Developing Measures of Us Ports Productivity and Performance: Using DEA and FDH Approaches

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Abstract

The increasing competitiveness of the marine transportation industry has brought about demands that ports and container terminals productivity be improved. To provide adequate supply of cargoes for the increasing traffic, ports must either expand facilities or improve efficiency of operations. Under such a competitive environment, port performance measurement is not only a powerful management tool for port operations, but also constitutes a most informative input for regional and national port planning and operation. Measuring port and container terminal productivity is an interesting issue, especially if an automated system across terminals and port is required. Amongst other methods, the efficiency of container port or terminal production can potentially be analyzed by Data Envelopment Analysis (DEA) or by the Free Disposal Hull (FDH) Model. This paper aims to evaluate the efficiency of major North American container ports and terminals using DEA and FDH models. The results show that the above two techniques lead to different conclusions. Furthermore, we concluded that the availability of panel data, rather than cross sectional data, would improve the validity of the efficiency estimates derived from all applied mathematical programming techniques.

Key words: Data Envelopment Analysis (DEA), Free Disposal Hull (FDH), Container Terminals, Ports, Efficiency, Production.

INTRODUCTION

In the transportation arena container trade plays a key role in the process because of its technological advantages as compared with the traditional methods of transportation. In order to support the global trade development, U.S. and Canadian port authorities have increasingly felt pressure to improve efficiency by ensuring that services are provided on an internationally competitive basis. Compared with traditional port operation, containerization has improved production. Port productivity and efficiency is an important contributor to the United State's international competitiveness.

Under such a competitive environment port performance measurement is not only a good management practice for port operators, but also an important input for regional and national port planning and operations. Port efficiency has been evaluated by calculating the cargo handling relation at the berth (Tabernacle, 1995, Ashar, 1997), or by comparing actual with optimum throughput over a specific time period (Talley, 1998). Jara-Diaz et al., (2002) estimate a multi output cost function using a flexible form from a sample of 26 Spanish seaports over an 11-year period. Outputs are containerized general cargo, break bulk general cargo, liquid bulk, dry bulk, and total rent received for leases of port space. The results support the presence of economies of scale and scope. In recent years, significant progress has been made in the measurement of efficiency in relation to production activities. In particular, non-parametric frontier methods such as Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) have been developed with application across a wide range of sectors including port services.

Turner et al., (2003) study productivity of ports in the North America using a panel data during 1984 – 1997. To measure efficiency of ports, they employed the Data Envelopment Analysis (DEA) technique. This study aims to provide new information on efficiency estimation for the period of 1996 to 2001 by applying the two alternatives techniques of DEA and FDH to the North American's (USA and Canada) leading container ports.

PORT PRODUCTION MEASUREMENT

Performance measurements play a significant role in the development of port terminals or other forms of organizational Decision Making Units (DMU). There are several methods that are applicable for evaluating performance of ports including regression analysis (Tongzon, 1995). In recent years, Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) are two of many available alternative techniques for estimating an approximation to the efficient frontier. These two mathematical programming techniques allow the measurement of the relative distance that an individual Decision Making Units lies away from this estimated frontier. The frontier defines the relationship between inputs and outputs by depicting graphically the maximum outputs obtainable from the given inputs.

Evaluation among ports is made by comparing indicator values for different given ports over time. Performance indicators suggested by UNCTA (1976), as shown in Table 1, shows productivity and effectiveness measures and can be used as a reference point.

TABLE 1. Performance Indicators Suggested by UNCTAD

Financial Indicator	**Operational Indicators**
Tonnage worked	Arrival Late
Berth Occupancy Revenue per ton of cargo	Waiting Time
Cargo handling revenue per ton of cargo	Service Time
Labor Expenditure	Turn-around Time
Capital equipment expenditure per ton of cargo	Tonnage per ship
Contribution per ton of cargo	Fraction of time berthed per ship per shift
Total contribution	Tons per ship-hour in port
	Tons per ship-hour at berth
	Tons per gang hours
	Fraction of time gangs idle
Source: UNCTAD (1976, pp7-8)	

Data Envelopment Analysis (DEA) is a non-parametric method of measuring the efficiency of decision making unit (DMU) with multiple outputs and inputs. DEA is an appealing technique due to at least two reasons: First, its ability to analyze several outputs simultaneously and to derive efficiency rating within a set of analyzing units, are particular suitable for measuring port efficiency. Second, DEA technique does not require assumptions regarding associated functional forms. Instead, DEA will provide a piece-wise linear function to represent an empirical maximum possible frontier. In Figure 1, it plots the empirical relationship between an input and an output from a set of 7 hypothetical ports, A, B, C, D, E, F, and G. Using DEA will determine that ABCD form an efficient frontier.

FDH as a deterministic non-parametric method, assume that does not have a particular functional form for the boundary and ignore measurement error. FDH uses mathematical programming techniques to envelop the data as tightly as possible, subject to certain production assumptions, which are maintained within the mathematical programming context. Using FDH for any given level of outputs remains feasible if any of the inputs is increased, whereas the latter means that with given inputs it is always possible to reduce or maximize outputs. Notice that the FDH methodology is particularly suited to detect the most obvious cases of port inefficiency as this technique is very assertive regarding the measurement of port inefficiency. To each port declared FDH inefficient, it is possible to find at least one port in the sample that presents a superior performance relative to the first (dominated) municipality (Lovell et al., (1993).
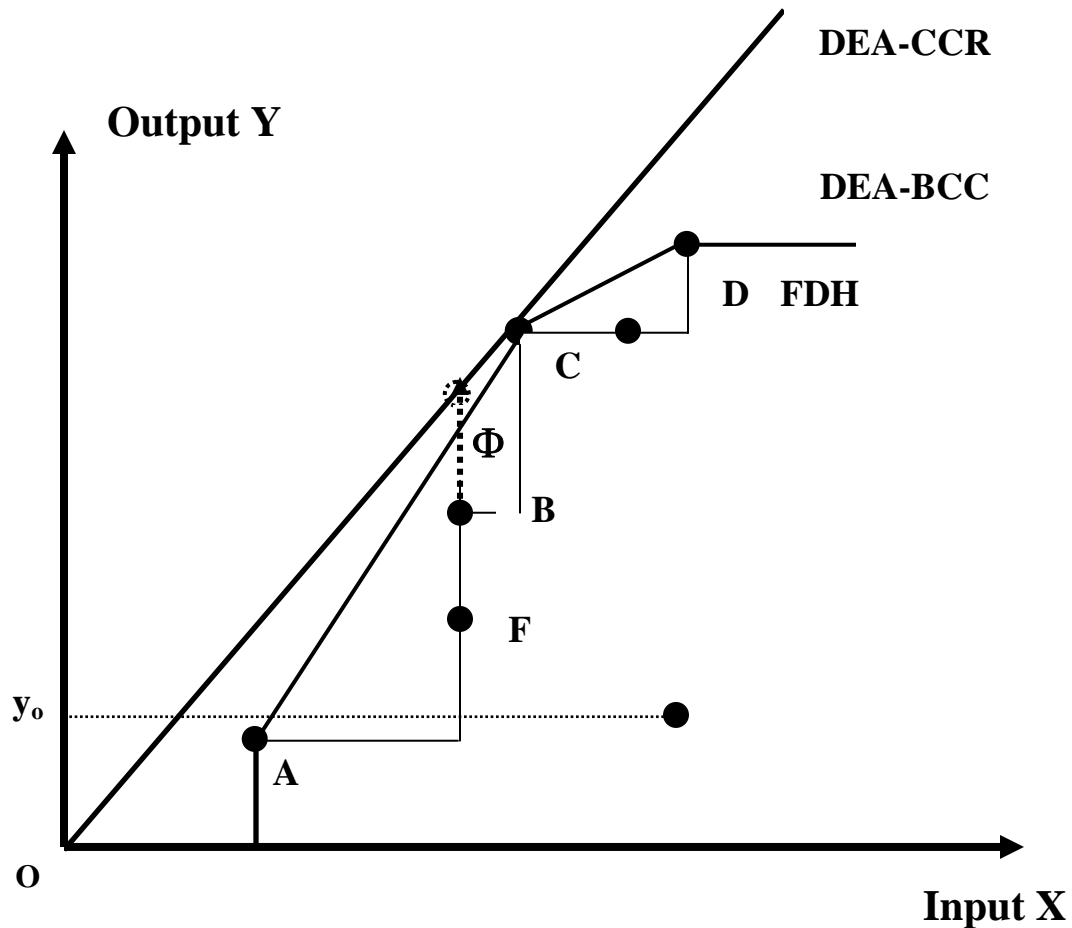
FIGURE 1: Non-parametric Deterministic Frontiers

Port output can be multi-dimensional depending on the objective that ports want to achieve. Roil and Hayuth (1993) have advocated the use of this approach in measurement of port efficiency and demonstrated, based on data, how the relative efficiency ratings could be obtained.

Since its introduction by Charnes et al., (1978), DEA technique has been applied in many different contexts. In transportation, there are applications in airports [Martin and Roman (2001), Bazargan and Vasigh (2003)], multi-airport systems (Pathomsiri et al., 2006), ports [Roll and Hayuth (1993), Cullianane et al., (2004), Turner et al., (2004)]. The concept of DEA is developed around the basic idea that the efficiency of a DMU is determined by its ability to transform inputs into desired outputs.

Data Envelopment Analysis (DEA), is also known as the CCR model, as Charnes et al. (1978) proposed. Later on there are many variations to deal with particular types of data and assumptions. One form that we use in this study is an output-oriented and variable return-to-scale (VRS). The DEA-BBC model Banker et at., 1984, on the other hand, allows for variable returns to scale and it is graphically represented by the piecewise linear convex frontier (Figure 1). FDH model DEA-BBC, and DEA-CCR models define different production possibility wets and efficiency results. The idea may be explained

by using a graphical illustration of hypothetical single input/output ports, as shown in Figure 1. An input oriented efficiency measurement problem can be written as a series of j linear programming enveloping problems, with constraints differentiating between the DEA-BBC, DEA-CCR and the FDH models as shown in the following mathematical form:

$$\min \theta$$

Subject to

$$\theta x_r - X\lambda \geq 0 \qquad r = 1,2,......S$$

$$Y\lambda \geq y_r \tag{1}$$

$$\lambda \geq 0 \qquad \text{(DEA - CCR)}$$

$$e\lambda = 1m \qquad \text{(DEA - BCC)}$$

$$\lambda_r \in \{0,1\} \qquad \text{(FDH)}$$

This study examines operational efficiency of ports with respect to containerized cargoes across regions in the US and Canada. One of the results is an index or a performance score which can be used for performance comparison across ports. The score can also be used for benchmarking purpose. In the subsequent study, we plan to develop the causal relationship between this performance score and port factors. Such relationship would be useful for port managers and policy makers to understand factor affecting productivity of ports and ultimately derive a strategy to enhance the operational efficiency. At this stage, we address the efficient measurement by using the DEA and FDH techniques and compare them. The proposed methodology is implemented with a sample of 30 ports operating in the U.S. and Canada during 1996 – 2001.

ANALYSIS

Container port infrastructure productivity is a key performance measure and is influenced by industry structure, conduct and demand. For this reason, this study has two distinct objectives: measurement of the trend in infrastructure productivity during the study period, and examination of the factors that determines infrastructure productivity through DEA and FDH methodologies. Based on the study issues and literature, this study follows Wang et at., (2003) and suggests data envelopment analysis and free disposal hull methodology be employed to evaluate container port infrastructure productivity during the study period.

The input and output variables should reflect actual objectives and process of container terminal productivity as accurately as possible. As discussed previously, the DEA and FDH empirical analysis uses one output measures: TEUs handled (the number of twenty foot container equivalent units). Container throughput is the most appropriate and analytically tractable indicator of the effectiveness of port production. The input measures used are: Berths (the number of container berths), length (the length of the

berths), TotalArea (the total area of the berths), storage (ports many times are used as a storage area, because the container yards act as buffer between sea and inland transportation or transshipment), Shipshore Cranes (Quay Cranes are very critical for port operation). In addition, front-end handlers, yard tractor, and yard chassis, are important yard equipment. Measures of these variables are going to be inputs into the model. The measurement of terminal production, therefore, is a mean of quantifying efficiency in the utilization of these three variables. Given the characteristics of container port production, the total quay length and the terminal area are the most suitable proxies for the land factor and the quay gantry cranes is the most suitable proxy for the equipment factor input. A summary of the major characteristics of the input and output variables is presented in Table 2.

TABLE 2: Descriptive Statistics for Input and Output Variables

	Number Berths	Length	Total Area	Storage	Shipshore Crane	Front-End Handlers	Yard Tractors	Yard Chassis	Size
Min	1	272	40,000	1,000	1	0	1	0	9,609
Max	70	7,806	5,259,612	159,400	42	271	407	250	4,900,000
Mean	9.61	2,430	1,389,851	24,782	12.16	36.86	57.21	32.99	885,787
Median	7	1,978	830,000	13,200	10	12	31	16	653,526
S.D.	9.57	1,742	1,274,279	30,081	9.86	57.65	80.92	40.37	1,024,811

The DEA and FDH models can be distinguished according to whether they are input or output oriented. Marlow and Paixao (2002) argue that the development of agile ports requires the implementation of a two-stage integration process, the internal and the external one. These port measurement indicators, besides considering quantitative aspects, will focus mainly on qualitative issues and will bring increasing visibility within the port. Qualitative performance indicators are at the heart of lean ports and consequently of port networking. A port usually is able to know or to predict its container throughput for the ensuing year. This happens because a container port has a stable customer base of shipping lines. In addition, a container terminal can also attempt to predict its future throughput by styling historical data. For these reasons an input oriented model is most appropriate on the analysis of container production given the output.

The sampling frame for this study consists of the most important U.S. and Canadian Container Ports from the 1996 to 2001. Although twenty five ports of all regions (West-Gulf-East) have been included in this study, a couple of ports had to be removed for some years due to incomplete input data. Therefore the sample size for the analysis comprises a total of 174 observations. The secondary data has been collected from the Containerization International Yearbook and the U.S. Department of Transportation Maritime Administration. Table 3 lists all ports along with their TEU outputs during 1996 – 2001. Among them, Los Angles (LA) port served the most TEU whereas Saint John (St. John) port served the least with only 49000 TEU in 2001. Because the data source often reported the required data at the aggregate level of the whole port, rather than on

the basis of the individual terminals this study initially intended to investigate individual ports.

TABLE 3: List of Ports with the annual TEU*

Port	1996	1997	1998	1999	2000	2001
Halifax	392273	459176	425435	466364	545010	545010
Montreal	852530	870368	932701	993486	1014148	1100000
St. John	37202	42898	42720	48147	48274	49000
Vancouver	616692	724154	840098	1070171	1163178	1200000
Baltimore	474816	476012	476012	496108	498016	499500
Boston	127087	137400	139470	147674	138904	146677
Charleston	1078590	1151401	1259259	1482995	1632747	1158751
Galveston	9609	14376	18800	68874	82943	82943
Gulfport	150000	153350	153350	62937	141426	158948
Hampton Roads	1141357	1232725	1294361	429869	1347517	1400000
Houston	799481	935600	968169	1031071	1074102	1106325
Jacksonville	613448	675196	753928	771862	708028	710000
Long Beach	3067336	3504603	3323801	4408680	4600787	3361379
Los Angeles	2682802	2959715	3377998	3828852	4879429	4900000
Miami	656798	685000	813000	777821	868178	868178
Mobile	40300	45500	47500	11389	13510	15000
New Orleans	261007	165440	155933	286630	278932	280000
NY/NJ	2269500	2518750	2500000	2983342	3006493	3100000
Oakland	1498202	1531188	1575406	1663756	1776922	1776922
Philly	95086	112588	221537	156192	179039	165334
Port Everg.	701281	719326	724900	715585	694792	694792
Portland	302171	294930	259308	293262	290943	271000
San Francisco	15700	17703	20300	39547	50147	52005
Savannah	650253	730936	729974	793708	948883	945500
Seattle	1473561	1455814	1543726	1490050	1488267	1488267
Tacoma	1073471	142700	1142700	1271011	1376379	1376379
Wil. DE	162886	161824	206140	196950	220000	188028
Wil. NC	103579	105786	113368	100546	96360	94500

* TEU is the abbreviation for "Twenty foot Equivalent Unit", referring to the most common standard size of 20 ft. in length.

RESULTS AND ANALYSIS

Given 29 seaports studied over a six year period, the maximum sample size would be 174 observations. However, data availability affected the actual sample size. For the model, any variations or missing data within an observation resulted in the exclusion of that observation from the sample. For example, in the analysis, Freeport (TX), was not included for the years 1996 to 2001 as they either have no OSG cranes or lack reliable information during such period. For purposes of this study then, they were not considered as a containerport during this period.

Table 4 shows performance scores from solving DEA-CCR, DEA-BCC and FDH models respectively for 1996 to 1998. The average values of 0.6417, 0.8206 and 0.9612 for the 1996, 0.6159, 0.7934 and 0.9500 for the year 1997, and 0.6380, 07948, and 0.9523 for the 1998.

TABLE 4: Port Efficiency of CCR- BCC and FDH Models for 1996 to 1998

Port	1996			1997			1998		
	CCR-I	BCC-I	FHD-I	CCR-I	BCC-I	FHD-I	CCR-I	BCC-I	FHD-I
Halifax	0.42441	0.50016	1.0000	0.43511	0.51388	1.0000	0.42219	0.49615	1.0000
Montreal	0.51199	0.51665	1.0000	0.46264	0.47161	1.0000	0.52003	0.52383	1.0000
St. John	0.19414	1.00000	1.0000	0.20031	1.00000	1.0000	0.20174	1.00000	1.0000
Vancouver	0.43082	0.51419	0.7782	0.44278	0.52684	0.7782	0.54161	0.61408	0.7782
Baltimore	0.34548	0.36333	0.7368	0.48683	0.48966	0.7368	0.32231	0.34215	0.7368
Boston	0.22144	0.46597	1.0000	0.25514	0.45639	1.0000	0.22428	0.46191	1.0000
Charleston	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Galveston	0.02851	0.65542	0.6554	0.03733	0.65542	0.6554	0.05148	0.65542	0.6554
Gulfport	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Ham. Roads	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Houston	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Jacksonville	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Long Beach	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Los Angeles	0.89277	1.00000	1.0000	0.87607	0.98137	1.0000	1.00000	1.00000	1.0000
Miami	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Mobile	0.45281	1.00000	1.0000	0.52742	1.00000	1.0000	0.50010	1.00000	1.0000
New Orleans	0.81235	1.00000	1.0000	0.46846	1.00000	1.0000	0.35508	0.68684	1.0000
NY/NJ	0.51515	0.52485	0.7444	0.50630	0.51185	0.7444	0.51508	0.53134	0.7444
Oakland	0.68624	0.69422	1.0000	0.77525	0.77823	1.0000	0.66503	0.66615	1.0000
Philly	0.21350	0.86058	1.0000	0.22688	0.86058	1.0000	0.42357	0.86058	1.0000
Port Everg.	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Portland	0.29038	0.40785	1.0000	0.24947	0.38207	1.0000	0.22923	0.36306	1.0000
San Franci.	0.05059	0.79319	1.0000	0.05366	0.79319	1.0000	0.05843	0.79319	1.0000
Savannah	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Seattle	0.67054	0.68113	1.0000	0.67872	0.68086	1.0000	0.63679	0.63752	1.0000
Tacoma	1.00000	1.00000	1.0000	0.35949	0.49429	0.9356	1.00000	1.00000	1.0000
Wil. DE	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Wil. NC	0.22778	1.00000	1.0000	0.20225	0.61934	0.7494	0.19734	0.62273	0.7494

In Table 4 the index value of 1.0000 represents a perfect efficiency score. For 1996, eleven out of twenty-nine ports identified to be efficient when the DEA-CCR input-oriented model is applied. Using DEA-BCC input-oriented model, sixteen out of the twenty-eight ports are efficient compared with the twenty-four efficient when the FDH model is applied.

Table 5 shows performance scores from solving DEA-CCR, DEA-BCC and FDH models respectively for 1999 to 2001. The average values of 0.5753, 0.7984 and 0.9815 for 1999, 0.6365, 0.8348 and 0.9716 for the year 2000, and 0.6753, 08595, and 0.9716 for the year 2001.

TABLE 5: Port Efficiency of CCR- BCC and FDH Models for 1999 to 2001

Port	1999			2000			2001		
	CCR-I	**BCC-I**	**FHD-I**	**CCR-I**	**BCC-I**	**FHD-I**	**CCR-I**	**BCC-I**	**FHD-I**
Halifax	0.35299	0.47757	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Montreal	0.43462	0.46383	1.0000	0.33810	0.36986	1.0000	0.49069	0.49749	1.0000
St. John	0.18245	1.00000	1.0000	0.15508	0.87291	1.0000	0.18855	0.87291	1.0000
Vancouver	0.52016	0.61966	1.0000	0.43341	0.59096	1.0000	0.61199	0.72538	1.0000
Baltimore	0.30388	0.34825	0.7368	0.23724	0.27747	0.7368	0.25527	0.28687	0.7368
Boston	0.19283	0.47745	1.0000	0.18115	0.98212	1.0000	0.26182	1.00000	1.0000
Charleston	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Galveston	0.14218	0.76583	1.0000	0.12615	1.00000	1.0000	0.17267	1.00000	1.0000
Gulfport	0.71829	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Ham. Roads	0.33971	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Houston	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Jacksonville	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Long Beach	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Los Angeles	0.93219	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Miami	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Mobile	0.10451	1.00000	1.0000	0.13329	1.00000	1.0000	0.16649	1.00000	1.0000
New Orleans	0.60338	0.96890	1.0000	0.60102	0.91726	1.0000	0.77001	1.00000	1.0000
NY/NJ	0.47835	0.48357	0.7444	0.39592	0.39654	0.7444	0.49518	0.49790	0.7444
Oakland	0.57566	0.58283	1.0000	0.55325	0.55329	1.0000	0.65993	0.66615	1.0000
Philly	0.26409	0.86058	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Port Everg.	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Portland	0.19918	0.37509	1.0000	0.19547	0.54376	1.0000	0.23445	0.56357	1.0000
San Franci.	0.09494	0.79319	1.0000	0.10652	1.00000	1.0000	0.11810	1.00000	1.0000
Savannah	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Seattle	0.50585	0.51525	1.0000	0.29377	0.31228	0.9744	0.37895	0.39655	0.9744
Tacoma	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000	1.00000	1.00000	1.0000
Wil. DE	1.00000	1.00000	1.0000	0.92347	1.00000	1.0000	0.93677	1.00000	1.0000
Wil. NC	0.16249	0.62391	1.0000	0.14880	0.55808	0.7494	0.16755	0.55808	0.7494

Also, in Table 5 the index value of 1.0000 represents a perfect efficiency score. In 2001 thirteen out of twenty-nine ports identified to be efficient when the DEA-CCR input-oriented model is applied, compared with nineteen and twenty-four efficient ports when the DEA-BCC input-oriented model and the FDH model are respectively applied.

These results are not surprising. Spearman's rank order correlation coefficient between the efficiency derived by DEA-CCR, and DEA-BCC, DEA-CCR and FDH, and DEA-BCC and FDH methods are 0.99273, 0.98118, and 0.99730 respectively. The positive and high Spearman's rank order correlation coefficients indicate that the rank of each DMU derived by the three methodologies is similar. Also, the small absolute value of the spearman's rank suggests that the efficiency of ports is not a significant influence by its size.

TABLE 6: A Projection of Inefficient DMU to be Efficient

Baltimore	Actual 2001	Projection Value by Type of DEA Model		
		CCR-I	BCC-I	FDH-I
# of Berths	13	2	3	4
Length	3,528	711	1012	1335
Total Area	3,690,000	532019	533318	2630700
Storage	12,000	3063	3442	1500
Shipshore Cranes	19	5	5	14
Front-End Handlers	172	37	46	1
Yard Tractors	239	33	33	14
Yard Chassis	72	14	13	11
Size (TEU)	499,500	499,500	499,500	868178

NY/NJ	Actual 2001	Projection Value by Type of DEA Model		
		CCR-I	BCC-I	FDH-I
# of Berths	37	12	13	12
Length	7806	3319	3376	2904
Total Area	5259612	1555713	1778802	1156500
Storage	159400	38145	39078	50813
Shipshore Cranes	42	21	21	19
Front-End Handlers	191	24	26	26
Yard Tractors	407	60	60	83
Yard Chassis	90	44	45	67
Size (TEU)	3100000	3100000	3100000	3361379

One of the most important issues in DEA and FDH methodologies is diagnosis. In this analysis we study the Baltimore and the New York / New Jersey ports. Table 6 shows how these ports could be able to improve their efficiency under performance measurement models. For instance, for the New York / New Jersey port, for DEA-CCR and DEA-BCC methodologies one possible case might be that the Shipshore Cranes should be reduced to 21 cranes. Based on the FDH results the Shipshore Cranes should be reduced to 19 cranes. A similar analysis could also be made for the other inputs variables as wells. In the case that one of these methodologies has given efficiency scores the projection value has to be similar as the actual value.

CONCLUSION

This paper compares cost efficient estimates of North American Ports using a variety of econometric and mathematical programming methodologies. The principal objective is to provide new information on the effects of the choice of methodology on cost efficiency estimates. The secondary objective is to analyze some of the results. The findings indicate that the choice of efficiency estimation methodology makes a significant difference in terms of the estimated cost efficiency values. The efficiency rankings are well-preserved within the two econometric methodologies.

Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) are two non-parametric approaches of DEA and FDH that have been studied comparatively within the North American ports. Analysis of the efficiency of the DEA-CCR, DEA-BCC and the FDH models confirms that these methodologies tend to give significantly different results. Thus, for port operation, the choice of methodology is really important in terms of efficiency and studying to identify the potential source for improvements in the production of inefficient ports. In addition, results from applying the FDH is more likely to identify as efficient DMUs, that are not performing well. Thus, DEA has a potential to provide efficient goals for the DMUs to work towards.

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