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Liner Companies' Container Shipping Efficiency Using Data Envelopment Analysis

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Abstract

The liner shipping industry moves products around the world. There are thousands of container ships circling the globe at all times, making the global economy possible. Liner shipping companies ship anything that can fit into a cargo container. The standard containers measure 20 feet in length by 8 feet in width or 40 feet in length by 8 feet in width. According to Alphaliner (2015), there are at least 100 linear shipping companies in the world. This study will evaluate the efficiency of different-sized liner shipping companies using Data Envelopment Analysis: it will consider operational aspects and will only include revenue as a financial output. The study predicts that companies with the best fleet utilization will have the highest efficiency scores even when their overall revenue may be less than other companies.

Purpose

The purpose of this study is to evaluate the efficiency of different-sized liner shipping companies using Data Envelopment Analysis (DEA).

Background

The liner shipping industry moves products around the world. There are thousands of container ships circling the globe at all times, making the global economy possible. Liner shipping companies ship anything that can fit into a cargo container. Liner container shipping companies use standard sized containers measuring 20 feet in length by 8 feet in width or forty feet in length by 8 feet in width. According to Alphaliner (2015), there are at least 100 linear shipping companies in the world. The liner shipping companies' fleets of ships can range in size from 6 container ships to 590 container ships. The industry standard for measuring how many containers a ship can hold that are twenty feet in length is Twenty Foot Equivalents or TEUs. One liner container shipping company, Maersk, is so large it controls 15% of TEUs carrying capacity in the world (Alphaliner 2015).

The container shipping industry is extremely competitive, and the rate charged for shipping a container is very volatile. In 2016 the rate that liner container shipping companies can charge went down. The liner shipping companies have to be as efficient as possible to stay profitable. According to the companies' quarterly reports, analyzed in this study, many liner shipping companies in 2016 were not profitable even with large revenues, so efficiency is of the utmost importance.

Liner shipping companies' fleets of ships are made up of owned and chartered vessels. Owned ships are ships the company actually owns. Chartered ships are ships owned by other companies, but are contractually in service to the charting company for a certain period to make shipments between ports.

This study employs Data Envelopment Analysis (DEA) to analyze the efficiency of different-sized liner shipping companies. The inputs used here are fleet make-up (number of owned or chartered ships) and TEUs. The outputs are the number of TEUs transported and revenue.

Literature Review

There are two DEA versions that can be used, the Charnes, Cooper, and Rhodes (CCR) version (Charnes et al. 1978) and the Banker, Charnes, and Cooper (BCC) version (Banker at al. 1984). This study uses the CCR version; the CCR model is used in situations where outputs increase proportionally for increase in inputs. DEA has been applied in many industries, such as: telecoms (Tsai et al. 2006); hospitals (Bates et al. 2006); international banking (Casu and Molyneux 2003); and the hotel industry (Haugland et al. 2007).

In terms of DEA's applications in the transportation and logistics field, interested readers can refer to Markovits-Somogyi (2011) 's review, which showed that of the 64 transport studies using DEA, the majority represented studies on airports and seaports (23 and 21 respectively) followed by public transport (10), railways (9), airlines (4), and others (2). Compared to studies in other transport modes, productivity and efficiency studies in the shipping industry are very limited (Bang et al. 2012). These other transport modes include airlines (Chiou and Chen 2006); (Gillen and Lall 1997), (Merkert and Hensher 2011), (Fethi et al. 2002), (Scheraga 2004)]; railways (Oum and Yu 1994); and third party logistics (Zhou et al. 2008).

Another study that used DEA in transportation was Gutierrez et al. (2015), in which the Data Envelopment Analysis was used to assess the relative efficiency of container shipping agents operating at Spanish ports, and studied the factors influencing it. The analysis considered labor as input, and numbers of loaded and unloaded containers handled as outputs. This study of Spanish ports highlighted which ports were the most efficient at unloading containers from ships. The study considers operational units other than dollars in the analysis.

Panayides et al. (2011) measured operational and market efficiency of 26 major shipping companies including 15 container lines, 6 dry bulk, and 5 tanker firms. They used both Suitability, Feasibility, and Acceptability (SFA) and DEA models, and suggested that the efficiency estimation results from the two alternative approaches were similar in ranking for the sample firms. When it came to inputs and outputs for the market efficiency they used profits and the book value of equity as inputs, and the market value of equity as the output. For operating efficiency, they used total assets, number of employees, and capital expenditure as inputs and sales (in dollars) as the output. They found that container shipping companies were more efficient in terms of operating performance and less efficient in terms of market performance than other groups of shipping companies. The study differed greatly from Bang et al. (2012) because it compared shipping companies that were used in different lines of the shipping industry, i.e. container shipping companies vs. dry bulk carriers vs. tanker firms. Bang et al. (2012) only compared the efficiency of container shipping companies. The Panayides et al. (2011) study only considered financial inputs and outputs in dollar amounts unlike Bang et al. (2012), who considered operational statistics in units other than dollars.

There is only one major study in liner shipping efficiency using DEA. The study by Bang et al. (2012) measures two dimensions of relative efficiency of container shipping lines. One is operational efficiency. This means maximizing operational output(s) or the amount of cargo carried by liners, by utilizing fleet capacity and the number of ships deployed as operational inputs. The other is financial efficiency, which is concerned with maximizing financial outputs (revenues and operating profit), and utilizing total assets and capital expenditure as financial inputs. The study currently being undertaken will differ from the above because the fleet capacity will be separated by owned and charted ships and owned ship capacity and chartered ship capacity. There will be two outputs: cargo carried in TEUs as an operational output and revenue financial output. According to Alphaliner (2015) the container shipping industry judges companies by TEUs transported and by revenue, that is why these two outputs are being used in this study's DEA model.

The current study will consider more operational aspects and only include revenue as a financial output. The current study predicts that companies with the best fleet utilization will have the highest efficiency scores even when their overall revenue may be less than other companies.

Input & Output Variables Analysis

This study uses the CCR version for the data envelopment analysis because this model is used in situations where outputs increase proportionally for increase in inputs. The study considers 12 Decision Making Units (DMUs) comprised of the following liner shipping companies: Maersk, CMA CGM Group, Hapag- Llyod, Hamburg Sud Group, Hanjin Shipping, OOCL, MOL, Yang Ming Marine Trans., NYK Line, K Line, Hyundai M.M, and ZIM). These 12 liner companies were chosen because they are in the top 100 liner shipping companies according to Alphaliner (2015) and have public information published on their companies' operations. There are four inputs and two outputs in this study. The inputs are operational. The inputs are number of owned ships, TEU capacity of owned ships, number of charted ships, and TEU capacity of charted ships. The outputs are number of TEUs transported by the company's fleet and revenue of the liner shipping company.

Inputs

Number of owned ships is based on the number of ships a company owns.

Number of chartered ships is based on the number of ships owned by other companies, but that are contractually in service to the charting company for a certain period of time to make shipments between ports like an owned ship.

TEU capacity stands for Twenty Foot Equivalent, the industry standard for measuring how many containers a ship can hold that are twenty feet in length. TEU capacity is separated by owned fleet TEU capacity and chartered fleet TEU capacity.

Outputs

Volume of TEUs transported by each company is the number of TEUs transported in a year by their fleets.

Revenue is the other output. Each company makes so much revenue from their operations.

These four inputs and two outputs will be plugged into a DEA model to determine the relative efficiency of the twelve DMUs.

DEA Model

DEA is a non-parametric approach to relatively evaluate the performance of a homogeneous set of entities referred to as Decision Making Units (DMU's) in the presence of multiple weight inputs and multiple weight outputs. DEA was first initiated by Charnes, Cooper and Rhodes (CCR) (Charnes et al. 1978) to compare the efficiency of multiple service units that provide similar services by considering their use of multiple inputs in order to produce multiple outputs.

DEA is a linear programming model that attempts to maximize a DMU's efficiency, expressed as a ratio of outputs to inputs, by comparing a particular unit's efficiency with the performance of a group of similar service units that are delivering the same service (Charnes et al. 1978). The units that are rated equal to 1 after the model is calculated are relatively efficient. The units that are rated below 1 after the model is calculated are considered inefficient. Because the DEA linear programming model was formulated by Charnes, Cooper, and Rhodes, it is referred to as the CCR Model (Fitzsimmons & Fitzsimmons, 2010):

> Definition of Variables: Let E_k, with k = 1, 2, …,K, be the efficiency ratio of unit k, where K is the total number of units being evaluated. Let u_j, with j = 1, 2, …, M, be a coefficient for output J, where M is the total number of output types considered. The variable uj is a measure of the relative decrease in efficiency with each unit reduction of output value. Let v_i, with I = 1, 2, …, N, be a coefficient for input I, where N is the total number of input types considered. The variable v_i is a measure of the relative increase in efficiency with each unit reduction of input value. Let O_{jk} be the number of observed units of output j generated by service unit k during one time period. Let I_{ik} be the actual units of input I used by service unit k during one time period. (Fitzsimmons & Fitzsimmons, 2010, p. 204)

Objective Function:

$$\text{Max } Ee = \frac{u_1 O_{1e} + u_2 O_{2e} + \ldots + u_M O_{Me}}{v_1 I_{1e} + v_2 I_{2e} + \ldots v_N I_{Ne}}$$

where e is the index of the unit being evaluated. This function is subject to the constraint that when the same set of input and output coefficients (uj's and vi's) is applied to all other decision making units being compared, no DMU will exceed 100 percent efficiency or a ratio of 1.0.

Constraints:

$$\frac{u1\ O1k + u2O2k + \ldots + uMOMk}{v1\ I1k + v2I2k + \ldots + vNINk} <= 1.0 \quad k = 1, 2, \ldots, K$$

where all coefficient values are positive and non-zero.

To solve this fractional linear programming model using standard linear programming software requires a formulation. Note that both the objective function and all constraints are ratios rather than linear functions. The objective function is restated as a linear function by scaling the inputs for the unit under evaluation to a sum of 1.0.

$$\text{Max } Ee = u_1O_1e + u_2O_{2e} + \ldots + u_MO_{Me}$$

Subject to the constraint that:

$$v_1I_{1e} + v_2I_{2e} + \ldots v_NI_{Ne} = 1$$

For each service unit, the constraints are similarly reformulated:

$$u_1O_{1k} + u_2O_{2k}\ldots + u_MO_{Mk} - (v_1I_{1k} + v_2I_{2k}\ldots + v_NI_{Nk}) <= 0 \quad k = 1, 2, \ldots, K$$

where:

$$uj >= 0 \quad j = 1, 2, \ldots, M$$

$$vi >= 0 \quad i = 1, 2, \ldots, N$$

Sample Size

The following relationship relating the number of service units K used in the analysis and the number of input *N* and output *M* types being considered is based on empirical findings and the experience of DEA practitioners:

$$K >= 2(N+M)$$

(Fitzsimmons & Fitzsimmons, 2010, p. 204)

Data Analysis and Results

This study considered 12 liner container shipping companies as its DMUs. The liner companies were selected because the companies were in the top 100 liner shipping companies in the world according to Alphaliner (2015) and had public financial statements for accuracy of information. These liner companies range in size from 7 to 285 owned ships; from 26 to 365 chartered ships; owned TEU capacity from 32,053 to 1,180,000 TEUs; chartered TEUs from 63,902 to 1,213,154 TEUs; volumes transported from 2,360,000 to 19,044,000 TEUs; and revenues from $2,991,100,000 to $23,729,000,000. The inputs of number of owned ships, owned ship TEU capacity, number of charted ships, and charted ships were entered into the DEA model. The outputs of TEUs transported and revenue were entered into the DEA model. Table 1 contains the input and output data for the 12 DMUs. It also contains mins, maxs, standard deviations, and averages for all of the data categories. Table 2 contains the DEA model results which are the efficiency scores for the 12 DMUs and the shadow prices for the inefficient DMUs. DMUs 1, 2, 3, 4, 5, and 7 were below 1 so they are inefficient. DMUs 6, 8, 9, 10, 11, and 12 were equal to 1 so they are efficient. Table 3 contains the results for improving the inefficient DMUs 1, 2, 3, 4, 5, and 7. For example, in order to be efficient, DMU 1 (Maersk) needs to keep the same current revenue and volume of TEUs transported, but to reduce its fleet size of both owned and charted ships and to reduce its TEU capacity for both owned and charted ships.

Results Data Tables

Table 1. Input and Output Data for 12 DMUs Representing Liner Container Shipping Companies

		Outputs		Inputs			
		In TEUs (Twenty Foot Equivlent Units)	In USD	Owned		Chartered	
DMU	Operator	Volume Transported in TEUs	Revenue	Ships Owned	TEU Capacity	Chartered Ships	TEU Capacity
1	Maersk	19,044,000	23,729,000,000	285	1,830,000	305	1,132,000
2	CMA CGM Group	12,995,000	15,241,700,000	88	603,820	375	1,213,154
3	Hapag- Llyod	7,401,000	9,764,795,330	71	521,640	106	444,360
4	Hamburg Sud Group	4,101,000	6,261,000,000	48	310,000	82	315,000
5	Hanjin Shipping	4,624,140	4,690,479,000	37	274,000	58	344,000
6	OOCL	5,575,874	5,927,023,000	51	362,325	52	199,096
7	MOL	3,994,000	6,949,842,624	16	98,152	79	456,302
8	Yang Ming Marine Trans.	4,018,355	3,812,657,751	75	499,488	26	63,902
9	NYK Line	4,000,000	6,827,780,911	48	279,294	51	216,429
10	K Line	4,100,000	5,946,525,728	12	80,150	56	310,367
11	Hyundai M.M	3,023,000	3,983,763,060	23	173,000	34	218,000
12	ZIM	2,360,000	2,991,100,000	7	32,053	74	326,211
	Average	6,269,697	8,010,472,284	63	421,994	108	436,568
	Min.	2,360,000	2,991,100,000	7	32,053	26	63,902
	Max	19,044,000	23,729,000,000	285	1,830,000	375	1,213,154
	Standard Deviation	4894505.994	5928957355	74.42562894	479168.5746	111.422075	360570.3373

Note: All data is from is the Companies' annual reports and from Alphaliner.com collected for the year ending 2015. Data was retrieved in November 2016.

Conclusion

This study employed Data Envelopment Analysis to analyze the efficiency of different-sized liner shipping companies. The results of the DEA model show that the companies with the smaller sized fleets seem to be more efficient. The smaller companies seem to have used their TEU capacity more efficiently to move more containers around the world. Whether ships were owned or chartered did not seem to affect the results as much as TEU capacity to TEU volume transported might have affected efficiency scores. This study provides the container shipping industry with information about the efficiency of companies with different size fleets and TEU carrying capacity. The industry should realize that fleets that seem to turn over more containers in their volume of TEUs transported to the size of their fleets and carrying capacity are more efficient. So, liner shipping companies that are smaller and turn over shipments faster seem to be more efficient. One possible explanation for the seemingly large amount of excess capacity is the shipping routes. The larger liner companies tend to run longer routes, while the smaller liner companies run shorter routes.

Limitations

This study was limited by available information and the specificity of the information available. Even though volume of transported TEUs is an industry standard of how much a company ships, it does not mean that those containers are filled and generating revenue. A factor like this would skew results. Liner shipping companies run many different kinds of routes with their ships. Some companies' ships make short trips up and down a coast, while other companies' ships do long ocean crossings. The difference in shipping routes that a company operates their fleet in could have a large bearing on how fast a turn around they can have on the volume of TEUs the company can transport. Companies

Table 2. Efficiency Scores and Shadow Prices

	DMU 1	DMU 2	DMU 3	DMU 4	DMU 5	DMU 6	DMU 7	DMU 8	DMU 9	DMU 10	DMU 11	DMU 12
OBJ	0.6896	0.6920	0.8474	0.7515	0.8665	1	0.9384	1	1	1	1	1
U1	1.7705E-08	5.3252E-08	3.0581E-08	4.3887E-08	1.8738E-07	9.4808E-08	0	2.4886E-07	0	0	1.4058E-07	0
U2	1.4852E-11	0	6.3606E-11	9.1283E-11	0	7.9528E-11	1.3503E-10	0	1.4646E-10	1.6817E-10	1.4434E-10	3.3433E-10
V1	0	0	0.0052	0.0074	0.0083	0	0	0	0	0	2.4852E-03	0
V2	2.6866E-07	5.0455E-07	0	0	0	1.4386E-06	8.8973E-06	1.4474E-06	1.7577E-06	2.0182E-06	7.2279E-07	2.0877E-05
V3	0	0	0	0	0.0119	0	0.0016	0	0	0	2.4053E-02	0
V4	4.4907E-07	5.7317E-07	1.4222E-06	2.0411E-06	0	2.4046E-06	0	4.3355E-06	2.3522E-06	2.7008E-06	0	1.0141E-06
CONST0	0.6896	0.6920	0.8474	0.7515	0.8665	1	0.9384	1	1	1	1	1
CONST1	0	0	0	0	0	0	0	0	0	0	0	0
CONST2	0	0	0	0	0	0	0	0	0	0	0	0
CONST3	0	0	0	0	0	0	0	0	0	0	0	0
CONST4	0	0	0	0	0	0	0	0	0	0	0	0
CONST5	0	0	0	0	0	0	0	0	0	0	0	0
CONST6	2.4421	0.6467	0.6553	0.1170	0.5342	1	0	0	0	0	0	0
CONST7	0	0	0	0	0	0	0	0	0	0	0	0
CONST8	0	0	0	0	0	0	0	1	0	0	0	0
CONST9	1.3478	0	0.4348	0.5514	0	0	0	0	1	2.22045E-16	0	0
CONST10	0.0087	2.2901	0.4897	0.3032	0.4014	0	1.0734	0	0	1	0	0
CONST11	0	0	0	0	0	0	0	0	0	0	1	0
CONST12	0	0	0	0	0	0	0.1895	0	0	0	0	1

Table 3. Improvements for Inefficient DMUs

How to improve				Owned		Chartered	
DMU	Operator	Volume Transported in TEUs	Revenue	Ships Owned	TEU Capacity	Chartered Ships	TEU Capacity
1	Maersk	19044000	23729000000	**189**	**1261976**	**196**	**780632**
2	CMA CGM Group	12995000	17450772841	**60**	**398123**	**84**	**376564**
3	Hapag- Llyod	7401000	9764795330	**60**	**398123**	**84**	**376564**
4	Hamburg Sud Group	4101000	6261000000	**36**	**220696**	**51**	**236723**
5	Hanjin Shipping	4624140	5552899711	**32**	**225712**	**50**	**230930**
6	OOCL	5575874	5927023000	51	362325	52	199096
7	MOL	4848187	6949842624	**14**	**92107**	**74**	**394970**
8	Yang Ming Marine Trans.	4018355	3812657751	75	499488	26	63902
9	NYK Line	4000000	6827780911	48	279294	51	216429
10	K Line	4100000	5946525728	12	80150	56	310367
11	Hyundai M.M	3023000	3983763060	23	173000	34	218000
12	ZIM	2360000	2991100000	7	32053	74	326211

running short routes might be able to ship more containers because their trips are shorter. This study did not consider these two issues that could potentially affect shipping efficiency of the liner companies. Future research might want to look into these factors mentioned above.

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