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Evolution of global container operator efficiency: A DEA approach

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Abstract— **Improving port efficiency can therefore have a significant impact on the whole maritime economy. Recognizing this fact, many governments have consistently prioritized the ports as a central element of infrastructure to promote regional economic growth. This paper treats container terminal operators as the Decision Making Unit, which represents a divergence from previous port efficiency studies. We compile a panel data of 141 global container terminal operators from 1997 to 2005 to study the efficiency of container operator production. We use the Data Envelopment Analysis (DEA) to compute efficiency scores. We add country and port characteristics into our model except output/input. We examine the contribution of productivity to operator output based on the long time series. The efficiencies of different operators in same port are showed to investigate the core sources of productivity growth.**

Keywords- Frontier efficiency model; Data envelopment analysis; Container terminal operators; Port globalization

I. INTRODUCTION

Production economics has established causal links between features of ports and port production. In recent years, data envelopment analysis (DEA) has gained considerable importance for port production. A key question in research on port production is which inputs produce the most port throughput given their inputs. Many previous studies of port production using port-based data cannot reveal the port effects, when multinational terminal operation has become dominant.

Generally speaking, there are two types of port effects in container terminal operation. The first (and conventional) port effect concerns the effect of port characteristics such as the average water depth in a port. A given terminal's output are affected by the water depth in the port where the terminal is located in. It is suggested that locating in a port with a more water depth may make every terminal more productive, not just those are more equipped.

The second (and even more difficult) port effect to uncover is the effect of the group average of output on the individual terminal output. Seaports are characterised by global competition in a number of dimensions. Seeking to exploit network effects in the containerisation era, terminal operators have tried to expand their line of activities through vertical and/or horizontal integrations along the transport chain. Instead of treating ports as the decision marking unit (DMU), this paper treats container terminal operators as the DMU.

The port industry in the world has a very global structure, and global and multinational players are becoming increasingly dominant. Two generic internationalisation strategies in port globalisation: (1) Horizontal merger initiated by leading stevedores, and (2) Vertical integration initiated by global carriers. We are motivated to develop a model to determine the efficiency of terminal operation.

Another difference of this study from previous studies is that we use two-stage approach. Previous studies on port efficiency used either SFA or DEA. Our two-stage approach uses DEA for within-terminal inputs and then uses regression for external inputs, which should be able to complement the DEA with the aggregate data.

II. LITERATURE REVIEW

The production and cost theories in economics make it possible to estimate production and cost functions empirically, and thus to investigate the productivity and technological change of a firm. There have been numerous productivity or efficiency studies of ports. Wanhill [1] indicated that the productivity of ports depends on the right trade-off between the costs of providing infrastructure (berth) and the time costs of the ship's stay in the port. The manual on port planning prepared by the UNCTAD Secretary in 1978 for developing countries follows the same line of work as Wahnill's study [1]. It relied on Monte-Carlo simulation techniques to calculate the costs of different types of terminals according to terminal features and ships' stay in port. Similar works include Janson and Sheneerson [2], Sheneerson [3][4], and Fernández, de Cea and Fernández [5]. They all adopted a queuing model as the basic form of port service production function and assumed ships' arrival is random and follows a Poisson distribution. These studies are helpful for individual port planning.

All these studies focused on one particular port and assumed that the demand for ports is exogenous i.e. any decision made by a port has no effect on its demand. This assumption is erroneous for most container ports in the world. Containerization significantly reduces product differentiation among ports, and globalization eliminates the national boundaries of port hinterlands. Nowadays, it is very easy for shippers to switch from one container port to another. Indeed, port competition has been a hotly debated policy issue in Hong Kong, Singapore, and Western European countries. Any

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policy suggestion aimed at improving port productivity, which ignores effects on demand, is questionable.

Ports are characterised by their geographical and operational settings. An empirical estimation of the port production function is presented by Chang [6], and Tongzon [7], whereas Kim and Sachis [8], Martínez-Budría [9], and Jara-Díaz, Martinez-Budría, Cortes and Basso [10] estimated the cost functions of ports in both single-output and multi-output cases.

Large multi-port operating companies continued to seek new operating concessions in the container terminal sector. The general discussion of multinational behavior brings together a number of economic theories (e.g. [11]). Buckley and Casson [12] established the internalization theory and discussed the five advantages of internationalization, namely increased ability to control and plan, the opportunity for discriminatory pricing, avoidance of bilateral monopolies, reduction of uncertainty, and avoidance of government intervention. Studies of other multinational service industries have received increased attention from researchers, e.g. multinational banks [13], hotels [14], insurance companies [15] and airports [16]. There has, to date, been no efficiency study on global terminal operators. One reason for this is because existing port studies in the literature are based on port data but not terminal data, while global terminal operators operate in several countries. Our terminal-based data collection makes a study into port globalisation feasible.

In all efficiency studies, efficiency is measured by comparing observed and optimum costs, production, revenue, or whatever the organization is assumed to pursue, subject to the constraints on quantities and prices. The optimal quantity is termed frontier and the efficiency is then the distance between the observed quantity and the frontier. In empirical research, two methods are widely used to calculate or estimate the frontier functions and thereby measure efficiency: data envelope analysis (DEA) and stochastic frontier analysis (SFA). The stochastic frontier model was proposed by Aigner, Lovell, and Schmidt [17] and Meeusen and van den Broeck [18]. Cullinane, Wang, Song and Ji [19] compared the results from both DEA and SFA on port efficiencies and found high correlations between the results from the two approaches. DEA is a deterministic method based on linear programming and was first introduced by Charnes, Cooper and Rhodes [20] whereas stochastic frontier analysis is an econometric method accounting for random shocks and measurement errors. In port literature, Dowd and Lechines [21], and Talley [22] used index number approaches, which allow comparisons of the efficiency among various ports and throughout time for a single port, to study the ports' productivity. Index number procedures generally construct a ratio-type productivity/efficiency measure, without the need for statistical estimation of a production or cost function. Many studies which have used these two methods to study port efficiency assume the homogenization of the global port industry. Instead, we consider the characteristics of terminal operators and examine factors that explain why the global terminal operators often play a leading role in the port industry.

To sum up, it may be stated that the so-far research on the port efficiency comprises numerous successful attempts to utilize DEA and SFA approaches. One of major drawbacks of DEA is that the conclusions are drawn on the ground of one year data. Since many factors are of long-term character and fluctuates as time passes. The two-stage approach used in this paper is able to handle the time-varying factors. Besides, multiple port operation has made an impressive progress but there is little knowledge in the literature. This study should be able to supplement the previous research of port efficiency.

III. METHODOLOGY

The analysis is divided in two stages [23]. In the first stage, the DEA model is used to evaluate the efficiency of container terminal operation. DEA is a non-parametric technique that allows multiple inputs and multiple outputs in the production frontier analysis. The DEA analysis includes the terminal inputs only and gives an efficiency score to each terminal. Therefore, the first-stage considers the inputs provided by DMU.

In the second stage, the external factors outside DMU's control are considered. We wish to explain the efficiency scores by considering the external inputs. We believe that considerable insights can be achieved from a causal regression model of panel data. In particular, the time factor is included in a panel model in the second stage, while DEA cannot capture the time-varying effects.

A. Estimation of Efficiency Scores

The first-stage is to estimate the efficiency scores for each decision-making unit (DMU). The DEA approach assumes that all DMUs with a single frontier. Charnes, Cooper and Rhodes (CCR) efficiency concept is employed here with the assumption of constant returns of scale.

Assume that there are n DMU's (j=1,2,…,n) with m inputs (i=1,2,…,m) and s outputs (r=1,2,…,s). Denote the i-th input and r-th output for DMU_j as x_{ij} and y_{rj}, respectively. The efficiency rating for any given DMU_d can be computed using the following CCR model in the form of linear programming (LP) [20][24].

$$\max \sum_{r=1}^{s} \mu_r y_{rd} = E_{dd} \tag{1}$$

subject to:

$$\sum_{i=1}^{m} \omega_{id} x_{ij} - \sum_{r=1}^{s} \mu_{rd} y_{rj} \geq 0 \,, \quad j = 1,2,...,n \tag{2}$$

$$\sum_{i=1}^{m} \omega_{id} x_{ij} = 1 \tag{3}$$

$$\omega_{id} \geq 0 \,, \quad i = 1,2,...,m \tag{4}$$

$$\mu_{rd} \geq 0 \,, \quad r = 1,2,...,s \tag{5}$$

where the input weights ω_{id} and output weights μ_{rd} are parameters to be estimated. Eq. (2) conforms that the weighted

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outputs cannot be more than weighted inputs. Eq. (3) is posed to avoid an infinite number of solutions. Eq. (4) and (5) are posed to find positive values for input weights and output weights.

The DEA is technically to evaluate the container terminal production. The terminal utilizes labour, equipment and land inputs to accomplish the container handling. In this production, the major equipment inputs are superstructures within the terminal. The quay superstructure (e.g. quay cranes) is used to transfer containers between shore and ships. Yard superstructure (e.g. rubber-tyred gantry crane, RTG) is used to handle containers in the stacking yards. The land inputs are berth number, quay length, terminal area, storage capacity. The labour inputs include labour costs, working hours, berth time, etc. However, the labour inputs are not included because it is very difficult to collect the labour inputs. If the labour inputs would be included in the DEA analysis, the number of valid observations will be significantly reduced.

The output is measured by TEU throughput of each terminal, because it is the most important and widely available for container ports and terminals.

B. *Determinants of Efficiency Scores*

We attempt to estimate the port efficiency versus several inputs. These basic port inputs consist of three primary components: (1) the superstructures within the terminal (e.g. cranes), (2) the infrastructure of ports (e.g. water depths), and (3) geographical setting of the port (e.g. location). Component 1 denotes the hardware inputs and directly related to the terminal's efficiency and services (e.g. loading and discharging of containers). As Component 1 has been considered in the first stage, Component 1 data are excluded in the second stage.

Component 2 represents the geographical characteristics of the port and is related to the accessibility of ports. Component 3 is a group of dummy variables indicating the geographical settings of port and is related to the managerial issues of ports. In addition, we add the port group dummy to the regression models and we expect port group to enhance the operator's efficiency. To investigate the hypothesis, the dynamic panel model specification is:

$$efficiency_{it} = \beta \text{ (port group)}_{it} + r_1 \text{ (operators characteristics)}_{it} + r_2 \text{ (country characteristics)}_{it} + r_3 \text{ (geographic location)} + r_4 \text{ (time trend)} + \varepsilon \quad (6)$$

A common practice in the DEA literature for determining the efficiency is to employ tobit or probit estimator. Simar and Wilson (2007) verified that such an approach is inappropriate and so we use simple linear regression, instead.

It is expected that terminal efficiency can be enhanced without capital investment. To achieve this, efficient and cost effective connections to the hinterland of a port are possible means.

IV. Analysis and Discussion

A. *The Data*

The data used in this analysis are from multiple sources. Most of the information has been collected from Containerisation International Yearbooks and operators' websites. The combined database contains 637 valid observations covering top 100 container ports over year 1997-2005. The panel data is unbalanced, due to missing values of certain data. A summary of the statistical summary of data is shown in Table 1.

B. *Terminal Efficiency Estimates*

Data Envelopment Analysis (DEA) is applied for each year of data from 1997 to 2005. The DEA scores ranks he terminal from most efficient (CCR score =1) to least efficient operator (CCR score =0). These CCR scores provide the estimates of a terminal's efficiency on the basis of within-terminal inputs, which are controlled by DMUs.

A number of patterns emerge in the rankings of all terminals. The upper half of the list (the most efficient ports) is primarily terminals in European, Hong Kong and Singapore ports. The middle of the list is generally developing ports, e.g. Chinese ports, while those ports are expanding and some extra capacities are provided for future demand. The least efficient ports are primarily in Central American and Mid Asian, where the port throughput is relatively small.

C. *Determinants of Efficiency*

The ordinary least square (OLS) is applied to the regression model. Table 2 reports the results from OLS regressions with standard error. There may be several terminal operators in a port: some belong to port group, others are individual operators. The operators in the same port have similar port characteristics and same country characteristics. This situation can create an environment to measure the port group on efficiency while other factors are same. In column (2) and (4) of Table 2, we adjust the standard errors by allowing for correlation in the error term within a port. The overall fit of the model is reasonable with adjusted $R^2 = 0.4$.

This result suggests that the water depth (Depth) and the number of liner calls (Call) enhance the terminal efficiency. The number of operators (Operator) and the number of terminals (Terminal) reduce the terminal efficiency. It is obvious that the intra-port competition drives the operators to provide slack capacity. Surprisingly the results show that a less-efficient operator uses more EDI (EDI). A possible reason for this is that operators who invest more in EDI are probably less efficient to begin with and hope to use EDI to improve the efficiency.

On the geographical context, the results suggest that Asian ports are most efficient, African ports are second most efficient, and North American ports are least efficient. The observed relation between location and port should not be taken simply according to the coefficients. Typical African ports are of small throughputs and provision of insufficient inputs of equipment. This underdeveloped operation of African and Latin American ports gives a wrong impression

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that African ports are efficient. Also it is not statistically significant at conventional levels.

The time effect is non-linear (Figure 1). The rate of efficient improvement increases over time. There are at least two reasons behind the efficient improvement. The first one is the technological advancement in shipping. The cargo handling technologies have substantially advanced from panamax ships to post-panamax ships to very large container ships. The second one is that scale economies. The world sea-borne trade increases approximately 4% per year since 1970s. The terminal operation enjoys the economies of scale.

The results further reveal that the port grouping enhances the terminal efficiency (Figure 2). Terminal operation is a critical element in shipping. The global network of terminal operations is required to serve customers at many locations and is capital intensive. Terminals, as asset intensive infrastructure, focus on scale and strive for the lowest possible costs, because scale advantages are core drivers in the competitive market.

It may not be surprising that carrier-based terminal operators achieve similar efficiency as individual operators. Carrier-operating terminals give shipping lines certain advantages, principally preferential terminal access. As the results, the integrated liner-terminal strategy may not outperform the individual operators, liner and terminal business should be independent. It is noted that Hapag-Lloyds (a leading shipping line) have sold off their terminals.

V. Concluding Remarks

In this paper, we consider a two-stage model that allows not only for DEA scores of technical efficiency but also a parametric function of the temporal pattern. This two-stage method is an extension of the DEA model in which it allows for a time-varying factor in the parametric function. Unlike other models, which were based port data, this model is based on a panel dataset with terminal data.

We also apply this model with port group effect, indicating that the efficiency measures are sensitive to grouping. A somewhat unexpected finding is that the background of terminal operators is not sensitive to the terminal efficiency. This study demonstrates that the DEA and parametric model can feasibly be applied in the port sector.

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TABLE I. RESULTS OF REGRESSION MODELS

Variables	Mean	Std. Dev.	Minimum	Maximum
A. Output				
TEU: Container Throughput in TEUs (000's)	936.4	1,741.7	4.6	20,600
B. Inputs for DEA				
1. Cargo Handling Equipments:				
CHQ: Cargo handling capacity at quay in tonnage [a]	385.0	470.7	23.9	5,416.2
CHY: Cargo handling capacity at yard in tonnage [b]	5,116.5	7,060.9	38.6	62,731.8
2. Terminal Infrastructures:				
Berth: Number of berth	5.1	5.2	1	37
Qlength: Length of quay line in meter	1,361.3	1,181.6	200	9,000
Tarea: Terminal area in squared meters (000's)	604.9	844.6	7.7	8,092
3. Storage Facilities:				
Storage: Storage capacity in number of TEUs (000's)	23.2	72.4	0.6	1,200
Reefer: Number of electric reefer points	480.6	539.7	4	3,768
C. Individual Characteristics				
1. Terminal and port level:				
EDI *(in fraction of total sample)*	0.3			
Depth: Depth of water in meter	13.2	3.5	4.5	32.0
Call: Number of liners calling the terminal	16.2	14.5	1	114
Operator: Number of operators in port	3.7	2.6	1	10
Terminal: Number of terminals in port	6.8	6.2	1	31
2. Port group dummies (in fraction of total sample):				
GLC: Global Carrier	0.09			
GLS: Global Stevedore	0.15			
Other: not belong to any of above groups	0.76			
3. Country level:				
GDP: GDP in current US$ (billion) [c]	2,240	3,270	5.4	12,500
EXP: Goods exports in US$ (billion) [c]	271	249	0.4	972
IMP: Goods imports in US$ (billion) [c]	308	365	1.8	1,670
4. Continental Distribution (in fraction of total sample):				
AS: Asia	0.37			
EU: Europe	0.27			
NA: North America	0.17			
LA: Latin America	0.06			
OC: Oceania	0.09			
AF: Africa	0.04			
Period	1997-2005			
Number of Countries	39			
Number of Ports	78			
Number of Terminal Operators	141			
Number of Observations	637			

[a] The aggregated capacity of: (1) quay cranes; (2) ship shore container cranes.

[b] The aggregated capacity of: (1) gantry cranes; (2) yard cranes; (3) yard gantries; (4) reachstackers; (5) yard tracktors; (6) yard chasis trailers; (7) forklifts; (8) straddle carriers; (9) container lifters; (10) mobile cranes.

[c] The country data can be found at the World Bank website: http://devdata.worldbank.org/dataonline/old-default.htm

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TABLE II. RESULTS OF REGRESSION MODELS

Model Number	(1)	(2)	(3)	(4)
Dependent variable	DEA Score	DEA Score	DEA Score	DEA Score
Independent variables				
EDI	-0.0099 (0.0261)	-0.0572 (0.0266)**	-0.0058 (0.0252)	-0.0517 (0.0261)**
Depth	0.0838 (0.0466)*	0.0942 (0.0400)**	0.0873 (0.0460)*	0.0963 (0.0398)**
Call	0.0440 (0.0138)***	0.0295 (0.0160)*	0.0413 (0.0134)**	0.0311 (0.0159)*
GDP	-0.1389 (0.0391)***	-0.1320 (0.0648)*	-0.1223 (0.0381)***	-0.1387 (0.0639)*
EXP	-0.0492 (0.0383)	0.0923 (0.0585)	-0.0462 (0.0377)	0.0898 (0.0582)
IMP	0.2360 (0.0614)***	0.0950 (0.0842)*	0.2116 (0.0610)**	0.1030 (0.0838)
Operator	-0.0696 (0.0208)***	-0.0971 (0.0588)*	-0.0697 (0.0206)***	-0.0945 (0.0577)*
Terminal	-0.0048 (0.0185)	-0.0224 (0.0533)	-0.0071 (0.0183)	-0.0245 (0.0524)
EU	-0.2274 (0.0326)***	-0.2250 (0.0732)***	-0.2201 (0.0322)***	-0.2280 (0.0718)***
NA	-0.3310 (0.0609)***	-0.2747 (0.1278)**	-0.3428 (0.0603)***	-0.2730 (0.1259)***
LA	-0.0705 (0.0501)	-0.0065 (0.1068)	-0.0741 (0.0494)*	-0.0155 (0.1047)
OC	-0.2261 (0.0437)***	-0.2064 (0.1279)*	-0.2236 (0.0429)***	-0.2034 (0.1254)*
AF	-0.0020 (0.0612)	-0.0029 (0.1490)	0.0133 (0.0608)	-0.0043 (0.1462)
Port Group			0.0892 (0.0253)***	0.0423 (0.0292)*
GLC	0.0485 (0.0388)	0.0624 (0.0411)*		
GLS	0.0456 (0.0359)	0.0636 (0.0398)*		
Time	-0.2472 (0.0693)***	-0.1699 (0.0533)***	-0.2464 (0.0687)***	-0.1716 (0.0534)***
Time squared	0.1432 (0.0382)***	0.0913 (0.0293)***	0.1426 (0.0378)***	0.0917 (0.0293)***
Constant	0.6362 (0.0631)***	0.6472 (0.0792)***	0.6203 (0.0627)***	0.6454 (0.0785)***
Observations	637	637	631	631
Adjusted R-squared	0.41	0.39	0.38	0.39

Notes: 1. Numbers in parentheses are standard deviations.

2. Significance levels: 10, 5, 1 percent (one to three stars).

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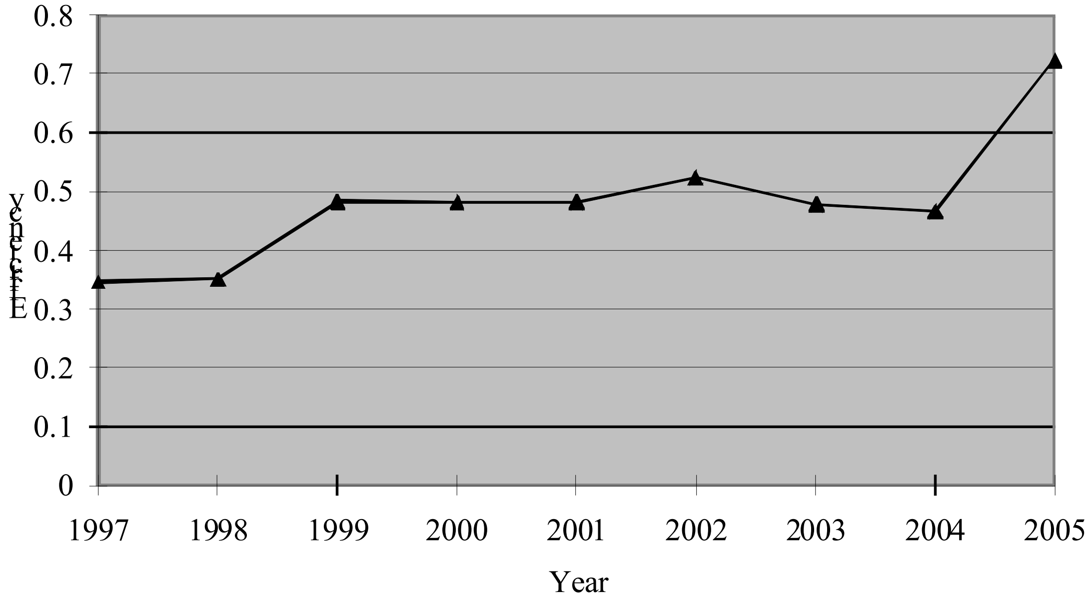

Figure 1. Year-by-year average efficiency for all terminal operators.

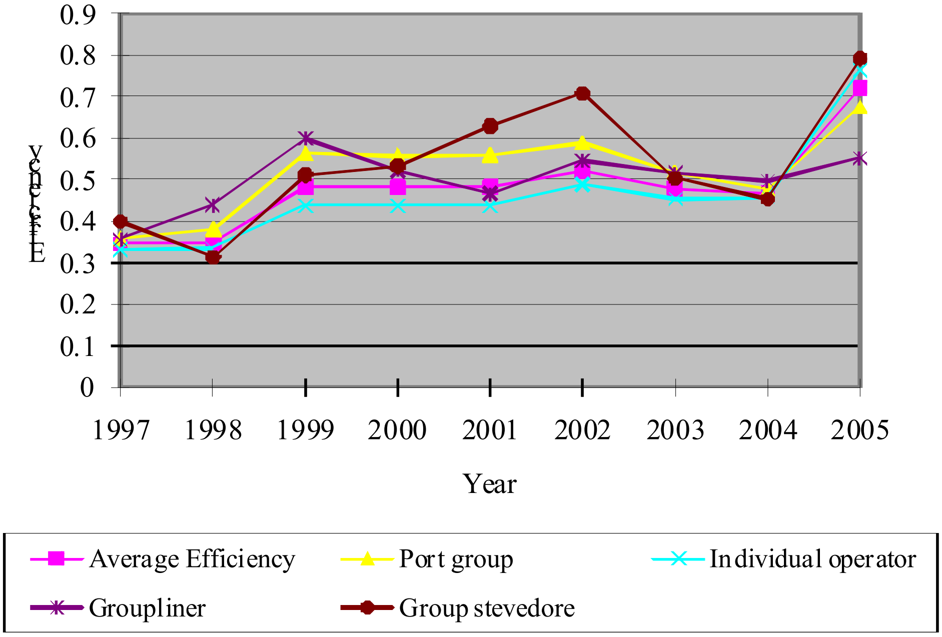

Figure 2. Year-by-Year efficiency comparison.