■ 論 文 ■

An Analysis of the Productive Efficiency and Competitive Strength of Container Ports using the DEA, Super-efficiency, and FDH Methods

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목 차

Key Words : Container Port, Productive Efficiency, DEA, Super-efficiency, FDH

ABSTRACT

The purpose of this paper is to investigate the productive efficiency and competitive strength of world container ports using the DEA, Super-efficiency, and FDH methods with the raw data from previous research by Jun et al.(1993). The super-efficiency measure examines the maximal radial change in input, outputs for an observation to remain efficient. Therefore, it provides a means of distinguishing between efficient observations, which would otherwise seem identical. FDH provides a good test mechanism for examining the practical implications of the choice available among alternative efficiency measures and orientations, because of the lack of convexity of its production possibility set. Both methods are complementary to DEA. This paper follows the traditional productivity analysis method overcoming the limitation of previous studies by using the DEA, FDH and Super-efficiency methods, and proposing to measure the relative competitive strength of worldwide container ports. The main empirical results of this paper are as follows: Firstly, the ports of Singapore, Hongkong, Kilrung, Busan, Tokyo, and Longbeach were found to be efficient in the CCR model. The ports of Felixstowe, Bangkok, Singapore, Hongkong, Kilung, Busan, Tokyo, and Longbeach were found to be efficient in the BCC model. Secondly, super-efficiency rankings under CRS and input-oriented model are as follows: Longbeach, Keelung, Singapore, Busan, Tokyo, and Honkong. However, it was difficult to differenciate the rankings under the VRS and input-oriented model, due to major difficulties posed by the ports of Singapore, Hongkong, and Longbeach. Thirdly, the FDH method shows that the inefficient ports are Bremerhaven, Antwerp, Le Havre, Kobe, Seattle, New York. The policy implications of this study are as follows: Firstly, when port authorities want to measure the international competitive strength of container ports and enhance their productive efficiency, they should consider the traditional method as well as introducing the Super-efficiency and FDH methods. Secondly, according to the analysis results of the super-efficiency and FDH methods, port authorities should recommend benchmarks ports and dominated ports as reference ports in order to enhance the productive efficiency of their container ports that have an efficiency rating of less than 1. Efficient ports whose efficiency ratings are over 1 in the input-oriented Super-efficiency model should also consider the usage of input and output elements used by more efficient ports.

I. Introduction

Container transport emerged, with the advent of containerships, container handling equipment and modern container terminals, in order to accommodate the new revolution of the multi-modal transport system. Container throughput in the world exceeded 100 million TEUs in 1992 and within 7 years, 1999, it recorded 200 million TEUs. International full containers increased by over 300% while transhipment increased ten-fold between 1981 and 1999 and presently 60% of world transhipment volumes are handled in Asia.[1]

Containerization, the movement of cargo in containers, is a system with an ocean component and a land component. There is a tendency to assume that if the terminal works at maximum efficiency, then the entire system benefits. In the most general sense productivity measures output per unit of input. Container terminal productivity deals with the efficient use of labor, equipment(or capital) and land. Terminal productivity measurement is a means of quantifying the efficiency of the use of these three resources.[2] However, there are additional factors affecting port efficiency, such as the level of technology applied, the degree of cooperation with handling and shipping organizations, the nature of port ownership and the manner in which this is manifested in port operations.[3]

In evaluating the performance and efficiency of a marine terminal, it is common practice to compare its actual throughput with its optimum throughput, where throughput may be measured as the tonnage or number of containers handled by the terminal in a specified time period. Thus whether the performance of the terminal is evaluated to be good or poor will depend upon the determined optimum throughput.[4]

In order to support trade oriented economic development, port authorities have increasingly been under pressure to improve port efficiency by ensuring that port

1) Lee, Jae-Wan, "Challenges Faced in Container Port Development in Asia and the Pacific Region," *Proceedings of 16th International Conference of The Korea Port Economic Association*, July 6-7, 2001, pp. 47-48.
2) Dowd T.J. and Leschine T.M., "Container Terminal Productivity: A Perspective," *Maritime Policy and Management*, Vol. 17, No. 2, 1990, pp. 107-108.
3) Roll Y. and Hayuth Y., "Port Performance Comparison Applying Data Envelopment Analysis(DEA)," *Maritime Policy and Management*, Vol .20, No. 2., 1993, pp. 153-154.
4) Talley W.K., "Optimum Throughput and Performance Evaluation of Marine Terminals", *Maritime Policy and Management*, Vol. 15, No. 4, 1988, p. 327.

services are provided on an internationally competitive basis. Ports form a vital link in the overall trading chain and, consequently, port efficiency is an important contributor to a nation's international competitiveness. Thus monitoring and comparing one's port with other ports in terms of overall efficiency has become an essential part of many countries' microeconomic reform programmes.[5]

The purpose of this study is to propose the Super-efficiency and FDH(Free Disposal Hull) approaches for measuring the performance and efficiency of container ports in a competitive environment, because efficiency ratings are a powerful management tool for port operators and should be a significant starting point for regional and national studies of container port operation. Moreover, the Super-efficiency and FDH methods can overcome the difficulties associated with the previous DEA(Data Envelopment Analysis) model. The Super-efficiency method can be used to classify efficient container ports into ranking order, and the FDH mehtod can be used to classify the dominating port(efficient port) and dominated port(inefficient port) with respect to benchmark ports.

The paper is organized as follows. Secton II presents a brief survey of previous studies listed by author. Section III proposes the basic concept of Super-efficiency and FDH models and analyzes the result of empirical analysis. The data used for comparing the efficiency results(competitive strength) with empirical results comes from Jun, Il-Soo, Kim, Hak-So, and Kim, Bum-Jung(1993). Section IV concludes with a brief summary of this paper.

II. Survey of Previous Studies

Previous studies dealing with the productivity and efficiency of container ports have been widely published during the last 10 years. However, this present study focuse on the Super-efficiency and FDH methods which are closely related with the DEA method. Therefore the reviews is limited to studies using the DEA method for analyzing the competitive strength of container ports. Y. Roll and Y. Hayuth(1993)[6], Jose Tongzon(2001), Valentine and Gray(2002)[7] used the DEA

5) Tongzon J., "Efficiency Measurement of Selected Australian and Other International Ports Using Data Envelopment Analysis," *Transportation Research Part A*, Vol. 35, 2001, pp. 113-114.

method. In Korea, Jun, Il-Soo, Kim, Hak-So, and Kim, Bum-Jung(1993)[8], Ha, Dong-Woo(1996)[9],The Federation of Korea Industries (1997)[10] and Oh,Sung-dong and Park,Ro-Kyung(2001)[11] presented the measurement of productivity with international competitive strength. A summary of the main previous studies is shown to <Table 1>.

〈Table 1〉 Summary of Main Previous Studies

Classification \ Author	J. Tongzon(2001)	Y. Roll and Y. Hyuth(1993)	V.F. Valentine and R. Gray(2002)
Country Analyzed	World	Israel	Europe and East-North Asia
Ports Analyzed	World Container Port	20 Hypothetical Ports	12 ports in Europe and North-East Asia
No. of Samples	16	20	12
Model Utilized	DEA Model: CCR and Additive DEA Model Outputs:Cargo Throughput, Ship Working rate Inputs: No. of crane, No. of container berth, No. of tugs Terminal area, Delaytime, Labor	DEA Model: CCR model Outputs: cargo throughput, level of service, user's satisfaction, ship calls Inputs: manpower, capital, cargo uniformity	A. Cluster Anlaysis 1. organisational structure 2. ownership B. DEA Analysis 1. Inputs: No. of Containers, Total length of berth, Container berth length 2. Outputs: Total tons throughput

6) Roll Y. and Y. Hayuth, "Port Performance Comparision Applying Data Envelopment Analysis(DEA)," *Maritime Policy and Management*, Vol. 20, No. 2, 1993. pp. 153-161.

7) Valantine V.C. and Gray R., "Competition of Hub Ports: A Comparison between Europe and the Far East," *Proceedings of the 2nd International Gwangyang Port Forum and Int'l Conference for the 20th Anniversary of Korean Association of Shipping Studies*, Korean Association of Shipping Studies, April 24-26, 2002, pp. 161-176.

8) Jun, Il-Soo, Hak-So Kim and Bum-Jung Kim, *An Enhancement Plan for International Competition Power of Korea's Container Ports*, Marine Industry Research Institute, December 1993, pp. 219-258.

9) Ha, Dong-Woo, *An Analysis of Competition Surroundings among the Main Container Ports of East-North Area*, Korea Maritime Institute, December, 1996.

10) The Federation of Korea Industries, *The Enhancement Assignment for Competition Power of Ports*, Industry Policy 97-3, September 20, 1997.

11) Oh, Sung-Dong and Ro-Kyung Park, "A Method of Measuring the International Competitiveness of Container Ports: A DEA Approach, Focused on Productivity Analysis," *Journal of Korea Port Economic Association*, Vol. 17, No. 1, May 2001, pp. 27-51.

Scholar / Classification	Jun,I-S,Kim,H-S,Kim,B-J (1993)	Ha, Dong-Woo (1996)	FKI(1997)	Oh, S-D, Park, R-K (2001)
Country Analyzed	World	East-North Asia	World	World, North-East Asia
Ports Analyzed	20 Container Ports	7 Container Ports	-	28 Container Ports
No. of Samples	20	7	9-13	28
Model Utilized	1. Traditional Analysis Method (TGS/ha,TEU/m,TEU/set per year, TEU/ha per year, TGS Revolving Rate and Slot Revolving Rate) 2. Composite Utility Function Method (port location,port facilities, Total cargo and Transhipment, Port Fees, Service level, Mode of port operation)	TEU/Berth, TEU/m TEU/GC	Commission Records, Logistics Cost, Service level, Location	DEA Model: CCR and BCC 1. Inputs: Length of berth, No. of G/C, CY Area, CFS Area 2. Outputs: Total Cargo handled, Port Fees

III. An Analysis of Productive Efficiency and Competitive Strength of Container Ports using the DEA, Super-efficiency, and FDH Methods

1. Productivity measurements and factors affecting container terminal productivity

Containerization, the movement of cargo in containers, is a system with an ocean component and a land component. A container terminal is a facility which provides a package of activities and services to handle and control container flows from vessel to rail, or road, and vice versa. The container terminal is the physical link between the ocean and land modes of transport and a major component of the containerization system. The latter is a dynamic system within which various enterprises(carriers, terminal operators, stevedores, laborers, port authorities, shippers, railways, truckers, government and others) interact. Each influences productivity and at one time or another may be the primary determinant of or constraint on the control of productivity at a specific terminal or within the entire system.[12]

Efficiency can simply be expressed as a ratio of output to input, provided that one unit of input produces one unit of output. Therefore, in the case of multiple inputs and outputs, efficiency can be expressed as the sum of the weighted outputs divided by the sum of the weighted inputs.[13]

When we define productivity(Productive Efficiency) as the ratio of input to output, productivity and efficiency have the same meaning. Recently, total productivity, partial productivity, total factor productivity have been suggested as measures of productivity and efficiency. However, because of several factors which need to be considered, the limits on the productivity of a container terminal may be imposed by either physical or institutional factors or a combination of both. Dowd and Leschine(1990)[14] described the general components used for measuring the productivity of container ports.

2. DEA Model[15]

The DEA method enables the derivation of relative efficiency ratings within a group of analyzed units by applying a mathematical programming technique. It describes a kind of "efficiency envelope" which contains the most efficient units in the group. The efficiency of all other units is then compared with this envelope.[16] The DEA model can be subdivided into the CCR(Charnes, Cooper, and Rhodes, 1978) and the BCC(Banker, Charnes, and Cooper, 1984) models.[17]

12) Dowd T.J. and T.M., Leschine , *op.cit.*, p. 107.
13) Valentine V.F. and R. Gray, *op.cit.*, p. 167.
14) Dowd T.J. and T.M. Leschine, *op.cit.*, p. 111.
15) Borger, B.D. and K. Kerstens, "Cost Efficiency of Belgian Local Governments: A Comparative Analysis of FDH, DEA, and Econometric Approaches," *Regional Science & Urban Economics*, Vol. 26, 1996, p. 148.
16) For the main advantages of DEA with detailed explanation, refer to Roll and Hayuth, (1993), *op.cit.*, p. 154.
17) For more detailed explanation about CCR and BCC models, refer to the Tonzon (2001), pp. 116-119.

The main feature of the CCR model is that it assumes an environment of the constant returns to scale(CRS), whereas BCC model provides for variable returns to scale(VRS). Moreover, the BCC model can provide the scale efficiency, which comes from the CCR efficiency score divided by the BCC efficiency score. However, the DEA model has two major limitations. Firstly, the DEA model does not permit the classification of rankings among efficient ports which have an efficiency score of 1. Secondly, the DEA model can not easily determine which benchmark ports to use with the dominating and dominated ports. the super-efficiency model solves the first problem, while the FDH model overcomes the second limitation.

The deterministic non-parametric methods, which originate from the seminal contribution of Farrell(1957), are based on piecewise linear frontiers calculated using mathematical programming techniques. This approach(DEA) enables the derivation of relative efficiency ratings within a group of analyzed units by applying a mathematical programming technique. It describes a kind of efficiency envelop which contains the most efficient units in the group. The efficiency of all other units is then compared with this envelope.[18)]

A Basic DEA equation is as follow:

$$C(y)^{DEA} = [\, c \mid Y^t z \geq y, C^t z \leq c, \;\; I^t{}_k z = 1, z \in \;\; R^k{}_+] \tag{1}$$

where Y is the k x n matrix of observed outputs,
C is the k × 1 vector of observed costs,
z is a k × 1 vector of intensity or activity variables,
Ik is a k × 1 unit vector,
y is an nx1 vector of outputs,
c is a scalar representing a cost or budget level

This dual or indirect correspondence denotes the set of budget or cost levels, c, which allow us to produce the output vectors, y.

Cost efficiency, CEi, is calculated with respect to this DEA dual reference technology by solving the following linear program for each observation(see Fare

18) Roll Y. and Y. Hayuth, *op.cit*, p. 154.

and Grosskopf, 1985):

$$\min_{\lambda_{DEA}, z} \quad \lambda_{DEA}$$

$$s.t. \quad Y^t z \geq y^0, \; C^t z \leq c^0 \lambda_{DEA}, \quad I^t_k z = 1 \qquad (2)$$

$$\lambda_{DEA} \geq \quad z \geq 0$$

where y0 is an n×1 vector of outputs,

c^0 is the cost of the observation being evaluated,

λ^*_{DEA} is the optimal value of cost efficiency,

z^* is the optimal activity vector.

The optimal value of λ^*_{DEA} is smaller than unity for inefficient observations and equals unity for efficient observations. The optimal activity vector, z^*, indicates the projection point on the boundary of the convex hull relative to which observations are being evaluated.

3. Super-efficiency Model[19]

Andersen and Petersen(1993) explained super-efficiency as a means of distinguishing between efficient observations. In particular, the super-efficiency measure examines the maximal radial change in inputs and/or outputs for an observation to remain efficient, i.e. how much can the inputs be increased(or the outputs decreased) without becoming inefficient. The larger the value of the super-efficiency measure the higher an observation is ranked among the efficient units. Values of super-efficiency are therefore not restricted to 1(for the efficient observations), but can in principle take any value greater than or equal to 1.

19) Holvad, Torben, " An Analysis of Efficiency Patterns for a Sample of Norwegian Bus Companies," *mimeo*, University of Oxford, 2001. p. 282.(http://www.trg.dk/td/ papers/ papers01/Kol-tra/Holvad/606.pdf). For more detailed mathematical explanation on Super-efficiency, refer to the following paper.
Anderson P., and Petersen N.C., "A Procedure for Ranking Efficient Units in Data Envelopment Analysis," *Management Sciences*, Vol. 39, No. 10, pp. 1261-1264.

4. FDH Model[20]

Deprins *et al.*(1984) suggested the FDH model as an alternative to the DEA model (see, for example, Tulkens, 1993; Lovell and Vanden Eeckaut, 1994). It differs from DEA in that FDH drops the convexity assumption.[21]
The basic equation of FDH is as follow:

$$C(y)^{FDH} = [\, c \mid Y^t z \geq y, \quad C^t \leq c, \quad I^t{}_k z = 1, \quad z_i \in [0,\ 1]] \tag{3}$$

The difference between DEA and FDH is that a constraint is added: $z_i \in [0,\ 1]]$ for all i=1,...,k. In other words, consistent with allowing for non-convexity the elements of the activity vector z are constrained to be either zero or one. We observe that the optimal values($\lambda^*_{FDH}$and z^*) have an identical interpretation as in DEA, except that only one component of z^* can differ from zero.

5. Empirical Analysis and Explanation

This study focused on the measurement of productive efficiency of container ports with the evaluation of international competitive strength using the DEA, Super-efficiency, and FDH methods. Therefore, raw data which are used for an empirical analysis presented in this paper come from Jun, Il-Soo, Kim, Hak-So, and Kim, Bum-Jung(December 1993) whose paper dealing with international competitive strength was outlined in <Table 1>. In this section, the results of analyses using the DEA subcategories, CCR and BCC, and the super-efficiency methods will be shown. Secondly, the results of FDH analysis will be analyzed in

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20) Borger, B.D. and K. Kerstens, *op.cit.*, p. 149.

21) Non-convexity assumption of FDH gives the following economic meanings in terms of theory, empirical analysis, and managerial relevance: First, FDH rests on the most parsimonious postulate. Second, FDH reference set always fares best because its frontier always lies at least as close(and often lies much closer) to the data than those of DEA models. As a result, efficiency scores are always higher than those of DEA models. Third, FDH frontiers show the extremely conservative character. Therefore it is good for the measurement of past managerial performance of certain ports.(Tulkens, 1993, pp.206-207).

terms of the dominating & dominated container ports. Thirdly, the results of CCR, BCC, Super-efficiency and FDH will be compared along with an analysis of international competitive strength according to the efficiency rankings.

(1) Data

<Table 2> comes from Jun, Il-Soo, Kim, Hak-So, and Kim, Bum-Jung (December 1993, pp.276-278) for measuring the DEA, Super-efficiency, and FDH productive efficiency of container ports. The 20 container ports analyzed consisted of 6 ports from the European region (Bremerhaven, Hamburg, Rotterdam, Antwerp, Felixstowe, Le Havre), 9 ports from the Asian region(Bangkok, Singapore, Hongkong, Kaohsiung, Keelung, Busan, Tokyo, Kobe, Yokoham), and 5 ports from the American region(Los Angeles, Long Beach, Oakland, Seattle, New York).

(2) Selection of Input and Output Variables

Dowd and Leschine(1990) argue that the productivity of a container port/terminal depends on the efficient use of labour, land and equipment. The terminal productivity measurement, therefore, is a means of quantifying the efficiency with which these three resources are utilized. As a measure of the output of port production, Bernard(1991)[22] questions whether the usage of total tonnage handled at a port, should be applied to container terminals. Since the basic unit of output measurement is a container and since, irrespective of its size and (especially) of its weight, the facility inputs for the movement of any container are more or less the same, his argument is based on the fact that the use of total tonnage handled seems to be an illogical metric for the assessment of output at a container terminal or port.

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22) Bernard, J., *European Deep-Sea Container Terminals: Locational and Operational Perspectives*, PhD Thesis, University of Liverpool, 1991.

〈Table 2〉 Facilities, Cargos handled, and Port Fees of Main Container Ports in the World

Variables / ports	Length of Quay (m)	No. of G/C	CY Area (ha)	CFS Area (ha)	Total quantity of cargos transported (Thousand TEU)	Port Fees (One hundred million Won)
Bremerhaven	12246	25	196.8	18.3	1277	142678
Hamburg	7388	35	316.5	35.3	2189	166422
Rotterdam	17381	45	462.2	5.42	3766	118145
Antwerp	15235	30	441.9	34.68	1761	116729
Felixstowe	3376	19	151.2	7.36	1434	129751
Le Havre	6100	20	180	10.5	919	118604
Bangkok	1240	12	83	12.3	1171	43092
Singapore	3809	44	140	6.1	6354	87249
Hongkong	5411	40	158.1	12	6162	189363
Kaohsiung	4912	36	194.1	7.75	3913	84901
Keelung	3192	20	33.9	2.9	2005	84901
Busan	5573	16	87	2.8	2588	117349
Tokyo	3174	23	194.5	15.87	1784	159661
Kobe	6625	41	184.4	18.05	2635	158350
Yokohama	4750	31	168.1	8.83	1796	141958
L.A.	5847	33	307.8	3.35	2038	178456
Long Beach	6259	36	248.6	2.1	1768	247432
Oakland	5022	29	170.8	3.5	1195	171067
Seattle	4150	25	161.1	8.1	1155	120986
New York	8718	49	543.5	17.68	1865	171902

One possible solution for representing the output of a container terminal might be to measure the throughput in terms of the number of container movements across the quayside or, alternatively, in terms of the monetary value of these movements, as indicated by the revenue associated with this operation.[23] The first step toward conducting a relative efficiency analysis is to define the characteristics that best describe port performance, i.e. the outputs to be highlighted, the combination of production factors available to the port and the conditions under which the port operates which define the inputs.[24] For the purpose of this example, 2 outputs and 4 inputs were chosen. That is, Input variables are the length of quay, the number of G/C, Area of CY, Area of CFS. Output variables

23) Cullinane K., D.W. Song and R. Gray, "A Stochastic Frontier Model of the Efficiency of Major Container Terminals in Asia: Assessing the Influence of Administrative and Ownership Structures," *Transportation Research Part A*, Vol. 36, 2002, pp. 743-762.

24) Roll, Y. and Y. Hayuth, *op.cit.*, p. 154.

are total quantity of goods transported, port fees in <Table 2>.

(3) Empirical Analysis of Productive Efficiency of Container Ports using DEA, Super-efficiency, and FDH Methods

1) DEA Analysis[25]: CCR and BCC models

Ⅰ. Technical and Scale Efficiency under the Constant Returns to Scale(CCR Model) and Variable Returns to Scale(BCC Model)

<Table 3> which lists the efficiency results of the CCR model shows that The

〈Table 3〉 Efficiency Results of CCR Model

Ports \ Items	Efficiency Scores	Reference Group and Shadow Price	Rankings by Efficiency Scores
1. Bremerhaven	0.778	12. 1.216	13
2. Hamburg	0.672	13. 0.674, 12. 0.501	18
3. Rotterdam	0.695	17. 0.233 12. 0.178 8. 0.456	17
4. Antwerp	0.531	12. 0.995	19
5. Felixstowe	0.981	17. 0.196 12. 0.145 13. 0.403	7
6. Le Harve	0.818	12. 0.811 13. 0.146	11
7. Bangkok	0.905	13. 0.200 8. 0.128	9
8. Singapore	1.0		1
9. Hongkong	1.0		1
10. Kaohsiung	0.722	9. 0.293 12. 0.173 8. 0.261	15
11. Keelung	1.0		1
12. Busan	1.0		1
13. Tokyo	1.0		1
14. Kobe	0.7	12. 0.016 11. 0.466 17. 0.341 9. 0.171	16
15. Yokohama	0.788	17. 0.215 11. 0.420 13. 0.333	12
16. L.A.	0.837	12. 0.112 17.0.589 8.0.019 9.0.095	10
17. Longbeach	1.0		1
18. Oakland	0.925	17. 0.594 11. 0.257 12. 0.020	8
19. Seattle	0.742	13. 0.112 11. 0.103 9. 0.015 17. 0.369	14
20. New York	0.504	12. 0.181 17. 0.291 9. 0.001 13. 0.491	20

25) More detailed explanation, please refer to the followings.
Banker R.D., A. Charnes and W.W. Cooper (1984), "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis," *Management Sciences*, Vol. 30, pp. 1078-1092.
Charnes, A., W.W. Cooper and E. Rhodes (1978), "Measuring the Efficiency of Decision Making Units," *European Journal of Operational Research*, Vol. 2, pp. 429-444.

ports of Singapore, Hongkong, Keelung, Busan, Tokyo, and Longbeach are efficient. The efficiency of ports of Felixstowe, Le Havre, Bangkok, L.A., and Oakland are over 80%. An efficiency of 60-70% is observed for the ports of Bremerhaven, Hamburg, Rotterdam, Kasung, Kobe, Yokohama, and Settle. The ports of Antwerp and New York have shown the lowest efficiency.

〈Table 4〉 Efficiency Results of BCC Model

Items / Ports	Efficiency Scores	Reference Group and Shadow Prices	Scale Efficiency	Change of Scale Efficiency	Rankings	
					VRS	EOS
1.Bremerhaven	0.796	17. 0.195 12. 0.805	0.978	drs	13	16
2. Hamburg	0.684	12. 0.408 17. 0.267 9. 0.019 13. 0.306	0.983	drs	14	12
3. Rotterdam	0.707	17. 0.083 8. 0.331 12. 0.587	0.982	irs	15	11
4. Antwerp	0.532	12. 0.992 7. 0.008	0.997	irs	17	9
5. Felixstowe	1.0		0.981	irs	1	14
6. Le Harve	0.827	5. 0.205 12. 0.777 7. 0.017	0.988	irs	11	11
7. Bangkok	1.0		0.905	irs	1	20
8. Singapore	1.0		1.0		1	1
9. Hongkong	1.0		1.0		1	1
10. Kaohsiung	0.772	8. 0.435 12. 0.291 11. 0.091 7. 0.183	0.934	irs	18	19
11. Keelung	1.0		1.0		1	1
12. Busan	1.0		1.0		1	1
13. Tokyo	1.0		1.0		1	1
14. Kobe	0.7	12. 0.017 13. 0.006 11. 0.471 17. 0.337 9. 0.169	1.0		16	1
15. Yokohama	0.796	17. 0.186 11. 0.411 5. 0.111 13. 0.291	0.990	irs	13	10
16. L.A.	0.87	9. 0.031 17. 0.529 11. 0.32 5. 0.036 12. 0.083	0.962	irs	10	17
17. Longbeach	1.0		1.0		1	1
18. Oakland	0.944	17. 0.477 11. 0.325 12. 0.022 5. 0.176	0.980	irs	9	15
19. Seattle	0.804	5. 0.806 11. 0.192 7. 0.002	0.923	irs	12	18
20. New York	0.505	12. 0.161 5. 0.139 17. 0.264 9. 0.001 13. 0.434	0.998	irs	20	8

<Table 4> shows the technological efficiency under variable returns to scale with scale efficiency(EOS: economies of scale). The efficiencies of all ports are increased except for Kobe Port(0.7-->0.7), compared to those of <Table 3>.
The scale efficiencies of the ports of Bremerhaven, and Hamburg show the high levels(0.978 and 0.983 each) with decreasing returns to scale. All of the other ports except for the efficient ports show increasing returns to scale. When we measure the international competitive strength of the ports, according to the rankings of their efficiency scores, the rankings of both the CCR and BCC models except rankings of EOS(economies of scale) show similar results.

2) Super-efficiency Analysis

〈Table 5〉 Efficiency Results of Super-efficiency Model: CRS and Input-oriented

Items / Ports	Efficiency Scores	Reference Group(R. G.) and Shadow Price	Rankings by Efficiency Scores
1. Bremerhaven	0.778	12. 1.216	13
2. Hamburg	0.672	12. 0.501 13. 0.674	18
3. Rotterdam	0.695	8. 0.456 12. 0.178 17. 0.233	17
4. Antwerp	0.531	12. 0.995	19
5. Felixstowe	0.981	12. 0.145 13. 0.403 17. 0.196	7
6. Le Harve	0.818	12. 0.811 13. 0.146	11
7. Bangkok	0.905	8. 0.128 13. 0.200	9
8. Singapore	1.0(1.857)	4 times appeared as R. G.	1(3)
9. Hongkong	1.0(1.238)	5 times appeared as R. G.	1(6)
10. Kaohsiung	0.722	8. 0.261 9. 0.293 12. 0.173	15
11. Keelung	1.0(1.892)	4 times appeared as R. G.	1(2)
12. Busan	1.0(1.454)	11 times appeared as R. G.	1(4)
13. Tokyo	1.0(1.299)	7 times appeared as R. G.	1(5)
14. Kobe	0.7	9. 0.171 11. 0.466 12. 0.016 17. 0.341	16
15. Yokohama	0.788	11. 0.420 13. 0.333 17. 0.215	12
16. L.A.	0.837	8. 0.019 9. 0.095 12. 0.112 17. 0.589	10
17. Longbeach	1.0(2.212)	8 times appeared as R. G.	1(1)
18. Oakland	0.925	11. 0.257 12. 0.020 17. 0.594	8
19. Seattle	0.742	9. 0.015 11. 0.103 13. 0.112 17. 0.369	14
20. New York	0.504	9. 0.001 12. 0.181 13. 0.491 17. 0.291	20

<Table 5> and <Table 6> show the result of the super-efficiency measurement. The super-efficiency rankings of the efficient ports under the CRS and input-oriented models are as follows: Longbeach, Keelung, Singapore, Busan, Tokyo, and Honkong. However, it was difficult to differenciate the rankings under the VRS and input-oriented models, because of "big" as indicated in the <Table 6> in Singapore, Hongkong, and Longbeach.

〈Table 6〉 Efficiency Results of Super-efficiency Model: VRS and Input-oriented.

Items / Ports	Efficiency Scores	Reference Group(R. G.) and Shadow Price	Rankings by Efficiency Scores
1. Bremerhaven	0.796	12. 0.805 17. 0.195	13
2. Hamburg	0.684	9. 0.019 12. 0.408 13. 0.306 17. 0.267	14
3. Rotterdam	0.707	8. 0.331 12. 0.587 17. 0.083	15
4. Antwerp	0.532	7. 0.008 12. 0.992	17
5. Felixstowe	1.0(1.102)	6 times appeared as R. G.	1(8)
6. Le Harve	0.827	5. 0.205 7. 0.017 12. 0.777	11
7. Bangkok	1.0(2.560)	4 times appeared as R. G.	1(4)
8. Singapore	1.0(big)*	2 times appeared as R. G.	1(3)
9. Hongkong	1.0(big)*	4 times appeared as R. G	1(2)
10. Kaohsiung	0.772	7. 0.183 8. 0.435 11. 0.091 12. 0.291	18
11. Keelung	1.0(2.518)	6 times appeared as R. G	1(5)
12. Busan	1.0(1.532)	10 times appeared as R. G	1(6)
13. Tokyo	1.0(1.304)	4 times appeared as R. G	1(7)
14. Kobe	0.7	9. 0.169 11. 0.471 12. 0.017 13. 0.006 17. 0.337	16
15. Yokohama	0.796	5. 0.111 11. 0.411 13. 0.291 17. 0.186	13
16. L.A.	0.87	5. 0.036 9. 0.031 11. 0.32 12. 0.083 17. 0.529	10
17. Longbeach	1.0(big)*	8 times appeared as R. G	1(1)
18. Oakland	0.944	5. 0.176 11. 0.325 12. 0.022 17. 0.477	9
19. Seattle	0.804	5. 0.806 7. 0.002 11. 0.192	12
20. New York	0.505	5. 0.139 9. 0.001 12. 0.161 13. 0.434 17. 0.264	20

* The efficiency score indicated as "big" appears within the super-efficiency model when a unit remains efficient under arbitrary large increased inputs (input oriented) or decreased outputs (output oriented), respectively

3) FDH Analysis

<Table 7> shows the results of FDH Analysis including FDH efficiency scores, Benchmarks Ports, Number of dominated, Dominated ports, Number of dominating ports, Dominating ports. <Table 7> presents the input-oriented model. The input-oriented model aims at reducing the input amounts by as much as possible while maintaining at least the present output levels. The output-oriented model maximizes output levels, under at most the present input consumption. In general, the input-oriented model is recommended, because it gives rise to efficiency scores of 1 or below. It is easy to compare the efficiency scores among container ports compared to those of the output-oriented model.

In <Table 7>, various comments are in order. Firstly, the efficiency degrees provided in column 2 are " radial" ones, i.e. equiproportionate input reduction as suggested theoretically. Thus, the 0.5333 figure mentioned for the second quoted inefficient port means that had this port been operating on the assumed efficient frontier, it could have achieved the same output with only 53.33% of all its inputs(and possibly even less for some of them). It is also to be noted in column 7, that this method identifies, for each inefficient ports, one which dominates it, in the sense that it uses no more inputs and strictly less of some of them, while producing more of all of the outputs. This information is very useful for management, as it provides factual evidence of better achievement from within the enterprise. If so, what is measured as inefficiency is rather to be attributed to these characteristics. But if no such characteristics can be identified, the measure then reveals rather convincingly exactly what is sought for, namely situations where inputs are used I in larger quantities than elsewhere, with less of all output achieved, i.e., pure technical inefficiency. For each ports found inefficient, such a careful case by case examination of characteristics is called for, before the inefficiency diagnosis can be confirmed.[26)]

The main empirical results are as follows.

Firstly, in <Table 7>, the inefficient ports are Bremerhaven(0.9883), Antwerp (0.5333), Le Havre(0.95), Kobe(0.9756), Seattle(0.9385), New York(0.6735). And their benchmark ports(dominated ports) are Tokyo(Tokyo), Busan(Busan and

26) The explanation of the empirical results is cited from the following paper. Tulkens, H., " On FDH Efficiency Analysis: Some Methodological Issues and Applications to Retail Banking, Courts, and Urban Transit," *The Journal of Productivity Analysis*, Vol. 4, 1993, pp. 192-193.

Tokyo), Fellixstowe(Fellixstowe), Hongkong(Hongkong), Fellixstowe (Fellixstowe), and L.A(Hongkong and L.A.).

Secondly, the dominating(dominated) relationships among the ports are as follows. Fellixstowe(Le Harve, and Seattle), Hongkong(Kobe, and New York), Busan (Antwerp), Tokyo(Bremerhaven, and Antwerp), L.A.(New York).

Thirdly, although the port of Bremerhaven is slightly inefficient(0.9883), this port appeared 4 times as a benchmarks port. The explanation for this is associated

〈Table 7〉 Dominating & Dominated Container Ports Using FDH Method: Input-Oriented Model

Items / Ports	FDH Efficiency Score	Benchmarks Ports	No. of Dominated	Dominated Ports	No. of Dominating	Dominating Ports
1.Bremerhaven	0.9883	Tokyo	1	Tokyo		
2. Hamburg	1					
3. Rotterdam	1					
4. Antwerp	0.5333	Busan	2	Busan, Tokyo		
5. Felixstowe	1	Hamburg			2	Le Harve, Seattle
6. Le Harve	0.95	Felixstowe	1	Felixstowe		
7. Bangkok	1					
8. Singapore	1					
9. Hongkong	1	Bremerhaven			2	Kobe, New York
10. Kaohsiung	1					
11. Keelung	1					
12. Busan	1	Bremerhaven			1	Antwerp
13. Tokyo	1	Bremerhaven			2	Bremerhaven, Antwerp
14. Kobe	0.9756	Hongkong	1	Hongkong		
15. Yokohama	1					
16. L.A.	1	Bremerhaven			1	New York
17. Longbeach	1					
18. Oakland	1					
19. Seattle	0.9385	Felixstowe	1	Felixstowe		
20. New York	0.6735	L.A.	2	Hongkong, L.A.		

with input and output structure of these container ports.

Fourthly, the relationships between the benchmarks ports and the dominated ports are not all identical. 4 out of 6 cases are matched with each other: Tokyo(Tokyo), Busan(Busan and Tokyo), Fellixstowe(Fellixstowe), Hongkong (Hongkong), Fellixstowe(Fellixstowe), and L.A(Hongkong and L.A.).

4) Comparison with the previous study by Jun, Il-Soo, Kim, Hak-So, and Kim, Bum-Jung(1993)

Jun, Il-Soo, Kim, Hak-So, and Kim, Bum-Jung(1993, p.290) presented international rankings among container ports after measuring the several kinds of factors affecting the productivity of ports. The rankings are as follows:
1: Rotterdam(0.7163), 2: Singapore(0.7082), 3: Hongkong(0.6834), 4: Kaohsiung(0.6201), 5: Kobe(0.6012), 6: Hamburg(0.5646), 7: Yokohama(0.5552), 8: Antwerp(0.5476), 9: New York(0.5436), 10: Los Angeles(0.5350), 11: Bremerhaven(0.5323), 12: Longbeach(0.5185), 13: Tokyo(0.5182), 14: Felixstowe(0.5073), 15: Oakland(0.4939) , 16: Seattle(0.4905), 17: Le Havre(0.4901), 18: Busan(0.4852), 19: Keelung(0.4271), 20: Bangkok(0.4256).

CCR and BCC models of DEA can suggest rankings according to the efficiency scores. Therefore, it is possible to compare the international competitive strength values of the container ports with the efficiency scores.

However, it is difficult to calculate rankings, when using the input and output-oriented FDH models, because 15 out of 20 ports are efficient container ports, whereas only 5 are inefficient container ports(Antwerp, New York, Seattle, Le Havre, Kobe Ports). However, the relationship between the dominated & dominating ports and the benchmarks ports is shown for the implicit rankings among the efficient container ports.

5) Rankings of International Competitive Strength by Efficiency Score

In <Table 8>, if we compare the results of Jun,I-S et al.(1993) and Oh and Park(2001) with the other efficiency scores, with the exception of FDH, the rankings of 7 out of the 20 ports are roughly matched with each other. Therefore we can say that 35% of the rankings of international competitive strength as measured by their efficiency scores match each other among the international ports.

If we look more closely at the results of <Table 8>, there is a major difference between the rankings of Jun *et al.*(1993) and the other rankings. The main reason for this is that Jun *et al.*(1993) considered several factors for judging the competitive strength of the ports, whereas in this study we considered only 2 outputs and 4 inputs. Therefore, several sets of input and output should be used for measuring the productive efficiency in order to minimize the difference in the rankings according to the efficiency scores.

〈Table 8〉 Rankings of International Competition Power by Efficiency Score

Items / Ports	CRS	VRS	EOS	Jun,I-Se t.al (1993)	Oh and Park (2001)	Super-efficiency (CRS)	FDH	Matching the Ranking Order
1. Bremerhaven	13	13	16	11	11	13	15	Yes
2. Hamburg	18	19	12	6	8	18	1	No
3. Rotterdam	17	15	13	1	2	17	1	No
4. Antwerp	19	17	9	8	6	19	20	No
5. Felixstowe	7	1	10	14	15	7	1	No
6. Le Harve	11	11	11	17	19	11	17	Yes
7. Bangkok	9	1	20	20	14	9	1	No
8. Singapore	1	1	1	2	3	3	1	Yes
9. Hongkong	1	1	1	3	4	6	1	Yes
10. Kaohsiung	15	18	19	4	5	15	1	No
11. Keelung	1	1	1	19	17	2	1	No
12. Busan	1	1	1	18	12	4	1	No
13. Tokyo	1	1	1	13	13	5	1	No
14. Kobe	16	16	1	5	7	16	16	No
15. Yokohama	12	13	10	7	10	12	1	Yes
16. L.A.	10	10	17	10	1	10	1	Yes
17. Longbeach	1	1	1	12	16	1	1	No
18. Oakland	8	9	15	15	20	8	1	No
19. Seattle	14	12	18	16	18	14	18	Yes
20. New York	20	20	8	9	9	20	19	No

6) The Effectiveness of DEA, Super-efficiency and FDH Method as the Indicator of Port Competition Power

It is possible for us to make the following conclusion from <Table 3>, <Table 4>, <Table 5>, <Table 6>, <Table 7>, and <Table 8>.

Firstly, the CCR, and BCC models of DEA can provide the basic efficiency rankings for the container ports.

Secondly, the super-efficiency model can be used to provide the efficiency rankings among the efficient container ports which have an efficient score of 1.

Thirdly, the FDH method provides a useful method for suggesting the relative levels of efficiency and inefficiency, among the container ports in terms of productive efficiency, and thus provides an alternative approach to DEA for measuring the international competitive strength.

Fourthly, according to the results of the FDH method, the port authority of inefficient port should emulate the management techniques used by benchmark ports and dominated ports, in order to enhance their efficiency.

IV. Conclusion

Productive efficiency is the key factor in the economic activity of every sector of the economy and at various levels of the economic hierarchy. The measuring of productive efficiency constitutes in itself one of the crucial steps in the efforts that are made to raise productivity. Data on productive efficiency serves as a tool for policy-makers at all levels of economic activity and is essential for improving the efficiency with which the various systems operate. Ongoing reviews of productive efficiency, while evaluating what remains to be improved, should also investigate connections between productive efficiency and organizational characteristics. Identifying external factors that may influence productive efficiency, and defining the relationship between them, may help to create a management tool that could be used to develop a decision making system for productive efficiency-increasing activities.[27]

This study proposed the introduction of the DEA, Super-efficiency, and FDH

27) Sachish, A., (1996), *op.cit.*, p. 341.

methods for measuring the productive efficiency of container ports, for use as one of the nonparametric methods. The results of an empirical analysis of the input and output-oriented FDH model were shown with the CCR, BCC, and Super-efficiency models using the raw data provided by Jun, Il-Soo, Kim, Hak-So, and Kim, Bum-Jung(1993).

The main empirical results are as follows.

Firstly, the Ports of Singapore, Hongkong, Kilrung, Busan, Tokyo, and Longbeach were found to be efficient in the CCR model. The ports of Felixstowe, Bangkok, Singapore, Hongkong, Kilung, Busan, Tokyo, and Longbeach were found to be efficient in the BCC model.

Second, the super-efficiency rankings under the CRS and input-oriented model are as follows: Longbeach, Keelung, Singapore, Busan, Tokyo, and Honkong. However, it was difficult to differentiate the rankings under the VRS and input-oriented model, because of major difficulties involving Singapore, Hongkong, and Longbeach.

Thirdly, in <Table 7>, the inefficient ports are Bremerhaven(0.9883), Antwerp (0.5333), Le Havre(0.95), Kobe(0.9756), Seattle(0.9385), and New York(0.6735). And their benchmark ports(dominated ports) are the ports of Tokyo(Tokyo), Busan(Busan and Tokyo), Fellixstowe(Fellixstowe), Hongkong(Hongkong), Fellixstowe(Fellixstowe), and L.A(Hongkong and L.A.).

Fourthly, the dominating(dominated) relationships among the ports are as follows. Fellixstowe(Le Havre, and Seattle), Hongkong(Kobe, and New York), Busan(Antwerp), Tokyo(Bremerhaven, and Antwerp), L.A.(New York).

Fifthly, although the port of Bremerhaven is slightly inefficient(0.9883), it appeared 4 times as the benchmark port. This is related to the input and output structures of these container ports.

Sixth, the relationship between the benchmarks port and the dominated ports is not identical. 4 out of 6 cases are matched with each other: Tokyo(Tokyo), Busan(Busan and Tokyo), Fellixstowe(Fellixstowe), Hongkong(Hongkong), Fellixstowe(Fellixstowe), and L.A(Hongkong and L.A.).

Seventh, 35%(7 out of 20 ports) of the rankings of international competitive strength according to the efficiency scores match each other among the international ports.

The policy implications of this paper are as follows.

Firstly, the DEA, Super-efficiency, and FDH methods have the merits of providing an alternative to DEA for measuring the productive efficiency of container ports.

Secondly, the FDH method is superior to DEA in terms of its being able to reveal the dominated port, dominating port, and benchmark port.

Thirdly, when port authorities want to measure the international competitive strength of container ports and enhance their productive efficiency, they should consider both the traditional method as well as the introduction of the Super-efficiency and FDH methods including DEA.

Fourthly, according to the analysis results of the FDH method, port authorities should recommend benchmarking ports and dominated ports as reference ports in order to enhance the productive efficiency of container ports having an efficiency score of less than 1.

The limitation of this study are as follows.

Firstly, several sets of input-output models are not suggested for finding out the exact elements or factors affecting the productive efficiency.

Secondly, the relationship between DEA, Super-efficiency, and FDH requires a more detailed analysis, and this will be the object of our next paper.

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논문투고일: 2002. 3. 25.
1차 심사일: 2002. 4. 22.