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Evaluating Impacts of Institutional Reforms on Port Efficiency Changes: Malmquist Productivity Index for World Container Ports

SANGHYUN CHEON

Post Doctoral Researcher
The University of California Transportation Center
University of California at Berkeley
Phone: 510-289-0137
Fax: 510-643-5456
Email: hcheon@berkeley.edu

*Please contact the corresponding author before citing the paper

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ABSTRACT

This paper attempts to systematically estimate efficiency changes of world seaports from 1991 to 2004 during which time substantial institutional changes have been realized in the global container port industry. This paper also attempts to evaluate how this institutional reform efforts influence seaport infrastructure efficiency in the global port industry. The concept of Malmquist Total Factor Productivity Index based on Data Envelopment Analysis (DEA) allows to measure changes in port efficiency and identifying sources of efficiency gains and losses. It also allows us to decompose efficiency change into the different sources: *catch-up effect* and *frontier-shift effect*. The results of analysis suggest the following: the roles of efficient management, strategic capital investment and institutional restructuring and reform are not minimal but substantial for the operation of ports over the medium-long term. Given the current globalized shipping market and scopes of port activities, the strategies to combine institutional restructuring and capital investment can suggest the potential to partly overcome the limitations of the external conditions, as can be found from such examples as the port of Dubai and the port of Singapore. Finally, improvement in productive efficiency of world container ports largely came from the actual practice of port ownership and asset management over the last decade.

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INTRODUCTION

Ports are the backbone of international trade by providing the direct linkage from international to regional or local transport systems and trade chains. For the last two decades, world seaborne trade has increased annually (UNCTAD 2002) and, in the US, the share of Gross National Product (GNP) exported has doubled. Seaports handle 99 percent of international trade by weight or 61 percent by value in the US. The international average for the same figure is approximately 90 percent by weight.

Total world container throughput will reach more than 360 million TEU[1] by the end of 2007, with an average 6.6 percent of annual growth rate (DSC 2002). Based on the confirmed plans for port expansion, global container port capacity increases to 450 million TEU by 2007 from 351 million TEU in 2001. Total investment requirements from 2001 to 2007 have been approximately US$ 14 billion to meet the global demand, if current levels of port performance and utilization are retained. This investment has been directed to provide more than 5,000 ha of container yard, 930 ship-to-shore cranes, and 144 km of additional quayline. In addition, US $ 2.8 billion would be additionally needed for yard equipment globally.

The current level of global interactions demands seaports to achieve better productivity as a fundamental link in the overall trade and supply chains so that surrounding localities can gain competitive advantage. There is thus a huge interest amongst port authorities in increasing port productivity. They need to effectively compete with other neighboring ports to deal with growing pressure from shippers for lower port and shipping charges. It is critical within this context to understand sources of port efficiency gains over short- and long-term. A continuous assessment of the port performance and productivity will allow policy makers to devise appropriate strategies for sustaining a competitive edge in the global markets.

Institutional reform and private sector participation in the port sector are underway at the national and state government levels in many countries. The practices and processes of private

[1] Twenty-foot equivalent unit. A standard linear measure used to quantify container flows. Containers generally come in three sizes: twenty, forty, forty-five feet.

participation are not uniform in the sense that the activities of ports are complex and the services they provide diverse. Yet the common intended objectives are to increase efficiency and to enhance the quality of services by improving port management with more responsiveness to the needs of port users. The private sector participation also seeks to diversify the sources of financing and transfers the commercial risk of port operation to the private sector, while the public sector retains the regulatory control and risk. Private investments in port projects increased from $10 million in 1991 to $4.3 billion in 1997. During the 1990s, a cumulative amount of $12 billion has been invested by the private sector in numerous port projects (World Bank 2001).

Research has not sufficiently addressed theoretical and practical interests generated from the current phase of globalization, requirements for efficiency improvement, and institutional reforms in the contemporary port sector. Few studies have thus far tried to estimate changes in efficiency of world seaports during the last decades during which time substantial institutional changes have been realized in the global container port industry. Moreover, it has been rarely discussed what the sources of efficiency gains or losses can be attributed to and how these institutional changes have influenced seaport infrastructure efficiency.

This paper have three objectives: (a) to systematically estimate efficiency changes of world seaports from 1991 to 2004, (b) to identify sources of efficiency changes of world seaports, (c) to evaluate the impacts of institutional reforms on port efficiency changes. This paper is organized as follows: Firstly, I conduct comprehensive reviews on roles of institutions in port efficiency. Secondly, I review the concept and method of efficiency change measurement and describe the data. Thirdly, I present the results of analysis and discuss policy implications, mainly focusing on evaluating sources of efficiency gains for world major ports during the last decade and roles of port institutional reforms on port efficiency change.

IMPACT OF INSTITUTIONS ON PORT EFFICIENCY

There have been conflicting views on the impact of port institution on port infrastructure productivity: Liu (1995), examining the relationship between technical efficiency of ports and port ownership controlling port size with a dummy variable, argues that there is no significant advantage to private or public ownership when the policy environment is competitive. Notteboom et al. (2000) similarly shows that it is difficult to prove that port ownership has a significant effect on port performance.

Some studies reach different conclusions. Coto-Millan et al. (2000), in examining port efficiency of 27 Spanish ports from 1985-1989, claims that the most efficient Spanish ports are those that are smaller in size and had adopted a significantly more centralized management system than clearly showed a greater level of management autonomy. Baird (2000) also argues that an outright sale of port land, combined with a transfer of operation and regulation functions to the private sector will not definitely increase the operation of efficiency, and it may even be counterproductive. Due to long-term pay back and high capital costs in the port industry, an almost total dependence on the private sector will result in significantly delayed investments on the crucial operation of facilities and equipment. Consequently, port ownership has an inverted U-shaped effect on port operation efficiency.

Estache et al. (2002), based on analysis of the Malmquist Productivity Index (MPI), claims that the reform of decentralization and privatization taken at Mexican ports has generated large short-term improvements in the average performance of the port industry. Cullinane et al. (2002), employing both cross-sectional and panel data versions of stochastic frontier models, assessed the relative efficiency of selected Asian container ports and concluded that privatization should have some relation with an improvement in efficiency. Tongzon and Heung (2005) examines the issue at the terminal level in order to evaluate whether port privatization is a necessary strategy for ports to gain a competitive advantage and concludes that private sector participation in the port industry, to some extent, can improve a port’s operational efficiency.

The previous studies suggest meaningful intuition and improved understanding of the global port sector. Despite the merits of the studies, a few things should be pointed out: Firstly, many studies gather and utilize data from the largest 10 to 30 container ports as targets of port productivity evaluation. In some cases, ports selected for the analysis can already be regarded as successful ports. This relatively small and biased scope of sampling, directed by data availability, makes it difficult or inadequate for sorting out and clearly examining the issues: "whether the efficiency gap between successful ports and unsuccessful ports are mainly explained by the difference of port ownership and institutional structure?" and "whether transform of port institution and private sector participation have allowed ineffective ports to become more successful?"

Secondly, the variable capturing port ownership does not mean a coherent aspect of actual port institutional practice. Many previous studies have mainly taken two approaches to capture institutional aspects of ports: Firstly, port institutions have been dichotomized into either public or private ownership. Nonetheless, since ports are complex institutional systems involving multiple levels of governments or private sector activities, the dichotomy of port ownership between "public" and "private" may not realistically reflect multiple and complex aspects of port production: e.g. who does own port infrastructure and/or superstructure? How is terminal operation function organized? At what government levels ports are regulated?

Another attempt has been to create an index to capture multiple aspects of complex port institutions, by aggregating the multiple characteristics at different levels of port organizations. However, these multiple aspects should be disintegrated and distinguished when they are examined to evaluate as an influence of productivity improvement. Port institutional features such as decentralized corporate *structure* and autonomy at a port authority are not always synonymous with more strategic institutional *practice* and asset management through diverse mechanisms at container port operation levels. Therefore, it is difficult to sort out where the sources of efficiency gap or improvement come from. Did it originate from the fact that port managers and authorities can become more productive through exercising their autonomy based on decentralized organizational structure? Or is it caused by the separation of container terminal operation function from government hands and putting the function in the control of more specialized entities?

Innovative aspects of this paper can be attributed to actively addressing these issues: It analyzes a number of sampled ports, approximately 100 major container ports located around the world. The analysis is also based on perspectives of distinguishing institutional structure (corporate structure of port authorities) and practice (port ownership and asset management practice). Finally, this paper focuses more on changes of efficiency and institutions to mainly assess impacts of institutional reforms on efficiency changes, rather than cross-sectionally evaluating different efficiency levels of ports that are subject to various institutional typologies. It is essential to considering temporal impacts of institutional changes on changes in port infrastructure productivity.

PROPOSED HYPOTHETICAL TESTS

In order to more clearly examine and sort out the complexity inherent in the relationship between institutional features and the efficiency of ports, as I noted, I suggest that port institutional characteristics are captured by using two different variables reflecting institutional structure and managerial and institutional practice of ports:

The corporate structure of port authorities reflects the general organizational layout and condition for port management. Economic theories imply that, as the corporate structure and administration of port authorities is more decentralized, the level of autonomy that the port authorities can exercise becomes larger partly because they can be free from politics. The more decentralized administrative structure may thus be a necessary condition in which port managing agencies act more proactively and effectively with better management. It is particularly so since port managers are able to seek their own interests in managing ports (e.g. increase port productive efficiency).

Port ownership focuses more on capturing actual institutional practice regarding the assignment of port assets and functions among different levels of governments, port agencies, and terminal operators. It also actually measures whether a port authority and public government is separated from day-today terminal operation and management of terminal assets. This reflects micro-level institutional practice on port asset management because it mainly tries to capture how port assets and functions are actually transferred to leaseholders and concessionaires in general, and whether a port’s terminal operation is actually separated from the overall port management and regulation. When the transfer is implemented, more players can be brought into port production and service. It may create managerial effects that would be influenced by some mechanisms including a more intense level of intra-port competition and more independence of actual production system. While the variable of corporate structure is an institutional condition that can partly reflect the level of proactive and strategic management of ports, the variable of port ownership, in fact, focuses more on the actual practice of port management and operation.

The design of institutional variables implies that the level of autonomy at a port level may not be always synonymous with the actual practice of terminal operation and port management in the port sector. In other words, autonomy at a port level may not automatically lead to better and strategic management and improving port efficiency, unless it is accompanied by the actual practice of port management and operation at the port and its terminals. I contend that examining the two variables separately, rather than having an aggregated index, can allow measuring sources of port efficiency more effectively.

METHODS: MEASRUING PORT EFFICIENCY CHANGE

The analysis of port efficiency and its changes have revolved around partial productivity indicators in the past (e.g. Australian Bureau of Industry Economics, 1993; Productivity Commission, 1998). Yet this type of index is too simple to reflect the real process of port production, representing limited view and conflicting aspects on port productivity. In order to resolve analytically inconsistent results from partial indicators, the concept of total factor productivity began to be applied based on multiple inputs and outputs. While a few methods (e.g. Stochastic Frontier Production Function; Data Envelopment Analysis[2]) have been proposed and applied, the main idea is predicated on the concept that efficient firms are

[2] Data Envelopment Analysis (DEA) is a methodology directed to creating efficiency frontiers based on a piecewise linear surface, instead of fitting a regression plane through the center of data (least-squared regression approach) in order to benchmark relative efficiency of Decision Making Units (DMUs). The early discussion about the methodology is detailed in (Charnes, Cooper, and Rhodes, 1978) and (Banker, Charnes, and Cooper, 1984). The earlier works to assess port efficiency by using DEA are Roll and Hayuth (1993), Martinez et al. (1999), Tongzon (2001), Wang et al. (2002), and

operating on the production frontier (Farrell, 1957; Cooper et al., 2004).

The concept of Malmquist Total Factor Productivity Index, or Malmquist Productivity Index (MPI) allows to measure changes in port efficiency and identifying sources of efficiency gains and losses (Cook and Zhu, 2005). MPI can be estimated based on multiple applications of Data Envelopment Analysis (DEA) to benchmark ports' efficiency between two different time periods. The basic idea is that if efficiency change has occurred over the long period, temporal changes in efficiency can be attributed to two different sources related to port conditions, planning, and management. These are: (a) *frontier shift effects* and (b) *catch-up effects* (Nishimizu & Page, 1982; Grifell & Lovell, 1993; Estache et al., 2004).

On the one hand, the *frontier shift effect*, represented by the shift of the productive efficiency frontier in a production function, can occur because of such significant change as technological progress. Port efficiency gains from the frontier shift effects can come from the capacity to keep up with latest technologies that are possibly driven by various factors such as institutional reforms to increase (or by increasing) market competition. To keep abreast with new technology requires quite effective long-term strategic planning and timely capital investment at a port and policy making level.

The *catch-up effect*, on the other hand, is also referred to as technical efficiency change that can be represented by a port's movement along the production frontiers, which is possible even within a relatively short period of time. The catch-up effect is so termed since the concept implies the capacity of ports to managerially follow best practices in order to operate on the frontiers at any point in time. The efficiency gains caused by the catch-up effect can be mainly attributed to managerial capacity of ports to (a) respond to port demand by flexibly adjusting production scales (changes in scale efficiency) and to (b) adjust input factors timely (changes in 'pure' technical efficiency). Not only incentive changing policies but also many other management systems and conditions could possibly promote this sort of behavioral change.

Cullinane et al. (2004; 2005). This paper is one of the few works (e.g. Estache et al. 2004) to evaluate the sources of port efficiency changes through MPI.

The period this paper is interested in measuring efficiency change is 1991 to 2004 when the global seaport sector during this period has experienced huge sums of port reform and rapid technological development. Since it is quite a long term period, it is reasonable to consider the decomposition of efficiency change into the different sources above stated. It is therefore meaningful to adopt MPI to investigate the overall changes in port efficiency and to separate the efficiency change into different sources. The differentiation produces different policy implications as it identifies the sources of inefficiency of ports. For example, if a port does not efficiently utilize its existing assets and input factors, but tries to attribute its inefficiency to its level of technology and lack of long term capital investment, the result of these courses of actions would be creations of ineffective and unreasonable policies. In this perspective, examining the sources of inefficiency not only enriches efficiency benchmarking analysis but also eventually provides some foundations to further examine the influence of port institutions on port efficiency in later works.

FORMAL CONCEPT OF INDEX

The MPI index formally measures the total factor productivity (TFP) change between the two time periods. Originally, it calculates the ratio of the distances of data in each time period relative to a common technology. If technology in period t_1 is regarded as the reference technology and the base year for the comparison is period t0, the Malmquist TFP change index between period t_0 and t_1 is represented as the following:

$$\frac{TFP_{t1}}{TFP_{t0}} = \frac{d_{t1}(x_{t0}, y_{t0})}{d_{t1}(x_{t1}, y_{t1})}, \qquad \text{--- (1)}$$

where $d_{t1}(x_a, y_a)$ represents the distance from the observation in period a to the period t_1 technology. A value of the above index greater than 1 indicates a percentage improvement in TFP during the two time periods, t_0 and t_1.

Fare et al. (1994) refines this index suggesting the alternative practice to avoid having to choose between technologies in periods t_0 and t_1. The alternative concept is based on the geometric mean of two indices that are comprised by two times of benchmarking of one period in comparison to another. The first is evaluated with respect to period t_1 technology and the second with respect to period t_0 technology:

$$\frac{TFP_{t1}}{TFP_{t0}} = \left[\frac{d_{t1}(x_{t0}, y_{t0})}{d_{t1}(x_{t1}, y_{t1})} \frac{d_{t0}(x_{t0}, y_{t0})}{d_{t0}(x_{t1}, y_{t1})} \right]^{\frac{1}{2}}$$

$$= \frac{d_{t0}(x_{t0}, y_{t0})}{d_{t1}(x_{t1}, y_{t1})} \left[\frac{d_{t1}(x_{t1}, y_{t1})}{d_{t0}(x_{t1}, y_{t1})} \frac{d_{t1}(x_0^t, y_0^t)}{d_{t0}(x_{t0}, y_{t0})} \right]^{\frac{1}{2}} \text{ --- (2)}$$

Equation (2), represented by distance functions, can be mathematically rewritten as the following; that is represented by output-oriented efficiency scores (ϕ), since the efficiency scores are the ratios of distance in the production frontiers:

$$\underset{A}{\frac{\phi_{t0}(x_{t0}, y_{t0})}{\phi_{t1}(x_{t1}, y_{t1})}} \underset{[\qquad\qquad B \qquad\qquad]}{\left[\frac{\phi_{t1}(x_{t1}, y_{t1})}{\phi_{t0}(x_{t1}, y_{t1})} \frac{\phi_{t1}(x_0^t, y_0^t)}{\phi_{t0}(x_{t0}, y_{t0})} \right]^{\frac{1}{2}}} \text{ --- (3),}$$

where $\phi_{t\alpha}(x_{t\beta}, y_{t\beta})$ represents output-oriented efficiency scores produced by the benchmarking of a Decision Making Unit in the year of β in comparison to the year of α.

Here, the part of *(A)* in equation (3) represents change in technical efficiency (catch-up effect) between periods t0 and t1, while *(B)* measures technological change (frontier shift effects) during the same periods. It has been argued that, in order to properly measure total factor productivity using this concept, constant returns to scale (CRS) distance functions are required. The reason is the following: A change in technical efficiency, representing the catch-up effect, consists of changes in scale efficiency and changes in non-scale technical efficiency, or 'pure' technical efficiency. As the DEA under Variable Returns to Scale (VRS) does not measure the impact of production scales on efficiency, the MPI with the VRS distance functions cannot measure change in scale efficiency (Fare et al., 1994). It thus leads to the misspecification of size of shift frontier effects.

By introducing some VRS DEA models, equation (2) or (3) can be turned into a more refined index in equation (4) (e.g. Fare et al., 1994; Zhu, 2003; Cooper, 2004) which has also been recently applied in a MPI study in the port sector (e.g. Estache et al., 2004).

$$\frac{d_{t0}^{V}(x_{t0},y_{t0})}{d_{t1}^{V}(x_{t1},y_{t1})}\left[\frac{d_{t1}^{V}(x_{t1},y_{t1})}{d_{0}^{V}(x_{0},y_{0})}\frac{d_{t0}^{C}(x_{t0},y_{t0})}{d_{t1}^{C}(x_{t1},y_{t1})}\right]\left[\frac{d_{t1}^{C}(x_{t0},y_{t0})}{d_{t0}^{C}(x_{t0},y_{t0})}\frac{d_{t1}^{V}(x_{t1},y_{t1})}{d_{0}^{V}(x_{1},y_{1})}\right]^{\frac{1}{2}}$$

$$= \underbrace{\frac{\phi_{t0}^{V}(x_{t0},y_{t0})}{\phi_{t1}^{V}(x_{t1},y_{t1})}}_{A'}\underbrace{\left[\frac{\phi_{t1}^{V}(x_{t1},y_{t1})}{\phi_{0}^{V}(x_{0},y_{0})}\frac{\phi_{t0}^{C}(x_{t0},y_{t0})}{\phi_{t1}^{C}(x_{t1},y_{t1})}\right]}_{A''}\underbrace{\left[\frac{\phi_{t1}^{C}(x_{t0},y_{t0})}{\phi_{t0}^{C}(x_{t0},y_{t0})}\frac{\phi_{t1}^{V}(x_{t1},y_{t1})}{\phi_{0}^{V}(x_{1},y_{1})}\right]^{\frac{1}{2}}}_{B} \quad \text{--- (4)}$$

where ϕ^{V} is output-oriented efficiency scores under VRS and ϕ^{C} is output-oriented efficiency scores under CRS.

In equation (4), the change in technical efficiency, (*A)* in equation (2), is separated into the change in 'pure' technical efficiency *(A')* and the change in scale efficiency *(A")*. Therefore, the index can clearly decompose total factor productivity change into three different sources: 'pure' technical efficiency change *(A')*, scale efficiency change *(A")*, and technological progress *(B)*. The product between 'pure' technical efficiency change *(A')* and scale efficiency change *(A")* is called total technical efficiency change (TTEC), representing *the catch-up effect*. This separation is interesting especially because changes in scale efficiency of ports are often determined by the changes in external demand driven by the economic sizes and strengths of port hinterlands (Estache 2004). Port authorities and managers may not have strong control on these, while it is possible that port planning and strategic management still can do something about over the long term.

DATA AND SCOPE

One of the main goals of this analysis is to survey efficiency changes between 1991 and 2004 for 98 world scale container ports and major national gateway ports. In order to trace the change of port efficiency, we construct a time series database, basically including two years of information for each port: 1991 and 2004. The top 75 ports are firstly selected based on the throughput of 2001.[3] Each of the 75 ports handled at least more than 800,000 TEU[4] per year

[3] The year 2001 was the most recent year for which port throughput data are confirmed.
[4] Twenty-Foot Equivalent Unit

and their total accumulated throughputs approximately amounts to more than 75 % of a total of 245 millions of TEU handled by 533 container ports in the world. Secondly, data are collected for the largest ports in the countries that do not possess the top 75 ports in the world. The database can thus cover the fairly large scale container ports situated in almost countries. After eliminating some landlocked countries that do not have major seaports and some countries for which port data are not accessible, the data on a total of 138 ports were collected for the year 2004; 100 ports for 1991. The MPI was implemented with the 98 ports that have data on both years.[5]

Port Input and Output Data

Economic theory implies that effective handling of container volumes depends largely on efficient use of port land, labor, and capital (Dowd and Leschine, 1990). Currently, information on port labor does not have reliable sources of data generally in the port sector. It is partly due to the fact that the structure of port labor is particularly complex, consisting of different types of full time jobs, part time positions, and contracted jobs, that are not directly managed and administered by port authorities. It is thus very difficult to trace all the information even in one port authority level. Especially when a study deploys large scale benchmarking frameworks across many regions, it is not possible to acquire reliable sources of labor information.

However, it has been recently claimed that port land and capital input such as berth and quay length, terminal area, and capacity of container cranes, directly affects container terminal efficiency (Notteboom et al., 2000) while labor can be measured through other capital input variables. Due to the considerable amount of collinearity, the number of workers in a dock can be proxied by the number of container cranes at a container terminal (Marconsult, 1994; Tongzon, 2005). Yet, Cullinane et al. (2004) states that, with the rapid development of

[5] This approach can be partly limited for a full consideration the restructuring of the global port industry as the database leaves out four major container ports that did not exist in 1991 but became the global Top 30 in 2004: i.e. ports of Yantian, Qingdao, Gioia Tauro, and Laem Chabang. Therefore, the impact measured through MPI in this paper may underestimate the total factor productivity changes during the period.

manufacturing and transportation technology, new equipment, such as automated guided vehicle and automatic stacking cranes deployed at the container terminal yard, advanced ports are able to use lower numbers of port labor. Therefore, collinearity, or predetermined relationship, between port labor and container cranes observed in the past will not be necessarily static and continuously linear in the future. In spite of their intuition on the newly emerging relationship, they cannot successfully suggest new ways of measuring labor deployed in ports. Given the characteristics of container port production and the limitation of information, *total container berth length* (meter); *container terminal area* (square meters); *capacity of container cranes* (tonnage) including large quayside cranes and mobile cranes in container terminals, are selected for the proxies of factor input for container production.

There are also multiple outputs produced in a port. While contemporary ports diversify their production activities by integrating more logistics ability like manufacturing, packaging, and delivery into traditional cargo and vessel services, the main focus of large scale container ports is still organized around handling container volumes as much as possible. Moreover, the emphasis on efficient container handling has not weakened as ports seek diversification of their production but are strengthened more and more by trying to become a regional transshipment hub. In other words, the volume of containers handled may be a precondition that ports can develop other types of production activities by integrating new concepts of logistical capacity. Considering the focus of this study to benchmark world-scale and national gateway container ports, this study regards *container volumes handled* (total throughputs) at a port level as port output, with a unit of TEU handled.

As Cullinane et al. (2004) mention in their critique, the previous DEA analyses of container port efficiency can fluctuate over time; when time is not considered, port efficiency can be biased. In order to reduce the impacts of severe output fluctuation that may be caused by such unexpected external shock as labor dispute or severe weather conditions, we use the averages of three years for outputs to come up with throughput values for the two observation years, 1991 and 2004, respectively. In detail, to come up with the values of throughputs of 1991 for the ports in the sample, we use the average values of 1989, 1990, and 1991 for each port. For 2004, the averages of 2002, 2003, and 2004 were used.

The secondary data on port input and output are generally acquired from three different sources and were confirmed by cross-checking. The main source is acquired from Containerisation International-Online (CIO) for the year of 2004 data, and Containerisation International Yearbook (CIY) 1992 for the year of 1991 data. An attempt at confirming the data was made by examining another source of data from Ports and Terminals Guide (PTG) 2005. When there are unreasonable or missing figures in the CIY and CIO data, they were crosschecked with the PTG data. If the PTG data did not provide information needed to confirm the data, individual port websites and official were contacted to confirm the validity of information regarding port inputs and outputs. It is not unusual to have discrepancy on information among these three sources. When this is the case, the majority opinions are usually followed. If the majority opinions do not exist, showing a large scale of gaps among the three sources, the final data takes the median values of the three sources. The descriptive statistics of major input and output variables are summarized in Table 1.

Table 1. Descriptive Statistics of the Input and Output Variables

		Output	Inputs		
		Container Throughput (TEU)	Berth Length (m)	Terminal Area (sq. meter)	Container Crane (Tonnage)
1991	Mean	679132	1906	694016	467
	Standard Error	100334	228	82225	54
	Median	328809	1068	362000	267
	Standard Deviation	993258	2258	813982	533
	Kurtosis	9.33	8.31	5.33	6.47
	Skewness	2.85	2.56	2.15	2.36
	Minimum	606	92	4500	31
	Maximum	5313900	13799	4441284	2925
	Sum	66554927	186748	68013564	45729
	Total N	98	98	98	98
2004	Mean	2178146	2885	1278395	1017
	Standard Error	333335	272	138351	96
	Median	1291486	2158	828288	739
	Standard Deviation	3299853	2692	1369609	946
	Kurtosis	15.44	2.92	3.32	2.55
	Skewness	3.62	1.75	1.86	1.68
	Minimum	33208	91	60000	50
	Maximum	20508333	13329	6834710	4254
	Sum	213458292	282771	125282684	99626
	Total N	98	98	98	98

Port Institution Data

There have been few databases that include comprehensive information on world port institutions. This study utilizes a database constructed from a dissertation research by the author of this paper (Cheon, 2007). The database on port institutions is based on original data collections through multiple methodologies such as (i) reviews of secondary literature, (ii) surveys of primary port planning documents and online websites, and (iii) short telephone interviews with port planners. A descriptive transcript about institutional contexts and aspects for ports, acquired through these processes, are transformed to codes depending on the categorizations of corporate structure and ownership practice of ports, noted in Appendix 1. The coded data are also classified for their institutional changes between the two periods, 1991 and 2004.

RESULTS: EFFICIENCY CHANGE OF WORLD PORTS, 1991-2004

Appendix 2 presents the changes in total factor productivity for the major world ports from 1991 and 2004. Overall, during the last decade, the world major hub and national gateway ports improve their efficiency by more than 2.4 times (Average MPI = 2.418). There are three outliers the port of Guangzhou (10.167), the port of Jawaharlal Nehru (12.754), and the port of Salalah (40.758), which show extremely high levels of efficiency changes compared to other ports during the period. Particularly, the port of Salalah achieved its improvement of total factor productivity mostly through changes in scale efficiency. When excluding the outliers, the other 95 ports improved their efficiency by more than 82% (Average MPI = 1.823) over the last decade (Table 2). Their sources of efficiency changes can be attributed to (1) 33.3% increase of ‘pure’ technical efficiency (TEC = 1.333), (2) 26% increase of scale efficiency (SEC = 1.262), and (3) 28.6% efficiency improvement due to technological progress (PFC = 1.286).

Appendix 2 and appendix 3 also show that the majority of ports in the world improve their average total factor productivities (83 ports) from 1991 to 2004, while 15 ports have decreased their efficiency over the same period: Miami, Nagoya, Helsinki, Oakland, Keelung, Bangkok, Manila, Busan, Copenhagen, La Spezia, Fremantle, Houston, Lisbon, Piraeus, Kobe, Rijeka, and Buenos Aires.

Table 2. Descriptive Statistics of MPI, TEC, SEC, and EFC

		MPI	TEC	SEC	PFC
N	Valid	95	95	95	95
	Missing	0	0	0	0
Mean		1.823	1.333	1.262	1.286
Median		1.626	1.017	1.114	1.238
Std. Deviation		1.006	1.119	.550	.217
Skewness		1.200	3.418	3.404	.401
Std. Error of Skewness		.247	.247	.247	.247
Kurtosis		1.541	17.572	18.198	-.543
Std. Error of Kurtosis		.490	.490	.490	.490
Minimum		.225	.13	.25	.919
Maximum		5.241	8.48	4.79	1.818
Sum		173.231	126.65	119.88	122.209

The problems of some ports above have been well known and reported. For example, port of Busan has recently experienced severe congestion problems in their container terminals. The port now hopes to resolve this problem by opening newly developed privatized terminals, and restructuring of port governing structures in the country with a scheme of corporatization. The port of Bangkok's deterioration in efficiency could be caused by the port of Laem Chabang, located next to the port of Bangkok. As most volumes of container cargoes have been moving to the port of Laem Chabang, the old port, the port of Bangkok, is intended to focus more on general or bulk cargoes due to its traditional layouts of piers and berths. The port of Houston is the one of the largest oil ports in the world and its focus has been more and more oriented to handling liquid bulks, thereby it may reduce its efficiency in container handling. There are also some other Japanese, US, and Southern European ports which have experienced troubles in improving productivity. Finally, it seems that the port of Manila in the Philippines has not caught up to the higher levels of inter-port competition in the South Asian region.

Table 3 and Figure 1 illustrate clearly the relationships between MPI and three sources of efficiency change of ports.

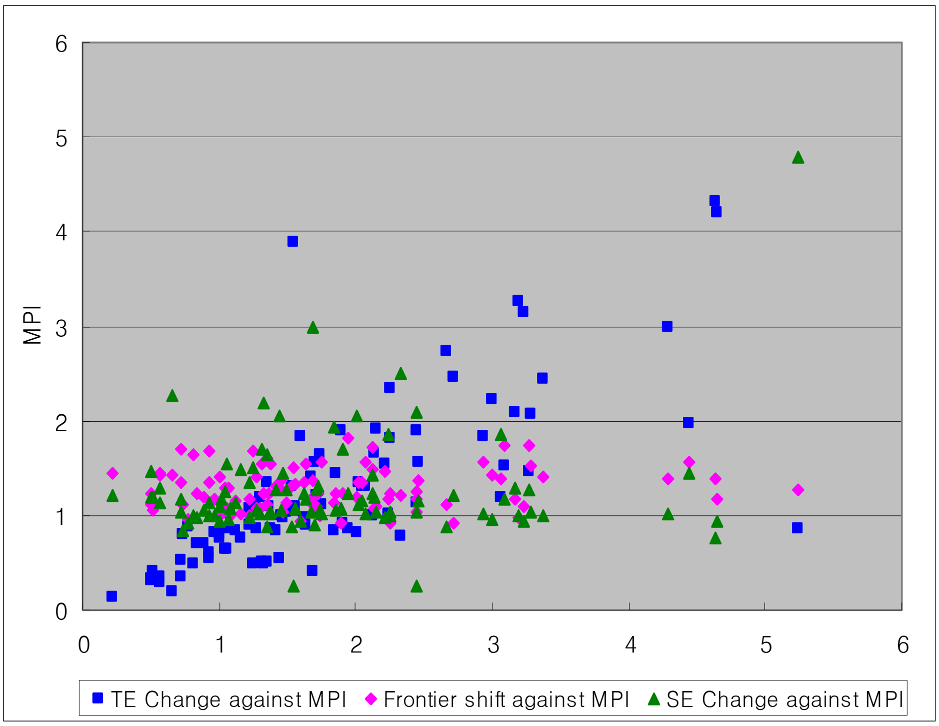
Table 3. Correlations of MPI and Sources of Efficiency Change

		MPI	TEC	SEC	PFC
MPI	Pearson Correlation	1	.588(*)	.193(*)	.090(*)
	t-statistics (2-tailed)		(4.928)	(5.216)	(5.184)
TEC	Pearson Correlation	.588(*)	1	-.388	-.145
	t-statistics (2-tailed)	(4.928)		(-.488)	(0.389)
SEC	Pearson Correlation	.193(*)	-.388	1	.005
	t-statistics (2-tailed)	(5.216)	(-.488)		(-.406)
PFC	Pearson Correlation	.090(*)	-.145	.005	1
	t-statistics (2-tailed)	(5.184)	(0.389)	(-.406)	
	N	95	95	95	95

** Correlation is significant at the 5% level (2-tailed).*

- *MPI: Malmquist Total Factor Productivity Index*
- *TEC: 'Pure' Technical Efficiency Change*
- *SEC: Scale Efficiency Change*
- *PFC: Efficiency Change caused by Productivity Frontiers Shift*

Figure 1. Correlations between MPI and Components of TFP



In Table 3, the changes in total factor productivity (MPI) are explained in a statistically meaningful way by all three sources of efficiency changes decomposed by MPI.

Firstly, efficiency gains from non-scale technical efficiency have the stronger impacts on the improvement of overall productivity of ports (*Pearson's r* = 0.588, see Table 3). The stronger impact of non-scale technical efficiency rather than scale efficiency or technological progress implies that over the last decade, the improvement of port efficiency has been achieved by focusing more on increasing "pure" technical efficiency. In other words, what this analysis implies is that hinterland conditions is neither the strongest nor the single source of change in port inefficiency.

Non-scale technical efficiency can increase mainly by the courses of actions that improve the ability and flexibility to rationalize factor inputs in order to maximize port outputs. These can often be driven by adoptions of port reform efforts and better managerial practices to catch up other best practices. This result is at odds with a preconception that port efficiency is most likely shaped by the external demand for port services from hinterlands and thereby there is not much role for port authorities to play in terms of port management. While port throughputs may possibly be strongly influenced by external demand, improvement of port efficiency certainly requires larger roles of port long-term planning, strategic management, and effective market regulation to create institutional structures and incentives to introduce better port management.

Secondly, efficiency gains from the adjustment of port production scales also have substantial impacts on the improvement of overall productivity of ports, while the impacts are smaller than pure technical efficiency *(Pearson's r* = 0.193, see Table 3). The scale of port production and scale efficiency are strongly influenced by exogenous factors such as demand from hinterlands (Estache et al., 2004). Since they meet the necessary preconditions by which ports can possibly increase their outputs vis-à-vis the given inputs, large and strong hinterland economies are certainly one of the advantages for a port in achieving increased efficiency over the last years. The ports located remotely from the global production networks and shipping routes thus have obviously strong disadvantages in increasing their port efficiency.

However, many larger scale ports operate at the size of decreasing returns to scale, which implies that the larger ports do not always reap the benefits of strong hinterland economies by properly sizing their production scales to improve their productivity levels.

Certainly here, the normative roles of ports need to be considered in the sense that ports in many parts of the world still aim to increase their total output levels rather than their efficiency. If they have been traditionally regarded as output maximizers as a way of sustaining regional trades rather than being efficiency maximizers, they have usually been allowed to enjoy the status of regional monopolists or national oligopolists. The business loss made by port authorities or the capital for long-term investment in port infrastructure has been compensated by tax revenues, since under this view, it is theoretically reasonable to use public resources based on the amount that a port generates economic externalities for the regions.

However, from a policy making point of view, it is not clear whether allowing the regional monopoly of a port is always an effective choice to achieve multiple but conflicting goals: sustaining regional trade and effectively utilizing public resources. More often than not, the real issue is not a choice of what values policy makers select, but whether they can come up with appropriate amounts of the public resources to be spent to compensate and support the role of ports under regional monopoly. While their production costs may possibly be clearly estimated, the scopes of the benefits are much vaguer and geographically more disperse, and the social costs of allowing regional monopoly are clearly shown from their lack of interest in increasing productivity and changing the bureaucratic behaviors and organizational inertia.

In the past, the choice between the two conflicting values could be made by policy makers in the national or the upper-level governments that guide port authorities to follow the overall guidelines for managing and operating ports and terminals. However, given the increasingly fiercer competition in the contemporary global port sector, ports are asked to be equipped with the strong capacity to create and respond to the external demand as quickly and flexibly as possible in order not to lose their own competitive edge. Given the current market conditions, achieving the two conflicting objectives simultaneously becomes one of many necessary conditions for ports to sustain their competitive edge in many parts of the world.

The strong abilities to analyze the medium-term market demand, monitor the current resources and assets, and match them to find the future gaps through marketing and supply chain management are certainly parts of the areas in strategic planning that port managers and authorities can work on in order to improve the medium-term scale efficiency.

Finally, with the strong influence of total technical efficiency (TEC plus SEC) on total factor productivity change (MPI), technological progress (PFC) also shows a statistically meaningful impact on changes in total factor productivity (MPI). Yet its size of impact on total factor productivity is smaller and its variance is smaller depending on ports (see Table 3 and Figure 1). Over the last few decades, the global port sector has experienced an amazingly rapid development in their container handling, managerial, and security technologies. For example, the port of Rotterdam maintains (non-human) automated driving container cranes that pick up containers from the yards to distribute them directly to rail-cars or trucks. And the recently developed diverse container scanning and monitoring technologies are sometimes argued to be something that could allow ports to improve not only productive efficiency but also cost efficiency eventually in the future. Certainly, ports like Singapore and Hong Kong have been one of conspicuous examples that have made strategic and aggressive capital investment in the most cutting-edge technology. And, more recently, the moves by the European ports such as the port of Rotterdam and the port of Antwerp have been impressive.

However, in terms of technology, many large-scale leading ports can speedily assimilate with each other by a relatively easier way of changing, or at least maintaining, the status quo, i.e. heavy capital investment in the new technology. The fact that the frontier shift effects among ports have a substantially smaller variance (Figure 1) than other sources of efficiency change would certainly imply the limitation of the sole dependence on this strategy. Obviously, the change of technology through strong capital investment may be much easier than changes of behaviors, institutions, or hinterland market conditions. However, an easier way of making changes has inherently low entry barriers so that others can copy the strategies and set up the environments more easily. In this sense, making technical progress does not necessarily become a substantially effective strategy but a minimum necessity when ports attempt to achieve port efficiency, competing with others for advantages in the global market.

This analysis shows that, while it is still one of the important factors in shaping port efficiency, the external environment does not always either a determining or predominant source that causes port inefficiency. This holds especially true if geographical conditions are similar so that the ports share fairly similar sizes of hinterlands and strengths of economies. Ports that have innovative management with emerging technology obviously have stronger potential to operate more efficiently in the long term. If the level of inter-port competition is fierce enough among the ports that share same hinterlands (e.g. Northern Europe), it is more probable that efficient management and technical progress play substantially stronger roles in improving efficiency of ports. Thereby it gives the ports the higher competitive edge in the current global seaport sector. The port of Dubai has been one of the examples of this for the last several years. Dubai has not only tried to formulate its strategy toward new port technologies, but also created new sections of markets by innovating their institutions and increasing the strategic capacity to prepare for and respond to the future demand. It may be unfortunate for the US port sector that the government rejected the deal of purchasing the former P&O terminals by the port of Dubai. This is so because the decision is not driven by economic advantages or disadvantages but mostly by the political dimensions of the deal, which may eventually prevent some US ports from overcoming their inefficiency.

RESULTS: INSTITUTIONAL CHANGE AND SOURCES OF EFFICIENCY CHANGE

Change in Port Ownership Practice and MPI

Table 4 compares the changes in port efficiency (MPI) between ports that have experienced private sector participation in port ownership (Group 2) and those that have not (Group 1).[6] From 1991 to 2004, in general, the ports in Group 2 have a higher MPI than Group 1. The group means are statistically different at the 10 percent level based on ANOVA (F=3.364, *p*=0.070), while it is not rejected that their means are statistically different based on either Welch's test or the Brown-Forsythe test (2.591, *p*=0.114).

[6] Among 98 ports that have data for MPI, ports with maximum MPI values (Salalah) and minimum values (Buenos Aires) are excluded for this analysis due to the fact they are extreme outliers. In addition, the analysis excludes two Taiwanese ports that recentralize their terminal operation function for the reform purpose in transition.

Table 4. Port Ownership Change and MPI, TEC, SEC, and PFC

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
MPI	No OWN Change	55	1.79	.90	.12	1.55	2.04	.50	4.63
	OWN Change	39	2.45	2.41	.39	1.66	3.23	.51	12.75
	Total	94	2.06	1.72	.18	1.71	2.42	.50	12.75
TEC	No OWN Change	55	1.41	1.24	.17	1.08	1.74	.31	8.48
	OWN Change	39	1.65	1.85	.30	1.05	2.25	.20	8.87
	Total	94	1.51	1.52	.16	1.20	1.82	.20	8.87
SEC	No OWN Change	55	1.19	.42	.06	1.08	1.30	.25	2.98
	OWN Change	39	1.37	.69	.11	1.15	1.59	.26	4.79
	Total	94	1.26	.55	.06	1.15	1.38	.25	4.79
PFC	No OWN Change	55	1.26	.23	.03	1.20	1.32	.92	1.74
	OWN Change	39	1.31	.20	.03	1.24	1.38	1.00	1.82
	Total	94	1.28	.22	.02	1.24	1.33	.92	1.82

TEC: technical efficiency change, SEC: scale efficiency change, PFC: technology progress

In terms of the source of efficiency changes, scale efficiency change (SEC: F=2.427, *p*=0.123) shows a larger and statistically more meaningful, though not significant, difference between Group 1 and Group 2 than technical efficiency change (TEC: F=0.587, *p*=0.446) and technology change effect (PFC: F=1.058, *p*=0.306). It implies that the impact made by the separation of terminal operation function from government hands can be directed more to scale efficiency change.

When only 63 ports in the dataset ranked within the Top 100 are considered[7], the whole picture is depicted a bit differently in Table 5. The gap between the two groups in the MPI is more strongly confirmed at the five per cent level from ANOVA (F =5.184, p=0.026) and the 10 per cent level from the Welch and the Brown-Forsythe (3.611, p=0.068) tests.

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[7] In terms of production scales in 2001

Table 5. Port Ownership Change and MPI of Ports Ranked within 100

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
MPI	No OWN Change	38	1.66	.82	.13	1.39	1.93	.51	4.29
	OWN Change	25	2.79	2.88	.58	1.60	3.97	.51	12.75
	Total	63	2.11	1.98	.25	1.61	2.61	.51	12.75
TEC	No OWN Change	38	1.13	.55	.09	.95	1.32	.34	3.00
	OWN Change	25	1.91	2.17	.43	1.01	2.80	.40	8.87
	Total	63	1.44	1.47	.18	1.07	1.81	.34	8.87
SEC	No OWN Change	38	1.19	.37	.06	1.07	1.31	.83	2.49
	OWN Change	25	1.36	.77	.15	1.04	1.68	.88	4.79
	Total	63	1.26	.56	.07	1.12	1.40	.83	4.79
PFC	No OWN Change	38	1.29	.21	.03	1.22	1.36	.93	1.74
	OWN Change	25	1.26	.19	.04	1.18	1.33	1.00	1.60
	Total	63	1.27	.20	.03	1.22	1.32	.93	1.74

TEC: technical efficiency change, SEC: scale efficiency change, PFC: technology progress

In terms of sources of efficiency, the largest gap can be found in TEC. According to ANONVA, Welch, and Brown-Forsythe, their means are statistically different at the 10 percent level, while their median values do not show large gaps from each other. This is possibly because, for larger ports, their efficiency improvement is much easier to be realized from a technical efficiency change than increasing scale efficiency, given that their production scales were already large enough in 1991 and sometimes even exceeded optimum production scales. The difference between mean and median values also suggests that significant efficiency achievement may be realized unevenly from some selected ports that have been efficiently managed over the last decade (e.g. a few Chinese ports and Jawaharlal Nehru).

More facts can be clearly observed when 14 ports that experienced leasehold and concession in their terminals but resided outside of the Top 100 in 2001 are examined. For the 14 ports in Group 2, all show improvement in SEC (except Bridgetown) and significant improvement in PFC. Especially, their improvement in PFC is significantly higher and statistically different at the five percent level than the 17 ports in Group 1. Six out of 14 ports in Group 1 show negative improvement in TEC (Constantza in Romania, Fremantle in Australia, Helsinki in Finland, Lisbon in Portugal, Montevideo in Uruguay, and St. Petersburg in Russia), thereby leading three ports to end up having negative total factor productivity improvement despite their institutional transformation efforts (Fremantle, Lisbon, and Helsinki).

Change in Port Corporate Structure and MPI

Table 6 presents the difference in efficiency change between ports; which, in the last decade, have implemented decentralization in corporate and management structure (Group B) and those that have not (Group A). In general, the ports in Group A have a larger MPI than Group B. However, there is no statistically meaningful difference in all categories of efficiency sources. The ports in Group B have even a lower mean TEC than ports in Group A, while the reverse is the case for the two other sources of efficiency. Overall, due to the lack of statistical significancy, it is difficult to conclude that changes in corporate structure has either promoted or discouraged the changes in port efficiency.

Table 6. Port Corporate Structure Change and MPI

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
MPI	No MGT Change	70	2.13	1.91	.23	1.67	2.58	.50	12.75
	MGT Change	17	1.96	1.02	.25	1.43	2.48	.51	4.45
	Total	87	2.10	1.77	.19	1.72	2.47	.50	12.75
TEC	No MGT Change	70	1.59	1.67	.20	1.19	1.99	.20	8.87
	MGT Change	17	1.16	.75	.18	.78	1.54	.40	3.14
	Total	87	1.50	1.54	.17	1.17	1.83	.20	8.87
SEC	No MGT Change	70	1.25	.59	.07	1.11	1.39	.25	4.79
	MGT Change	17	1.40	.45	.11	1.17	1.63	.83	2.49
	Total	87	1.28	.56	.06	1.16	1.40	.25	4.79
PFC	No MGT Change	70	1.27	.22	.03	1.22	1.32	.92	1.82
	MGT Change	17	1.31	.17	.04	1.23	1.40	1.06	1.60
	Total	87	1.28	.21	.02	1.23	1.32	.92	1.82

Improvement in productive efficiency of container ports is mainly generated from the actual institutional practice of ports through concessioning and leasing port assets, rather than decentralization and corporatization at port authority levels. Unlike concession contracts, port corporatization is predicated on relational contracts on the basis of statute (Williamson, 1979; Gómez-Ibáñez, 2003). The corporatization scheme can be originally loosely defined and produce various mechanism of implementation (Everette, 2005). Unless they are specifically secured through additional legal or institutional mechanisms, the productive efficiency benefits may not be as high as those of concession contacts that include detail statements regarding efficiency or performance targets. In contrast, disintegrations of port ownership have promoted intra-port competition and contributed to attracting new investment for upgrading terminals from global terminal operators, shippers, and other private cargo handlers.

From another angle, this result also reflects that, over the last decade, the roles and powers of terminal operators and cargo handlers have become much stronger in the port industry. For many parts of the world, globally franchised operators and cargo handlers have tried to capture new sections of the market where economic opportunities have not yet been taken. It has therefore allowed some selected ports that had higher, but not yet realized, potential to harvest larger scale efficiency and economies of scale and, at the same time, to separate terminal operation from direct duties under the governments' wing.

CONCLUSION

This study conducts extensive analyses on productive efficiency change of world ports and decomposes the sources of efficiency changes over the last decade to investigate whether port strategies and institutional reforms can be seen as potentials to increase port efficiency vis-à-vis the larger environments that ports cannot control easily. Finally, it has also observed how these are influenced by not just regional hinterland conditions, but also policies and strategies that many ports have sought to sustain within the paradigm of contemporary global port industry and to capture the emerging shipping markets.

The interesting points that these analyses demonstrate can be summarized by the following:

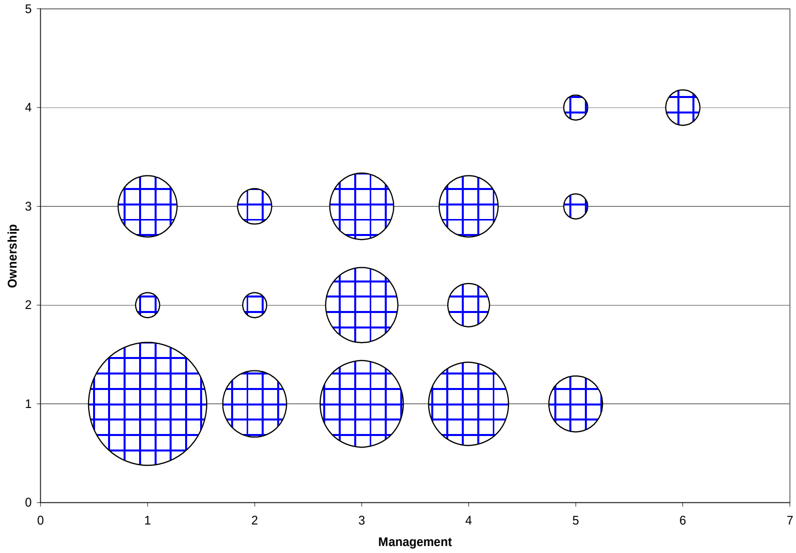
- Ports in the world have improved their efficiency over time due to improvement in management, production scale adjustment, and technological progress.

- Some of the most efficiently managed ports in the world can be found in Asia, Central America, and the Middle East, that recently have moved fast and been physically well-structured (e.g. Shanghai and Guangzhou) and some other Asian ports that have been traditionally managed quite efficiently (e.g. Hong Kong and Busan).
- Although scale efficiency mainly representing influences from external environments is still one of the important factors to shape port efficiency, it is neither determining nor predominant.
- Therefore, for ports of fairly similar sizes and strengths of hinterland economies where levels of inter-port competition are fierce, the roles of efficient management, strategic capital investment and institutional restructuring and reform are not minimal but substantial for the operation of ports over the medium-long term. Given the current globalized shipping market and scopes of port activities, the strategies to combine institutional restructuring and capital investment can suggest the potential to partly overcome the limitations of the external conditions, as can be found from such examples as the port of Dubai and the port of Singapore.
- However, the strategy focusing only on aggressive investment in technological progress has limitations in that it is relatively easier for other ports to replicate. Thereby it could lack the possibility to increase relative efficiency and competitiveness.
- Regarding the relationship between port infrastructure efficiency and corporate structure, it is not possible to accept the hypothesis, “The more decentralized corporate structure of port authorities does always lead to proven higher productivity of ports, based on growing autonomy in management of port authorities.” On the other hand, improvement in productive efficiency of container ports largely came from the actual practice of ownership and asset management over the last decade.

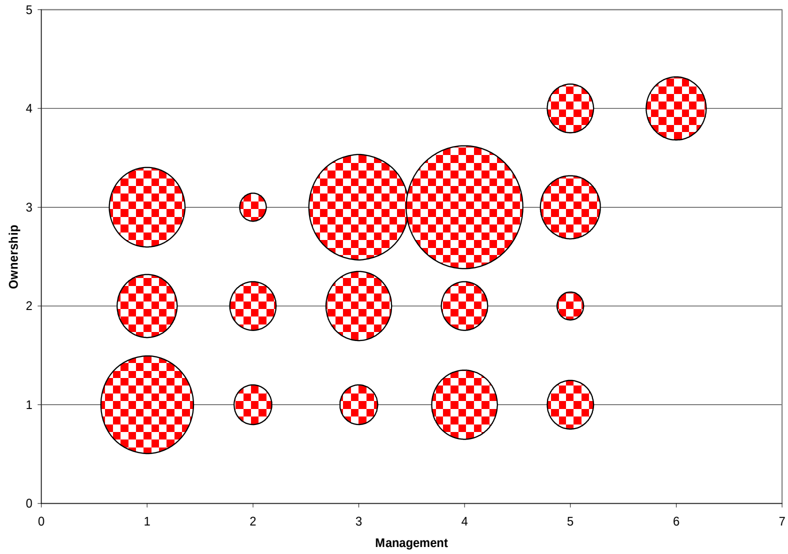
The lesson is that, therefore, the direct business side of terminal operation and management can be pursued through private sector participation. The government sector should focus more on policy making on environmental, safety, and customs regulations. They also collaborate with other partners on long-term planning and finance for port and nautical infrastructure, and creating a market structure to reduce regional and national monopolistic characters.

Appendix 1. Port Ownership and Corporate Structure in the World in 1991 and 2004

Year 1991



Year 2004



Notes: **Management Structure Categories**:
(1) National Government (or national port authority), (2) State or Provincial Government (or state port authority), (3) Local Government Department, (4) Statutory Authority or Corporation, (5) Government-Owned Corporation, and (6) Private Enterprise

Ownership Categories:
(1) Public Operating Port, (2) Mixed Ownership Port, (3) Public Landlord Port, and (4) Non-Government Port

Appendix 2. Malmquist Productivity Index: TFP Change from 1991 to 2004

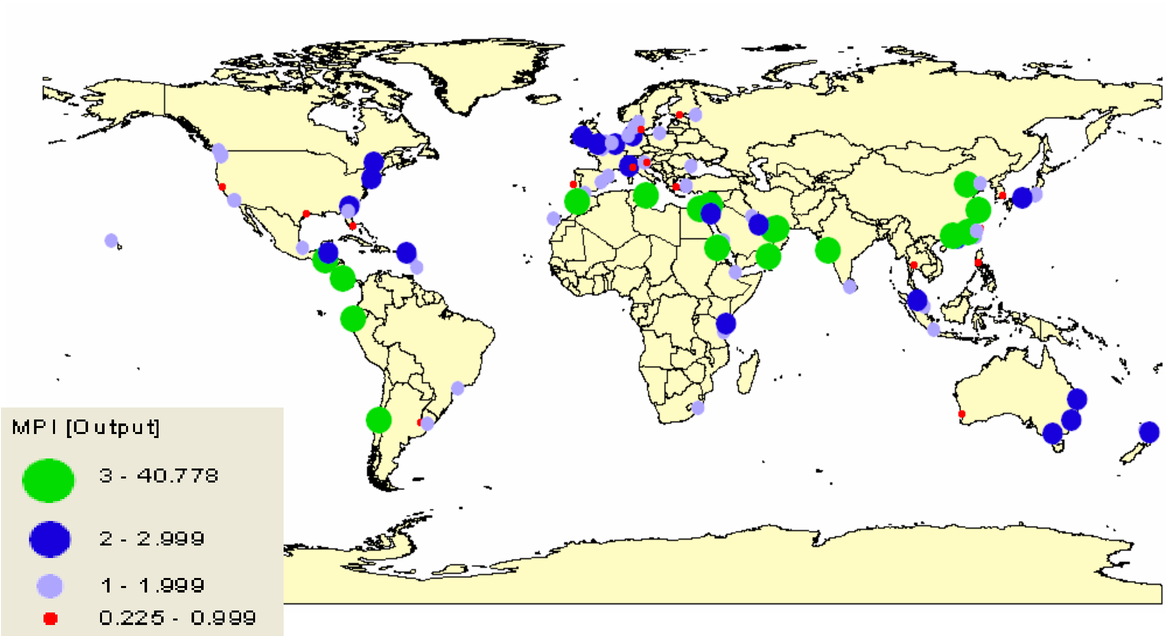
PORT NAME	MPI	rank	Change in Technical Efficiency	rank	Change in Scale Efficiency	rank	Change in Technical progress	rank
Hong Kong	2.119	33	1.000	51	1.238	33	1.711	4
Singapore	1.638	50	0.902	57	1.179	41	1.541	15
Busan	0.734	89	0.792	72	0.831	95	1.116	74
Kaohsiung	1.712	46	1.217	38	1.276	27	1.103	77
Shanghai	3.231	12	3.138	8	0.934	89	1.103	76
Rotterdam	1.447	59	0.552	81	2.048	9	1.281	46
Los Angeles	1.158	73	0.760	75	1.488	18	1.025	87
Hamburg	2.009	37	0.815	70	2.055	8	1.200	59
Long Beach	1.841	42	0.841	68	1.934	10	1.132	71
Antwerp	2.234	28	1.022	49	1.855	12	1.179	63
Port Klang	2.213	29	1.545	28	0.980	83	1.462	20
Dubai	3.173	14	2.096	15	1.295	25	1.168	65
New York/New Jersey	2.337	25	0.774	73	2.492	4	1.211	57
Bremen/Bremerhaven	1.903	39	0.914	56	1.694	14	1.228	54
Felixstowe	1.413	60	0.846	67	1.273	29	1.312	43
Tokyo	1.361	62	1.088	45	1.019	70	1.228	55
Yokohama	1.047	78	0.651	78	1.246	31	1.290	45
Manila	0.774	88	0.876	59	0.914	90	0.966	93
Tanjung Priok	1.065	76	0.867	60	0.951	84	1.293	44
Algeciras	1.755	43	1.115	43	1.010	74	1.558	13
Kobe	0.506	96	0.341	94	1.198	38	1.238	49
Tianjin	4.647	5	4.207	5	0.945	86	1.169	64
Nagoya	0.929	83	0.551	82	0.999	78	1.686	6
Keelung	0.839	86	0.699	77	0.982	81	1.222	56
Guangzhou	10.167	3	7.983	3	1.166	45	1.092	79
Colombo	1.375	61	0.860	63	1.040	64	1.537	16
Oakland	0.886	85	0.709	76	1.051	59	1.190	61
Charleston	1.279	68	0.856	64	1.057	58	1.413	27
Genoa	2.660	20	2.729	10	0.877	94	1.111	75
Le Havre	1.471	57	0.985	54	1.441	21	1.036	86
Osaka	2.249	27	1.816	23	1.006	75	1.231	51
Valencia	1.347	64	1.358	33	0.884	93	1.123	72
Barcelona	1.005	80	0.767	74	0.935	88	1.402	28
Tacoma	1.730	45	1.068	46	1.319	24	1.228	53
Seattle	1.114	74	0.846	66	1.141	48	1.154	67
Xiamen	5.241	4	0.863	62	4.789	2	1.268	47
Melbourne	2.464	21	1.562	27	1.145	47	1.378	33
Dalian	1.051	77	0.637	79	1.540	16	1.072	83
Durban	1.601	52	1.832	22	0.936	87	0.934	94
Jawaharlal Nehru	12.754	2	8.868	1	1.204	36	1.194	60
Salalah	40.778	1	0.542	83	52.907	1	1.421	25
Jeddah	1.219	71	1.067	47	0.981	82	1.164	66
Piraeus	0.512	95	0.404	91	1.192	39	1.062	84
Marsaxlokk	3.281	10	2.070	16	1.035	66	1.531	17
Southampton	2.151	30	1.907	18	1.032	67	1.093	78

Vancouver BC	1.697	47	1.563	26	0.898	91	1.210	58
Khor Fakkan	3.090	15	1.516	29	1.174	43	1.736	3
Savannah	2.134	31	1.659	24	1.187	40	1.083	80
Taichung	1.218	72	0.892	58	1.358	23	1.005	89
Bangkok	0.809	87	0.493	88	1.000	76	1.642	8
Houston	0.568	93	0.354	93	1.133	50	1.418	26
Santos	1.003	81	0.803	71	1.097	52	1.140	70
Sydney	2.054	35	1.319	35	1.151	46	1.353	38
Montreal	2.073	34	1.304	37	1.018	71	1.562	11
La Spezia	0.719	91	0.359	92	1.177	42	1.702	5
Miami	0.970	82	0.828	69	0.991	79	1.182	62
Honolulu	1.301	67	1.196	39	1.012	73	1.075	82
Zeebrugge	1.533	55	1.315	36	0.886	92	1.315	42
Haifa	4.287	8	2.997	9	1.026	69	1.395	31
Jacksonville	1.452	58	0.993	53	1.064	56	1.374	34
Gothenburg	1.735	44	1.651	25	1.059	57	0.992	90
Buenos Aires	0.225	98	0.127	98	1.212	35	1.455	21
Damietta	3.376	9	2.437	12	0.991	80	1.398	29
Las Palmas de Gran Canari	1.855	41	1.439	31	1.046	61	1.232	50
Puerto Limon	3.065	16	1.191	40	1.865	11	1.380	32
Veracruz	1.349	63	0.515	85	1.639	15	1.599	9
Izmir	1.626	51	0.976	55	1.228	34	1.356	37
St Petersburg	1.949	38	0.865	61	1.240	32	1.818	1
Brisbane	2.937	18	1.845	21	1.016	72	1.568	10
Auckland	1.552	53	1.099	44	1.065	55	1.326	41
Helsinki	0.924	84	0.605	80	1.135	49	1.346	40
Lisbon	0.564	94	0.303	96	1.284	26	1.449	22
Dublin	2.452	22	1.887	20	1.042	63	1.247	48
Guayaquil	3.006	17	2.218	14	0.950	85	1.426	23
Aarhus	1.082	75	1.017	50	1.077	54	0.988	91
San Antonio	4.445	7	1.977	17	1.442	20	1.560	12
Fremantle	0.659	92	0.203	97	2.277	5	1.425	24
Casablanca	4.633	6	4.328	4	0.767	96	1.396	30
Puerto Cortes	1.245	70	0.491	89	1.503	17	1.686	7
Montevideo	1.330	65	0.495	87	2.186	6	1.229	52
Tauranga	2.448	23	1.125	42	2.093	7	1.039	85
Aqaba	2.717	19	2.459	11	1.202	37	0.919	95
Gdynia	1.888	40	1.897	19	1.083	53	0.919	95
Santo Tomas de Castilla	3.198	13	3.256	7	0.999	77	0.983	92
Shuaiba	1.668	49	1.408	32	1.037	65	1.142	68
Djibouti	1.688	48	0.416	90	2.983	3	1.362	35
Mina Sulman	2.254	26	2.352	13	1.043	62	0.919	95
Dar-es-Salaam	1.490	56	1.033	48	1.265	30	1.141	69
Port Sudan	3.265	11	1.468	30	1.275	28	1.745	2
Pointe-a-Pitre	1.018	79	0.856	65	1.170	44	1.016	88
Constantza	1.315	66	0.500	86	1.705	13	1.542	14
Koper	1.271	69	1.127	41	1.048	60	1.077	81
Bridgetown	1.550	54	3.889	6	0.263	97	1.513	18
Oranjestad	2.445	24	8.483	2	0.247	98	1.168	65

Belize City	2.130	32	1.000	51	1.434	22	1.485	19
Rijeka	0.499	97	0.306	95	1.460	19	1.116	73
Copenhagen	0.724	90	0.519	84	1.029	68	1.357	36
Mombasa	2.024	36	1.349	34	1.114	51	1.347	39
Average	***2.418***		***1.470***		***1.787***		***1.285***	

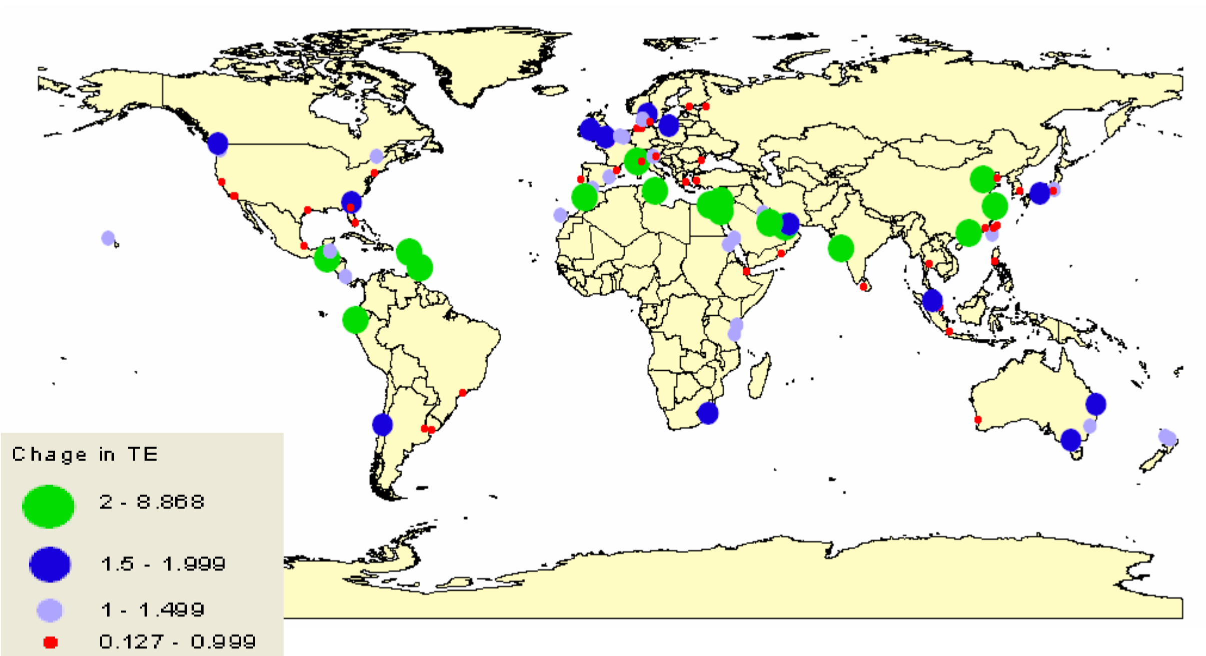
Appendix 3. MPI: Port Efficiency Change 1991~2004

A. Total Factor Productivity Change



Legend

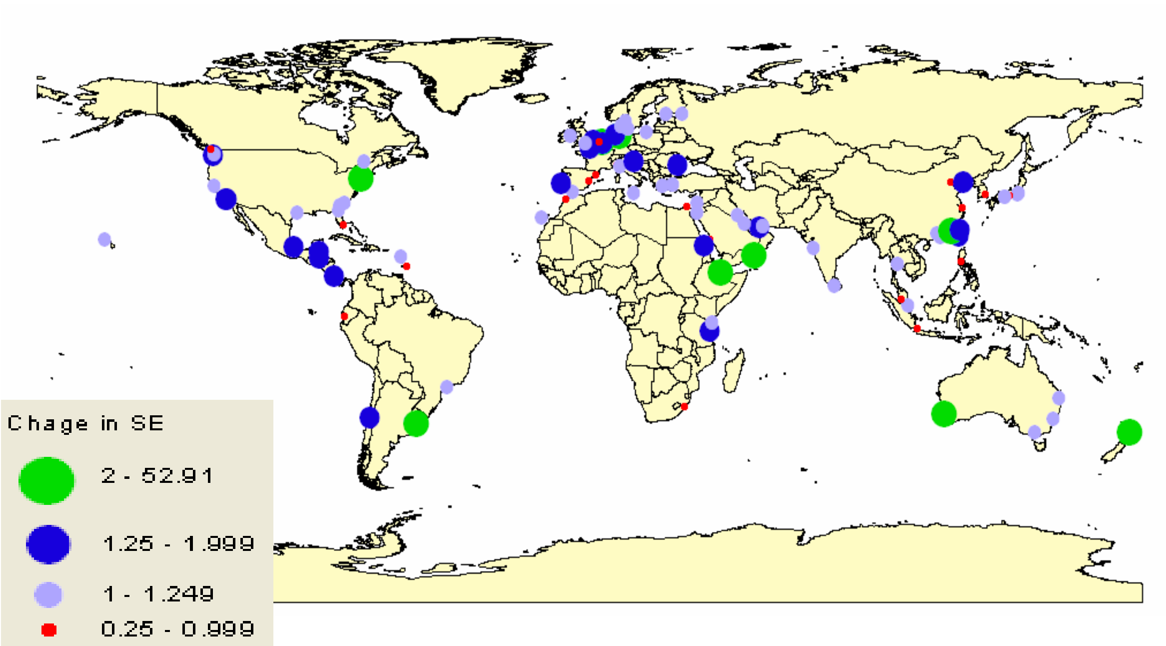
B. Non-scale Technical Efficiency Change (TEC)



Legend

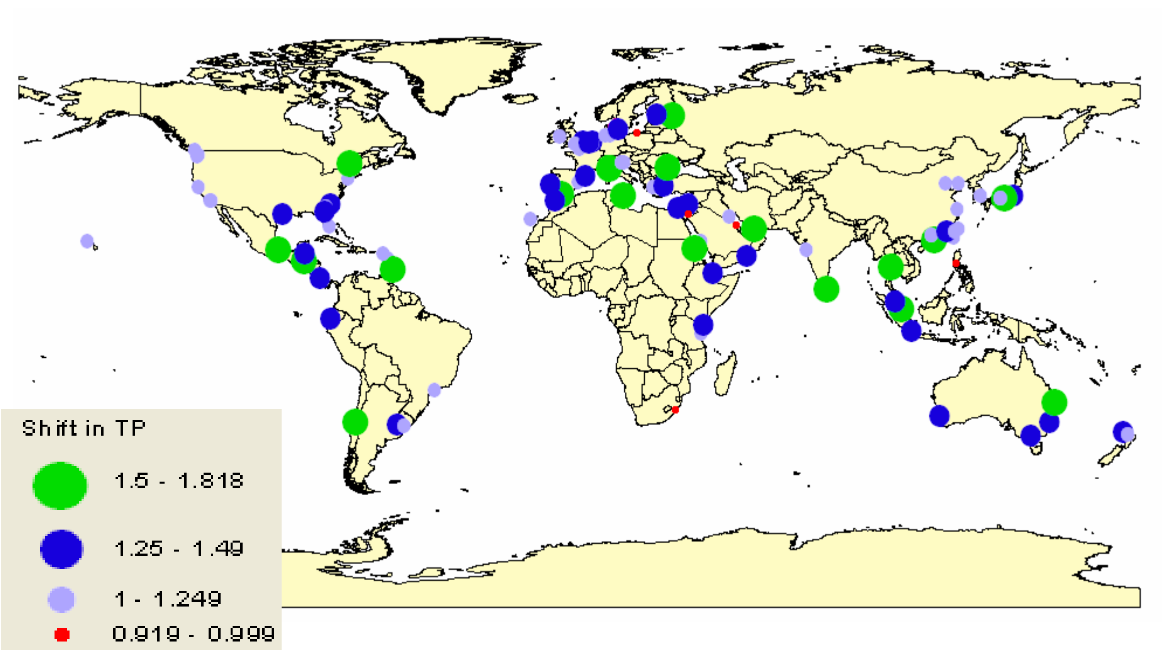
Appendix 3. MPI: Port Efficiency Change 1991~2004 (Continued)

C. Scale Efficiency Change (SEC)



Legend

D. Efficient Frontier Shift: Technological Progress (PFC)



Legend

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