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Economic Efficiency of the International Port System: An Analysis through Data Envelopment

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Abstract

In this paper based on the methodology of analysis of Data Envelopment (DEA), the overall technical efficiency was determined, as the allocative efficiency and the economic efficiency for the 32 ports that handled the greater number of TEUs in the international context for 2012 according with the study of World Shipping Council (2014) and Manzanillo port that is the most representative of Mexico´s ports this indicator. The results shows that in general for 2012, most of the ports were characterized by low levels of economic efficiency, with the exception of Kobe, Japan; Tianjin, China; Hong Kong, China; and Shanghai, China that were efficient for this year. While the ports of Rotterdam, Netherlands; and Bremen-Bremerhaven, Germany distinguished themselves as the most inefficient. Regarding Manzanillo port, Mexico, was placed in an intermediate position reaching a value of 50.82 percent of economic efficiency.

Keywords: economic efficiency, DEA, international port system, Mexico

1. Introduction

The ports are key pieces in the countries competitiveness, with inefficient ports, the exports and imports costs will put up the price. Having an impact in the economic growth (Ojeda, 2011). In this sense, an economic analysis of the ports performs supreme importance, given its role as intermodal node and the logistic platform in the chain of transport. For it, it is of great interest to measure and evaluate the inefficiencies in the presentation of the port services.

Ports are complex organizations where operators engaged in diverse activities intersect, have different objectives and are subject to different levels of competition and regulation. For it, it is suitable to analyze the port focusing the study on a concrete activity, which must be clearly specified. The most analyzed activities are the developed ones for the port authorities and for the terminuses of manipulation of load, fundamentally, those of containers. Therefore, the study aims to determine the technical, allocative and economic efficiency of container terminals in major ports around the world in 2012, using the methodology of Data Envelopment Analysis, also known by its acronym in English DEA.

The research begins with an analysis of the technical efficiency of ports where it is considered that, from the combination of inputs and outputs, the level of technical efficiency of each port is determined by the result of the optimal use of inputs. For completeness, we also calculate the technical efficiency and scale variables yields.

Subsequently there is calculated the efficiency of input costs-used to determine the allocative-efficiency, which shows the relationships of observed inputs that minimize production costs of ports, given the prices of inputs. Then, allocative efficiency is obtained from the ratio of cost efficiency and technical efficiency. Finally, economic efficiency is the product of technical efficiency and allocative efficiency is determined.

The objective of this research is to identify for the year 2012, the importance of technical efficiency with variable returns and allocative efficiency-prices-in determining the economic efficiency of major ports in the international arena in general, and in particular, in Manzanillo port, ace dwells representative of the port sector in Mexico.

2. Materials and Methods

Technical efficiency analysis using the "frontier function", are considered the most appropriate alternatives for measuring port efficiency, because for its application are used indicators of *inputs* and *outputs*, calculable for these studies (González & Trujillo, 2007).

Efficiency analyzed under the nonparametric method of Data Envelopment Analysis (DEA) was initiated by Farrell (1957) and reformulated as a mathematical programming problem by Charnes, Cooper and Rhodes (1978). Given a number of production units, which are Decision Management Units (DMU), an efficiency frontier sample of production units is constructed. The method allows us to determine the relative efficiency of ports and thus examine its position relative to the optimal situation.

The DEA methodology belongs to the group of so-called boundary methods, in which production is evaluated for production functions, where the production function is defined as the maximum output attainable with a certain combination of inputs or, the minimum level of inputs necessary to produce a certain level of outputs (Coelli et al., 1998).

The Farrell efficiency based on input or just input efficiency plan (x, y) relative to a technology T is defined as:

$$E=min\{E>0, (Ex,Y)\in T\}$$

Also, the Farrell efficiency based on output or output efficiency is defined as:

$$E=max\ \{F>0, (x,Fy)\in T\}$$

Farrell focused the problem of efficiency in his estimation from the observed data in the production units, providing an analytical framework to the neoclassical concept of "Pareto efficiency". In his work he distinguished between technical efficiency and allocative efficiency. In any production process, technical efficiency oriented to the inputs is given by the minimum consumption of inputs necessary to achieve a determinate volume of outputs. Moreover, a firm is allocatively or prices efficient, when it combines the inputs in the proportion that minimizes costs. In the first, inputs and outputs are compared in physical units, and the second, the prices of factors of production are added. The combination of these two indicators provides a measure of efficiency called "economic" or "global". Afriat (1972) adds another aspect to the concept of efficiency when considering the range in which the business is producing

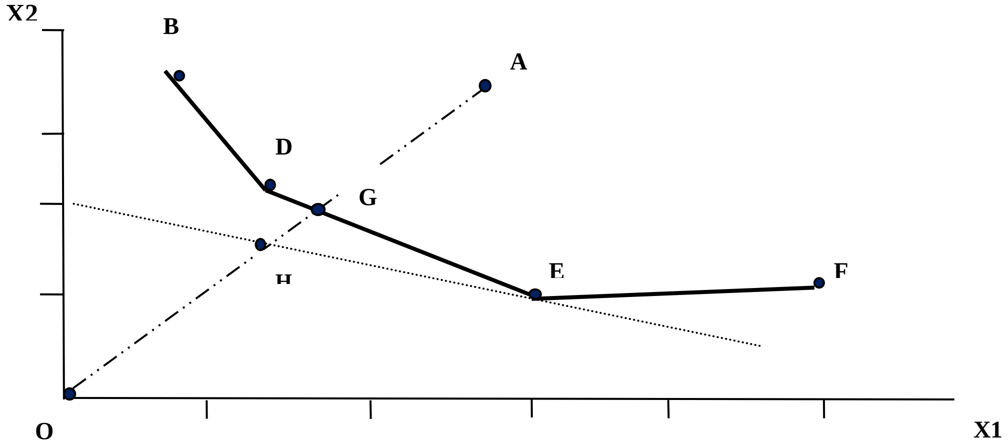

Figure 1. Technical, allocative and overall eficiency

Source: Thanassoulis, 2001.

Note. The combination of physical units of production and the prices provides a measure of efficiency called "economic" or "global".

The solid black line indicates isoquant segments representing all possible combinations of a number of inputs (*X1*, *X2*) that are necessary to produce an output. *A* is the point inside production possibilities representing the activity of a DMU, which produces the same amount of output, but with more of both inputs.

As seen in Figure 1, technical efficiency of a DMU, is determined in the following manner: $\frac{OG}{OA}$

Allocative efficiency is defined as an input $\frac{OH}{OG}$

The overall efficiency is determined with $\frac{OH}{OA}$

2.1 Technical Efficiency

The literature on technical efficiency has its origin in the early years of the decade of the 50's. The first formal definition of technical efficiency comes from Koopmans (1951:460) "it is one in which an increase in any of the outputs requires a reduction in at least one of the remaining or the increase of any of the inputs", and the first measure of technical efficiency is given by Debreu (1951) and Shephard (1953), although with different orientation (output and input, respectively).

The DEA models can be classified according to:

- The type of efficiency measure to provide: radial and non-radial models.
- The orientation of the model input-oriented, output-oriented or input-output oriented.
- The type of returns to scale that characterizes the production technology is understood as the way in which factors of production can be characterized by the existence of returns to scale: constant or variable scale (Note 1).

The study of Farrell (1957) is supplemented by the work of Charnes, Cooper and Rhodes (1978), which started from CRS constant returns to scale, so that a change in the levels of inputs leads to a proportional change in the level of output, which requires many optimizations as decision units (DMU). It has two orientations: *input* (comparison between the minimum level of inputs required for a given level of outputs, and actually taken) and orientation output: (The comparison between the maximum attainable output for a given level of inputs, and the actually achieved). It can be written in general terms in 3 ways: fractional, multiplicative and envelope.

The input-oriented measures focus on reducing the amounts of inputs in production, while maintaining the number of outputs. The CRS model is as follows:

$$\mathrm{Min}_{\theta\lambda}: \theta$$
$$\mathrm{s.t} \quad yj \le \lambda y$$
$$\lambda X \le \theta\, xj$$
$$\lambda Z = zj$$
$$\lambda \epsilon R^{+}$$

Where Y is an $N \times r$ matrix of the products of the companies sample (N denotes the number of enterprises and r the number of products); X is an $N \times m$ matrix of inputs (m indexes inputs considered); Z is an $N \times$ s matrix contains all the information about the variables S of the firms N; yj, xj and zj are vectors of the outputs, inputs and observed variables, respectively, of the company.

Later, Banker, Charnes and Cooper (1984) extended the original model to include variable returns to scale (VRS). Whereas various circumstances such as imperfect competition, restrictions on access to funding sources, etc, may cause the units not operating at optimal scale and modifying the linear program so that enter a convexity constraint. To differentiate it from the previous model it is called variable returns to scale (VRS), being the input oriented model as follows:

$$\theta^{*} = \min \theta$$
$$\mathrm{St.}\ \sum_{j=1}^{n} \lambda_j\ x_{ij} \le \theta x_{io} \qquad \text{I = 1,2,...,m;}$$
$$\sum_{j=1}^{n} \lambda_j\, x_{ij} \ge y_{ro} \qquad \text{r= 1,2,...,s;}$$
$$\sum_{j=1}^{n} \lambda_j = 1$$
$$\lambda_j \ge 0 \qquad \text{j= 1,2,...n.}$$

where:

n represents a DMU

x_{io} represents the inputs

y_{ro} represents the outputs

Then θ = 1 is feasible value and θ ^ * represents the result of the input oriented efficiency.

Technical efficiency is interpreted as the distance from O to G on the distance A. The result is the measurement of technical efficiency usually represented as θ_o^*. To evaluate the performance of A, it is used Farrell efficiency measurement. This measurement can be represented as follows (Cooper et al., 2006) (see Figure 1).

$$0 \le \frac{OG}{OA} \le 1$$

Therefore, technical efficiency can only have values between 0 and 1. A score close to zero must be understood as the unit being evaluated that is far from the efficient isoquant and thus it is technically inefficient unit.

2.2 Technical Efficiency of Scale

From the proposal of Banker et al. (1984), it was decomposed overall technical efficiency, into pure technical efficiency and efficient technical scale. To do this it must compute the two models: CRS and VRS on the same data, if there is a difference in the two measurements for a particular DMU, then it means that the DMU has scale inefficiency and inefficiency value is the difference between CRS and VRS measurement (Coll & Blasco, 2006).

The Global Technical Efficiency (GTE) can be decomposed into Pure Technical Efficiency (PTE) and Scale Efficiency (SE).

Therefore OTE = ETP * SE

$$SE = \frac{\theta\ CCR}{\theta\ BCC}$$

where:

CCR = constant returns to scale;

BBC = variables returns to scale.

2.3 Allocative Efficiency

Allocative efficiency, also known as price efficiency, was introduced by Farrell (1957), and can be calculated when the prices of inputs or products are known. Thus, the allocative efficiency of inputs reflects the combination of inputs in optimal proportions given the prices therefore; in a similar way when the output prices are known, can be calculate the efficiency of revenue and a global basis, taking the prices of both: inputs and outputs can be calculated efficiency profit. We then say that the allocative efficiency complements the measurement of technical efficiency (Thanassoulis, 2001).

The price or allocative efficiency is the ratio between the length of the line from the origin to the point projected on efficient isocost of the proposed unit. So for the unit "*A*" must be the efficiency is given by (see Figure 1):

Allocative efficiency: $$EA = \frac{OH}{OG}$$

This indicator can provide a measure of allocative efficiency and can take values from 0-1, so if the results give a value less than unity means that there is an inefficiency in prices (Coll & Blasco, 2006).

2.4 The Allocative Efficiency of Inputs

According to the proposed of Farrell, allocative efficiency of inputs is obtained in two stages, first the technical efficiency is determined as shown in the preceding paragraphs; then required to calculate cost efficiency, introducing prices for inputs.

To illustrate the cost efficiency, w represents the prices of inputs, where minimizing input costs associated with the production of a given output is intended. The model is as follows (Bogetoft & Otto, 2011):

Min wx st. $(x, y) \in T$

Using DEA with constant returns, C_{jo} is the lowest cost at which a DMU can produce and is solved with the following model is calculated (Thanassoulis, 2001):

$$C_{jo} = Min\ \sum_{i=1}^{m} w_{ij0}\, x_i \quad :$$

$$\text{s.t } \sum_{j=1}^{N} \lambda_{i\ j} x_{ij} \le x_i \qquad \text{i = 1…m}$$

$$\sum_{j=1}^{N} \lambda_j\, y_{rj} \ \ge\ y_{rj0} \qquad \text{r = 1…s}$$

$$\lambda_j \ge 0, \qquad j = 1 \ldots N\ \ge 0, x_i\ \ge 0, \forall i.$$

where:

j are the DMUs;

x_{ij} are the inputs;

y_{rj} are the outputs;

w_{ij} are the prices inputs.

To then get the index of cost efficiency, the ratio of the minimum optimal cost with respect to the observed cost is calculated for each port.

$$CE_i = \frac{w_i x_i^*}{w_i x_i}$$

$w_i x_i^*$ represents the optimum minimum cost;

$w_i x_i$ represents the actual cost;

Finally allocative efficiency index is calculated as the ratio between cost efficiency and technical efficiency.

$$\text{AE} = (x^o, y^o) = \frac{CE\ (x^o, y^o)}{ET(x^o, y^o)}$$

2.5 Overall or Economic Efficiency

The overall efficiency, also called economic efficiency, and is the length of the line from the origin to the point representing the considered unit. Thus the Economic efficiency of the unit "D" is given by:

Economic Efficiency $\text{EE} = EE_D = \frac{OH}{OA}$

Therefore Economic Efficiency is determined as follows:

$$\frac{OH}{OA} = \frac{OG}{OA} * \frac{OH}{OG}$$

So the Economic efficiency is the product of technical efficiency and allocative efficiency.

3. Model Development

It is proposed to develop a model for this research with returns to scale constant CRS and returns to scale variables VRS with input orientation, that is to say optimization of the inputs where they diminish more than could to be more efficient, since the inputs try to be minimized, as well as his respective prices to a quantity of outputs.

The amount of DMUs were 32 which were selected based on the study of the World Shipping Council (2014), considering the ports with a major number of TEUs handled in the international context for the year 2012. Though in the study Mexico ports do not appear among the most important, for this work there joined the port of Manzanillo that is the most representative of the country in this indicator (STC, 2014), in order to locate comparatively to the best port of Mexico in this sector in the worldwide.

To each of the inputs previously selected, was associated with a "price" in such a way that it could estimate the ideal cost with regard to the observed cost.

To calculate the efficiency of scale, technical efficiency with variable yields and overall technical efficiency the following inputs and outputs were used

Inputs:

- Length of spring.
- Number of cranes.

Output:

- Number of TEUs annually.

In order to calculate the cost efficiency the following inputs prices were used:

- Maintenance of the spring.
- Investment in equipment.

4. Results and Discussions

In 2012, in general the results of technical efficiency, scale and allocative efficiency-allocative-were very low. In ports with the highest indicators in these efficiencies are: at first Tianjin, China, the only efficient to get 100 percent in all port efficiencies, in the second block Qingdao, China and Kaohsiung, Taiwan, China are located, to reach 100 percent in three of the least studied efficiencies. In the third group are Shanghai, China; Hong Kong, China; and Kobe, Japan with 100 percent in two of the revised efficiency. Finally, they were efficient in only one indicator ports of New York-New Jersey, USA; and Yingkou, China. As regards Manzanillo, Mexico, was not only inefficient but the highest values were 67.21 and 75.5 percent in pure technical efficiency and allocative respectively (see Table 1).

On average technical and scale efficiencies were of the order of 60.74 percent. That is to say, container terminals were found to be technically inefficient, and this was due to having excess inputs or not being properly exploited, to the number of containers that move annually is also reflected in the results of the efficiency of scale that most ports are occurring on a size scale that is not optimal.

Table 1. Efficiencies of major ports of the world, 2012

Port	**Scale Efficiency**	**Pure Technical Efficiency**	**Overall Technical Efficiency**	**Allocative Efficiency**	**Economic Efficiency**
Shanghai, China	85.56	100	85.56	100	100
Singapore, Singapore	51.21	54.49	27.9	97.38	53.06
Hong Kong, China	57.9	100	57.9	100	100
Shenzhen, China	88.41	94.6	83.64	18.43	17.43
Busan, South Korea	92.94	24.64	22.9	47.18	11.63
Ningbo-Zhoushan, China	93.08	60.26	56.09	34.47	20.77
Guangzhou Harbor, China	95.35	82.26	78.43	20.34	16.73
Qingdao, China	100	100	100	99.73	99.73
Jabel Ali, Dubai United Arab Emirates	97.92	32.53	31.85	45.31	14.74
Tianjin, China	100	100	100	100	100
Rotterdam, Netherlands	99.17	21.5	21.32	6.96	1.5
Port Kelang, Malaysia	96.04	38.09	36.58	27.67	10.54
Kaohsiung, Taiwan, China	100	100	100	6.58	6.58
Hamburg, Germany	92.41	22.12	20.44	86.09	19.04
Antwerp, Belgium	92.11	16.52	15.22	53.36	8.82
Los Angeles, U.S.A.	82.19	13.81	11.35	70.45	9.73
Dalian, China	76.63	86.11	65.98	98.55	84.86
Yokohama, Japan	71.01	24.03	17.06	89.65	21.54
Tanjung Pelepas, Malaysia	80.51	49.65	39.97	53.72	26.67
Xiamen, China	61.49	97.65	60.05	99.86	97.51
Bremen-Bremerhaven, Germany	83.13	18.26	15.18	13.58	2.48
Tanjung Priok, Jakarta, Indonesia	57.08	43.2	24.66	89.88	38.83
Long Beach, U.S.A.	58.17	62.75	36.5	99.6	62.5
Laem Chabang, Thailand	54.56	84.98	46.37	81.34	69.12
New York-New Jersey, U.S.A	79.42	100	79.42	40.98	40.98
Ho Chi Minh, Vietnam	43.49	38.47	16.73	68.18	26.23
Lianyungung, China	43	84.74	36.44	80.53	68.24
Kobe, Japan	60.95	100	60.95	100	100
Yingkou, China	47.92	100	47.92	97.58	97.58
Jeddah, Saudi Arabia	38.6	64.53	24.91	72.3	46.65
Valencia, Spain	36.58	58.14	21.26	83.5	48.55
Manzanillo, Mexico	18.6	67.21	12.5	75.6	50.82

Source: Personal compilation based on DEA results.

Results of efficiency of major ports of the world.

It is observed that in general for 2012, most of the ports were characterized by low levels of economic efficiency, with the exception of Kobe, Japan; Tianjin, China; Hong Kong, China; and Shanghai, China that were efficient for this year to reach values of 100 percent. While the ports of Rotterdam, Netherlands; and Bremen-Bremerhaven, Germany distinguished themselves as the most inefficient. Regarding the port of Manzanillo, Mexico, was in an intermediate position reaching a value of 50.82 percent in their levels of economic efficiency (see Figure 2).

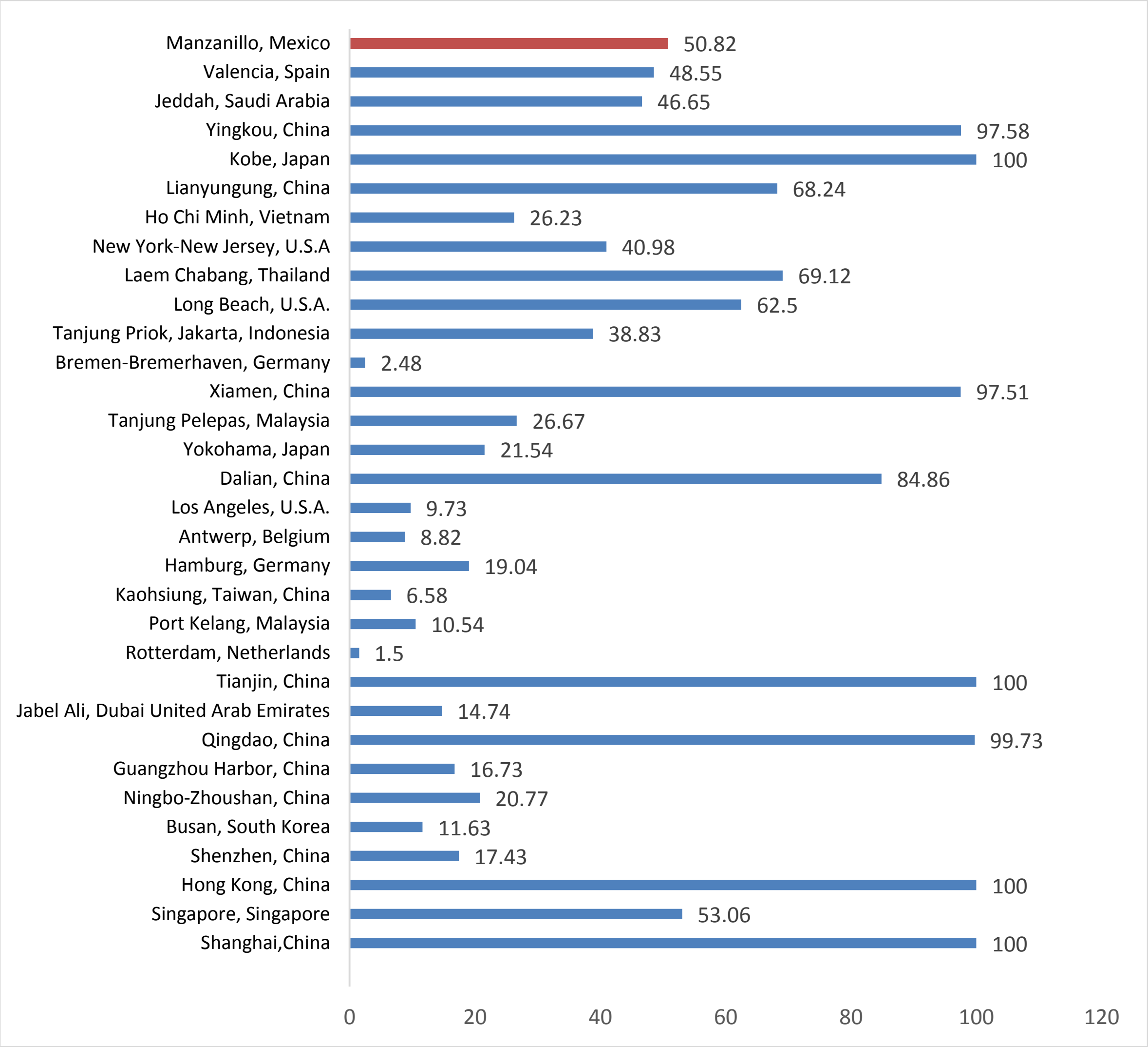

Figure 2. Economic efficiency of major ports of the word, 2012

Source: Own calculations based on Table 1.

Results of economic efficiency of major ports of the world.

It identifies the ports that were on average only economically efficient by 46 percent, which means that the transit of goods through the ports should be handled with a cost reduction of 54 percent. Situation that met reflected in the limited quantity of containers that were mobilized. In the specific case of the Manzanillo port, Mexico, the reduction in his costs should have appeared in 49.18 per cent (see table 1).

In the international context Chinese ports are those with the best technical and economic efficiencies, whereas the rest of the ports have problems in their optimal sizes and the ability to combine inputs in the proper proportions according to their prices. Reaching to Manzanillo, Mexico with a problematic similar to the one that this second group of ports have.

It is noted that the technical efficiency yields pure technical efficiency and allocative efficiency affecting these efficiencies proportionately -64 and 67 percent respectively in determining the economic efficiency of the main ports in the international arena in general, and particularly in the port of Manzanillo, as more representative of the port sector in Mexico.

5. Conclusions

This paper presents from the DEA methodology, measurement of technical efficiency, scale, allocative and economic model of constant and variable returns to scale input oriented. They are analyzed for the year 2012, the container terminals of the 32 ports handled a greater number of TEUs in the international context for 2012, taking as reference the study of World Shipping Council (2014). The port of Manzanillo is the most representative of the country in this indicator, in order to locate the best comparatively Mexico port in this sector at the global level is incorporated. Inputs were chosen as the length of the dock and the number of cranes used in a container terminal and the amount of output as they mobilized TEUs (Note 2) annually.

Overall ports had economic inefficiency, obtaining an average score of 46 percent, which means that to be more efficient should reduce costs by 54 percent. In the case of the port of Manzanillo, Mexico, the reduction in costs should be on a 49.18 percent.

Most ports were technically inefficient, with an average value of 60.74 percent, due to the ports have excess inputs or poorly utilized. It is therefore recommended further optimize search resources, in some cases replacing the mechanical cranes with others who have a higher technology. Is also required to develop strategies to increase the optimum production scale.

Both allocative-efficiency-allocative efficiency and technical efficiency with variable returns-pure technical efficiency-influence similarly in determining levels of economic efficiency, their average proportions were 64 and 67 percent respectively. While internationally ports are not known for their optimal production scales, is scale efficiency which reaches the highest average value -73 percent.

The results on the efficiency of price-allocative efficiency, realize the need to advance strategies for reduced costs and a better mix of inputs, if you want to address the issues of economic efficiency in a key sector of international and national activity.

Finally, Chinese ports are those with the best technical and economic efficiencies in the international context, a factor that cannot be isolated from the high economic growth that has taken this country in recent decades.

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Notes

Note 1. Returns to scale is a term to define the levels of change in output with respect to changes in input levels are measured by this concept. The scale returns can be variable, either increasing or decreasing, or they can be constant.

Note 2. The twenty-foot equivalent unit (TEU) is an inexact unit of cargo capacity often used to describe the capacity of container ships and containers.

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