 1995. Systematizing international benchmarking for ports. Maritime Policy Manage., 22: 171-177.

Tongzon, J.L., 2001. Efficiency measurement of selected australian and other international ports using data envelopment analysis. Transp. Res. Part A, 35: 113-128.

Valentine, V.F. and R. Gray, 2001. The measurement of port efficiency using data envelopment analysis. Proceedings of the 9th World Conference on Transport Research, July 22-27, 2001, Seoul, Korea.