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Analysis of U.S. Port Efficiency Using Double-Bootstrapped DEA*

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이중 부트스트랩 DEA 활용한 미국항만 효율성 분석

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국문요약

최근 제4차산업 혁명의 적용으로 물류비 절감을 위한 공급사슬 측면의 경쟁이 더욱 치열해지면서 항만전문가들은 효율적인 항만운영 비즈니스모델을 개발에 관심이 집중되어 있다. 본 연구는 세계 여러 항만 중 미국 항만 물류량이 많은 항만을 분석하여 적용 모델을 구성하고자 한다. 본 연구는 주로 미국 항만의 생산성을 연구하기 위해 DEA(Data Enclapment Analysis) 기법을 사용하였으며 미국 항만 운영의 성장 동력을 추가 조사하기 위해 Simar & Wilson(2007)이 제안한 이중 부트스트래핑 DEA 알고리즘을 적용했다. 본 연구에 사용된 외부 변수는 항만의 길이, 항만의 심도, 위치, 면적, 에이커, 외화 비율 및 TEUChange에 포함되며, 이 중 항만의 길이, 에이커, 외화 비율 및 TEUChange에 유의했다. 최적 방법론 선택의 효과를 평가하기 위해 관측 중단 모형(Tobit)을 적용하여 동일한 분석을 수행하고 서로 다른 두 기법에서 도출된 결과를 대조하였다. 본 연구에서 얻은 결과를 바탕으로 경영상의 시사점을 제안하고 결론을 도출하였다.

주제어: DEA알고리즘, 토빗모형 분석, 미국항만생산성

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Ⅰ. Introduction

Spurred largely by technology one of the greatest changes observed in business practices today is the expansion of supply chain domain from local to the global scale. Amid the trends of the globalization of business, container transportation through the ports has become the primary method for international movement of products due to its scale and scope of economy.

Port authorities have experienced extreme pressure due to increased competition in supply side to reduce operational costs. (Woo, Pettit, and Beresford 2011). In response to the necessity of developing the model for efficient port operations from the practitioner's perspective, vast amount of research in academia on the study of international port performance have been conducted in the past (Cullinane et al, 2004, Nguyen et al, 2015, Pjevcevic et al, 2011).

Among numerous ports in the world, U.S. ports are of our primary interest due to the great cargo volume transacted in North America; 13 of the top 15 ports in North America, accounting for 97 percent of all cargo handled, are located in the U.S. (Worldatlas, 2018). In this vein, we will attempt in our study to enhance the understanding of productivity, particularly for U.S. ports to provide useful insights to the industry professionals in the seaport organizations.

In methodology for measuring the performance of a certain business group, three techniques have been widely applied in the industry and academic arena: single-factor analysis, multi-factor analysis represented chiefly by DEA (Data Envelopment Analysis), and SFA (Stochastic Frontier Analysis).

Single factor analysis undertaken with respect to port operations primarily aims to find the port productivity highlighting only one factor among others such as total TEU (twenty foot equivalent unit). Numerous institutions for transportation have published rankings on the performance of ports in their periodicals or on the internet based on one performance factor. Some of those institutions that are actively engaged in transportation development paying attention to a single component include Bureau of Transportation Statistics, JOC (Journal of Commerce), American Association of Port Authorities, International Association of Ports and Harbors, World Shipping Council, and so on. The single factor technique for the evaluation of port performance accounts for great benefits stemming from simplicity and convenience in its estimation process. However, the rankings derived from the single factor method do not represent a comprehensive outcome due to the omission of some important factors within the management of companies such as costs or other output components.

Over the last few decades, in order to circumvent the weakness of the single factor method, many efforts have been exerted in the academic circle to approach dynamically employing a multi factor method for the measurement of efficiency in relation to productive activities (Cullinane et al, 2004). DEA, a nonparametric and linear programming based approach, became a predominant method for the productivity measurement incorporating many factors by separating the factors into input and output components (Chen et al, 2016, Mo et al, 2018, Marlow and Paixão 2002, Tongzon, 1995). Our study primarily applies this technique as well for the investigation of performance evaluation for U.S. ports. First, SFA is another method adopted among academicians for the research of productivity measurement. However, the method is beyond the scope of our study and hence we will curtail the discussion on the topic. Those readers who are interested in the SFA method are advised to refer to the topic that appears in the works in the academic boundary such as Aigner, Lovell, and Schmidt (1977), Green and Mayes (1991) and Battese and Coelli (1995).

Second, As the investigation of efficiency measurement evolves, scholars have attempted to determine the sources of productivity drivers for underlying firms implementing the two-stage DEA approach, which will shed light on the relation between the firms and its surroundings. In order to add contributions to this endeavor our study essentially navigates on delineating the environmental conditions encompassing the U.S. port operations. In a succinct manner, we can describe the purpose of our research as "What are the significant environmental factors that relate to the competitiveness and efficiency for the operation of major ports in the U.S.?

II. Literature Review

Considerably large amounts of research have been conducted to investigate the productivity in diverse industries applying the DEA technique since the inception of the CCR model in 1978 by Charnes, Cooper, and Rhodes (Charnes et al, 1978). In essence, the DEA technique is to derive efficiency scores for underlying firms based on nonparametric and linear programming methods. The method initially constructs the efficient frontier from the sample firms and computes the productivity index according to the proximity to the frontier.

Despite some crucial features in the DEA construction, we will make minimal efforts in our research to portrait the theory aspect of the model since our interest lies more on the application of the model rather than developing it.

Hence, we will mainly review the reports in this section that applied the DEA model endeavoring to gauge the productivity, particularly on ports starting with the studies on Chinese ports.

The astonishing economic development of the country demanded her to update unceasingly the infrastructure of her port operations, inducing many researchers to engage in the performance estimation of the ports in China. Ding et al (2015) attempted to investigate the productivity change for 21 small and medium sized port container terminals in China using DEA and MPI (Malmquist Productivity Index) and identified the contributing factors that have impacts on the efficiency changes. Their outcome uncovers that state-owned shipping lines were major players that have impacts on the product efficiency. Another study conducted by Zheng and Park (2016) related the issue by comparing the performance of ports in China and Korea. Their contribution lies on the fact that the performance rate of ports between the two countries were similar while previous works argued that the efficiency level of ports in China were superior to that of ports in Korea.

Some efforts to evaluate port efficiency in countries other than China were also made applying the DEA model. Al-Eraqui et al (2008) assessed the efficiency of 22 seaports in the Middle East and East African region drawing the conclusion that small ports were more efficient than relatively large ports in the region.

The study of Wanke and Barros (2015) was concerned with evaluating public-private partnerships for major public ports in Brazil reporting the positive influence of partnership on port scale efficiency.

Our work largely deals with identifying the environmental elements that might affect the operations for U.S. ports at the second step utilizing DEA scores obtained from the initial analysis. One noteworthy study on environmental factors for port operations is the research undertaken by Wanke and Barros (2016). They used the censored (Tobit) regression model to define the efficiency of 27 Brazilian ports from the panel data for periods ranged 2007 through 2011. Their regression analysis points out that eight variables out of ten used were significant. Most of the significant variables were referring to accessibility components such as highway, riverine, or railroad access and thus they are more vital factors than physical infrastructure in relation to the improvement of scale efficiency for the operation of Brazilian ports. Other scholars like Bang et al (2012) also engaged in the two-stage model using the censored (Tobit) regression analysis. Their attempt was to deduce the crucial factors that have impact on the operational and financial performance for 14 major shipping container lines. The outcome relates that the firm size (in terms of TEU capacity), ship size, the ratio of chartered vessels, use of new vessels, and the formation of alliances were significant elements that have operational impacts on the shipping liner companies in a positive manner.

Academic circles holds abundant reports that applied the censored (Tobit) model in other areas than the port operations. For example, Kirjavainen and Loikkanen (1998) applied the model in the second stage to study the efficiency differences for schools in Finland. Jackson and Fethi (2000) attempted to use the model to test commercial banks in Turkey. Besides, the usage of the Tobit model also appeared in the works of Fethi et al (2000), Loikkanen and Susiluoto (2002), Kutlar et al (2013), Bravo-Ureta et al. (2007), Vestergaard et al. (2002), Ruggiero and Vitaliano (1999), Chilingerian (1995), Oum and Yu (1994) and Bjurek et al. (1992).

Despite the existence of many academic literatures studying exogenous factors employing the censored (Tobit) regression model, Simar and Wilson (2007) argued that the model is not appropriate to apply when it uses DEA index as a dependent variable in the second stage. They made two critical observations in their arguments regarding the invalidity of using the censored (Tobit) model: First, the efficiency derivation might be biased since the ratings were derived from the data set without taking DGP (data generating process). this ultimately leads to the sensitivity to sampling errors. The second issue, which is more serious, is that since the efficiency scores are derived within the sample or the "reference set" (Cooper, Tone, and Seiford, 2007) the interdependence of the sample values might cause the correlation among the scores calculated. The correlation effect might result in the second stage estimates being inconsistent and biased when we apply censored (Tobit) regression analysis. Besides, the Tobit model accommodates the truncation of the dependent variable only in one direction. In other words, it cuts the variable in the negative direction but it still allows the range of the variable to be infinite in the positive direction.

To circumvent these issues, Simar & Wilson (2007) proposed using the truncated regression model along with efficiency index derived from the double bootstrapping process.

Accordingly, we will employ Simar & Wilson (2007) algorithm to investigate the environmental effects for operations in U.S. major ports.

A number of scholars have applied the Simar & Wilson algorithm (2007) for firms in a wide range of industries since the algorithm was first published. For example, Barros and Dieke (2008) applied it for the airports analysis; Barros et al (2010) for the Brazilian football clubs; Balcombe et al (2011) for rice farming in Bangladesh; Barros and Assaf (2009) for Angola Oil blocks; Lee and Worthington (2014) for mainstream airlines and low cost carriers in the U.S. airline industry; Assaf and Agbola (2011) for Australian hotels during the period of years 2004-2007; Matousek, Nguyen, and Stewart (2016) for banks in Vietnam using 10 years of panel data; Alexander, Haug, and Jaforullah (2010) for the secondary schools in New Zealand; Halkos and Tzeremes (2012) for European football clubs; Lee (2011) for 37 Australian universities; Wijesiri, Vigano, and Meoli (2015) for microfinance institutions in Sri Lanka; Assaf and Josiassen (2011) for UK airlines during the period of years 2002-2007.

We also observed a group of scholars who adopted the algorithm in their research to study particularly the port operations as well. One of them is Barrosa and Managi (2008). They attempted the analysis of Japanese seaports to navigate the effectiveness of strategic-group theory between the years 2003 and 2005. Their empirical findings suggest that the ports that implemented the port strategy performed better than those that did not adopt the strategy. They also discovered that asset configurations of the ports were a crucial factor in deciding the efficiency rate in the Japanese ports. Nguyen et al (2015) examined the performance of the three models; Standard DEA method, Stochastic Frontier Analysis, and the Bootstrapped method combined with the Simar & Wilson (2007) algorithm. Collecting 48 samples pertaining to the Vietnamese ports they derived efficiency scores of each and contrasted the features of the three techniques. From their empirical results, they argued that bootstrapped scores yielded better consistency and insensitivity to the sample size than the other two techniques.

Despite the publication of the research conducted on port operations for Japan and Vietnam, we failed to find the literature that applied the algorithm for the U.S. port operations. Hence, as far as authors know, our research is the first attempt to investigate the U.S. port operations employing the Simar & Wilson technique (2007).

III. Bootstrapping process

1. Obtaining efficiency scores through DEA technique

To conduct our research that aims to trace the driving source of efficiency for U.S. ports, the initial step is performing the DEA analysis to compute relative efficiency for individual DMUs (Decision Making Units) based on input and output elements of each unit. Although many variations of the DEA model were introduced in the academic literature, we will employ CCR input-oriented model in the first step due to its clarity of the model. The truncated regression analysis in the second stage will take the index obtained from the first step as a dependent variable.

The CCR input-oriented model is expressed as follows:

$$\begin{aligned} &\min \theta \\ &s.t. \\ &Y\lambda \geq y_0 \\ &\theta x_0 - X\lambda \geq 0 \\ &e\lambda = 1 \\ &\lambda \geq 0, (j = 1,2,3,...,J) \end{aligned}$$

2. Double bootstrapping

Addressing the two inherent flaws of the standard DEA technique and advocating the truncated regression model, Simar & Wilson (2007) suggested an algorithm that comprises the following seven steps.

1. Calculate $\hat{\delta}_i$ for each banks using the original data.
2. Apply Maximum likelihood to obtain in the truncated regression of $\hat{\delta}_i$ on z_i, to obtain an estimate $\hat{\beta}$ of β and an estimate $\hat{\sigma}_\varepsilon$ of σ_ε.
3. Repeat B_1 times to yield seventeen sets of bootstrap estimates $\left\{\hat{\delta}_{i,b} * \quad b = 1,...B_1\right\}$

   a) Draw ε_i from the $N(0, \hat{\sigma}_\varepsilon^2)$ distribution with left-truncation at $(1 - \hat{\beta} z_i)$.

   b) Compute $\delta_i * = \hat{\beta} z_i + \varepsilon_i$.

   c) Reconstruct pseudo data set $(x_i *, y_i *)$, where $x_i * = x_i$ and $y_i * = y_i \hat{\delta}_i / \delta_i *$.

   d) Obtain a new DEA estimate $\hat{\delta}_i *$ using the new data $(x_i *, y_i *)$.
4. Compute the bias-corrected estimator $\hat{\hat{\delta}}_i$ as follows:

$$\hat{\hat{\delta}}_i = \hat{\delta}_i - \hat{bias}_i$$

where $\hat{bias}_i = \left(\frac{1}{B_1} \sum_{b=1}^{B_1} \hat{\delta}_{i,b} * \right) - \hat{\delta}_i$

5. Use Maximum likelihood method to estimate the truncated regression of $\hat{\hat{\delta}}_i$ on z_i, yielding an estimate $\hat{\hat{\beta}}$ of β and an estimate $\hat{\hat{\sigma}}$ of σ_ε.
6. Loop over the next three steps (a-c) B_2 times to acquire a set of B_2 bootstrap estimates $\left\{(\hat{\hat{\beta}}_b *, \hat{\sigma}_b *) \quad b = 1,..., B_2\right\}$.

a) For each bank i=1,…n, ε_i is drawn from the $N(0, \hat{\hat{\sigma}})$ distribution with left truncation at $(1-\hat{\hat{\beta}}z_i)$.

b) For each bank i=1,…n, $\delta_i^{**} = \hat{\hat{\beta}}z_i + \varepsilon_i$ is computed.

c) Use Maximum likelihood method for the truncated regression of δ_i^{**} on z_i, to obtain an estimate $\hat{\hat{\beta}}^*$ of β and an estimate $\hat{\hat{\sigma}}^*$ of σ_ε.

7. Finally, using the estimate $\hat{\hat{\beta}}^*$ of β and $\hat{\hat{\sigma}}^*$ of σ_ε construct $(1-\alpha)$ per cent confidence intervals of the *j*-th element β_j of the vector β

IV. Finding and Discussion

1 Empirical DEA Results

DEA analysis requires using data for underlying firms. We acquired the data for our research from the BTS (Bureau of Transportation Statistics), a government operated institution. In our dataset, we included performance information for 25 U.S. ports in 2017.

Among many variables per port in the data file, we singled out Berth Length, number of Super PPX (Post-Panama Max) Cranes, number of general Terminals as input elements and Total TEU (twenty-foot equivalent unit) as an output component.

We relied on 'rDEA' package embedded in R to implement the algorithm proposed by Simar & Wilson (2007). However, we additionally had to code up in R for the necessary analysis since the package itself was not sufficient to conduct our research. For comparison purposes, we presented the implementation outcome of the same dataset using the censored (Tobit) model as well since the Tobit model is frequently used as an alternative to Simar & Wilson (2007) algorithm for studying environments of opertional efficiency. We also coded up in R for the analysis of the censored (Tobit) model.

Table 1. Descriptive Statistics

	Total TEU	Berth Length in feet	Number of Super PPX Cranes	Number of general terminals
Max	9,343	32,530	45	20
Min	57	1,850	0	1
Average	2,033	10,358	7.5	4.6
Median	1,108	8,422	0	3

The descriptive statistics in table 1 exhibits the characteristics of the variables used in our study. From the glance of the table, we can observe the skewness to right for all four variables, which accounts for the high concentration of capitals and high throughput in U.S. ports.

Table 2. DEA and Bootstrapped outcome

Ports	Total TEU Ranking	DEA score	Bias Corrected	Lower conf. int.	Upper conf. int.
Wilmington (DE)	20	1	0.93	0.89	1.03
Everglades	14	1	0.91	0.84	1.02
New Orleans	18	1	0.91	0.85	0.99
San Juan	12	1	0.88	0.79	1.06

New York, Jersey	3	1	0.82	0.7	0.94
Charleston	8	1	0.78	0.7	0.84
Savannah	4	1	0.66	0.6	0.71
Los Angeles	1	0.87	0.79	0.72	0.91
Mobile	25	0.85	0.79	0.74	0.87
Honolulu	11	0.83	0.78	0.74	0.88
Anchorage	19	0.81	0.76	0.71	0.84
Houston	6	0.81	0.74	0.71	0.82
Oakland	7	0.79	0.72	0.67	0.78
Long Beach	2	0.69	0.59	0.51	0.67
Wilmington (NC)	23	0.64	0.59	0.56	0.66
Jacksonville	13	0.62	0.54	0.49	0.66
Virginia	5	0.58	0.41	0.36	0.44
Tacoma	9	0.57	0.52	0.48	0.59
Boston	22	0.54	0.50	0.47	0.55
Philadelphia	17	0.48	0.42	0.38	0.50
Palm Beach	21	0.47	0.41	0.37	0.50
Baltimore	16	0.45	0.41	0.39	0.45
Seattle	10	0.45	0.37	0.33	0.40
Miami	15	0.38	0.32	0.28	0.36
Gulfport	24	0.23	0.21	0.19	0.23

As a preliminary step, we start our discussion by scrutinizing the impact of double bootstrapping technique conducted in the first stage of the analysis. Table 2 illustrates the DEA scores yielded from the standard CCR input model and bias corrected scores from bootstrapping process, and confidence intervals corresponding to each of the DEA scores in descending order. The first observation to make from the table is the discrepancy in ranking between the throughputs rates (Total TEU) displayed in the second column and the efficiency scores of each port shown in the third column. For example, the DEA scores of Wilmington (DE) through Savannah marked all one or hundred percent in efficiency level, whereas the TEU rankings are varied from three to twenty for the corresponding ports. Furthermore, the port with the highest TEU in U.S. earned 0.87 and the second highest in Total TEU marked as low as 0.69 or almost middle in terms of the ranking for DEA scores. Customarily throughput rates alone has been employed as a simple and convenient index for measuring port productivity. However, our empirical findings suggest that DEA numbers taking the input elements into account present considerable differences from the rankings based solely on a single factor. Hence, we encourage the port officials to consider using multi-factor analysis for the comprehensive estimation of port efficiency instead of relying on one element like Total TEU.

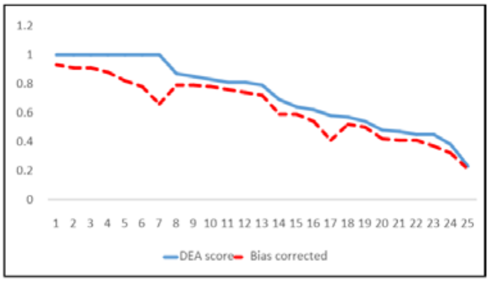

Figure 1. difference between DEA scores and Bias corrected scores

Figure 1 illustrates the difference between the DEA scores and the bias corrected scores derived from the bootstrapping procedure presenting a quick impression that there is a large gap between the two in certain units even from our eyeball estimation.

Delving into a more detailed comparison of the DEA scores and Bias Corrected scores in Table 2, we observe that the two are generally ranked in the same order.

However, indices of Savannah are well over-estimated in the standard model against those of the bootstrapped scores for Los Angeles, Mobile, Honolulu, Anchorage, Houston, and Oakland. Similar inconsistency also resides among ports in Charleston and Virginia. This phenomenon might be ascribed to the omission of DGP (Data Generating Process) on calculation of standard DEA scores, while the bias corrected scores were derived from bootstrapping. In addition, the high score zone generally reveals higher discrepancy between the standard index and bootstrapped scores than that in the low score area.

The 5th and 6th columns in the Table 2 exhibits high and low confidence interval adopting the estimation technique proposed by Simar & Wilson (2000). They suggested the way of constructing the estimated $(1-\alpha)$ per cent confidence interval of the j-th element β_j of the vector β, described as follows:

$$\Pr ob\left(Lower_{\alpha,j} \le \beta_j \le Upper_{\alpha,j}\right) = 1-\alpha ,$$

where α is some small value denoting the probability of committing type 1 error (we used the α level of 0.05 in our study) . $Lower_{\alpha,j}$ and $Upper_{\alpha,j}$ are calculated using the empirical intervals obtained from bootstrapped results, and thus

$$\text{Prob}(-\hat{b}_\alpha \le \hat{\hat{\beta}}_j * - \hat{\hat{\beta}}_j \le -\hat{a}_\alpha) \approx 1-\alpha$$

where $Upper_{\alpha,j} = \hat{\hat{\beta}}_j + \hat{b}_\alpha$ and

$$Lower_{\alpha,j} = \hat{\hat{\beta}}_j + \hat{a}_\alpha .$$

It is noteworthy to mention regarding the construction of confidence interval that since the algorithm computed the scores from empirical sampling distribution the average scores do not stand precisely on the middle point of lower and upper confidence intervals. The result in Table 2 informs that standard DEA numbers for New Orleans, New York & Jersey, Charleston, Savannah, Oakland, Long Beach, Virginia, Seattle, and Miami even exceed the upper confidence interval constructed from the bootstrapping technique.

2. Driving forces of U.S. port operations

Despite our efforts to study characteristics of efficiency scores yielded from the standard DEA model by contrasting against the structure of the bootstrapping technique, our primary interest lies in the identification of environmental factors that might affect U.S. port operations. According to the instructions delineated in the Simar & Wilson (2007) algorithm, we bootstrapped at the first stage to acquire the efficiency scores per U.S. port and then those were regressed on covariates chosen to identify the environmental variables. The external variables employed in our study comprise onDock Rail, ChannelDepth, Location, Area, Acres, ForeignCargoRatio, and TEUChange. Using the variables listed here, the second stage regression model can be expressed as follows:

$$\delta_i^{**} = \hat{\hat{\beta}} z_i + \varepsilon_i$$

Or, equivalently:

$$\delta_i^{**} = \beta_0 + \beta_1(OnDockRail)_i + \beta_2(ChannelDepth)_i + \beta_3(Location)_i + \beta_4(Acres)_i + \beta_5(ForeignCargoRatio)_i + \beta_6(TEUChange)_i + \varepsilon_i$$

On DockRail is a binary variable indicating whether the port has the on-dock rail system in place or not. The regression output in Table 3 uncovers that the null hypothesis regarding the on-dock rail system was rejected at the significance level of 0.01.

An on-dock rail system established in ports, which facilitates the speed delivery, will provide the ports with great strategic advantages since customers desperately want the products delivered to them immediately upon the arrival in the port to realize the reduction in inventory carrying cost.

Table 3. Truncated, Tobit, and OLS regression output

	Parameter	Estimate	Std. Error	t-value	Pr (>|t|)
Truncated	Constant	0.90	1.00	0.90	0.37
	OnDockRail	1.19	0.32	3.67	0.00 **
	ChannelDepth	-0.16	0.02	-0.98	0.33
	Location	-0.36	0.34	-1.05	0.29
	Acres	-0.00	0.00	-3.00	0.00 **
	ForeignCargoRatio	1.74	0.83	2.11	0.04 *
	TEUChange	0.06	0.01	4.68	0.00 **
	Sigma	0.46	0.09	5.33	0.00 **
Tobit	Constant	0.73	0.63	1.16	0.24
	OnDockRail	0.95	0.26	3.65	0.00 **
	ChannelDepth	-0.01	0.01	-0.93	0.35
	Location	-0.63	0.27	-2.33	0.02 *
	Acres	-0.00	0.00	-3.42	0.00 **
	ForeignCargoRatio	0.70	0.56	1.24	0.21
	TEUChange	0.05	0.12	4.42	0.00 **
	LogSigma	-0.77	0.17	-4.46	0.00 **

Significance level of 0.01: **, Significance level of 0.05: *

Congestion in some U.S. ports has become a large hamper to the speedy delivery. Port authorities in large ports in U.S. have attempted to relieve congestion problems by enlarging chassis pool, adjusting truck appointment, or extending gate hours (Tirschwell, 2015). However, as is evidenced in this research accommodating an on-dock rail system might be a good alternative to the gate moves or chassis pool due to port's direct access to the system for the delivery of products avoiding complexity in the land transportation. Consequently, we urge port professionals to reengineer the infrastructure of their facilities by investing their capital into the construction of the on-dock rail system if they do not have the system in place. Currently twelve ports in U.S. have the infrastructure equipped with the on-dock rail system.

Channel depth refers to the depth of waterway system or more practically a berth depth. It becomes a great restriction on the accessibility of containerships to the ports since post-Panamax containerships requires a channel depth of about 40 to 45 feet. The distribution of channel depth for major U.S. ports follows a normal distribution (Rodrigue, 2017). Based on our test the component was not significant. However, observing the trend that large ships are major players in the ocean field lately we expect that the channel depth will becomes a critical factor in the future. In practice, super post-Panamax containerships will be limited in their port calls when the channel is not deep enough.

The location is a binary variable to distinguish the place of the ports in the Pacific and Mountain Time zones versus Central and Eastern Time zones. The variable turned out to be insignificant in our analysis accounting for the indifference with respect to where they are located across the country.

The outcome of our test reveals acres of port has a non-positive influence on the ports' performance in U.S. asserting that large lot size does not ensure high efficiency. The empirical finding helps the practitioners in the maritime industry to realize how to adjust their capital investments since lots are not always utilized in a productive way according to this result.

Shipload cargo consists of domestic cargo and foreign cargo. Domestic cargo includes transportation done throughout the country, whereas foreign cargo refers to the movement of products on an international domain. As far as U.S. ports are concerned, some ports are heavily concentrated in domestic transportation and others are more engaged in foreign movement of products even though most ports handle both types of cargo movements. Our analysis dictates the significance of the variable. In other words, the efficiency of port operations increases as the ports put more emphasis on foreign trade, which might insinuate better utilization of port infrastructure established or achievement of increased throughput.

TEUchange refers to the percentage increase or decrease of the output from the previous year. Our empirical result indicates that the element is highly significant and might have a positive impact on the productivity for port operations in U.S.

In the Tobit model, OnDockRail, Acres, TEUChange are all significant at the alpha level of 0.01 and Location at 0.05. Location is the variable that is not significant whereas ForeignCargoRatio is in the Simar & Wilson (2007) technique. Generally, the two models show similar outcomes but not precisely the same outcomes, implying the weakness inherent in the Tobit model.

Ⅴ. Managerial Insights and Conclusion

Containerization has revolutionized the movement of products by lowering price and reducing the shipping time in the ocean particularly over the course of international trading. However, it requires a large amount of capital investment for ports to build infrastructures that facilitate container ships to load and unload products in efficient ways. Therefore, it naturally leads the maritime officials to intrigue about the productivity of their port operations. Considering that 13 of the top 15 ports in North America that handle 97 percent of all cargo transactions are located in U.S., we were concerned with the efficiency level of the major U.S. port operations. Among methods to measure productivity of U.S. ports, the DEA technique, a multi-factor technique and deterministic in nature has been adopted to undertake our research.

In our study, our primary interest lies not only in exploring the efficiency level of 25 U.S. ports employing the DEA method but also identifying the driving forces of port efficiency in the second stage applying the truncated regression analysis. Through the analysis, we were able to derive key managerial insights.

First, our work is the first attempt to employ the Simar & Wilson (2007) algorithm, which performs a two-stage DEA bootstrapping and truncated regression method to enhance the accuracy of extracting efficiency components for U.S. port operations. Considering the vulnerability of the censored (Tobit) model arising from the sensitivity to sampling errors, estimating efficiency applying truncated regression analysis with the bootstrapped index can present new insights. Nonetheless, no attempt has been made in the past for investigating the case of port operations in U.S using the Simar & Wilson (2007) technique.

Among others, we carefully decided the environmental variables for the analysis: on-dock rail, channel depth, location, acres, cargo ratio that foreign portion takes, and TEU change rate from the previous year. The outcome of our empirical test uncovered that on-dock rail, acres, cargo ratio, and TEU change were significant denoting that these covariates might affect the productivity of U.S. ports. Although the Simar & Wilson (2007) algorithm is the primary technique to achieve the aim of our research, we also experimented the analysis with the censored (Tobit) model for comparison purposes. The significant variables obtained from the two methods were not identical among them accounting for inherent issues residing in the censored (Tobit) model.

Second, the derivation of environmental variables is convincing. We urge port practitioners in U.S. to consider escalation of productivity by restructuring port infrastructure equipped with on dock rail system. Currently, certain large ports encounter congestion matters arising from heavy traffic inside the cities nearby the ports. Railroad systems might relax the congestion problem since the railway is a preoccupied facility used largely by ports and designated intermodals. The variable of acres turned out to be negatively significant implying that the lot size of the port does not ensure the productivity demanding better management of their facilities. Ratio that foreign trade takes from the entire cargo against the domestic portion of each port became significant as well implying high utilization of infrastructure by engaging more in the treatment of foreign products. From this finding, practitioners might need to ensure that their facility is designed to meet the characteristics of their own port since there are ports that domestic portion is predominantly larger than that of foreign trading in their transaction. The last variable significantly shown in the present study was TEU change from the previous year revealing that port efficiency is more sensitive to the output than the input elements. Practically, this empirical result implies that port managers should strive to develop strategies leading to the throughput increase besides maintaining facility and equipment at an efficient level. Surprisingly, channel depth of ports was not significant despite the growing concern today about the predicament of port calls for mega-ton size ships. Despite the empirical indication of insignificance for the variable from our research, we still encourage maritime officials to keep their windows open to observe the evolvement of ship size being operated in the ocean field.

In conclusion, there is a plethora of literature on productivity analysis applying DEA technique. Quite a large amount of literature found in the academic boundary handles topic on port management. However, a limited number of research was focused on the impacts of environmental variables in relative to the port operations. As a first experiment to study on U.S. port operations applying the Simar & Wilson (2007) algorithm, we present fresh insights to maritime professionals in regards to environmental matters around major ports in U.S.

In the future, practitioners need to keep paying attention to the productivity and quality of service that their ports provide to customers to take the leading role in the competitive transportation business.

Insights on the Korean ports, This study uncovers that the on dock rail system, acres, Foreign cargo ratio, and percentage change of the output from the previous year are the significant variables that affect the efficiency of the port operations in the U.S. The observations made in this work shed great light on the productivity of the Korean ports as well. Most of all, Korean ports should ameliorate the port infrastructure by incorporating more technical factors. Alth- ough Korean port authorities are aware of the importance of running smart ports and the smart components are being placed in their operations they need to spur the development of the smart system. Since the progress of conversion to the smart operating system in the U.S. ports is slower than that of Korea, technical advancement and the high equipment utilization in Korean ports will foster a competitive edge over the competition in the arena of global logistics.

In other words, the efficiency of the Korean port system will largely be affected by the structure of the logistics service in the smart port system. The blockchain, AI(Artificial Intelligence), Information processing functions using IOT(Internet of Things), robots including drone and automatic delivery devices, online fulfillment system, ASRS (Automated Storage and Retrieval System), Intelligent CCTV, and Twin systems placed in the smart maritime structure will propel the performance of the Korean port operations. The advanced GIS (Geographic Information System) that Korea developed will also be a promising feature when it is combined with marine equipment and other software for the operational efficiency of Korean ports.

In conclusion, the designing of the smart platform for logistics functions and the utilization of smart data and public data will greatly enhance the productivity of the logistics service to the customers. Hence, the efficiency of Korean ports will be maximized by taking advantage of the technical advancement available now and will be within the country despite the small port size and transaction volume in her marine business.

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Analysis of U.S. Port Efficiency Using Double-Bootstrapped DEA*

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Abstract

Due to increased competition in supply side to reduce operational costs, port professionals have experienced extreme pressure, which demanded academicians to develop the model for efficient port operations from the industry perspective. Among many ports in the world, U.S. ports are our primary interest to analyze in our study for its high volume of cargoes transacted in the U.S. ports. We primarily employed DEA (Data Envelopment Analysis) technique to research the productivity of U.S. ports and applied the algorithm of double bootstrapped DEA proposed by Simar & Wilson (2007) to further investigate the driving forces of the performance of U.S. port operations. The external variables employed in our study comprise onDock Rail, Channel Depth, Location, Area, Acres, ForeignCargoRatio, and TEUChange, out of which onDock Rail, Acres, ForeignCargoRatio, and TEUChange were significant. In order to evaluate the effects of methodology selection, we conducted the same analysis applying the Censored model (Tobit) and contrasted the outcomes drawn from the two different techniques. Based on the findings from this work we proposed managerial implications and concluded.

Key words: DEA, Simar & Wilson, U.S. ports, productivity, Environmental variables.