Efficiency Analysis
of
Container Ports and Terminals

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Declaration

I, Qianwen Liu, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Candidate's signature

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Abstract

In the past two decades the steady growth of seaborne trade has resulted in the increase of container ships, container ports and their terminals. The structure of the shipping market is, moreover, continuously evolving. On the carrier side, shipping companies form consortia and alliances; on the port side, global terminal operators and dedicated container terminals are emerging. The aim of this research is to evaluate the efficiency of container ports and terminals and to study how to improve the scale efficiency of any particular port/terminal. In particular we study how certain factors influence the efficiency of container ports and terminals.

Regional container ports and global container terminals are examined based on the econometrics benchmarking method Stochastic Frontier Analysis (SFA). Two datasets are used, a panel dataset for 32 container ports in the North Mediterranean Sea over a nine-year period, and a cross-sectional dataset for 165 container terminals worldwide. Net-effect and gross-effect SFA models are applied to both datasets.

Technical, scale and overall efficiencies of individual ports/terminals are evaluated. Operation and investment strategies are examined for selected ports and terminals. The majority of the container ports and terminals in our North Mediterranean Sea samples are found to be technically inefficient: 90% of container *ports* have their technical efficiency lower than 0.80; 95% of container *terminals* have their technical efficiency lower than 0.80. The research concludes that trading volume plays a key role in the efficiency of a container port. The annual percentage increase in port output is slower than what the technological improvement allows. Container terminals are proven to be more productive than multiple purpose terminals. Global terminal operators were not proven to out-perform local terminal operators as was expected. It

was also found that the container terminal operation industry is over-scaled. The research findings here can potentially affect decisions made by carriers, terminal operators and policy makers, as it provides an overview of efficiencies for all container ports/terminals in the two datasets and also examines in detail the sources of inefficiency for individual ports.

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Glossary

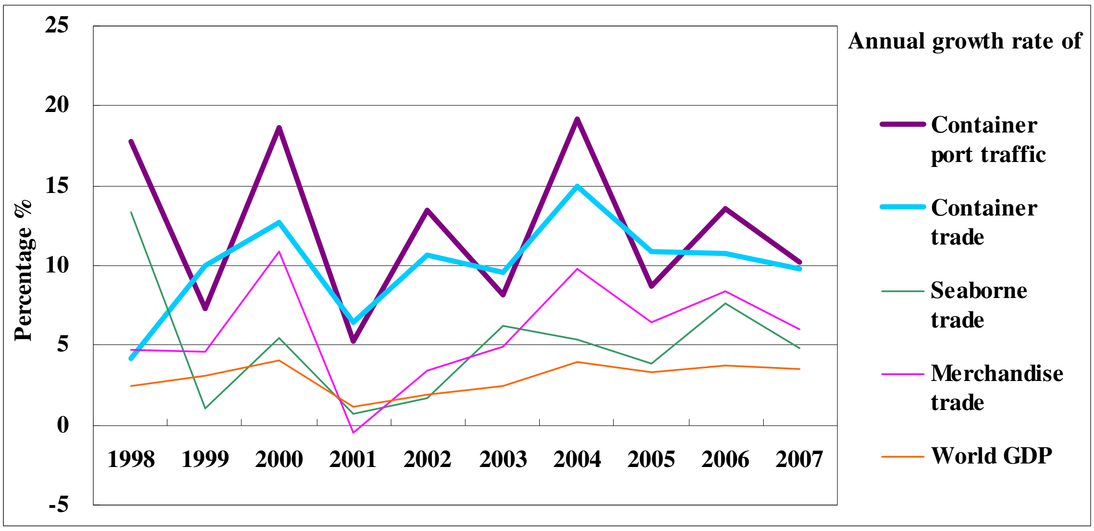
CI	Containerisation International
CRTS	Constant returns to scale
DEA	Data Envelopment Analysis
DRTS	Decreasing returns to scale
IRTS	Increasing returns to scale
i.i.d.	independent and identically distributed
LoLo	Lift-on / Lift-off
LR test	Likelihood-ratio test
MPSS	Most productive scale size
RoRo	Roll-on / Roll-off
RTS	Returns to scale
SE	scale efficiency
SFA	Stochastic Frontier Analysis
TE	technical efficiency
TEU	Twenty-foot Equivalent Unit

Chapter 1: Introduction

Container ports and terminals form an essential component of the modern economy. Containerisation since the middle of the 20th century has dramatically reduced the transport cost of international trade: before the container, the transport of goods was so expensive that few items were shipped halfway across the country, much less halfway around the world, but in the present day, an American brand car might be designed in Germany, the components are produced in Japan, Taiwan and Singapore, it is assembled in Korea, and the advertising campaign is delivered by a British company. The largely reduced transport cost derived by containerisation means that handling goods has become highly automated and efficient between most transport modes and transport goods from anywhere to anywhere has therefore become a feasible operation for many enterprises (Levinson, 2008). Once isolated factories have become integrated into a global network, and more multinational and international companies are present in many markets since they are able to choose the cheapest location in which to produce. As a result, today's economy is formed by the offshoring, outsourcing and extensive use of global supply chains, to which container handling and transport have contributed significantly. Since the introduction of the first internationally-standardised container in the 1960s, container trade has grown rapidly to reach an estimated 143 million in TEU and 1.24 billion in tonnage (UNTCAD, 2008), comprising over 70% of the value of world international seaborne trade (Drewry Shipping Consultants, 2006).

One of the main drivers of this boost in the container transport and handling industry is the increase of global GDP. Focussing on the past decade, the average annual global GDP growth from 1998 to 2007 was 3%. During the same period, the average growth of merchandise and seaborne trade were 6% and 5%, respectively, approximately double the global GDP growth, and the average growth of container trade was 10%, three times greater than global GDP growth. Trade has been more than proportionally affected by fluctuations in output, because the way production is now organised. The globalisation of the supply chain has increased its responsiveness: stages of production that were once local are now much more likely to be carried out abroad. We can observe that container port traffic is also more than proportionally affected by fluctuations in container trade, with a faster growing rate on average; it is because of transhipment traffic. Container trade is a part of seaborne trade and merchandise trade; the latter two outpace world output on average, and are also more than proportionally affected by fluctuations in world output, as shown in Figure 1. The 10-year trend in Figure 1 covers one downturn (in 2001), and the long-term trend of this growth pattern is expected to continue. Before the global economic downturn, the world's container port traffic had been growing at an average rate of 12% per year from 1998 to 2007, which is more than proportionally affected by fluctuations in container trade.

Figure 1: Annual growth rate of GDP, trade, container trade, and container port traffic



Source: IMF, WTO, UNTCAD (1999-2008)

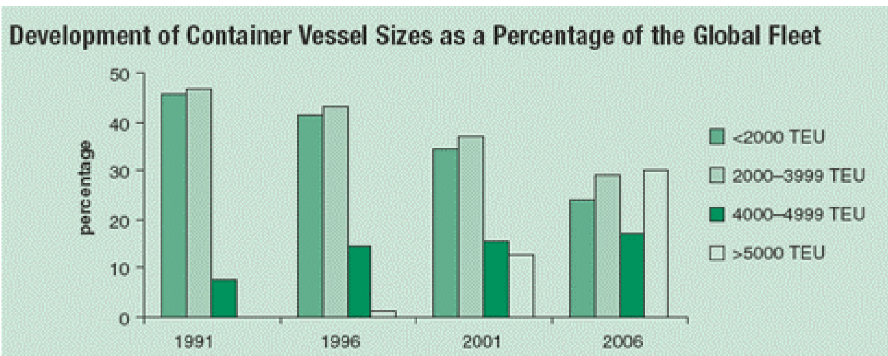
Figure 2: Major maritime trade routes: container traffic, 2007 (figures denote millions of TEUs)

Source: UNCTAD (2008)

When we discuss the growth of global container traffic, it is instructive to analyse how these flows are distributed geographically. There are three major sea lanes of containerised trade carried along the East-West axis (see Figure 2): the transpacific, between Asia and North America; the transatlantic, between Europe and North America; and the Asia-Europe sea lane.

Within this context, the Asia-Europe route became the largest containerised trading lane in 2007; this was strongly related to the fact that the main driver of world economic activity has been the robust and sustained growth of China, India and other Asia-Pacific emerging markets (ESPO, 2004; UNCTAD, 2007 and 2008). Among all regions in 2007, Asia's merchandise exports growth remained the most buoyant, at 13.5%; and Europe's merchandise exports have recorded their strongest annual growth since 2000, at 7% (WTO, 2007 and 2008). European demand increased not only in the traditional industrial economies, i.e. Northern Europe, but also in fast growing Eastern European countries and transition economies such as the Russian Federation. As the gateway for container traffic from Asia to Europe, the container ports situated in the north Mediterranean Basin play a crucial role on this sea leg, and in this research we will examine those ports in particular.

Figure 3: Evolution of container vessel size



Source: The Public-Private Infrastructure Advisory Facility (PPIAF) 2007

The growing demand for container transport has resulted in the evolution of large container ships. The first container ship to sail internationally in 1966 carried the equivalent of 200 modern 40-foot containers. Today, the largest container ships haul approximately 6,000 40-foot containers, a 30-fold increase (Levinson, 2008). Figure 3 illustrates the changes in container vessel size in the past decades, from which we can observe that the percentage of 5,000 Twenty-foot Equivalent Unit (TEU) or larger vessels has increased significantly. Larger vessel size imposes challenges for both carriers and container ports.

The ever-expanding container ship size is also the result of the existence of increasing returns to scale in container shipping. The large container ship indeed lowers the unit cost of transporting containers, but it also underlines the concentration of power in the container shipping market. The liner shipping market is a classical example of an oligopoly, which consists of a limited number of large shipping companies that are united in various forms of cartels, shipping conferences and alliances. From this perspective, the market concentration of the container shipping industry has risen markedly: the market share of the 10 biggest world carriers increased from 50% of the world capacity in January 2000 to 60% in January 2007, and during the same period the aggregate market share of the five biggest carriers rose from 33% to 43% (Cariou, 2008). The massive size of container carriers underscores not only the competition for power amongst the carriers but also brings to light the competition between carriers and their upstream and downstream industries.

The massive size of container ships directly challenges the efficiency of container ports. The competition between container ports was for a long time not very intensive because ports are location specific. However, with the increasing proportion of transshipment traffic within the total container port traffic (Drewry, 2006), the geopolitically-sensitive nature of container ports has been altered, and competition among ports has intensified. Ports are now not only competing with nearby ports, but also with ports relatively far away. For example, the Port of Gioia Tauro (South Italy, Mediterranean Sea) competes with the Port of Rotterdam (West Netherlands, North Sea) for the continental European market.

When we recognise the market concentration of the container carrier industry, we also notice a corresponding market concentration in the container port industry, which is derived from the new market structure of the container handling industry. Nowadays container terminals compete for more traffic with each other than the container ports do. The emergence of global terminal operators means that the market share is now concentrated in the hands of a few global terminal operators, e.g. PSA, APM, P&O. (Olivier, Parola, Slack and Wang, 2007). There are several reasons for the flourishing of terminal operators: (1) A dramatic increase in stevedoring costs, due to vessel size. Necessary upgrades on the facilities, i.e. channel depth, berth length, draught, ship-shore out-reach. (2) Port privatisation since the 1980s, which has allowed private money with a range of objectives and sources distinct from public sector funds to enter the capital-intensive port industry and tackle the unrelenting competition. (3) Increasing transshipment traffic, as just mentioned, which has changed the geopolitically-sensitive nature of container ports/terminals, because shipping lines and shippers prefer to call at terminals that provide good service rather than ports at specific locations. (4) Horizontal integration, which is occurring in the container terminal operator industry, in order to re-gain the bargaining power from mega-shipping companies and shippers, thus leading to the development of a few major international terminal operators.

The terminal operators may be either an independent stevedore company or a carrier-related operation company; and within these two types of terminal operator, we may observe either horizontal or vertical integration. Horizontal integration refers to the acquisition of additional business activities at the same level of the value chain. Horizontal integration develops in order to obtain optimal scale, to maintain a competitive position within the industry, and to gain greater bargaining power over their suppliers or consumers. Horizontal integration exists in both the container ocean carrier and container terminal operating industries. Vertical integration describes the expansion of a firm's business activities into upstream or downstream activities. Vertical integration exists between ocean carriers and terminal operators.

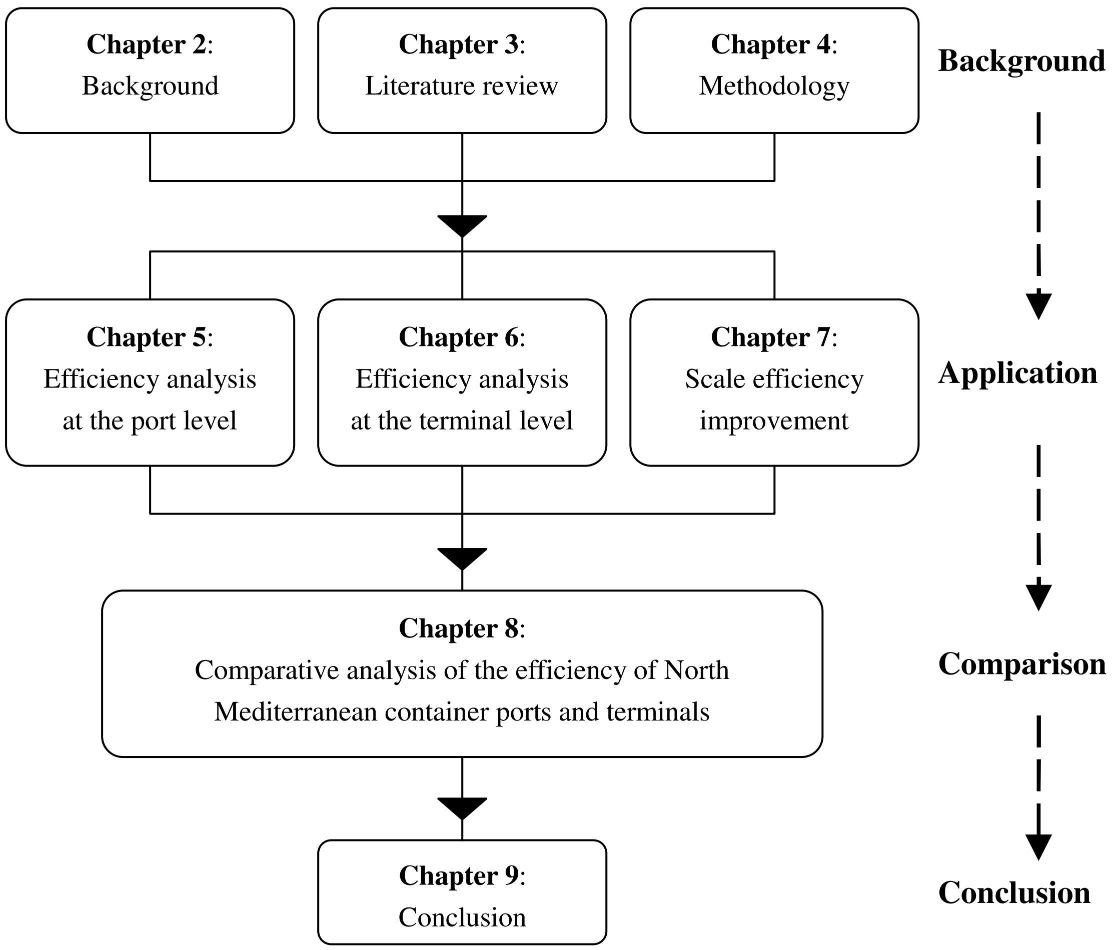
Carrier-operated terminals, also known as dedicated terminals, are commonly used by ocean carriers nowadays as a means of securing and controlling terminal capacity in order to enhance the reliability of their service. Vertical integration may also encompass inland transport and distribution centres, in order to ensure that the whole supply chain is integrated.

With this in mind, the efficiency of container ports and terminals has become ever more important. As a connecting link between different transport modes in the global logistics chain, container ports and terminals are vital to the efficiency of the whole chain. Apart from their pivotal role in the global trade network, intensifying port and terminal competition worldwide also highlights the efficiency of container ports and terminals as a key issue for operators. The growing proportion of transshipment traffic indicates that container port and terminal traffic will continue to outpace the growth of container trade, which in turn is growing more rapidly than merchandise trade and GDP growth in general. The increasing demand does not reduce the competition; on the contrary, ports and terminals compete harder for their customers, the shipping lines. The container shipping market is controlled by a few liner companies that have considerable bargaining power over the container handling industry, i.e. over ports and terminals. Ports and terminals must therefore be better able to accommodate increasing container traffic and compete for liner companies. Within this context, the efficiency remains a fundamental concern in the container handling industry.

The objective of this research is to evaluate the efficiency of the container handling industry to understand how the efficiency of container ports and terminals is influenced. The research also aims to examine the ways to improve the scale efficiency by considering particular ports and terminals. We address these two objectives from a quantitative perspective by evaluating the technical and scale efficiencies of container ports and terminals, and by examining the physical and organisational attributes that may impact the efficiency.

By studying separately the efficiency and structure of ports and terminals, we are able to compare and understand the differences between these two levels and outline specific effective management approaches for the container handling industry. We demonstrate how much change is required for specific ports/terminals in order to obtain their own optimal scale efficiency, through actual cases of container ports and terminals in the North Mediterranean Sea area. The capability of quantifying changes and performance improvements could facilitate the port managers and terminal operators in designing their investment strategies more effectively. But we also recognise that with an understanding of the different characteristics between container ports and terminals and the knowledge of how different operational factors affect efficiency and productivity, policy makers could design port regulation more effectively.

Figure 4: Structure of the thesis



The structure of the thesis depicted in Figure 4 indicates that in Chapters 2, 3 and 4, we establish the background and foundation of this study. Chapters 5, 6 and 7 provide the application of the efficiency analysis on container ports and terminals. In Chapter 8 we carry out the comparative analysis between the ports and terminals with case studies, and in Chapter 9 we provide conclusions and recommendations. This thesis can be outlined as follows:

Chapter 2 examines the ocean shipping market and position of container transport and handling within it by analysing the operation and cost structures of ocean carriers and sea ports. We also study the functions and configuration of the container ports and terminals, which is the basis for the model specifications in later chapters.

In Chapter 3 we survey the literature of efficiency analysis methods and focus on the prior literature covering the use of applied Stochastic Frontier Analysis (SFA) in the port and terminal industry. We look into three primary areas from prior literature. The first is the study objectives and scope of previous studies. The second concern is the variable specification, i.e. the definition of measures used for outputs, inputs and exogenous factors. The third is the model specifications and estimation techniques.

In Chapter 4 we design the models. We first specify the inputs, outputs and exogenous variables, functional forms for the deterministic part of the models and the distribution assumptions used for the random part of the models. The calculations of technical and scale efficiency are demonstrated.

In Chapter 5 we study efficiency at the container port level, using a panel dataset of 32 North Mediterranean Sea container ports from 1989 to 2006. We estimate port-specific technical and scale efficiency for each year. We focus on analysing the trend of port productivity and efficiency over time and study the impact of an exogenous variable, trading volume, on productivity and efficiency.

In Chapter 6 we study efficiency at the container terminal level. We examine 165 terminals of which 47 are from the Mediterranean Sea container ports studied in Chapter 5, and 118 are terminals from the world's top 20 container ports by throughput in 2006. We estimate terminal-specific technical and scale efficiency and analyse the impact of two exogenous factors on efficiency: terminal operator type (either local or global operator) and terminal type (either container or multi-purpose terminal).

We demonstrate in Chapter 7 how scale efficiency changes with port or terminal size (input level) given the input mix, using three typical examples with increasing, decreasing, and constant returns to scale, respectively. We discuss the size arc elasticity of scale efficiency through which it is possible to understand how to change the input level in order to obtain the economically optimal scale. We also demonstrate through panel data that scale efficiency changes according to input mix (combination).

Next in Chapter 8 we first discuss the sensitivity of efficiency results to different model specifications. We compare the returns to scale at both port and terminal levels in order to understand the different market behaviours between the two levels. We discuss the port-related policy in the North-Mediterranean Sea area and analyse five typical container ports of varying size and their different sizes of terminals, from EU, EU candidate, and non-EU countries.

In Chapter 9 we summarise the results of the thesis, outline our central conclusions and give suggestions for the direction of future research.

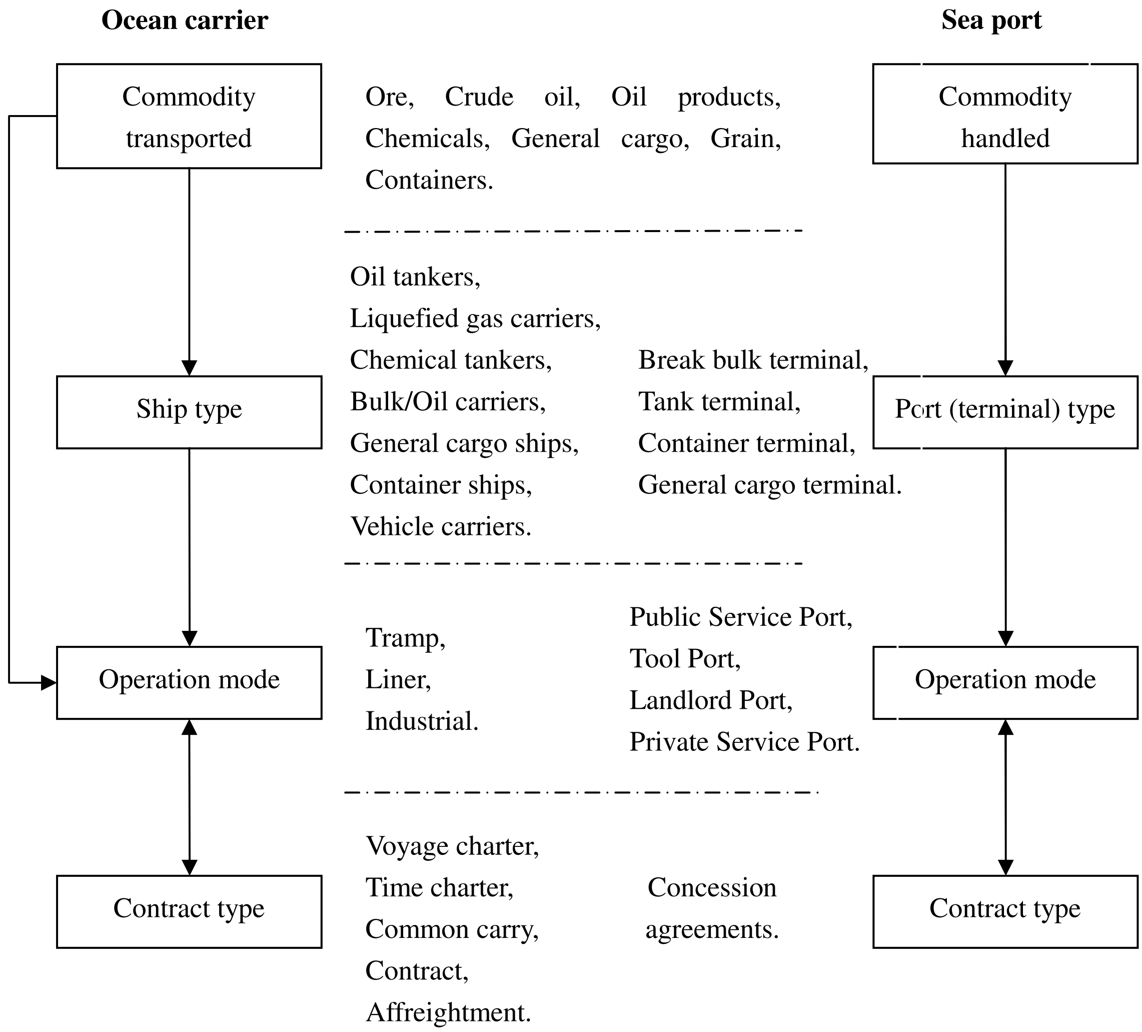
Chapter 2: Container Ports and Terminals

2.1 Container ports and terminals in the overall shipping market

The objective of this chapter is to illustrate and describe container transport and container ports and terminals within the context of the overall shipping industry. The ocean shipping industry is heterogeneous; it is characterised by a wide range of cargo, various functions of vessels, different operation methods and distinct regulatory arrangements and contracts. The container represents only one type of cargo that is moved in ports and terminals. Container transport is one method of moving goods which requires specialised ports and terminals.

The ocean shipping market is comprised of two main participants: ocean carriers and sea ports. The functions and operation features of the two main participants are driven by the requirements of transporting various commodities. The varying physical nature of commodities leads to different designs of ship to carry them and different terminals to handle them. Consequently, the type, value, and quantity of the commodity that needs to be delivered and handled, together with the capital requirement of the ship and infrastructure, determines the shipping and handling operation mode. The operating methods and contract methods are co-dependent. Figure 5 illustrates the relationships between these different components.

Figure 5: Key influential factors on ocean shipping operating mode



Source: Chrzanowski (1985)

2.2 The operation and cost structure of ocean carriers

To analyse the operation and cost structure of ocean carriers, the first thing taken into consideration is the operating mode, since this reflects decisions based on all aspects of the shipping process, as Figure 5 shows. The ocean shipping industry, when we consider its operational mode, is typically divided into three types: *liner shipping*, *tramp shipping* and *industrial shipping*. We can observe that it is difficult to divide the ocean shipping industry into neat unambiguous components and segments, due to the market fluctuation. In practice, shipping companies participate in more than one commodity market and also switch between operating modes.

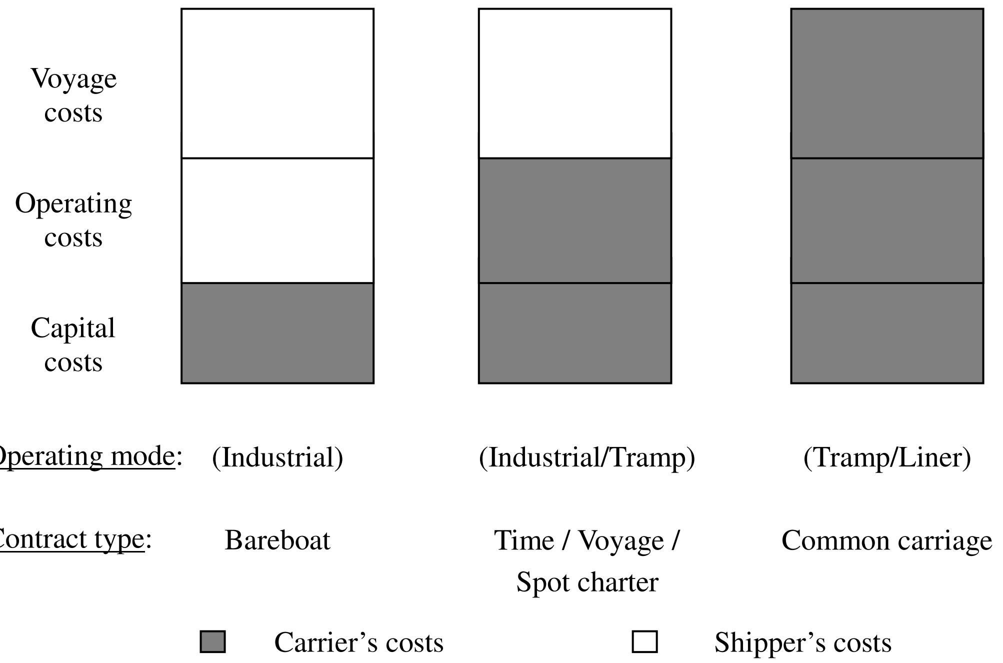
Liner shipping service provides a fixed service, at regular intervals, between named ports, and offers itself as a common carrier of any goods or passengers requiring shipment between those ports that are ready for transit by carrier's published dates. The rate of using the liner service is fixed by the carrier.

Tramp shipping is a contract-based service which offers services to selected customers who have a relatively large volume of commodities to transport. The carrier and the shipper negotiate and reach an agreement on the rate. One voyage usually carries commodities for one shipper. It satisfies the demand for spot transit and does not have a fixed itinerary for the long term.

Industrial shipping, also called special shipping, is characterised by its running on regular routes using specialised ships for certain goods. Big industrial organisations with large volumes of input materials or output products, for example, the Organization of the Petroleum Exporting Countries (OPEC), represent the major demand for industrial shipping. Industrial organisations usually cooperate and have their own fleets or rent fleets for long periods of time in order to transport goods.

The operation mode and cost structure of ocean carriers are inter-determined. The allocation of costs is distinct for different operation modes. The cost can typically be divided into three parts: capital costs, operating costs, and voyage costs. Capital costs, also called overhead costs, include the costs of purchasing new or second-hand ships. Operating costs include manning, insurance, repairs and maintenance, handling costs, and other cost associated with the vessel. Voyage costs include bunkers, port dues, and canal and seaway costs (Drewry, 2004).

Figure 6: Cost allocations of different ocean shipping modes



Source: Drewry (2004)

Different operating modes have different cost allocations between the shipper and the carrier. It is based on the form of affreightment and on shipping tariff rates. Figure 6 illustrates the cost allocation for different shipping modes. The grey area represents the carrier's cost, with carriers transferring their cost to customers (the shippers) via a tariff. The white area represents the cost that shippers need to cover, in addition to the tariff they have to pay to carriers.

Under a bareboat charter (or long-term charter contract, mainly used by the industrial shipping mode) only the capital cost is under the carrier's account. Shippers pay the rate to use vessels, the operating and voyage costs are not included in the rate, and they need to be covered by shippers in addition to the rate they pay; in other words, shippers operate the vessels themselves. In the spot charter market (also called voyage or time charter), which is mainly used by the tramp shipping mode, the rate that shippers pay covers the capital and operating costs and the voyage costs are not included but need to be covered by the shippers, apart from the tariff they pay.

Shippers in the tramp shipping markets have a large quantity of cargo but their demand is irregular, so usually the carriers operate the vessels in this shipping mode. The differences between spot charter and bareboat charter are, however, becoming increasingly blurry nowadays. For the case of the liner shipping mode, the shipping rate paid by the shipper covers costs. After paying the rate, shippers do not need to pay any extra charges, all the cost is covered in the rate and is managed by carriers.

2.3 The operation and cost structure of sea ports

The operation and cost structure of sea ports can be analysed in a similar way as the operation and cost structures of ocean carriers has been discussed in section 2.2. Sea ports' operation modes are closely related to how ports are financed. The World Bank (2007) has outlined four administration/operation models: Public Service Port, Tool Port, Landlord Port, and Private Service Port (see Table 1).

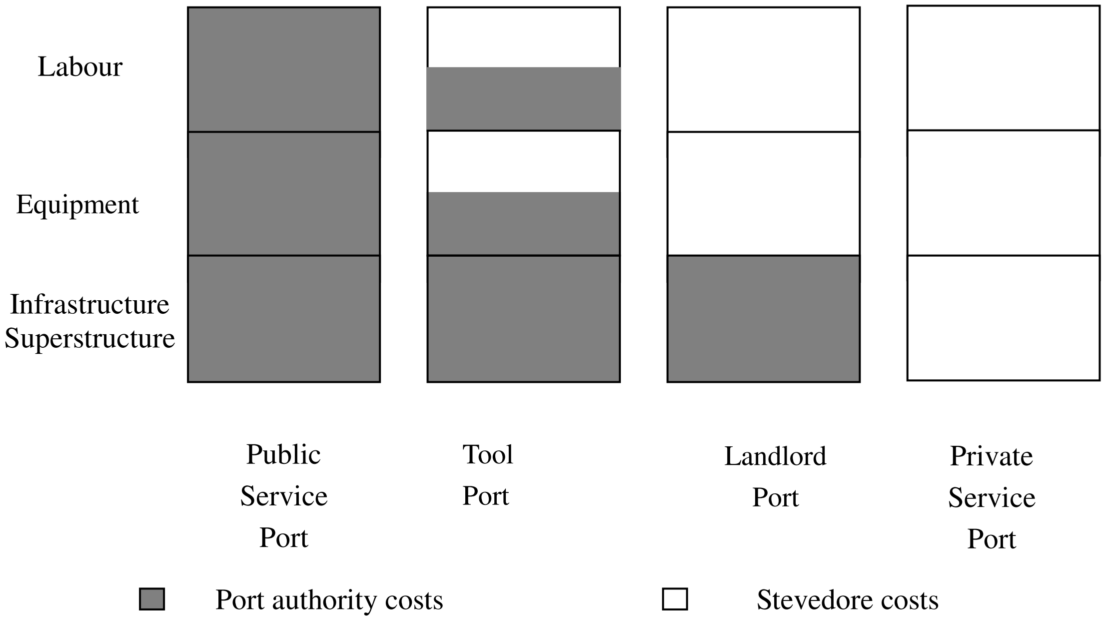
Table 1: Basic port administration/operation modes

Type	Infrastructure	Superstructure	Port labor	Other functions
Public service port	Public	Public	Public	Majority public
Tool port	Public	Public	Private	Public/private
Landlord port	Public	Private	Private	Public/private
Private service port	Private	Private	Private	Majority public

Source: World Bank (2007)

Sea ports consist of multiple agents, but their primary function is to handle cargo between sea and land and/or between ships. Therefore, we focus only on two main agents in the sea ports: the port authority and stevedores. Based on the World Bank's port administration modes, the cost allocation between port authority and stevedore in different port operating modes is depicted in Figure 7.

Figure 7: Cost allocations of different sea port management modes



Source: World Bank (2007)

In a *Public Service Port*, the Port Authority owns the land, infrastructure and equipment, all assets of the port, and performs all regulatory and port functions. The cargo handling operations are performed by labour that is directly employed by the Port Authority. All costs are covered by the Port Authority.

In a *Tool Port*, the Port Authority owns the land, infrastructure and most equipment including quay cranes, forklift trucks, etc., and the cargo handling operations are performed by labour that is employed both by the Port Authority and private operators. Port Authority staff usually operates all equipment it owns. Other cargo handling is usually carried out by private cargo handling firms contracted by the shipping agents or other principals licensed by the Port Authority. Therefore, the costs of infrastructure and superstructure are covered by the Port Authority. The equipment and labour costs are shared between Port Authority and stevedore.

In a *Landlord Port*, the Port Authority owns the land and infrastructure and the infrastructure is leased to private operating companies. The private operating company provides and maintains the equipment and employs labour to handle cargo. For this kind of port, only the cost of infrastructure falls under the account of the Port Authority; all other costs are covered by the stevedore.

In a *Private Service Port* port land, infrastructure and equipment are all owned by the private sector. All regulatory functions and operational activities and labour are performed by private companies.

The operation mode of the container ports follows the pattern as discussed above, but container ports are more capital-intensive because of their use of highly automatic container handling equipment. In the next section we discuss the function and configuration of container ports.

2.4 Functions and configuration of the container port/terminal

The container was designed to improve handling efficiency, primarily port handling efficiency, but also for all the handling between different transport modes. Standarisation of cargo handling therefore requires highly specialised facilities. The facilities of a container port are the same, regardless of their size and regulatory policy. The basic function of a sea port is to transfer goods and passengers between ships and shore and/or between ships (Goss, 1990). In order to fulfil this most basic function, a port provides different kinds of facilities and services. The World Bank classifies port assets into four different categories: basic port infrastructure, operational infrastructure, superstructure, and equipment (see Table 2).

Table 2: Categories of port asset

Basic Infrastructure	Access Channel, Breakwater, Locks, Berths, Rail and road connection
Operational Infrastructure	Inner channels and turning, revetments, quay walls, jetties, navigation aids, buoys, beacons, moorings, docks
Superstructure	Paving, surfacing, lighting, offices, repair shops
Equipment	Tugs, line handling vessels, dredging equipment, ship and shore handling equipment, cargo handling equipment

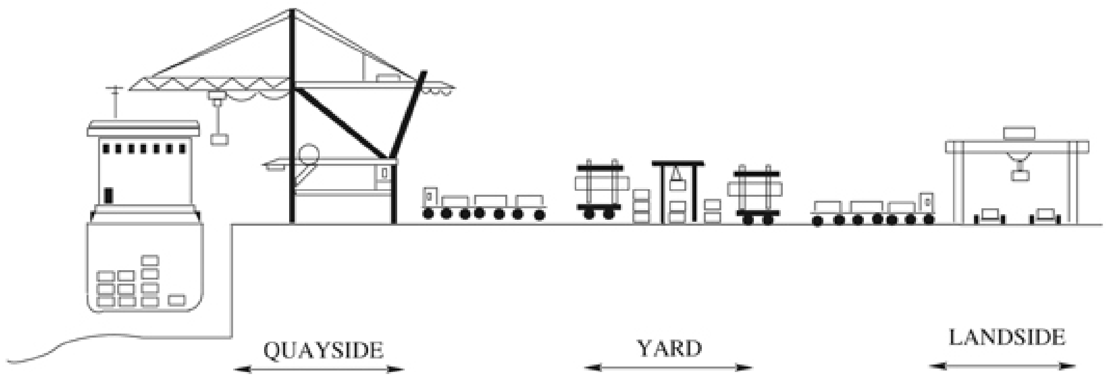
Source: World Bank (2007, p. 95)

Container ports are complex organisations hosting multiple simultaneous activities, e.g. tugging, pilotage, mending, etc., but container handling is the principal function of a container port, with handling constituting over 80% of the charges faced by a carrier bringing a container vessel to a port for loading and unloading (Tovar, Trujillo and Jara-Diaz, 2004). Because various activities take place in a container port, agents involved in container ports are diverse: port authorities, terminal operators, tug boats, consignees, etc. The objectives of different agents often differ, even if they carry out the same activities. Container transport within the port can be handled by a port authority, a terminal operator or inland logistics companies. For instance, a port authority's objective could be to create and maintain the labour capacity, whereas the terminal operator's objective could be to maximise the profit, and the inland logistics company's objective could be to improve service reliability. In this research we focus on container handling activity within the container port. We conduct analyses of data on both port and terminal levels, and take into account the management characteristics of port and terminal level management, in order to estimate the efficiency of container handling activities, regardless of the primary objectives of the agents.

Physically, a container port consists of one or more container terminals. In order to transport containers from ship to shore and within the port, the required facilities include berths for ships to park, area for container stacking and storage, and handling equipment to upload and unload containers. Among those facilities, the container handling equipment differentiates container ports from other ports. There is a vast variety of container handling equipment, but they can be classified into two main groups: quay crane and yard handling system. Figure 8 provides a schematic representation of the typical container terminal system. On the quayside, containers are transported between ship and shore and container quay cranes are the main equipment used for ship loading and unloading. It can be either mounted on the ship (ship-mounted cranes), or located on the quay, ship-to-shore (STS) cranes; the latter is widely used in container ports and terminals. On the yard side, containers are transferred to land transport modes or are arranged to be loaded on to other ships.

Two types of activities occur in the yard area: stacking of container and horizontal transport. Before containers are moved away they are stacked in the yard area. Stacking equipment for containers includes Straddle Carriers, Rubber Tired Gantry Cranes (RTGs), Rail Mounted Gantry Cranes (RMGs), Reach stackers, and Stackers for Empty Containers. Horizontal terminal transport is the movement of containers between the STS, the stacking area, and the landside operation. Equipment for horizontal transport includes trucks, trailers, straddle carriers, automated guided vehicles (AGV), and reachstackers.

Figure 8: A typical container terminal system



Source: Monaco, Moccia and Sammarra (2009)

In addition to the handling facility, terminal size, berth length, storage and trained labour are all important to the operation of container handling. A container port can be seen as the collection of its terminals in terms of physical structure. However, the operation objectives of ports and terminals cannot be compared because the operating agents are different.

2.5 Trend of market structure of container terminals

Functional wise, container ports and container terminals can be seen as identical, because they share the same fundamental functional objective: transport containers between ship and shore. However, aforementioned in the Chapter 1, container terminals stood out from container ports as a distinct industry. Ports are usually analysed by the degree of privatisation as we did in section 2.3, but in practice there is rare a 100% private port, so port operating is seen as public sector activity. Terminals operating, on the other hand, can be 100% private, so there are various forms of container terminal operating. In the later chapters, we examine the impact of different terminal operating on efficiency.

Global terminal operating and local terminal operating. Horizontal integration has resulted a few number of very large international container terminal operators. They operates terminals in different countries and different continents. Hence, the container terminal can be categorised into global or local terminal, depending on the operator's geographical coverage.

Dedicated terminal (carrier operated terminal) and independent terminal operator. Vertical integration between ocean carrier and terminal operator results in dedicated terminals. This is a strategy/practice used by the carrier to ensure the reliability of its service. Hence, the container terminal can be categorised into dedicated or independent terminal, depending on the operator's business coverage (core business).

Multiple purpose terminal and container only terminal. A terminal might handle three types of cargo: bulk, container and general cargo. Bulk cargo is unpacked homogeneous cargo, which is usually dropped or poured. Container cargo are heterogeneous goods which are moved in International Standard Organisation (ISO)-specified steel/aluminum boxes that can be lifted or rolled by equipment. General cargo constitutes the myriad of goods which are neither liquid nor bulk, nor containerisable. Container terminals specialise in handling containers only, whereas multi-purpose terminals can handle all three kinds of cargo. (*change p.102?*)

2.6 Conclusions

In this chapter we have examined the operation and cost structures of ocean carriers and sea ports in order to understand the position of container shipping and handling in the overall shipping industry. We have analysed the dynamics and interactions between container carriers and container ports and terminals. We have observed that intensified competition has led to horizontal integration among container carriers and also among container terminals, in order to gain more market power over competitors in their markets, as well as bargaining power with regard to each other and their other trading partners. Vertical integration has also become common practice to enhance the reliability of the whole supply chain. Efficiency has become an increasingly critical issue, as the competition between ports and between ports and carriers intensifies.

Within this context, we have surveyed the function and configuration of container ports and terminals as the basis for our model specification in later chapters. Container ports include many different agents with various activities. However, container handling is the most important activity within a container port, and that is why the efficiency of container handling activity is the focus of this research.

Chapter 3: Economic Performance Analysis: Literature Review

3.1 Introduction to alternative approaches for economic performance measurements

There are two main concepts related to economic performance: productivity and efficiency. The concept of productivity is commonly defined as a ratio of the volume measure of output to the volume measure of input used, whereas efficiency is a relative concept, i.e. the performance of a firm is compared to a benchmark. While there is no disagreement on this general notion, there are many different purposes for, and several distinct measures of, economic performance in the econometrics literature (OECD, 2001). In this chapter we review the literature of economic performance analysis and especially examine the Stochastic Frontier Analysis (SFA) studies that have been applied in container terminal/port areas. We first outline alternative approaches for measuring economic performance and review the analytical foundations of Stochastic Frontier Analysis (SFA), and then we examine the SFA literature of the container port/terminal industry in three primary areas: study objective, variable specifications and modelling techniques.

In the literature of transport studies, there are two main purposes to study economic performance: gross measures of productivity and shift measures of technical change (Oum, Tretheway and Waters, 1992). Widely used approaches to calculate productivity/efficiency include traditional regression estimation methods, index number, corrected original least squares (COLS), data envelopment analysis (DEA), and stochastic frontier analysis (SFA).

The *index number* approach constructs output and input aggregates by index formula and provides a productivity indicator. The formula aggregates inputs and outputs to the quantity indices on the basis of economic assumptions associated with the production. The strength of the index number approach is its ease of calculation. The limitation is the difficulty of disentangling technical changes from the effects of scale economies and input substitution. Total factor productivity (TFP) is the most widely used measure in the index number approach.

Data envelopment analysis (DEA) is a mathematical programming approach to estimate productive efficiency. The approach maps out a production frontier based on information on inputs and outputs. The degree of (in)efficiency is assessed by the distance between the observation and the frontier. The strength of the DEA approach is that no *a priori* structural assumption is placed on the production process. The drawbacks of the approach are (1) it is very sensitive to outliers; (2) it does not take into account the measurement error and other statistical noise, and it is therefore not possible to test the statistical significance of the efficiency index for a specific observation.

Original least squares (OLS) estimation method is a regression method that fits an 'average line' through the data. This average line is calculated by the production or cost function, which represents the production technique of the considered industry and indicates information such as the degree of returns to scale of the industry and individual firms in the industry. The strengths of this approach and of all the econometric/statistical methods are that (1) they are consistent with the underlying economic theory that offers a potential explanation for cost or production structures and distinguishes between different variables' roles which affects output; (2) there is an ample range of standard statistical tests available to assist the analysis. The weakness of using an 'average line' to represent the production function lies in the assumption of the traditional regression method; in other words, it assumes that economic agents are rational and efficient at any time. This assumption is not always true in reality. Therefore, the estimation bears this built-in inaccuracy.

Corrected original least squares (COLS) is a parametric approach to evaluate productive efficiency. It belongs to the regime of regression methods but differs from the OLS estimation method. In this approach, as with the OLS method, we calculate an 'average line' that cuts through the observations, and then shifts (corrects) the line to a position such that it encloses all the data. The corrected line represents the efficiency frontier. The degree of efficiency of an individual unit can then be measured against this frontier. The strengths of this approach are that (1) it reveals information about the production technique, and it distinguishes between different variables' roles in affecting output as all parametric methods do; (2) the adjustment from the average line to the 'frontier' allows for the measurement of relative efficiency. The drawbacks of this approach are (1) it requires *a priori* specification of the production or cost function, i.e. to adopt an arbitrary specification, which is common to all parametric methods; (2) it is not possible to measure error and other statistical noise (Greene, 1993); (3) it is sensitive to outliers, since the 'best' performer along any dimension serves as the anchor for how much the 'average' line needs to be corrected in order to become the frontier.

Stochastic frontier analysis (SFA) is a parametric and stochastic approach to estimate productive efficiency. The difference and major breakthrough of SFA compared to traditional regression analyses is that SFA calculates the inefficiency of economic agents based on distribution assumptions, so different individuals can have different inefficiencies. In common with the COLS approach, SFA relaxes the assumption that the behaviour of economic units is optimised. However, the procedure to calculate the frontier is different. SFA includes two random terms in order to take into account both inefficiency and normal statistical noise. Thus, it acknowledges that each economic unit will exhibit its specific inefficiencies and the efficiency production/cost frontier is estimated without shifting (correcting a traditional regression line to a frontier). As in COLS and DEA, the degree of (in)efficiency of individual economic units can be measured against this frontier. The advantages of this approach are (1) it reveals information about the production technique and distinguishes between different variables' roles affecting output; (2) it considers statistical noise and hence it is possible to test the validity of certain assumptions and hypotheses; (3) there is great flexibility in specifying the production technology (functional form); (4) it is possible to model the effects of environmental/exogenous variables. The drawbacks are (1) we need to impose an *a priori* structure when constructing the frontier functional form; (2) the assumptions concerning the distribution of the inefficiency term have to be imposed in order to decompose the error.

We can summarise the methods reviewed by observing that, on the one hand, the Index number approach is used primarily for measuring the effects of technology change; on the other hand, OLS, DEA, COLS and SFA are mainly considered for gross measures of productivity. However, the mathematical development and evolution of these approaches has blurred the boundary of their purposes and mathematical properties. A clear-cut classification of approaches between deterministic/stochastic, parametric/non-parametric, and neoclassical/frontier features is at present very difficult. Therefore, the choice of approach must be based on the objective of the research and the available data.

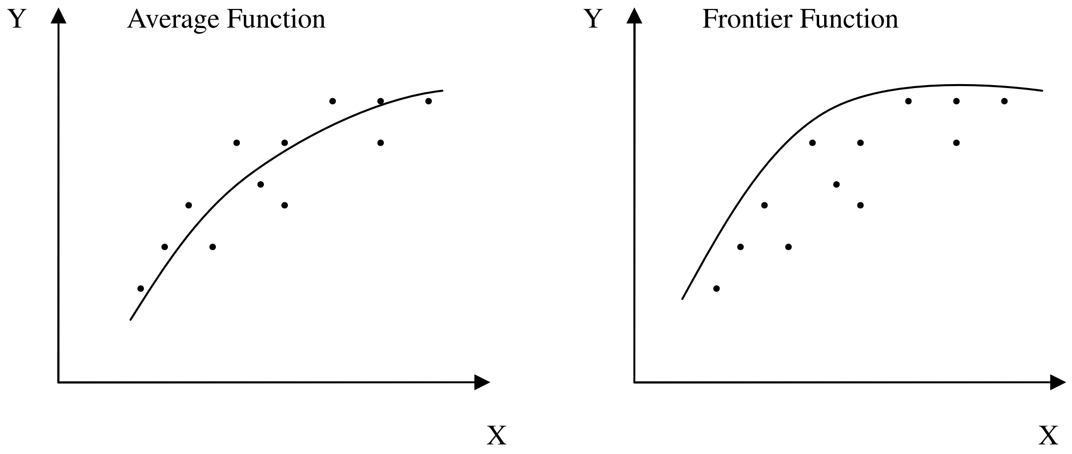
In our analysis the aim is to better understand the structure of the container port/terminal industry and analyse how to improve the efficiency of container ports/terminals. Efficiency here is a relative concept, i.e. the performance of an economic unit must be compared with a standard (Forsund and Hjalmarsson, 1974), and it is thus used to characterise the utilisation of resources. Therefore two outputs are required: the production structure of the container port/terminal industry and the efficiency index of individual ports/terminals in the industry. Given this consideration, SFA is the obvious choice. Its statistical and parametric (econometric) attributes are effective for analysing industry structures and the frontier attributes are designed for benchmarking the relative efficiency of individual container ports/terminals. In the next sections we analyse in more detail the characteristics of the SFA approach.

3.2 Analytical foundations of SFA

The SFA technique has evolved from two groups of econometric analysis: traditional regression analysis and frontier analysis. In traditional regression, economic transport studies have been driven by the development of econometric production and cost functions (Walters, 1963; Winston, 1885; Braeutigam, 1998). Similarly within SFA, these descriptive functions are an important aspect. We have noticed the close relationship; there is a crucial distinction between SFA and traditional regression analysis. In traditional regression analyses, econometricians assume that firms always reach the maximum (minimum) amount of output (cost) obtainable from given input bundles using fixed technology. A function is then fitted through a series of observations of inputs and outputs in order to obtain the 'average' production function and the function expresses the industry production structure (Aigner, Lovell and Schmidt, 1977). In frontier analysis, inefficiency in the production is acknowledged; firms are not always able to reach the maximum (minimum) amount of output (cost). A 'frontier' production (cost) function is evaluated to express the ideal industry production structure from which the degree of (in)efficiency for individual firms can be assessed. Figure 9 illustrates the difference between an 'average' production function and a production frontier.

There are two primary ways to identify the frontier, namely mathematical programming – later developed as the DEA approach, and regression analysis – later developed as the SFA approach. However, the concept of frontier has the same origin drawn from the seminal paper by Farrell (1957).

Figure 9: Frontier and average functions
(left) the *average function* of a single input and single output production technique.
(right) the *frontier function* of a single input and single output production technique.



Mathematical programming produces the envelope function by controlling the disturbance term (in either a single or simultaneous equation setting) which needs to be of only one sign; no assumptions need to be made about the functional form of the industry production. The only empirical assumption required for a programming application is that disturbance has one sign, that is, the observed point in the production space must lie on or below (above) the production (cost) frontier only. The ground-breaking works on the mathematical programming method were developed by Aigner and Chu (1968), Seitz (1970 and 1971), Timmer (1971), Carlsson (1972), Forsund and Hjalmarrsson (1974 and 1979). Based on those efforts, DEA has become a popular method for empirical studies. However, the potentiality of mathematical programming approaches is reduced because of the lack of available statistical inference procedures to compare the shapes of the frontier and the variables (Aigner and Chu, 1968).

SFA is a statistical modelling method for efficiency and benchmarking analyses. The SFA method identifies the frontier through a regression method with a composed error term. The composed error term was first proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977). Thereafter, SFA has been developed extensively in the literature. In the SFA approach the relationship between the observed production point (A: x_i, y_i) and the production function (f) can be expressed as :

$$y_i = f(x_i)\exp\{v_i - u_i\} \tag{3.1}$$

Where (x_i, y_i) is the observed input and output for unit i;

$f(\cdot)$ denotes the potential or maximal production technique;

u_i is the non-negative random variable associated with technical inefficiency;

v_i is the statistical noise.

In order to calculate the frontier function (3.1) and evaluate the efficiency of firms, there are a number of issues that need to be considered: functional form (f), distribution assumptions for the residual (u_i) and random noise (v_i), estimation method, and given the data availability, the choice of input variables (x_i) and output variables (y_i). These are the bases of economic performance analysis. In the next sections we will examine the building blocks of the SFA in the container port/terminal industry.

Frontier represents the 'best possible practice' in the industry or sample studied. Once the frontier is estimated, efficiency then can be evaluated against the frontier. Efficiency comprises technical efficiency, scale efficiency and allocative efficiency. *Technical efficiency* is defined as the relative production between the observed output and the best possible output. *Scale efficiency* is defined as the relative scale between the observed firm size and the optical firm size. *Allocative efficiency* is a measure of the benefit or utility derived from a proposed or actual choice in the distribution or apportionment of resources (Wang, Cullinane and Song 2005). The existing literature focuses efficiency analysis on technical efficiency. In this research, the efficiency analysis is focused on technical and scale efficiencies, formal definitions of efficiencies are given in the Chapter 4.

3.3 Study scope and objectives of the existing literature

Container port services cover a wide range of activities, and container ports are composed by complex organisations as discussed in Chapter 2. The main agents include port authorities, tug operators, consignees, and stevedores; and the main port activities are the provision of infrastructure and machinery, docking, container handling and administration. Although this literature review focuses on container ports, the analyses of agents and activities are nevertheless different. The most obvious distinction is that the study subjects of previous literature are either ports or terminals. As discussed in Chapter 2, port efficiency is not simply the average of all its terminals' efficiency. The objectives of a port are usually different from a terminal, so the efficiency cannot be compared directly. With regard to the container port studies, Estache, Gonzalez and Trujillo, (2002), Barros (2005), Trujillo and Tovar, (2007) and Gonzalez and Trujillo (2008) have explicitly stated that the activities studied were carried out by port authorities; but not all the literature stated explicitly the port activities under consideration, for example, Liu (1995), Coto-Millan, Banso-Pino and Rodriguez-Alvarez (2000) and Cullinane, Song and Gray, (2002) did not specify the port activities. Sometimes the concept of port is used synonymously with port authority, although the latter is just one of many agents that operate in ports. It should be acknowledged that the study of container ports as a homogenous entity is a difficult task. On the other hand, container terminal studies, namely by Notteboom, Coeck and van den Broech, (2000), Cullinane, and Song, (2003), Cullinane and Song, (2006), Tongzon and Heng, (2005), Sun, Yan and Liu, (2006), and Rodriguez-Alvarez, Tovar and Trujillo, (2007) are less ambiguous in terms of the activities and agents studied. At the terminal level, the activities are primarily container transfer, so it excludes many of the other agents found in a container port. It is fair to conclude that most port level research has aimed to study port authority efficiency, and most terminal level research has studied stevedore efficiency. However, if we look into the outputs and inputs specification, the distinction between port and terminal level studies is blurry, that is, on both levels of data the studies focus on the container transferring activities.

Geographic location is one of the most distinctive features of a sea port and therefore the selection of ports/terminals is important. Three types of sampling can be identified in the literature: worldwide, regional and national ports/terminals. The worldwide studies include Cullinane and Song, (2006), Tongzon and Heng, (2005) and Sun, Yan and Liu, (2006); those studies benchmark efficiency in a global context. Since terminal operators nowadays work more internationally, the sample with worldwide ports/terminals is important particularly if we need to examine the effects of global terminal operators. However, the samples are usually chosen among the top 20/30 container ports by throughput. The focus of these kinds of samples is large container ports/terminals. The region-specific studies including: Notteboom, Coeck and van den Broech, (2000) used a dataset including 36 European and four Far East container terminals; Cullinane, Song and Gray, (2002) studied 15 Asian container ports; Trujillo and Tovar, (2007) studied 22 European port authorities. Regional samples usually consist of ports and terminals from particular continental economic regions; those studies benchmark ports/terminals serving the same mass market but from different countries, and therefore compare the performance of ports/terminals under different regulations. The country-specific studies including: Liu (1995), who considers 28 commercial ports in the UK; Coto-Millan, Banso-Pino and Rodriguez-Alvarez (2000) with 27 Spanish ports; Estache, Gonzalez and Trujillo, (2002) with their study 13 Mexican port authorities; Cullinane and Song, (2003) with three Korean and two UK container terminals; Barros (2005) with 10 Portuguese port authorities; Rodriguez-Alvarez, Tovar and Trujillo, (2007) with three multipurpose port terminals in the Canary Islands, and finally Gonzalez and Trujillo (2008) who examine five Spanish port authorities. We can observe that country-specific port and terminal studies dominate the literature, and this is justified by the difficulty to collect consistent cross-country data.

In addition to the selection of samples, the types of he data also determine the specific objective of the study. As we can see in Table 3, cross-sectional data and panel data are the types of data most commonly used in the literature. Cross-sectional data are generally collections of multiple ports or terminals at a single point in time. This type of data enables researchers to evaluate and compare the efficiency of different ports/terminals and to study the structure of the industry. Different characteristics and their impacts on port/terminal productivity and efficiency are studied through cross-sectional data. Panel data contains observations on multiple ports/terminals observed over multiple time periods, so in addition to what cross-sectional data can do, panel data can be used to study efficiency changes. The impact of regulation and management changes are analysed by comparing pre- and post- change efficiency using panel data.

Regardless of sample selection and data type, the application of SFA studies is two-fold: to analyse the structure of the industry and to evaluate the individual units' relative efficiency within the industry. Based on these two general goals, SFA studies have different specific objectives, however, one of the most common objectives is the impact of certain factor(s) on container port/terminal efficiency or productivity (see Table 3, column *objective*). One factor studied intensively in the literature is ownership and its related concepts such as privatisation, decentralisation, and autonomy. Since being initiated by the UK in the 1980s, port privatisation and deregulation have been implemented by various countries and regions (Cullinane and Song, 2002). The question of whether privatisation can improve efficiency has been a major focus in the literature ever since (see Table 3). Panel data is used to study different between efficiency before and after privatisation. Estache, Gonzalez and Trujillo, (2002) examine the efficiency of post-reform (reform in 1993/94 including privatisation) in the Mexican port authorities. Cullinane, Song and Gray, (2002) show how Asian container ports are affected by administrative and ownership restructuring. Liu (1995) studies the efficiency of UK ports during the privatisation period. Cullinane and Song

(2003) focus on a set of UK and Korean container terminals over a period when the UK ports experienced the privatisation process, while the Korean port industry remained heavily influenced by government. Among these studies, most find positive impacts of privatisation on port efficiency, although Liu (1995) concludes that no significant relationship between the two factors could be found. Many studies seek to explain the relationship between ownership and efficiency, but there is no consistent conclusion. There are two broadly accepted reasons for the non-uniform results of ownership's effects on efficiency: (1) the selected samples of ports or terminals are mainly geographically specific, and thus the ownership structure has different effects in different regions and countries; (2) other variables which are not captured in the models affect the efficiency and cause inconsistent conclusions. Although more research needs to be developed on this topic, a cross-sectional analysis of the relationship between ownership and efficiency (Tongzon and Heng, 2005) suggests an inverted U-shaped effect of the two factors: to a certain extent, privatisation improves port efficiency, but after a certain level of private intervention, port efficiency is hampered. Other factors which have been studied in the literature, although less commonly, include the effect of port size, degree of returns to scale, and location.

The objectives of the studies are reflected by the variable specification in models, and in the next section, we review the literature on the specification of inputs, outputs and exogenous variables.

Table 3: Literature in empirical port efficiency studies by applying SFA

Reference	**Data description**	**Objective**	**Additional factors**	**Functional form**	**Outputs**	**Inputs**
Liu (1995)	panel data of 28 commercial UK ports 1983-1990	To test the hypothesis that public sector ports are less efficient than private ones	Ownership, Port size, Capital intensity, Port location	Translog production function	Turnover	1.Labour 2.Capital
Coto-Millan, *et al.* (2000)	panel data of 27 Spanish ports from 1985-1989	To estimate the economic efficiency	Individual technical efficiencies, Autonomy Port size	Translog cost function	Aggregated single variable of goods, passengers and vehicles	1.Price of labour 2.Price of capital 3.Price of intermediate consumption
Notteboom, *et al.* (2000)	Cross-sectional data of 36 European terminals plus 4 Far East container terminals in 1994	To measure and explain the relative efficiency of container terminals	Individual technical efficiencies, Geographical dispersion, Scale of the terminals, Functional role of ports, Ownership	Cobb-Douglas production function	Terminal traffic (TEU)	1.terminal quay length 2.terminal surface 3. terminal gantry cranes
Estache, *et al.* (2002)	panel data of 13 Mexican port authorities 1996-1999	To measure the efficiency gain from Mexican port reform	Individual technical efficiencies Average growth rate	Cobb-Douglas and Translog production function	Volume of merchandise handled	1.Number of workers 2.Length of docks
Cullinane, *et al.* (2002)	Cross-sectional and panel data of 15 Asian container ports 1989-1998.	To analyse the relationship between ownership and efficiency.	Individual technical efficiencies Size, Ownership	Cobb-Douglas production function	Throughput in TEUs	1.Terminal quay length 2.Terminal area 3.No. of cargo handling equipment
Cullinane, & Song.(2003)	Cross-sectional and panel data from 5 Korean and UK container terminals	To access the privatisation achievement of Korean ports	Individual technical efficiencies Privatization/ deregulation	Cobb-Douglas cost function	Turnover	1.Managerial service 2.Employees' salaries 3.Capital cost of terminal operations 4.Net book value of mobile and cargo handling equipment
Cullinane, *et al.* (2006)	Cross-sectional data of 57 container ports / terminals within top 30 container ports, 2001	To compare the DEA and SFA approaches in port efficiency analyses	Individual technical efficiencies Returns to scale	Cobb-Douglas production function	Throughput	1.Terminal/port quay length 2.Terminal/port yard area 3.No. of quayside gantry cranes 4.No. of yard gantry cranes 5.No.of straddle carriers
Barros (2005)	Panel data of 10 Portuguese port authorities, 1990-2000	To identify best practice in the management of seaports	Individual technical efficiencies Technical changes (Trend)	Translog cost function	1.number of ships 2.total cargo	1.Price of labour 2.Price of capital
Tongzon & Heng. (2005)	cross-sectional data of 25 container ports/terminals, 1999	To investigate the relationship between port ownership and efficiency	Individual technical efficiencies, Privatisation, Competitive advantage	Cobb-Douglas production function	Throughput in terms of TEU	1.Terminal quay length 2.Terminal surface 3.No. of quay cranes

Reference	Data description	Objective	Additional factors	Functional form	Outputs	Inputs
Sun, *et al.* (2006)	Panel data of 83 container terminal operators 1997-2005	To study the efficiency of container port production	Depth of water, No. of ship calls	Cobb-Douglas production function by Bayesian inference, Markov Chain Monte Carlo simulation.	Throughput	1.Handling capacity between ship and quay 2.Handling capacity between quay and yard 3.Number of berths 4.Length of quay lines 5.Terminal area 6.Storage capacity of port 7.Reefer points
Rodriguez-Alvarez, *et al*. (2007)	Unbalanced Panel data on 3 multipurpose port terminals in Canary Islands, Spain, monthly data from 1991 to 1998	To test the hypothesis that given technology and prices, terminal port inputs are not optimally allocated in the sense that costs are not minimized.	Individual technical efficiencies, Allocative efficiency, Technical changes.	Translog distance (production) function	1.Containers 2.Ro-Ro cargo 3.General break-bulk cargo	1.ordinary port workers 2.special port workers 3.capital 4.intermediate consumption 5.total area
Trujillo, & Tovar (2007)	Cross-sectional data of 22 European port authorities 2002	To evaluate the European Port Legislation and port efficiency improvement.	Individual technical efficiencies Containerisation rate	Cobb-Douglas distance (production) function	1. Containers 2. Rest of freight traffic 3. passenger	1.Number of employees 2.Surface area
Gonzalez, & Trujillo (2008)	Panel data of 5 Spanish port authorities, including 17 ports 1990-2002	To quantify technical efficiency evolution in transport infrastructure; To analyze impact of '90s port reforms	Technical efficiency, Technical change, Existence of oil refineries, Geographic location, Economic regulation.	Translog distance (production) function	1. Containers 2. Liquid bulk 3. Other cargo 4. Passengers	1. Berths 2. Surface 3. Labour

3.4 Variable specifications of the existing literature

We have discussed in Chapter 2 the activities conducted by a container port. Ideally, all activities and resources present in the port should be taken into account when we calculate efficiency. However, in the empirical research, the decision upon which variables to include in the efficiency evaluation function, largely depends on the availability and quality of the data. For instance, the definition of port outputs depends on the activities undertaken by the port, and therefore it can include the number of passengers arriving/departing/transferring in/from the port; the number of vehicles, or the volume of different handled goods.

Within the SFA port efficiency analysis literature, the majority of the studies consider a single output, i.e. throughput in TEU (Liu, 1995; Coto-Millan, Banso-Pino and Rodriguez-Alvarez, 2000; Notteboom, Coeck and van den Broech, 2000; Estache, Gonzalez and Trujillo, 2002; Cullinane, Song and Gray, 2002; Cullinane and Song, 2003; Cullinane and Song, 2006; Tongzon and Heng, 2005; Sun, Yan and Liu, 2006) The choice of single output is partly due to the fact that early SFA techniques were unable to handle multiple outputs. However, in the most recent transport economics literature, it has been argued that single output measurement will cause a certain level of bias in the estimation (Jara-Díaz, Tovar and Trujillo, 2005). For a multi-purpose port, a single output measurement of number of container (TEU) is not appropriate for two reasons: (1) apart from TEU, traditional general cargo is an output usually measured in Tonnage; (2) within the container handling ports there are two kinds of container: Ro/Ro container and Lo/Lo container, which require different handling facilities. Without a commonly understood means of expressing capacity for handling one type in terms of the other, they deserve to be counted as different outputs.

Some of the latest studies have incorporated multiple outputs. Barros (2005) uses the number of ship-calls and total cargo as outputs; Rodriguez-Alvarez, Tovar and

Trujillo (2007) examine containers (Lo/Lo TEU), Ro/Ro cargo and general break bulk cargo as outputs; Trujillo and Tovar (2007) consider as outputs the containers, the rest of freight traffic and passengers; Gonzalez and Trujillo (2008) examine containers, liquid bulk, other cargo, and passengers as outputs. Although some studies in the literature consider multiple outputs, TEU is still the prevalent measure of output in the container port industry because TEU is the most practical and suitable measure for container transport activities, including container handling and shipping. In the analysis if the option of adding other outputs is available, they should be included, although these variables are significantly less explanatory than TEU measurements.

The specification of inputs in the literature is not as unified as that of outputs (see Table 3 column *Outputs* and *Inputs*). We can recognise two groups of input specification that are not mutually exclusive. One group of studies considers as input variables: labour and capital (Liu, 1995; Coto-Millan, Banso-Pino and Rodriguez-Alvarez, 2000; Estache, Gonzalez and Trujillo, 2002; Cullinane and Song, 2003). Another group of studies specifies inputs based on the infrastructure and machinery information, that is, terminal quay length, terminal area, number of cargo handling equipment and storage capacity (Tongzon and Heng, 2005; Cullinane, Song and Gray, 2002; Cullinane and Song, 2006; Sun, Yan and Liu, 2006). In the studies considering labour and capital information as inputs, the configuration of container ports/terminals is slighted, because all the factors are aggregated into a single capital variable. In the second group the studies do not have labour information, but the specification reflects a more accurate configuration of the port, and there is an underlying assumption that the request for labour in the production is relative to the equipment according to a certain ratio. In this context it is necessary to be cautious, because this assumption is not always accurate, different equipment requires different numbers of workers and different skill levels.

In addition to inputs and outputs, other factors knowing as exogenous factors that influence the productivity and efficiency of container ports and terminals. Exogenous factors are not under the control of operators, e.g. legislation conditions, or they are under the operator's control but they are not direct inputs, e.g. the characteristics of the transport network. Therefore, the study objectives in these cases aim to examine whether and how certain exogenous factors affect productivity and efficiency of container ports and terminals. Other factors that have been examined in the literature include ownership, size, location and regulation (Table 3 column *Additional Factors*).

3.5 Estimation techniques in the existing literature

Two types of functions are commonly used in the literature in relation to the variable information: production and cost functions. When variables are measured by physical quantities, the production function is used; and thus it implies that we assume that the primary goal of the operator is to maximise outputs. When the variables are measured by monetary values, we consider the cost function; and this implies that the primary aim of the study is to minimise inputs cost as well as maximise outputs. Coto-Millan, Banso-Pino and Rodriguez-Alvarez (2000), Cullinane and Song (2003) and Barros (2005) in their studies examine the cost function. However, the majority of scholars estimate the production function due to the practical difficulty of obtaining the required financial information from port/terminal operators. It should be noticed that the production function can only handle single output models and the cost function can handle multiple output functions. A third group of functions has been developed in recent literature in order to overcome the shortfall of the single output production function, that is, the distance functions. Rodriguez-Alvarez, Tovar and Trujillo (2007), Trujillo and Tovar, (2007) and Gonzalez and Trujillo (2008) consider the distance functions. Prior to these analyses, multiple outputs could be examined through the cost function. The choice of production, cost or distance function is decided by the measure of inputs/outputs and the number of outputs in the study.

Regardless of the analytical choice among production, cost or distant functions, explicit functional forms need to be designated in order to estimate efficiency. In the functional form we specify inputs, outputs and exogenous variables. The role of the functional form is therefore important for SFA studies, because the choice of function influences how the production technique is presented mathematically and decides what features can be studied. In general, two functional forms are considered in the container port and terminal industry, namely Translog and Cobb-Douglas (see Table 3 column *Functional form*). This is due to their succinctness of calculation and straightforwardness in interpretation. Translog is flexible in representing the shape of the frontier function and we can describe sophisticated production techniques; whereas Cobb-Douglas is not as flexible as Translog, but it does require fewer observations to carry out the estimation. In the Cobb-Douglas form, the degree of returns to scale is consistant for the whole dataset (industry); in the Translog form, each observation has a specific degree of returns to scale. Cobb-Douglas cannot calculate scale and substitute elasticity, but the Translog form can. Due to these advantages, and when the number of observations is sufficient, the Translog form is in general preferred to Cobb-Douglas one.

Different studies have examined different factors (see Table 3 column *Objective* and *Addition Factors*) according to their research objectives, and the relationships between factors and efficiency can be analysed either qualitatively or quantitatively. Regarding the quantitative analyses, two approaches exist in the literature. Early SFA studies have developed a two-stage approach (Liu, 1995 and Coto-Millan, Banso-Pino and Rodriguez-Alvarez, 2000). In the first stage we estimate the parameters based on input and output information and generate an efficiency index; in the second stage we specify a regression of the exogenous factors (factors other than inputs and outputs) upon the efficiency index generated in the first stage. The objective is to examine the relationship between exogenous factors and efficiency. The problem with this approach is that in the first stage the estimation is under the assumption that inefficiency effects are identically distributed, but in the second stage the regression contradicts this assumption. Battese and Coelli (1995) have developed a one-stage approach to take account of the endogenous (inputs) and exogenous (environmental) factors simultaneously. However, the container ports/terminal efficiency literature still has scant analyses based on the one-stage approach (Tongzon and Heng, 2005).

3.6 Conclusions

In this chapter we have reviewed the literature on SFA applied to the container ports and terminals industry. We can highlight the following remarks. First, container ports and terminals are recognised as complex organisations where operators are involved in diverse activities, they have different objectives and are subjected to uneven levels of competition and regulation. Consequently, in the analysis we need to use the most homogenous samples and common measures of variables. Second, inputs, outputs and exogenous variable specifications are very important to the empirical research but they are usually under the restriction of data availability. Thirdly, Table 4 summarises the methodological aspects of the literature and we can see that most studies examine how certain factors affect efficiency (see Table 3 column A*ddition factors*), and few studies examine this relationship quantitatively (see Table 4 column *exogenous variables*). Additional factors (in Table 3) are factors other than inputs, but also included in the study. The exogenous factors are additional factors which are quantitatively studied in the production and efficiency simultaneously. The exogenous factors include: regulation, competition and other important information of the container port/terminal industry. Lastly, technical efficiency and allocative efficiency have been studied in the literature. However, in contrast to DEA studies, there are few SFA studies on container ports/terminals that analyse scale efficiency. Scale efficiency is an important topic because investment decisions are directly related to the input level and input mix, which decides the scale efficiency of a container port/terminal.

Table 4: Literature in empirical port efficiency studies by applying SFA - summary

Reference	Objective		Data description		Functional form	
	Exogenous variables	Firm--specific technical efficiency	Cross-sectional data	panel data	Translog	Cobb Douglas
Liu (1995)	√			√	√	
Coto-Millan, *et al.* (2000)	√	√		√	√	
Notteboom, *et al*. (2000)		√	√			√
Estache, *et al.* (2002)		√		√	√	√
Cullinane, *et al.* (2002)		√	√	√		√
Cullinane *and* Song (2003)		√	√			√
Cullinane, *et al*. (2006)		√	√			√
Tongzon *et al.* (2005)	√		√			√
Barros (2005)		√		√	√	
Sun, *et al.* (2006)	√			√		√
Rodriguez-Alvarez, *et al*. (2007)		√		√	√	
Trujillo, *et al.* (2007)		√		√		√
Gonzalez and Trujillo (2008)		√		√	√	

The study of container port/terminal efficiency is still a relatively recent field of analysis, which began in the 1990s. There is the need for further research to evaluate the economic performance within the context of our analysis. In this chapter we have identified the gaps present in this literature; we can now proceed in the next chapter to discuss in detail the chosen research methodology.

Chapter 4: Methodology

4.1 Introduction

In Chapter 3 we have reviewed the stochastic frontier analysis (SFA) literature applied in container port and terminal studies. In this chapter, based on the literature, we establish the methodology we are going to develop for this research. The main objectives of this research are to benchmark the technical and scale efficiencies of individual container ports and terminals and to study the elements that influence efficiency. To address these objectives, SFA models need to be designed to examine the factors that are features of the container port and terminal industry. In this chapter we will therefore discuss the variables specification, the choice of the functional form for the deterministic part of SFA models, the distribution assumptions for the random part of the models, the model estimation, the technical efficiency and the scale efficiency evaluation.

4.2 Variables specification

The selection of variables is the primary step in any econometric analysis, because it weighs the precision of the analysis and estimation. We aim to examine in this work container ports and terminals in their basic functions, that is, the transport of containers from sea to land or back to sea again. To fulfil these functions, a port needs a variety of facilities, but particularly two kinds: infrastructure and equipment. Those facilities are identified as inputs to the container ports/terminals production. Infrastructure measures include: berth depth, berth length (or quay length), terminal area, yard space, storage, whereas equipment measures include number of handling machinery and handling capacity. The output of a container port/terminal is the number of containers handled in that port/terminal per annum. Twenty-foot equivalent unit (TEU) is the international standard measure used for container ports; thus, we adopt TEU as the output measure.

Three exogenous factors which affect the production and efficiency are identified in this study. The first factor is trading volume. International trade is not under the control of operators, but it is a determinant of the overall demand for container transport and handling services. The volume of merchandise trade between Europe with the rest of the world is used as one exogenous factor. The second factor is the terminal type. Two kinds of container terminals are considered in this research: the container-only and the multi-purpose terminal. A container-only terminal's primary function is Lo-Lo handling of containers, whereas a multi-purpose terminal does not have a specific primary function. In addition to containers, a multi-purpose terminal handles general cargo, Ro-Ro, reefer and bulk. The typology of the terminals influences the output and efficiency but is not considered as a direct input variable. In long run, the terminal type could be changed by replacing terminal infrastructure and machinery. However, this change usually requires vast level of investment spanning across a long period of time. Since we consider a shorter time period, we cannot consider terminal type as an input variable but we are able to consider terminal type as an exogenous variable that influences production and efficiency. The third factor is operator type, and we identify two kinds of operators: global and local. If the operator has operations in more than one region[1] of the world, it is defined as a global operator; otherwise it is a local operator. Operator type is not a direct input of the output (number of containers going though the port/terminal), but firms with different operator types have different management characteristics; therefore, operator type potentially influences port production and performance.

[1] We classify 13 regions: North America, North Europe, South Europe, Far East, South East Asia, Middle East, Caribbean, Central America, South America, Oceania, South Asia, Africa and East Europe.

4.3 Deterministic part of the model: functional form

The choice of functional form is an important step for all statistical and econometric models, because the functional form identifies the relationship between inputs and outputs. The chosen function allows us, through the SFA approach, to analyse the relationships between different variables and between variables and the production technique. This is of crucial importance in order to understand the industry structure and to enable a comparison with studies in the same field. The function is structured using behavioural assumptions such as profit maximisation or cost minimisation and under a technology constraint, such as quasi-fixed input (Andreu et al., 1995). The behavioural assumptions are embodied in the mathematical expression of the function. The choice of function influences the shape of the frontier and the accuracy of the estimation. In Table 5 we list the most common functional forms in empirical studies.

Table 5: Algebraic functional forms

Linear	$y = \beta_0 + \sum_{n=1}^{N} \beta_n x_n$ (4.1)
Cobb-Douglas	$y = e^{\beta_0} \prod_{n=1}^{N} x_n^{\beta_n}$ or $\ln y = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x_n$ (4.2)
CES	$y = \beta_0 (\sum_{n=1}^{N} \beta_n x_n^{-\rho})^{-\gamma/\rho}$ (4.3)
Quadratic	$y = \beta_0 + \sum_{n=1}^{N} \beta_n x_n + \frac{1}{2} \sum_{n=1}^{N} \sum_{m=1}^{N} \beta_{nm} x_n x_m$ $n,m=1,\ldots N$ (4.4)
Translog	$\ln y = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x_n + \frac{1}{2} \sum_{n=1}^{N} \sum_{m=1}^{N} \beta_{nm} \ln x_n \ln x_m$ (4.5)
Generalised Leontief	$y = \sum_{n=1}^{N} \sum_{m=1}^{N} \beta_{nm} (x_n x_m)^{\frac{1}{2}}$ (4.6)

The *Linear function* is the most basic form of function. Although it is unable to describe a complex economic reality, it represents the foundation of linear regression. If a function is not linear in its original expression, but can be written as a linear function after some mathematical transformation, we call this function linear-in-parameter. Hence, we still can use linear regression techniques. Most of the complex functional forms are linear-in-parameter, as we will see later in this review.

The *Cobb-Douglas function* was introduced by Charles W. Cobb and Paul H. Douglas (1928). It is linear in logarithms and thus we can use linear regression techniques. The function represents decreasing/constant/increasing returns to scale when $\sum_{n=1}^{N} \beta_n < 1,\ = 1,\ > 1$, respectively. The elasticity of substitution between factors is always equal to 1.

The *Constant Elasticity of Substitution (CES) Function* was introduced by Arrow, Chenery, Minhas and Solow (1961). By looking at the expression given in Table 5, γ denotes the degree of homogeneity of the function which will give us the information on returns to scale; $\beta_0 > 0$ is the efficiency parameter which represents the "size" of the production function; β_ns represent the distribution parameters which will help us to explain relative factor shares (such that $\Sigma \beta_n = 1$, allowing us to separate the elasticity of scale, γ, from the other parameters); and ρ is the substitution parameter, which will help us derive the elasticity of substitution, $\sigma = 1/(1+\rho)$. The function represents decreasing/constant/increasing returns to scale when $\gamma <, =, > 1$, respectively. Marginal products are: $\frac{\Delta y}{\Delta x_i} = \gamma \beta_0^{-\rho/\gamma} \beta_i \frac{y^{1+\rho/\gamma}}{x_i^{\rho+1}}$. The marginal rate of technical substitution (MRTS) between the two inputs is: $\frac{\Delta x_i}{\Delta x_j} = \frac{\beta_i}{\beta_j} (\frac{x_j}{x_i})^{\rho+1}$. For the constant returns to scale case (γ=1), the elasticity of substitution of a CES production function will be $\sigma = 1/(1+\rho)$. If $\rho = -1$, then $\sigma = \infty$, this is the case of perfect substitution. If $\rho = \infty$, $\sigma = 0$, this is the case of no substitution. If $\rho = 0$, in this case the elasticity of substitution is equal to unity, $\sigma = 1$.

The *Translog Function* was introduced by Christensen, Jorgenson, and Lau (1971, 1973, 1975). Translog is a quadratic function with all arguments in logarithm. The first two groups of terms in Translog correspond to the Cobb-Douglas or log-linear specification; the second-order (the last group of) terms introduce non-linear relationships and cross-relationships among the variables into the model. This function allows for free elasticities of substitution and it can provide quadratic approximation to an unknown form of a twice continuously-differentiable function. Translog corresponds to a second order Taylor-series progression. Translog is the generalisation of Cobb-Douglas, whereas Cobb-Douglas is a special case of Translog.

There have been other functional forms developed in the literature: *Leontief* was first introduced by Diewert (1971); the *generalized Box-Cox* by Berndt and Khaled (1979), the *Fourier* by Gallant (1981); the *Laurent* by Barnett (1983); the *McFadden* by McFadden (1978); the *"asymptotically ideal model" (AIM)* developed by Barnett and Jonas (1983) and then Barnett and Yue (1988); the *Normalized Quadratic* by Lau (1978); and the *Symmetric Generalized MacFadden* by Diewert and Wales (1987), which was extended by Kohli (1993) to the *Symmetric Normalized Quadratic*. Those forms are not discussed in detail here because, although developed in theoretical research, they are rarely used in empirical studies.

The functional forms discussed above can be divided into two main groups: simple functional forms and flexible functional forms.[2] Linear, Cobb-Douglas and CES forms require fewer observations and they satisfy most regularity conditions. The drawback of these functional forms is that they cannot model very sophisticated technologies. Quadratic, Translog and Generalized Leontief are flexible functional forms. The advantage of flexible functional forms is their flexibility to model fairly sophisticated technologies (Guilkey, Lovell and Sickles, 1983). In a more formal definition, those functional forms do not *a priori* constrain the various elasticities of substitution; they all provide a second order local approximation to an arbitrary twice differentiable production or cost function (Appelbaum, 1979). The consequence of

[2] Flexible form we discussed here is up to second-order. Third-order flexible forms have also been studies, but have fewer applications in empirical studies. There is another class of functional forms, the semi-flexible forms. The estimation of these functional forms requires simulation techniques, which are beyond this research.

this ‘flexibility’ is that they exhibit weak (mathematical) global behaviour. Substantive work is available in the literature comparing the mathematical performance of different flexible functional forms; Translog is recommended as the most favourable choice by many scholars (Berndt, Darrough and Diewert, 1976; Gagne and Ouellette, 1998; Guilkey, Lovell and Sickles, 1983).

In this research the functional forms that most suitably address our objectives are the Cobb-Douglas and Translog, because the Cobb-Douglas definition is a special case of Translog, that is, the Cobb-Douglas form is nested in the Translog form. The performance of these two forms can thus be easily compared. As can be concluded from the literature, Translog and Cobb-Douglas functional forms are the most commonly used, therefore, we can compare of our results with the previous literature when necessary.

After having discussed the functional form for the deterministic part of the SFA model, we will next discuss the distributions for the stochastic parts of the model.

4.4 Stochastic part of the model: distributions

The distinct feature of SFA is the composed error term, which requires the specification of two distribution assumptions in order to estimate the efficiency. The compound error term is:

$$\varepsilon = v - u \tag{4.7}$$

v is the statistical noise;

u is the inefficiency;

u and v are distributed independently of each other and of the regressors.

In the literature v is always normally distributed and u is specified by several one-sided distributions. Normal distribution for v is

$$f_v(v) = \frac{1}{\sqrt{2\pi}\sigma_v} \exp\{-\frac{v^2}{2\sigma_v^{\ 2}}\} \qquad (4.8)$$

The density function of u can be Half Normal, Exponential, Truncated Normal and Gamma distribution. Table 6 lists these four one-sided distributions and their conjugations with Normal distribution.

Table 6: Distribution assumptions for the inefficiency term

	Distribution	Conjugation with Normal distribution
Half Normal	$f_u(u) = \frac{\sqrt{2}}{\sqrt{\pi}\sigma_u} \exp\{-\frac{u^2}{2\sigma_u^{\ 2}}\}$ (4.9)	$f(\varepsilon) = \frac{2}{\sigma}\phi(\frac{\varepsilon}{\sigma})\Phi(-\frac{\varepsilon\lambda}{\sigma})$ Where $\sigma = (\sigma_u^{\ 2} + \sigma_v^{\ 2})^{1/2}$, $\lambda = \sigma_u / \sigma_v$,
Exponential	$f_u(u) = \frac{1}{\sigma_u}\exp\{-\frac{u}{\sigma_u}\}$ (4.10)	$f(\varepsilon) = (\frac{1}{\sigma_u})\Phi(-\frac{\varepsilon}{\sigma_v} - \frac{\sigma_v}{\sigma_u})\exp\{\frac{\varepsilon}{\sigma_v} + \frac{\sigma_v^{\ 2}}{2\sigma_u^{\ 2}}\}$
Truncated Normal	$f_u(u) = \frac{1}{\sqrt{2\pi}\sigma_u\Phi(-u/\sigma_u)}\exp\{-\frac{(u-\mu)^2}{2\sigma_u^{\ 2}}\}$ (4.11)	$f(\varepsilon) = \frac{1}{\sigma}\phi(\frac{\varepsilon+\mu}{\sigma})\Phi(\frac{\mu}{\sigma\lambda} - \frac{\varepsilon\lambda}{\sigma})[\Phi(-\frac{\mu}{\sigma_u})]^{-1}$ Where $\sigma = (\sigma_u^{\ 2} + \sigma_v^{\ 2})^{1/2}$, $\lambda = \sigma_u / \sigma_v$,
Gamma	$f_u(u) = \frac{u^m}{\Gamma(m+1)\sigma_u^{\ m+1}}\exp\{-\frac{u}{\sigma_u}\}$, $m > -1$. (4.12)	$f(\varepsilon) = \frac{\sigma_v^{\ m}}{\sqrt{2\pi}\Gamma(m+1)\sigma_u^{\ m+1}}\exp\{\frac{\varepsilon}{\sigma_u} + \frac{\sigma_v^{\ 2}}{2\sigma_u^{\ 2}}\}$ $\bullet \int_w^\infty (t-w)^m \exp\{-\frac{t^2}{2}\}dt$ Where $w = (\varepsilon/\sigma_v) + (\sigma_v/\sigma_u)$

Source: Kumbhakar and Lovell (2000). $\Phi(\cdot)$ and $\phi(\cdot)$ are the standard Normal

In this research we use the Half Normal and the Truncated Normal distribution. For cross-sectional data models, Half Normal distribution is a special case of Truncated Normal distribution. Truncated Normal distribution assumes that the technical inefficiency in production follows a distribution that is truncated at zero of a normal distribution. When the normal distribution has a mean at zero, the Truncated Normal distribution collapses to Half Normal distribution; in other words, Half Normal is nested in Truncated Normal distribution. For panel data models two different kinds of Truncated Normal distribution are used: the Battese and Coelli models (1992) and (1995). The error distribution of these two models does not have a nested relationship, but they both nest the Truncated Normal distribution for cross-sectional data. In the next section we will discuss the distribution within the context of these models.

4.5 Model definitions

In this work we specify four models: two cross-sectional models with Half Normal and Truncated Normal distribution for the inefficiency term, respectively, and two panel data models with different Truncated Normal distributions.

Let us consider the two model specifications of cross-sectional models. The different distribution assumptions on the inefficiency term U result in two cross-sectional models: Half Normal and Truncated Normal distribution. The models are defined as follows:

$$\ln y^i = \ln x^i\, \beta + (V^i - U^i) \tag{4.13}$$

Where:

- y^i is the output obtained by the i-th firm;
- x^i is the vector of input quantities of the i-th firm;
- β is the vector of parameters;
- V^i_t are random variables representing statistic noise, which are assumed to be independent and identically-distributed (i.i.d.) $N(0, \sigma_v^2)$,
- U^i_t are non-negative random variables representing technical inefficiency, which can be assumed i.i.d. either
  1) $|N(0, \sigma_u^2)|$ - Half Normal distribution; or
  2) truncations at zero of the $N(\mu^i, \sigma_u^2)$ – Truncated Normal distribution.

σ_v is the variance parameter of noise term;

σ_u is the variance parameter of inefficiency term;

σ is the combined error term;

γ $=\sigma_u^2/(\sigma_v^2+\sigma_u^2)$. $\sigma^2=\sigma_v^2+\sigma_u^2$.

If γ is close to zero, it indicates that the deviations from the frontier are due mostly to noise. If γ is close to one, it indicates that the deviations from the frontier are due mostly to the technical inefficiency.

In the case of panel data, the first model specification is based on Battese and Coelli (1992). The definition of our models is:

$$\ln y^i_t = \ln x^i_t \beta + (V^i_t - U^i_t) \tag{4.14}$$

$$U^i_t = U^i \exp(-\eta(t-T)),$$

Where

y^i_t is the output obtained by the i-th *firm* at the t-th time period;

x^i_t is the vector of input quantities of the i-th firm at the t-th time period;

β is the vector of parameters;

V^i_t are assumed to be i.i.d., $N(0, \sigma_v^2)$ random errors;

U^i_t are assumed to be i.i.d. as truncations at zero of the $N(\mu^i, \sigma_u^2)$;

η is a scalar parameter.

We can observe that the cross-sectional model of Half Normal specification is a special case of cross-sectional model of Truncated Normal specification, when the mean is equal to zero, $\mu = 0$. The cross-sectional model of Truncated Normal specification is a special case of the Battese and Coelli model (1992), when T = 1; therefore, these three models are nested.

A more advanced panel model, which considers exogenous factors as covariates in the inefficiency distribution function, is specified by Battese and Coelli (1995). Our second model specification in the case of panel data is given by:

$$\ln y^i_t = \ln x^i_t \beta + (V^i_t - U^i_t) \tag{4.15}$$
$$m^i_t = z^i_t\delta,$$

Where:

Y^i_t, X^i_t, β and V^i_t are as defined in model (4.14);

U^i_t are assumed to be i.i.d. as truncations at zero of the $N(m^i_t, \sigma_u^2)$;

z^i_t is the vector of exogenous variables which may influence the efficiency of a port or terminal;

δ is the vector of parameters.

The model is a one-stage approach in order to take into account the endogenous (inputs, *x*) and exogenous (environmental, *z*) factors simultaneously. It nests the cross-sectional model of Truncated Normal specification when all the environmental parameters are 0 except the intercept; moreover it also nests the cross-sectional model of Half Normal specification as we mentioned before. However, we should notice that the two panel data models are not nested, because the parameterisation of U^i_t. are different.

When the exogenous variables are included in the deterministic part, the model is called a *net* effect model. The two cross-sectional models and the first panel data model are all *net* effect models. The *net* effect models assume that the exogenous variables have the same level of impact on output as operator-controlled inputs, however, the exogenous variables are not under the control of the operator, as for instance, rain for agriculture or international trade for the container shipping industry.

When the exogenous variables are included in the random inefficiency term, the model is called a *gross* effect model. The second panel data model is a *gross* effect model. The *gross* effect model considers that exogenous variables influence the efficiency directly but do not (directly) influence the output.

Many factors can be considered to influence both efficiency and output, by constructing both *net* and *gross* effect models with the same dataset; and by comparing the *net* and *gross* effect models we can identify how a factor influences the productivity and efficiency and thus better understand the production structure in the container port / terminal industry.

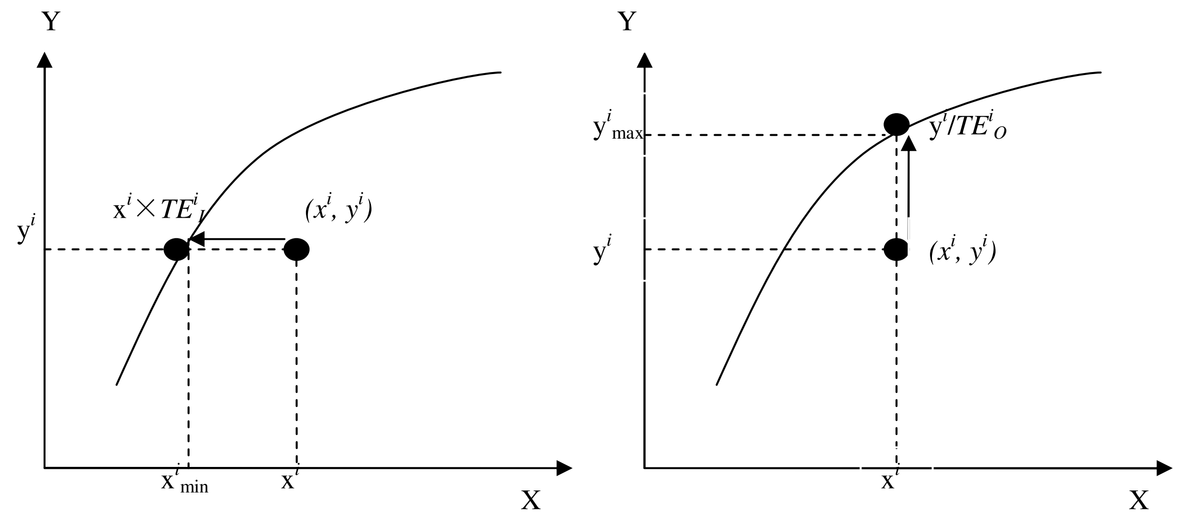
To estimate the parameters in these four models, we use two well-established statistical methods in order to fit the mathematical functional form to the data: *Maximum likelihood estimation* (MLE) and *ordinary least squares* (OLS). Both are well-established in the statistical literature. *MLE* determines the parameters that maximise the probability (likelihood) of the observed data. *OLS* determines the parameters that minimise the sum of squared distances between the observed data and the estimated function.

According to the estimation procedure of the software FRONTIER 4.1, OLS estimates all the parameters in the deterministic part of the model except the intercept; this is because the OLS estimation on the intercept parameter is biased (Kumbhakar and Lovell, 2000). MLE estimates the final parameters using the result from OLS as the starting point.

4.6 Technical efficiency

The formal definition of technical efficiency (TE) was given by Koopmans (1951), TE represents either the ability of a firm to minimise the inputs used in the production for a given output vector, or the ability of the firm to maximise the output from a given input vector. Therefore, there are two technical efficiency measures associated with the definition: an input-oriented measure and an output-oriented measure. Figure 10 illustrates the input-oriented and output-oriented measures for single input and single output cases. The curve represents the ideal performance. (x^i, y^i) is the actual performance of firm *i*: the firm uses input vector x^i and produces output vector y^i. Technical efficiency of the firm and (x^i, y^i) is indentified by input-oriented measure $TE^i{}_I = \frac{x^i{}_{\min}}{x^i}$, or output-oriented measure $TE^i{}_o = \frac{y^i}{y^i{}_{\max}}$.[3] The value of TE^i_O and TE^i_I can vary between zero and unity.

Figure 10: Input- and output-oriented technical efficiency measures



Input-oriented efficiency measurement with single input (input distance function)

Output-oriented efficiency measurement with single output (output distance function)

The choice of measurement depends on the nature of the industry. In the container port/terminal industry, a port authority and terminal operator can influence the production level through the use of commercial policies and different market strategies, but the provision of infrastructure is difficult to change over a short-term period. This leads to the use of an output-oriented measure that features the maximum output able to be reached for a given input-mix.

[3] $TE_{I,i}$ and $TE_{O,i}$, are input-oriented technical efficiency and output-oriented technical efficiency, respectively, and they are not necessarily equal to each other. It has been argued in Fare and Lovell (1987) and Deprins and Simar (1983) that the input efficiency measure is equal to the output efficiency measure if and only if production technology exhibits constant returns to scale.

The output-oriented efficiency ratio of production point i (x^i, y^i) can then be written as

$$TE^i = \frac{y^i}{y^i_{\max}}$$

In the Cobb-Douglas case

$$\ln y^i = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x^i{}_n + v^i - u^i$$

The technical efficiency for port i is

$$TE^i = \frac{y^i}{y^i_{\max}} = \frac{\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x^i{}_n + v^i - u^i)}{\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x^i{}_n + v^i)} = \exp\{-u^i\} \tag{4.16}$$

In the Translog case

$$\ln y^i = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x^i{}_n + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} \ln x^i{}_n \ln x^i{}_m + v^i - u^i$$

The technical efficiency for port i is

$$TE^i = \frac{y^i}{y^i_{\max}} = \frac{\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x^i{}_n + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} \ln x^i{}_n \ln x^i{}_m + v^i - u^i)}{\exp(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x^i{}_n + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} \ln x^i{}_n \ln x^i{}_m + v^i)} = \exp\{-u^i\} \tag{4.17}$$

Therefore, in both cases we can express the observation-specific technical efficiency as follows:

$$TE^i = \frac{y^i}{y^i_{\max}} = \exp\{-u^i\} \tag{4.18}$$

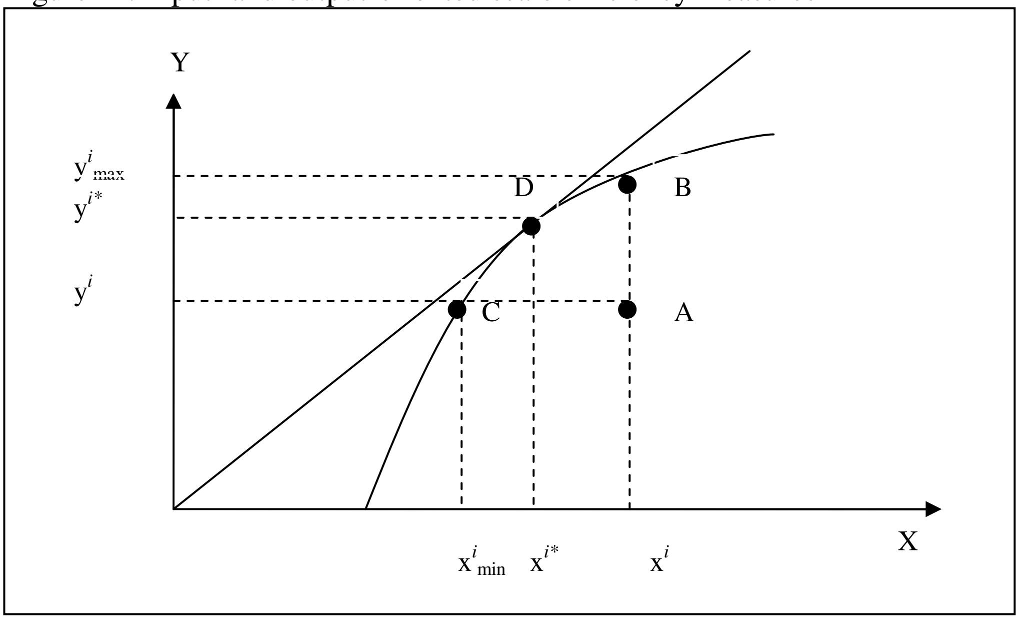
Once the parameters are estimated, the port/terminal specific efficiency can be calculated based on the inputs and output for that particular observation (port or terminal).

4.7 Scale efficiency

The mathematical definition of scale efficiency (SE) can be found in Balk (2001).

Similar to TE, SE measurement can be input-oriented and output-oriented. SE indicates how effective the input (output) level is, for a given output (input) mix. Figure 11 illustrates both the TE and SE measures. A is the actual observation point. Point B is the output-oriented TE optimal for observation A; it represents the maximum output that can be obtained, given the same level of input as observation A. Point C is the input-oriented TE optimal for observation A; it represents the minimum input that could be used for the same level of output as observation A. Both B and C are on the technical frontier. Point D, the tangent point of the frontier, represents the scale optimal that a firm can achieve with the same input and output combination. The output-oriented SE is measured by the slope ratio between OB and OD; whereas the input-oriented SE is measured by the slope ratio between OC and OD.

Figure 11: Input- and output-oriented scale efficiency measures



The output- and input-oriented SE are defined as follows:

$$SE_o(x^i) = \frac{y^i{}_{\max} / x^i}{y^{i*} / x^{i*}} \tag{4.19}$$

$$SE_I(x^i) = \frac{y^i / x^i{}_{\min}}{y^{i*} / x^{i*}} \tag{4.20}$$

In this study we use the output-oriented SE measure, because, as previous explained, for the TE measure the port and terminal operators can influence the production level, but they cannot so easily influence and change the production inputs. We therefore consider that the output-oriented SE measure represents the maximum output able to be obtained for a given input level and for the particular input mix of the examined port/terminal. The maximum attainable productivity at a level of input scale is called the most productive scale size (MPSS), which is the technically optimal scale of production for that particular input mix where scale elasticity is equal to 1 (Banker, 1984). The SE is measured as the ratio of the observed productivity to the MPSS at the observed level of input scale.

The Cobb-Douglas function is not able to estimate observation-specific SE because of its mathematical properties. In the case of the Translog production frontier:

$$\ln y = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x_n + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} \ln x_n \ln x_m + v - u$$

Where [β_{nm}] is symmetric and assumed to be negative definite.[4] Therefore the scale elasticity for any input bundle x is

$$\varepsilon(x) = \sum_{n=1}^{N} (\beta_n + \sum_{m=1}^{N} \beta_{nm} \ln x_m) \tag{4.21}$$

For a particular observed bundle x^i, the Translog production frontier is

$$\ln y^{i*} = \beta_0 + \sum_{n=1}^{N} \beta_n \ln x^i{}_n + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} \ln x^i{}_n \ln x^i{}_m \tag{4.22}$$

And the scale elasticity for this observed bundle x^i is

$$\varepsilon(x^i) = \sum_{n=1}^{N} (\beta_n + \sum_{m=1}^{N} \beta_{nm} \ln x^i{}_m) \tag{4.23}$$

The most productive scale size (MPSS) of the particular observed bundle x^i is $x^{i*} = t^* x^i$, and only when scale elasticity is equal to 1 (Banker, 1984) do we reach the maximum productivity at the observed bundle x^i, we can then write:

[4] Negative definiteness of [β_{nm}] is sufficient but not necessary. $\Sigma_n \Sigma_m \beta_{nm} > 0$ (Subhash, 1998).

$$\varepsilon(x^{i*}) = \sum_{n=1}^{N}(\beta_n + \sum_{m=1}^{N}\beta_{nm}\ln x^{i*}{}_m) = 1$$

$$\varepsilon(x^{i*}) = \sum_{n=1}^{N}(\beta_n + \sum_{m=1}^{N}\beta_{nm}\ln x^{i}{}_m) + (\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm})\ln t^* = 1$$

$$\varepsilon(x^{i*}) = \varepsilon(x^i) + (\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm})\ln t^* = 1$$

Therefore, we can write an explicit equation for t*,

$$\ln t^* = \frac{1-\varepsilon(x^i)}{\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm}} \tag{4.24}$$

Recall that the output-oriented scale efficiency is expressed as:

$$SE_o(x^i) = \frac{y^i{}_{\max} / x^i}{y^{i*} / x^{i*}} = \frac{(x^{i*}/x^i)\, y^i{}_{\max}}{y^{i*}} = \frac{t^* y^i{}_{\max}}{y^{i*}} = \frac{t^* f(x^i)}{f(t^* x^i)}$$

$$\ln SE_o(x^i) = \ln t^* + \ln f(x^i) - \ln f(t^* x^i)$$

For the Translog case:

$$\ln f(x^i) = \beta_0 + \sum_{n=1}^{N}\beta_n \ln x^i{}_n + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm}\ln x^i{}_n \ln x^i{}_m$$

$$\ln f(t^* x^i) = \beta_0 + \sum_{n=1}^{N}\beta_n(\ln x^i{}_n + \ln t^*) + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm}(\ln x^i{}_n + \ln t^*)(\ln x^i{}_m + \ln t^*)$$

Hence, the output-oriented scale efficiency for the Translog case is

$$\ln SE_o(x^i) = \ln t^* - \sum_{n=1}^{N}\beta_n \ln t^* - (\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm}\ln x^i{}_n)\ln t^* - \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm}(\ln t^*)^2$$

$$\ln SE_o(x^i) = (1-\varepsilon(x^i))\ln t^* - \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm}(\ln t^*)^2 \tag{4.25}$$

Replace $\ln t^* = \dfrac{1-\varepsilon(x^i)}{\sum_{n=1}^{N}\sum_{m=1}^{N}\beta_{nm}}$ as derived earlier,

Thus, the observation-specific scale efficiency can be calculated

$$\ln SE_o(x^i) = \frac{(1-\varepsilon^i)^2}{2\sum_n^N \sum_m^N \beta_{nm}}$$

$$SE_o(x^i) = \exp\left(\frac{(1-\varepsilon^i)^2}{2\sum_n^N \sum_m^N \beta_{nm}}\right) \tag{4.26}$$

We have demonstrated how to calculate TE for both Cobb-Douglas and Translog functions as well as SE for Translog.

4.8 Conclusions

In this chapter we have identified the methodology to estimate the container port/terminal structure and evaluated technical and scale efficiency (TE and SE) indices for individual ports and terminals. The procedure entails building the dataset, choosing the functional forms for the deterministic part of the model, specifying the variables, and choosing the distribution specifications of the (in)efficiency term. By undertaking these four steeps we have produced the model specification. We use two datasets: port level data in Chapter 5 and terminal level data in Chapter 6. We also use two functional forms: Cobb-Douglas and Translog, but variable specification depends on how the output, inputs and exogenous variables are explained in the model specifications. And finally, four distribution specifications are used in the research: Half Normal for cross-sectional data, Truncated Normal for cross-sectional data, Truncated Normal for both panel and cross-sectional data, Battese and Coelli models (1992 and 1995).

The models in the following chapters are numbered according to these four steps of model specification. The first number represents the data typology (1 = port data; 2 = terminal data). The second number identifies the functional form (1 = Cobb-Douglas; 2 = Translog). The third number refers to the variable specification (refer to Chapters

5 and 6). The fourth number indicates one of the four of the distribution specifications (ordered as the sequence mentioned in section 4.5). For example, Model 1.1.4.3 is the port level data (1), Cobb-Douglas form (1), variable specification (4) and Truncated Normal specification (Battese and Coelli, 1992) (3).

Chapter 5: Efficiency analysis at the port level

5.1 Introduction

In this chapter we evaluate data from a panel of 32 Mediterranean Sea container ports from 1989 to 2006. Reasons for the focus on this area are, first, the Mediterranean Basin is the gateway of a major international trade route, i.e. container traffic from the Asia to Europe, which has been estimated at 18.3 million TEU in 2006, with the breakdown of 12.5 million TEU on the leg from Asia to Europe, and 5.8 million TEU in the opposite direction (UNCTAD, 2007). Secondly, the Mediterranean partnership in the Mediterranean Basin provides an efficient and fair multi-national marketplace for both EU and non-EU countries; ports in this region therefore enjoy rather free markets and non-uniform regulatory structures. Thirdly, the location and geography of the Mediterranean Basin ensures homogeneity of weather conditions and other factors beyond the control of the container transport industry, and allows for the study of port characteristics such as port regulations, port configuration and economic conditions.

5.2 Data description

The 32 ports studied in this chapter are located in the North-Mediterranean Sea area (see Figure 12), and are represented by nine countries: France, Spain, Italy, Malta, Slovenia, Croatia, Montenegro, Greece and Turkey. Among the nine countries, France, Italy, Spain, and Greece are EU members throughout the entire research period and Malta and Slovenia have joined the EU in 2004; however, Croatia and Turkey are EU-candidate countries. Montenegro is also not an EU-member county, so its port policy is not directly affected by EU policy. The 32 container ports used in this research therefore have different policies, management structures and regulatory characteristics.

Figure 12: The location of the 32 container ports in the North-Mediterranean Sea area

Source: Image from Google Earth

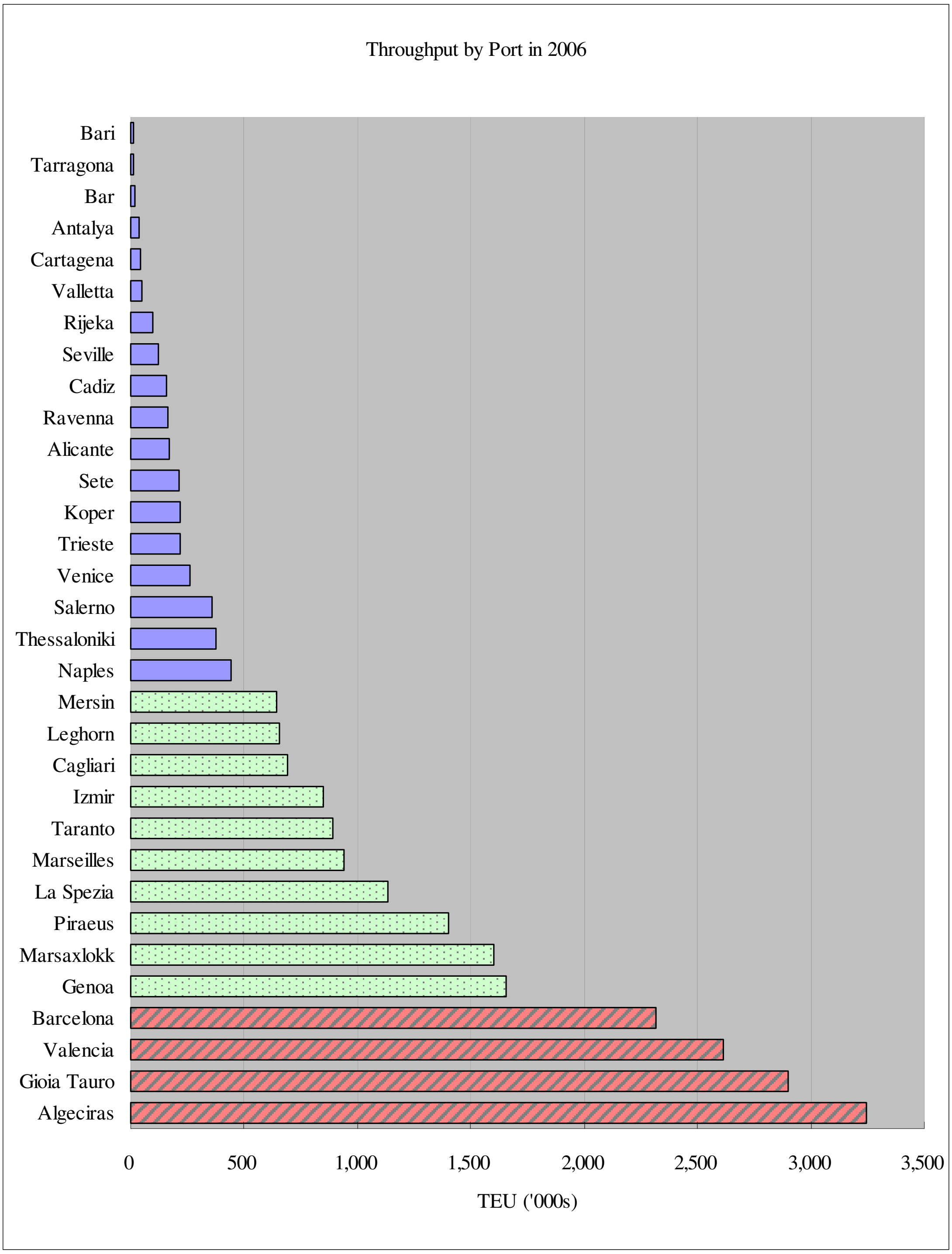
Not only does the regulation of ports differ, but the size of ports also ranges widely. From port throughput (see Table 7 and Figure 13), we can observe the different sizes of ports. Bari, Bar and Taragona can be categorised as small ports, as their throughput is below 500,000 TEU, whereas Gioia Tauro, Alicante and Valencia are relatively large ports, with throughput greater than 2,000,000 TEU. The analysis therefore includes a wide range of port sizes within the Mediterranean Basin.

Table 7: The 32 North Mediterranean Sea container ports' throughput in 2006

Country	Port	Throughput (TEU) in 2006
France	Marseilles	941,400
	Sete	210,404
Spain	Algeciras	3,244,641
	Alicante	172,729
	Barcelona	2,317,363
	Cadiz	155,370
	Cartagena	39,594
	Seville	122,611
	Tarragona	12,135
	Valencia	2,612,139
Italy	Bari	10,586
	Cagliari	690,392
	Genoa	1,657,113
	Gioia Tauro	2,900,000
	La Spezia	1,137,000
	Leghorn	657,592
	Naples	444,982
	Ravenna	162,052
	Salerno	359,707
	Taranto	892,303
	Trieste	220,661
	Venice	262,847
Malta	Marsaxlokk	1,600,000
	Valletta	47,920
Slovenia	Koper	218,970
Croatia	Rijeka	96,000
Montenegro	Bar	18,000
Greece	Piraeus	1,403,408
	Thessaloniki	376,940
Turkey	Antalya	36,618
	Izmir	847,926
	Mersin	643,749

Source: Containerisation International Yearbook (2007)

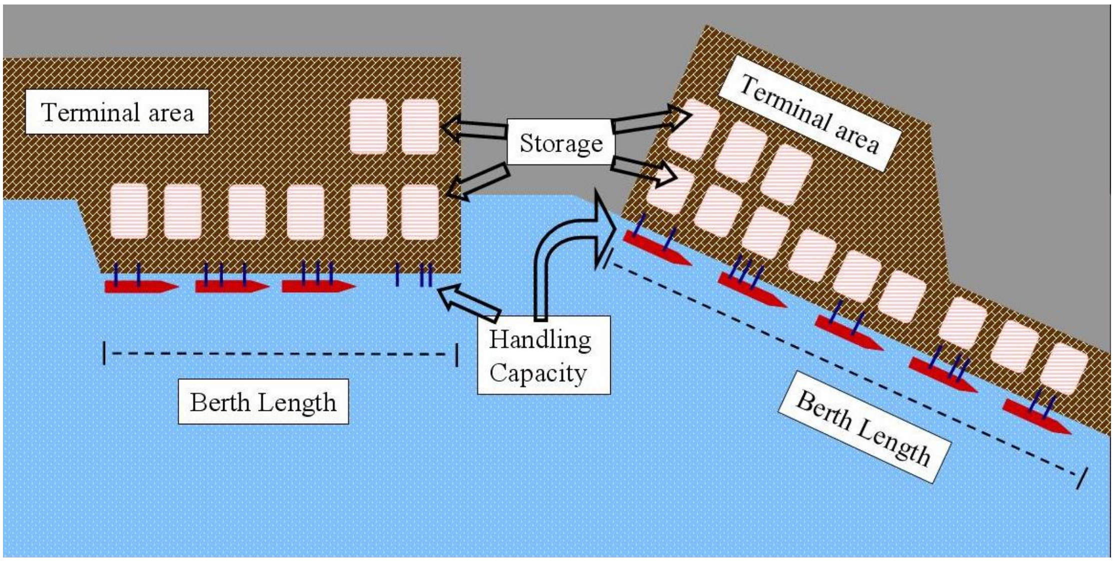
Figure 13: Ranking of the 32 North-Mediterranean Sea container ports' throughput in 2006



Source: Containerisation International Yearbook (2007)

The functions and facilities of a container port are the same regardless of their size and regulatory policy. In Chapters 3 and 4 we have discussed the variable specification. Accordingly, four variables have been collected and used as inputs in the models for this chapter: Berth Length (metres), Total Terminal area (square metres), Storage (TEUs), and Handling Capacity (tonnes). The four inputs represent different infrastructure categories, as shown in Figure 14.

Figure 14: Container port inputs information and their approximate representations



Berth Length and Total Terminal area represent Infrastructure and Handling Capacity and Storage fits into the Equipment category, thereby providing an overview of port assets. Comprehensive statistical information on these four assets is generally available from port authority reports, government statistical sites and private research companies. The widespread availability of this information highlights the importance of these assets for both public policy makers and private management.

The throughput of a port is measured in TEU, the sanctioned measurement of output for the container port industry. The data used in this chapter is collected from Containerisation International Yearbook (1998-2007).

In addition to throughput and the four inputs, we also include the trading volume between the EU and the rest of the world in the research as an exogenous variable. This information is collected from the World Trade Organization's International Trade Statistics. A summary of our variable specification is provided below in Table 8.

Table 8: Variable specification for port level data

Output	y	Annual throughput	TEU
Inputs	x_1	Berth Length	Metres
	x_2	Total terminal area	Square metres
	x_3	Storage	TEUs
	x_4	Handling Capacity	Tonnes
Exogenous factor	z_1	Trade volume	US dollars

Table 9: Descriptive statistics for port level data

Variable	y Annual throughput	x_1 Berth Length	x_2 Total terminal area	x_3 Storage	x_4 Handling Capacity	z_1 Trade volume ($bn)
Mean	621,970	1,857	489,054	27,232	416	6,830
Standard Deviation	759,366	1,479	540,504	108,381	360	1,820
Skewness	1.63	1.34	2.78	9.59	1.15	0.66
Range	3,259,724	8,919	4,564,350	1,199,990	1,933	5,120
Minimum	1,310	300	6,000	10	18	5,070
Maximum	3,261,034	9,219	4,570,350	1,200,000	1,951	10,200
Confidence Level (95.0%)	90,314	176	64,284	12,890	43	216

As we can observe, all six variables, one dependent, four independent and one exogenous, have positive skewness. The histograms of output y and input x_4, which produce the highest t-values among the four independent variables, are presented below in Figure 15. The horizontal axis is the value of the variable broken into intervals, whereas the vertical axis is the number (frequency) of observations belonging to certain intervals. We can see from Figure 15 that the observations in their original value concentrate on the left-hand side, and have a thin tail on the right-hand side, while the logged value of variables are distributed more evenly. The Cobb-Douglas and Translog forms, which we apply in this research, utilise the logged value of variables, so the importance of an evenly distributed series of observations across logged bin intervals can be seen.

Figure 15: Histograms of selected variables and their logged value histograms

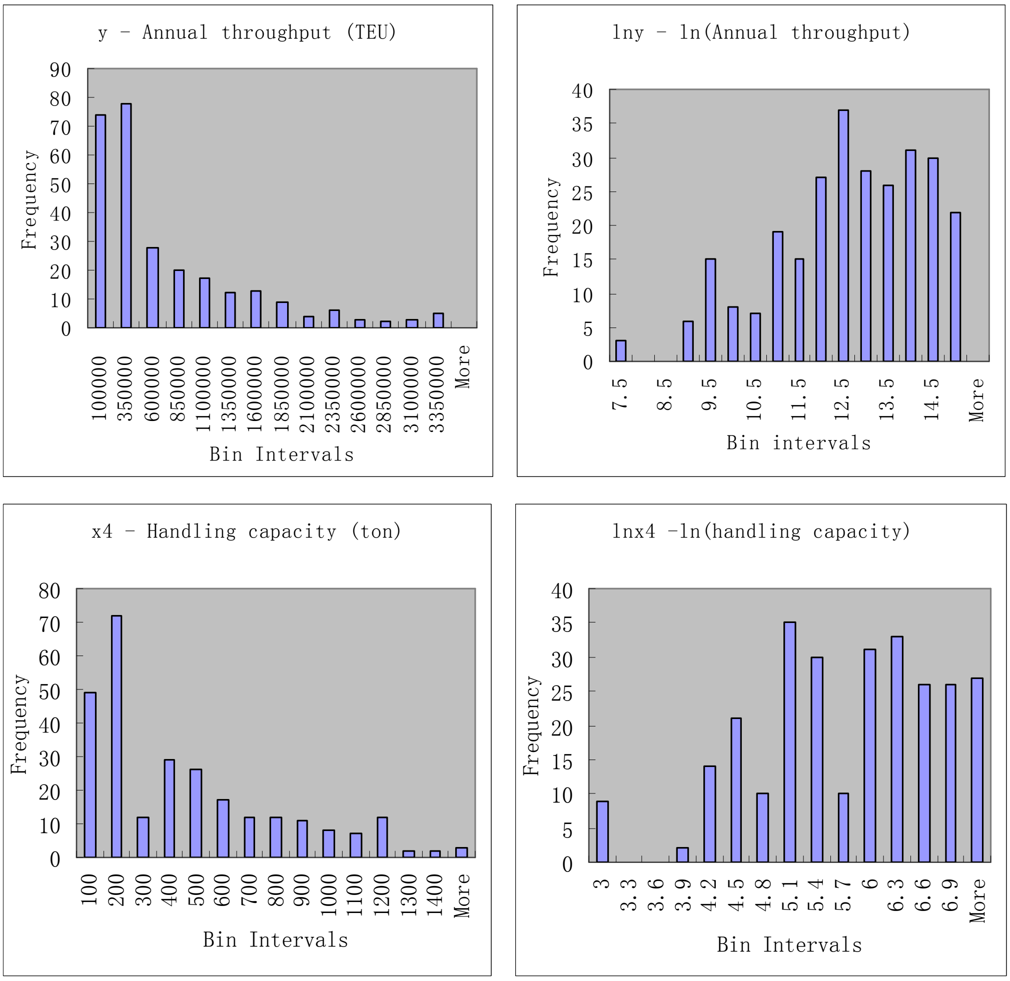


Table 10: Correlation between variables

	y	x_1	x_2	x_3	x_4	z_1
y	1					
x1	0.539551	1				
x2	0.519908	0.527151	1			
x3	0.122125	0.127548	0.202531	1		
x4	0.81555	0.596061	0.606651	0.07302	1	
z1	0.122736	0.068507	0.153407	-0.04966	0.142728	1

Table 11: R-squared values between variables

	y	x1	x2	x3	x4	z1
y	1					
x1	0.291115	1				
x2	0.270305	0.277889	1			
x3	0.014914	0.016268	0.041019	1		
x4	0.665121	0.355288	0.368026	0.005332	1	
z1	0.015064	0.004693	0.023534	0.002466	0.020371	1

The correlations between each two variables are displayed in Table 10 and the r-squared values are displayed in Table 11. The dependent and independent variables are reasonably correlated. For the four inputs with output, Handling Capacity (x4) has the highest correlation with throughput (output); whereas Storage (x3) has the lowest correlation with throughput; this finding suggests a relatively lower importance of container storage space to the efficient throughput of container traffic. Among the four inputs themselves, Berth Length (x1), Total terminal area (x2) and Handling Capacity (x4) are correlated to each other at ratio half. The exogenous variable, Trade volume (z1), does not have a strong correlation with output or input variables, which is surprising, because trade volume represents demand for container transport, and they were expected to be strongly related to output.

5.3 Model specification

Based on the variable specification and mathematical assumption, 11 models have been specified and estimated in this chapter Table 12 summarises the model specification.

Table 12: Models for port level efficiency analysis

Model specification / Factor parameters	Cobb-Douglas		Translog	
	Net effect model	*Gross* effect model	*Net* effect model	*Gross* effect model
	Truncated Normal B-C 1992	Truncated Normal B-C 1995	Truncated Normal B-C 1992	Truncated Normal B-C 1995
4 continuous inputs (basic model)	Model 1.1.1.3		Model 1.2.1.3	
4 continuous inputs, & time variable	Model 1.1.2.3		Model 1.2.2.3	
4 continuous inputs, & time variable trade volume	Model 1.1.3.3	Model 1.1.3.4	Model 1.2.3.3	Model 1.2.3.4
4 continuous inputs, & time variable, logged trade volume	Model 1.1.4.3		Model 1.2.4.3	Model 1.2.4.4

The four rows on the far left side in

Table 12Table 12 illustrate the different factor-parameters involved in the models. The first row of models with four physical inputs represents the basic models. The second row of models includes the time (trend) variable (T = 1, 2, … 9) in addition to the four inputs. The third and fourth rows of models include both the time and trade volume variable, in addition to the four inputs. In the third row the variable trading volume is in its natural unit and in the fourth row the trading volume variable is logged.

The rows in

Table 12Table 12 specify the variables involved in each model and the columns depict different mathematical assumptions about each model. The first category is the functional forms used for the deterministic part of the model, either Cobb-Douglas or Translog form. The second category is *net* effect and *gross* effect models. In the *net* effect model, the exogenous variables are in the deterministic part of the model and in the *gross* effect model, exogenous variables are in the random part. The difference between *net* and *gross* effect models shows how the exogenous factors affect the production technique and efficiency. In other words, the *net* effect model accounts for the impact of exogenous factors in the production technique, and consequently impacts on production efficiency, while the *gross* effect model accounts for the impact of exogenous factors into the production efficiency, but does not affect the production technique. The third assumption category in

Table 12Table 12 illustrates the distribution assumption imposed on the random term. Below is the breakdown of the model specification examples for both Cobb-Douglas and Translog for the deterministic part, along with two different error distribution assumptions.

Model 1.1.1.3 is specified as:

$$\begin{aligned} &\ln y^i{}_t = \alpha_0 + \sum_{n=1}^{4} \alpha_n \ln x^i{}_{nt} + v^i{}_t - u^i{}_t \\ &\mathrm{u}^{\mathrm{i}}{}_{\mathrm{t}} = \mathrm{u}^{i} \exp(-\eta(\mathrm{t}-9)) \\ &\mathrm{n} = 1, 2, \ldots 4 \\ &\mathrm{t} = 1, 2, \ldots 9 \end{aligned} \tag{5.1}$$

Where

$y^i{}_t$	is the output obtained by the i-th firms at the t-th time period;
$x^i{}_{nt}$	are the inputs by the i-th firms at the t-th time period, n = 1, 2, … 4;
α_0, α_n,	are the model parameters;
$v^i{}_t$	are the random errors and assumed i.i.d., $N(0, \sigma_v^2)$;
$u^i{}_t$	are non-negative random variables and assumed i.i.d., as truncations at zero of the $N(\mu^i, \sigma_u^2)$;
η	is a scalar parameter.

Model 1.2.3.4 is specified as:

$$\begin{aligned} &\ln y^i{}_t = \alpha_0 + \sum_{n=1}^{4} \alpha_n \ln x^i{}_{nt} + \frac{1}{2}\sum_{n=1}^{4}\sum_{m=1}^{4} \alpha_{nm} \ln x_{nt} \ln x_{mt} + \alpha_t T + v^i{}_{nt} - u^i{}_{nt} \\ &u^i{}_t \sim \mathrm{N}(\mathrm{m}^{\mathrm{i}}{}_{\mathrm{t}}, \sigma_{\mathrm{u}}{}^2) \qquad\qquad m^i{}_t = \delta_0 + z^i{}_t \delta_1 \end{aligned} \tag{5.2}$$

Where

$y^i{}_t$	is the output obtained by the i-th firms at the t-th time period;
$x^i{}_{nt}$ and $x^i{}_{mt}$	are the inputs by the i-th firms at the t-th time period, n, m = 1, 2, … 4;
T	is the trend variable, T= 1,2, … 9.
$z^i{}_t$	is the exogenous variable, trade volume;
α_0, α_n, α_{nm}, δ_0, and δ_1,	are the model parameters;

v^i_t are the random errors and assumed i.i.d., N(0, σ_v^2);

u^i_t are non-negative random variables and assumed i.i.d., as truncations at zero of the N (m^i_t, σ_u^2).

5.4 Estimation results

The technical and scale efficiency indices for each model is provided in Appendices 2- 12. However, we can begin the discussion of the model performance. Our analysis reveals that the Translog form is preferable to Cobb-Douglas for our port level data, according to the Log-likelihood Ratio (LR) test. The estimation result of the Cobb-Douglas models can be found in Appendix 1, but with regard to the Translog form, we observe that Table 13 demonstrates the estimation result of the six Translog models; the estimated values of parameters and their t-values are shown in brackets underneath.

Among the *net* effect models, Model 1.2.4.3, the basic model plus trend and logged trading volume variable, has the best fitness for this dataset. A noteworthy point is that the trend variable by itself does not improve model performance, but trend variable and trading volume together improve the model performance greatly. We can observe that the improvement of the likelihood value in Model 1.2.2.3, through the introduction of the time variable alone, is not worth the cost of the degree of freedom, but in Models 1.2.3.3 and 1.2.4.3, the likelihood value improved markedly after adding the trade volume variable. Therefore, the time variable and the trade volume variable together strengthen the explanatory power of the models.

For the *gross* models, Model 1.2.3.4 is preferred over Model 1.2.4.4, so for both net and gross effect models the variable specification of four inputs with the time variable and logged trade volume variable is preferable. When we compare the net and gross effect models, the net models perform much better in terms of the fitness of our data, according to the likelihood function value.

Table 13: Estimation results of port level Translog models by using FRONTIER 4.1 (Shading denotes gross models)

Model number	1.2.1.3	1.2.2.3	1.2.3.3	1.2.3.4	1.2.4.3	1.2.4.4
Intercept	**1.84** **(10.18)**	**1.83** **(10.04)**	**1.80** **(9.55)**	**1.60** **(40.51)**	**1.80** **(9.83)**	**1.21** **(11.10)**
Berth length	0.20 (1.58)	0.18 (1.35)	0.19 (1.40)	0.10 (1.29)	0.19 (1.38)	**0.38** **(3.72)**
Terminal area	-0.13 (1.46)	-0.14 (1.57)	**-0.18** **(1.99)**	**0.11** **(3.42)**	-0.17 (1.89)	0.14 (1.79)
Storage	0.01 (0.18)	0.00 (0.13)	0.01 (0.34)	0.00 (0.08)	0.01 (0.38)	0.05 (1.75)
Handling capacity	**0.52** **(6.00)**	**0.54** **(6.02)**	**0.56** **(6.17)**	**1.05** **(31.25)**	**0.56** **(6.32)**	**0.64** **(7.29)**
(Berth length)(Terminal area)	0.14 (1.67)	0.14 (1.64)	0.12 (1.49)	**-0.07** **(12.17)**	0.12 (1.47)	-0.17 (1.89)
(Berth length)(Storage)	0.02 (0.35)	0.02 (0.43)	0.03 (0.63)	**0.09** **(6.51)**	0.03 (0.60)	0.06 (1.64)
(Berth length)(Handling capacity)	0.05 (0.35)	0.03 (0.20)	-0.06 (0.42)	**-0.20** **(8.13)**	-0.06 (0.42)	0.12 (0.87)
(Terminal area)(Storage)	**0.11** **(2.67)**	**0.12** **(2.70)**	**0.13** **(3.25)**	**0.02** **(2.17)**	**0.13** **(3.19)**	-0.04 (1.17)
(Terminal area)(Handling capacity)	0.01 (0.12)	0.03 (0.35)	0.11 (1.14)	**0.65** **(116.50)**	0.11 (1.20)	**0.36** **(3.67)**
(Storage)(Handling capacity)	0.05 (1.27)	0.04 (1.11)	0.02 (0.64)	**-0.09** **(3.71)**	0.02 (0.64)	-0.01 (0.30)
1/2(Berth length)^2	-0.35 (1.27)	-0.27 (0.87)	-0.08 (0.28)	**0.45** **(3.76)**	-0.08 (0.28)	-0.19 (0.82)
1/2(Terminal area)^2	**-0.36** **(3.03)**	**-0.40** **(2.97)**	**-0.49** **(3.77)**	**-0.74** **(11.76)**	**-0.49** **(3.74)**	**-0.36** **(3.37)**
1/2(Storage)^2	**-0.06** **(3.07)**	**-0.06** **(3.11)**	**-0.06** **(3.37)**	**0.02** **(2.51)**	**-0.06** **(3.24)**	0.03 (1.88)
1/2(Handling capacity)^2	-0.19 (1.05)	-0.17 (0.93)	-0.14 (0.81)	-0.06 (0.72)	-0.14 (0.81)	-0.25 (1.38)
Europe Trading Volume (z or logged z)			**0.00** **(2.72)**	**-0.00** **(7.73)**	**1.01** **(2.95)**	-1.78 (1.61)
Trend		-0.01 (0.58)	**-0.10** **(2.60)**	**-0.18** **(16.65)**	**-0.12** **(2.93)**	-0.02 (1.43)
sigma-squared (σ^2)	6.33 (0.73)	5.76 (0.80)	4.89 (0.85)	**1.92** **(149.91)**	4.84 (0.87)	12.17 (1.33)
Gamma(γ)	**0.97** **(24.88)**	**0.97** **(25.07)**	**0.96** **(23.13)**	**1.00** **(857899.60)**	**0.96** **(23.49)**	**0.99** **(195.46)**
Mu(μ) or intercept of z	-2.73 (0.39)	-2.41 (0.41)	-1.90 (0.39)	**4.97** **(9.36)**	-1.86 (0.39)	43.22 (1.62)
Eta(η)	**0.04** **(6.45)**	0.05 (4.27)	0.05 (4.52)		0.06 (4.80)	
log likelihood function	-215.5488	-215.3798	-211.8514	-354.8292	-211.2890	-360.5937

Stochastic part of the model

In the *net* effect models μ is the mean of the normal distribution, which is truncated to Half Normal distribution to represent inefficiency. If μ equals 0, the inefficiency is Half Normal distributed. If μ does not equal 0, the distribution of inefficiency term is shifted Half Normal distribution. For all the *net* effect models, the μs are not significant, which indicates that the net models can be adequately specified with a Half Normal distribution rather than a Truncated Normal distribution. η is the parameter related to time; if η equals 0, the model is a time invariant model, which means that the technical efficiency level of a port stays the same over time. The ηs are positive and significant at the 95% significance level (see Table 13), indicating slow but stable technical efficiency improvement over time.

In the *gross* effect models the function of the exogenous variable z decides the mean of the associated normal distribution for inefficiency, which is equivalent to the function of μ and η in the *net* effect models. The intercept and the parameter of exogenous variable z are both significant in Models 1.2.3.4 and 1.2.4.4. The parameter of z has negative values in both models, indicating that the increase of trading volume reduces inefficiency.

In both *net* effect and *gross* effect models γ depicts the relationship between the standard deviation of the two error terms *u* (inefficiency) and *v* (random error). As stated above, $\gamma = \sigma_u^2/(\sigma_v^2+\sigma_u^2)$. If γ is close to zero, it indicates that the deviations from the frontier are due mostly to noise. If γ is close to one, it indicates that the deviations are due mostly to technical inefficiency. In all six models, γ is close to 1, meaning that inefficiency dominates the overall error. This suggests that a 'deterministic' frontier might be adequate to describe the production technique. Deterministic frontier here means that the model only contains one random term, the inefficiency term, but does not have the statistic noise term. If the models we have estimated include a very small proportion of deviation from the frontier, this deviation is due to the statistic noise, and it is worthwhile to see if the Deterministic model with fewer parameters can have better model performance.

Trend variable

The trend variable is different from the time-related variable η in the random part of the model. The trend variable represents the annual percentage change in output due to technological change over time. η, on the other hand, represents the technical efficiency changes over time. It is common to expect a technique improvement (positive sign) in any industry over time. In the port industry, this can be expected to have been driven over time by new container handling techniques. However, surprisingly, the signs of the trend variable in all the models in this study are negative. There are several factors which may contribute to the negative trend, of which the most important of these is overcapacity.

Overcapacity is frequently designed into the productive infrastructure specified for its core operation, but is also one of the practices firms use in order to prevent new entrants into the market. In many industries firms keep excess capacity for production or service in relation to the level of demand. In the port industry, however, excess capacity plays a more crucial role; productive headroom not only attracts more traffic to the port, but is also a signal of its reliability, a crucially important factor for port users. Hence, overcapacity is a common and necessary characteristic of players in the port industry. With the ever-growing trading volume and volatile market, a bigger capacity reservation is a rational strategy. The growing proportion of excess capacity is reflected by the 'negative' technique change in the infrastructure efficiency.

The second factor which may contribute to the 'negative' technique change is the relationship between the investment and traffic growth (adjustment to the demand). In rapidly developing countries such as China, the traffic growth rate is high, which means that newly-invested capacity will be fulfilled almost immediately. In developed regions such as Europe, the traffic growth rate is low, taking longer to fulfill the newly-invested facility. The North Mediterranean case implies that investment comes first and traffic growth follows. If we consider the relationship between the investment and traffic growth the other way around, traffic growth in developed regions is easier to predict and plan for: growth is usually stable; but in emerging economies the prediction is problematical. Hence, it is easy to have over-investment and under-investment. We can observe that investment and traffic growth are two interactive factors. In emerging economies, container port capacity needs to match the fast growing demand, so traffic growth leads ports' capacity, whereas in developed economies, such as the North Mediterranean Sea area, investment in port capacity leads to traffic growth. In this region it is difficult to attract new lines or new traffic to ports unless spare capacity already exists. Hence, a negative annual percentage change in container port output due to technological change over time is reasonable in the North Mediterranean Sea area.

Other issues which may affect port infrastructure efficiency and may cause a negative technique change include:

·Hub-and-spoke network: the size of vessel handled in hub ports and spoke ports is largely different; hub ports usually handle both large and small vessels with a high volume of container traffic, while spoke ports handle mainly small vessels with a relatively low volume of container traffic. Hub ports require greater space to accommodate different size vessels, which may indicate inefficiency within port operations.

·Dedicated berth/terminal: in an attempt to 'lock in' some shipping lines with extended contracts to increase revenue predictability and avoid volatility associated with spot trade, ports may agree to dedicated berths/terminals and build excess capacity for preferred customers. This business optimisation strategy may have the effect of driving utilisation down over time.

·Transshipment traffic: Gateway traffic is ship-port-land traffic; transshipment traffic is ship-port-ship traffic. Handling gateway traffic requires various kinds of port space. Transshipment traffic, however, uses only part of the terminal space, the usage of quay side is high, and the usage of gate side is low. Thus, a port with a high proportion of transshipment traffic does not have a very high technical efficiency score for its overall infrastructure performance. Therefore, an increase in the amount of transshipment traffic could contribute to a decrease in port efficiency.

·Ownership of the port: when the public sector owns a port, it tends to provide facilities ahead of time. Conversely, the private sector tends to utilise every possible space, and investment cycle trends are shorter and more frequent. Different investment cycles and strategies would affect port productivity and efficiency.

Exogenous factors

Factors not under the control of firms but that nevertheless influence the production are considered to be exogenous factors. For the container port industry the prevailing level of global trade is such a factor. It can be considered as either endogenous or exogenous to the product activity, depending on the purpose of the research. In this research we apply both assumptions to separate models. The data used to represent trading volume is the trade between Europe and the rest of the world in millions of U.S. dollars. Our data source is the World Trade Organization (WTO).

Models 1.2.3.3 and 1.2.4.3 are *net* effect models in which the exogenous variable, trading volume, is in the deterministic (systematic) part of the model. For this model, trading volume is treated as an input, although it is not an input influenced by the port. The rationale and assumption of using *net* effect models is that ports have built the knowledge and technology of how to tackle volatile markets, so the market condition is considered as an internal factor to their decision-making and hence does not influence efficiency directly. Models 1.2.3.4 and 1.2.4.4 are the *gross* effect models, in which trading volume is the random part of the model. Therefore, in this model the market condition is considered to affect the efficiency of ports directly (hence exogenously), but not affect productivity. The assumption of using *gross* effect models is that the trading condition is unstable and unpredictable; therefore, ports could not build this knowledge into their production technology.

We have used both types of model in this research in order to understand the effect of exogenous factors on the port industry, rather than reach a conclusion about which assumption is true. Very different technical efficiency indices are generated by the two kinds of model. The *net* effect models generate a stable technical efficiency growth situation for every port (see Table 14), while the *gross* effect models generate a very irregular pattern of efficiency index (see Table 15). One may question the steady efficiency growth pattern illustrated in the *net* effect Models 1.2.3.3 and 1.2.4.3 (see Appendix 9 and Appendix 10), which appears as extremely steady growth for the whole study period. The trading volume is ever-growing over time, so may this growth be due entirely to the increasing trading volume? The answer is no. Let us turn to Models 1.2.1.3 and 1.2.2.3, which are also *net* effect models; these do not include the trade volume variable, however, their technical efficiency indexes are in the same growth pattern as Models 1.2.3.3 and 1.2.4.3, which includes the trade volume variable. This indicates that the technical efficiency growth is real rather than nominal. The difference between technical efficiency indices generated by Models 1.2.4.3 and 1.2.4.4 indicates that the trade volume (traffic demand) plays a significant role in infrastructure technical efficiency. This result suggests that how to tackle the environmentally observed trade conditions factor is a crucial question for port operators. In the next section the efficiency indices will be discussed in detail.

Production elasticities

Partial production elasticity indicates the percentage change of the output when changing one percent of that particular input, *ceteris paribus*. Parameters of inputs are related to the production elasticities, although they usually cannot be directly interpreted as the elasticity. We have standardised the data to their geometric means by inputs. By doing so, the first-order parameters in the Translog function can now be directly interpreted as estimates of the production elasticities. Owing to the performance advantages of model 1.2.3.4 using the Translog form, this is assumed to best represent reality, and its parameter estimates form the basis of this discussion.

In the *gross* effect Model 1.2.3.4, almost all parameters are significant (see Table 13). The elasticity we discuss here is a point elasticity, which is different at each point on the production curve. As we standardise the variables to their sample means, the point elasticities of discussion are at the geometric means of: output 232,133 TEU; Berth Length 1,357m; Total Terminal area 263,694 m^2; Storage 2,808 TEU; and Handling Capacity 268.5 tonnes. We recognise that among the four inputs, Handling Capacity most affects the output; 1% of handling capacity increase (2.7 tonnes) can raise the output by 1.05% in TEU (about 2,500 TEU). Berth length and Terminal area have moderate effects on the output. 1% of the Berth length increase (14m) or an increase of 1% of the terminal area (2,637 m^2) will increase output by 0.1%, about 230 TEU. Storage has very little effect on the TEU, and this parameter is not significant. With this information we can conclude that, in general, expanding the handling capacity should be an investment priority.

The technical efficiency index

The technical efficiency indices generated from all our models can be found in the Appendices. The efficiency value is between 0 and 1, with 1 being the most efficient. The smaller the number, the lower the efficiency.

While among the four *net* effects models Model 1.2.4.3 has the best mathematical performance, the technical efficiency indices generated by the four models are almost identical (see Appendix 7, Appendix 8, Appendix 9 and Appendix 10), so we are able to focus our discussion of *net* effects models on Model 1.2.4.3. In the *net* effects model index (from Model 1.2.4.3., see Table 14), regardless of port size (see Figure 13 for port throughput) and efficiency level, the technical efficiency improves over time for all ports. Among them, the four ports with very high technical efficiency levels are, Algeciras, Barcelona, Gioia Tauro, and Piraeus. Among them, Piraeus is a medium sized port with about 1.5 million TEU throughput in 2006, while the other three ports are all large ports with more than 2.5 million TEU throughput in 2006. The implication here is that large ports seem better able to tackle the volatile market conditions than smaller ports.

Table 14: Representative ports' technical efficiency from the *net* effect model (1.2.4.3)

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.88	0.88	0.89	0.90	0.90	0.91	0.91	0.91	0.92
Alicante	0.17	0.19	0.21	0.23	0.24	0.26	0.28	0.30	0.32
Antalya	no	no	no	no	no	no	0.02	0.03	0.03
Bar	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.09
Barcelona	0.87	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.91
Bari	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02
Cadiz	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.12
Cagliari	no	no	no	0.25	0.26	0.28	0.30	0.32	0.34
Cartagena	0.15	0.17	0.18	0.20	0.22	0.24	0.26	0.28	0.29
Genoa	0.59	0.60	0.62	0.64	0.65	0.67	0.68	0.69	0.71
Gioia Tauro	0.84	0.85	0.85	0.86	0.87	0.87	0.88	0.89	0.89
Izmir	0.69	0.71	0.72	0.73	0.74	no	0.77	0.78	0.79
Koper	0.12	0.14	0.15	0.17	0.18	0.20	0.22	0.24	0.26
La Spezia	0.55	0.56	0.58	0.60	0.62	0.63	0.65	0.66	0.68
Leghorn	0.18	0.20	0.21	0.23	0.25	0.27	0.29	0.31	0.33
Marsaxlokk	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.55	0.57
Marseilles	0.34	0.36	0.38	0.40	0.42	0.44	0.45	0.47	0.49
Mersin	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.41
Naples	0.37	0.39	0.41	0.43	0.45	0.47	0.49	0.51	0.52
Piraeus	0.81	0.82	0.83	0.84	0.84	0.85	0.86	0.87	0.87
Ravenna	0.07	0.08	0.09	0.11	0.12	0.13	0.15	0.17	0.18
Rijeka	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.07
Salerno	0.23	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39
Sete	0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07
Seville	0.63	0.65	0.66	0.68	0.69	0.71	0.72	0.73	0.74
Taranto	no	no	no	no	0.41	0.43	0.45	0.47	0.49
Tarragona	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.10	0.11
Thessaloniki	0.21	0.23	0.25	0.27	0.29	0.31	0.33	0.35	0.37
Trieste	0.05	0.06	0.07	0.08	0.09	0.10	0.12	0.13	0.15
Valencia	0.58	0.60	0.61	0.63	0.65	0.66	0.67	0.69	0.70
Valletta	0.35	0.37	0.39	0.41	0.43	0.45	0.47	0.49	0.51
Venice	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.41

The technical efficiency (TE) indices (see original result table in Appendix 11) generated by the *gross* effects models (from Model 1.2.3.4) do not show a clear pattern as do the TE indices generated by the *net* effects models. The efficiency level for the same ports does not always grow over time. For example, port Izmir has a technical efficiency reduction in 2000 and 2001, from value 1 in 1999 it drops to 0.12 in 2001. Port La Spezia has a technical efficiency drop in 2003, from value 0.98 to 0.52. Port Gioia Tauro has a technical efficiency drop in 1999, from value 0.99 to 0.14. For those ports, the technical efficiency suddenly drops in some years and then grows gradually year on year. By checking the infrastructure information during the years when technical efficiency drops, we can discover an interesting relationship between investment and infrastructure efficiency: efficiency drops after investment in infrastructure is made.

It is not difficult to explain the apparent technical efficiency reduction after investment. When traffic through the port nearly reaches capacity, or the use of the facility is high, infrastructure efficiency is also high. When the port invests in infrastructure and facilities, capacity increases, so the utilisation of the facility drops until the slack is taken up, thus infrastructure efficiency temporarily declines. The demand placed by traffic passing through the port is ever-growing, so the utilisation of port infrastructure and facilities also grows to meet the increased capacity. Therefore, the infrastructure efficiency improves until the port once again invests in infrastructure and facilities.

In Table 15 we notice that not all ports experience the steady efficiency growth pattern as they do in Table 14. Here we can classify the technical efficiency patterns observed into three groups: a) *Ports with steady growth efficiency*: ports where technical efficiency grows steadily during the study period; b) *Ports with investment during the study period*: ports where technical efficiency grows steadily when no major investment occurs, whereas when investment occurs, infrastructure efficiency declines sharply in that year; and c) *Ports with an irregular efficiency pattern*: ports where technical efficiency grows but follows a non-obvious growth pattern.

Table 15: Representative ports' technical efficiency from the gross effect model (1.2.3.4)

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
a) Ports with steady growth efficiency									
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.04	0.07	0.11
Cadiz	0.02	0.02	0.04	0.05	0.06	0.11	0.10	0.14	0.19
Cagliari	N/A	N/A	N/A	0.14	0.18	0.20	0.38	0.37	0.75
Koper	0.06	0.08	0.11	0.14	0.21	0.27	0.40	0.56	0.82
Marseilles	0.06	0.08	0.20	0.14	0.19	0.23	0.32	0.32	0.39
Naples	0.11	0.13	0.11	0.16	0.20	0.24	0.23	0.30	0.42
Rijeka	0.01	0.01	0.02	0.04	0.05	0.11	0.28	0.25	0.37
Seville	0.12	0.16	0.24	0.31	0.38	0.46	0.60	0.74	0.95
Taranto	N/A	N/A	N/A	N/A	0.27	0.34	0.37	0.34	0.50
Thessaloniki	0.23	0.16	0.21	0.25	0.30	0.42	0.63	0.81	1.00
Trieste	0.02	0.06	0.03	0.05	0.05	0.05	0.09	0.13	0.17
Valencia	0.18	0.30	0.14	0.24	0.28	0.28	0.28	0.39	0.59
Valletta	0.14	0.17	0.21	0.21	0.28	0.36	0.52	0.66	0.62
Venice	0.15	0.17	0.21	0.29	0.38	0.49	0.60	0.72	0.75
Sete	0.02	0.03	0.02	0.02	0.03	0.03	0.40	0.72	1.00
b) Ports with investment during the study period									
Alicante	0.87	0.12	0.21	0.30	0.35	0.45	0.57	0.49	0.64
Genoa	0.11	0.14	0.35	0.37	0.14	0.17	0.25	0.62	0.91
Gioia Tauro	0.99	0.14	0.19	0.22	0.31	0.40	0.34	0.42	0.44
Izmir	0.75	1.00	0.54	0.12	0.23	N/A	0.56	0.66	0.85
La Spezia	0.22	0.28	0.42	0.66	0.79	0.98	0.52	0.79	0.77
Piraeus	0.40	0.97	0.28	0.29	0.52	0.72	0.83	0.69	0.83
Salerno	0.18	0.23	0.43	0.47	0.76	1.00	0.42	0.72	0.75
c) Ports with an irregular efficiency pattern									
Algeciras	0.34	0.79	0.19	0.33	0.41	0.57	0.76	0.98	0.82
Bar	0.04	0.02	0.04	0.03	0.06	0.06	0.10	0.14	0.23
Barcelona	0.11	0.09	0.11	0.13	0.17	0.22	0.28	0.25	0.18
Bari	0.06	0.00	0.00	0.00	0.02	0.05	0.05	0.03	0.04
Cartagena	0.50	0.63	0.11	0.06	0.09	0.11	0.08	0.13	0.17
Leghorn	0.09	0.09	0.07	0.09	0.11	0.22	0.14	0.14	0.17
Marsaxlokk	0.35	0.18	0.13	0.20	0.26	0.26	0.30	0.36	0.52
Mersin	0.49	0.61	0.31	0.09	0.21	0.11	0.57	0.76	0.99
Ravenna	0.12	0.07	0.06	0.17	0.02	0.25	0.32	0.39	0.44
Tarragona	0.02	0.04	0.05	0.05	0.44	0.57	0.31	0.13	0.21

We already understand that ports in group b) have received major infrastructure investment during the year their technical efficiency drops. After having examined the ports in group a) and c), we found that these ports have also undergone infrastructure expansion during the study period. We derive that the amount of capacity expansion due to investment is smaller than the growth of demand, so on the technical efficiency index there is no technical efficiency drop after the investment, but it nevertheless shows increasing technical efficiency. Therefore, we can observe that group a) and b) use different investment strategies: Group a's investment strategy is more moderate and Group b's investment strategy is more aggressive. The aggressive investment strategy moves ahead of demand or even generates further demand in future years, while the moderate investment strategy follows and fulfills demand. The balance between investment in port capacity and demand can be shown by comparing the two groups; for ports in Group a, demand exceeds investment and for ports in Group b, investment exceeds demand.

As mentioned earlier, from the mathematical point of view, the *net* effect model is a better fit than the *gross* effect model in so far as our data according to the likelihood function value is concerned. From an empirical point of view, both models provide valuable analytical insights, and the difference of the technical efficiency indices between the two models indicates the importance of the exogenous factor, trade volume, in the port efficiency. From the theoretical point of view, the *gross* effect models are more sensitive to investment shocks than the *net* effect models, which allows us to highlight the effects of investment on efficiency.

The scale efficiency index

As with the technical efficiency index, the scale efficiency value is between 0 and 1, value 1 being most efficient. The smaller the number, the lower the efficiency. The scale efficiency index is only calculated for Model 1.2.1.3. As we stated in Chapter 4, Cobb-Douglas cannot calculate scale efficiency due to its mathematical features. However, the Translog form can calculate the scale efficiency when there is no exogenous variable in the deterministic part of the model. Therefore, only the basic Model 1.2.1.3 could be used to evaluate scale efficiency thereby casting further light on some of the favourable technical efficiency results seen earlier in relation to larger ports.

Table 16: Representative ports' scale efficiency from the gross effect model (1.2.3.4)

Port Name	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Algeciras	0.56	0.62	0.61	0.56	0.56	0.56	0.63	0.63	0.55
Alicante	0.25	0.10	0.11	0.11	0.10	0.10	0.10	0.08	0.08
Antalya	n/a	n/a	n/a	n/a	n/a	n/a	0.92	0.92	0.92
Bar	1.00	0.79	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Barcelona	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.08	0.27
Bari	0.58	0.94	0.94	1.00	0.93	0.93	0.93	0.94	0.94
Cadiz	0.30	0.30	0.30	0.30	0.31	0.31	0.31	0.31	0.31
Cagliari	n/a	n/a	n/a	0.83	0.83	0.85	0.85	0.82	0.85
Cartagena	0.18	0.18	0.12	0.11	0.11	0.11	0.11	0.11	0.11
Genoa	0.52	0.53	0.60	0.99	0.40	0.40	0.41	0.40	0.21
Gioia Tauro	0.85	0.53	0.53	0.53	0.53	0.53	0.58	0.58	0.59
Izmir	0.94	0.94	0.93	0.62	0.62	n/a	0.63	0.63	0.63
Koper	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
La Spezia	0.92	0.91	0.92	0.94	0.94	0.94	0.85	0.88	0.76
Leghorn	0.60	0.60	0.93	0.93	0.93	0.95	0.92	0.70	0.69
Marsaxlokk	0.80	0.59	0.57	0.56	0.56	0.55	0.54	0.55	0.55
Marseilles	0.29	0.29	0.33	0.30	0.30	0.30	0.30	0.29	0.29
Mersin	0.63	0.63	0.60	0.51	0.51	0.45	0.53	0.53	0.53
Naples	0.15	0.15	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Piraeus	0.11	0.14	1.00	1.00	0.63	0.63	0.63	0.61	0.61
Ravenna	0.92	0.78	0.75	0.83	0.83	0.83	0.83	0.83	0.83
Rijeka	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97
Salerno	0.13	0.13	0.17	0.17	0.17	0.17	0.10	0.11	0.11
Sete	0.42	0.42	0.34	0.34	0.34	0.34	0.34	0.26	0.26
Seville	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Taranto	n/a	n/a	n/a	n/a	0.89	0.84	0.80	0.78	0.78
Tarragona	0.99	0.99	0.99	0.97	0.99	0.99	0.99	0.99	0.99
Thessaloniki	0.97	0.93	0.93	0.93	0.83	0.90	0.96	0.92	0.92
Trieste	0.51	0.78	0.48	0.73	0.73	0.70	0.68	0.74	0.74
Valencia	0.73	0.70	0.50	0.59	0.53	0.58	0.58	0.55	0.53
Valletta	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Venice	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The pattern of scale efficiency indices is very different from that of the technical efficiency results. The scale efficiency change indicates that investment has been applied during a given year, but investment can result in either higher or lower scale efficiency, and it is not at all related to time. A fully elaborated discussion of scale efficiency will be presented in the Chapters 7 and 8.

5.5 Conclusions

In this chapter we have analysed the port infrastructure efficiency of 32 ports in the Mediterranean Basin region, by using two types of models, the *net* effect and *gross* effect model. These two different models assess the impact of the exogenous factor (trading volume) via the production technology and the inefficiency of production, respectively. The two models generate very different technical efficiency indexes. From the net effect models we can observe very clear technical efficiency improvements over time, while the gross effect models allow us to identify short-term efficiency drops due to investments; from this we understand that the gross effect models are more sensitive to investment shocks. As previously discussed in this chapter, this difference of results of the efficiency indices between the *net* and *gross* effect models indicates that trading volume has a very strong influence on port infrastructure efficiency. In order to survive in erratic market conditions, ports need to enhance their ability to operate an investment-intensive asset under conditions of high trading volume volatility.

Although infrastructure efficiency improves over time in both models (when not considering the investment shock), the production technique trend is negative in both models, which means that the annual percentage change in output is slower than the technological change. There are a number of potential factors causing this negative trend among which the most important are overcapacity and adoption of over-aggressive investment strategies.

Two types of investment strategy, aggressive investment strategy and moderate investment strategy, have been identified. In an expanding market, in the short term, the aggressive strategy may actively generate demand, while the moderate strategy is consistent with ports simply following the market in order to fulfill demand. In the medium term an aggressive strategy with trend to migrate to a moderate one as the limits of available trade volume in the region are reached. In the long term (10-20 years, allowing the development of certain asset to complete) a port that has received significant investment may create its own incremental volume as industry decides to locate around it for their own logistics needs.

When investment is being considered, container handling equipment should be prioritised, since this has a greater impact on port throughput than the other infrastructure facilities, although it is recognised that this conclusion does not take into account the relative cost of additional units of each resource. Therefore, one unit of container handling equipment provides a greater volume impact on port throughput than any other port resource. Any investment decision would of course take into account the size and divisibility of each unit, as well as its cost, lifetime and other economic factors.

The drawback of this analysis is that the data and analysis are conducted at the port level. The operation and management of the port industry is moving towards the terminal level, due to a surge in the number of global terminal operators. To address this trend, in the next chapter we carry out a terminal level analysis, which allows for a better understanding of the interaction between shippers and shipping lines.

Chapter 6: Efficiency analysis at the terminal level

6.1 Introduction

In the last chapter we have examined the efficiency of 32 Mediterranean Sea container ports. In this chapter we evaluate efficiency at the terminal level. A container port can be regarded as the collection of its terminals in terms of physical requirements. However, the operational objectives of ports and terminals cannot be compared because the operating agents are different. In the past decade container terminal operators have stood out from container ports as a distinctive industry, due to the capital intensity and the specialised nature of container transport. The transshipment traffic comprises an increasing proportion of the total container traffic, which means that shipping lines and shippers sometimes choose terminals that give them good service rather than to call ports at any particular location. Hence, it is desirable to study the efficiency of container terminals.

Container terminal operators can be classified on the basis of ownership, geography or service scale. *Ownership* signifies that there are private and public sector operators. This classification is not always clear-cut, however, because private involvement within a port can concern the entire port, a certain port service, or a specific subset of port operations (Trotman-Dickenson, 1996).

The second classification is by *geography*; container terminal operators can be classified as local terminal operators and as global terminal operators. The container port/terminal was once a geopolitically sensitive industry as mentioned in Chapter 2, but nowadays the location of a port is less important than its ability to offer services and inland connections that fit into alliance networks (van Klink, 1995; Wiegmans, Ubbels, Rietveld and Nijkamp, 2002; Notteboom and Rodrigue, 2005). Moreover, institutional changes during the 1990s have rapidly internationalised the container terminal operating industry (Olivier, Parola, Slack and Wang, 2007). However, although the emergence of the global container terminal operator has generated great attention, literature on efficiency does not yet include the geographic factor.

The third classification, *service scale*, is comprised of carrier-operated terminals and pure terminal operators. The two types of terminal operators have, however, very different objectives. Carrier-operated terminals, also known as dedicated terminals within the literature, have been in operation by some shipping companies since the 1960s (Olivier, Parola, Slack and Wang, 2007). Carriers operate terminals in order to make their supply chain more robust. Terminal availability and the whole chain reliability is their operating priority; this in turn contributes to the profitability of the entire supply chain.

On the other hand, pure terminal operators do not concern themselves with vertical integration in the supply chain, but rather focus on the profitability of their own terminal operations. However, in reality, many terminals are owned by a consortium of terminal operators and/or shipping lines. Shipping lines often have a minority shareholding in a multi-user facility. It is therefore a challenging task to distinguish between pure terminal operator and carrier-operated terminal in empirical studies.

In the container port and terminal efficiency literature, ownership is the most studied factor. In this chapter we will examine terminal operator type (local or global operator) in particular, and examine how the management characteristics influence production and efficiency.

6.2 Data description

We examine 165 terminals of which 47 terminals are from the 30 Mediterranean Sea container ports we studied in the last chapter, and 118 are from the world's top 19 container ports by throughput in 2006.[5] There are two reasons that we include terminals from the world's top container ports. First, the operation of container terminal is an industry with only a few global players, so the benchmark should be set against a global standard, even though this research focuses on the Mediterranean Sea area. The second reason is to introduce more observations so that the estimation results become more robust.

It is important to note that the information from the 47 North Mediterranean Sea terminals in this chapter is not necessarily the same as the North Mediterranean Sea ports in the previous chapter; the data here is from the Drewry Container Ports & Logistics database. However, the Containerisation International Yearbook (data source for Chapter 5) is one of the sources for the Drewry Container Ports & Logistics database; we therefore consider the two data sources to be consistent. We have collected information on 165 terminals in year 2006, so the data is in line with the final year's panel data information in Chapter 5. Terminals in the 30 North Mediterranean Sea ports used in this chapter are listed in Table 17, and terminals from the top 20 container ports by throughput in 2006 are shown in Table 18.

[5] 32 Mediterranean Sea container ports were included in the last chapter, but ports Bari and Leghorn in Italy are not included in this chapter. 47 terminals used in this chapter are from the 30 Mediterranean Sea container ports, the rest of the terminals are from the world's top 19 container ports by throughput in 2006. These are from 19 ports, because terminal information on Port Tanjung Pelepas in Indonesia is not adequate.

Table 17: Mediterranean container ports in our database

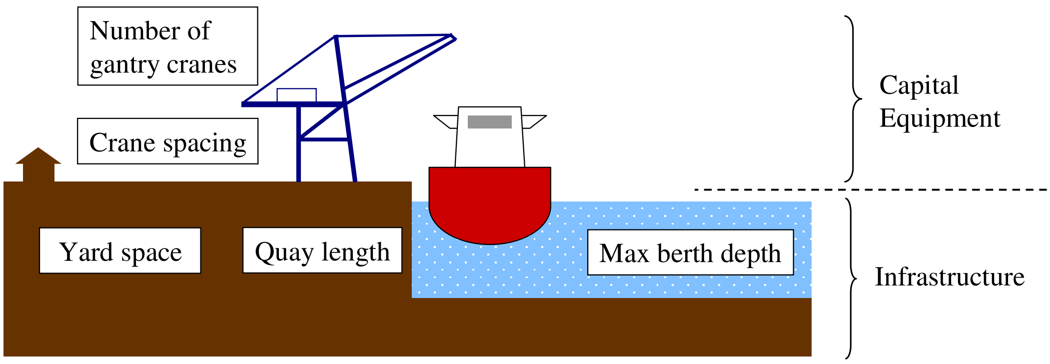
Country	Port	No. of terminals studied
CROATIA	RIJEKA	1
MONTENEGRO	BAR	1
SLOVENIA	KOPER (CAPODISTRIA)	1
FRANCE	MARSEILLES-FOS	2
FRANCE	SETE	1
GREECE	PIRAEUS	2
GREECE	THESSALONIKI	1
ITALY	CAGLIARI	1
ITALY	GENOA	3
ITALY	GIOIA TAURO	1
ITALY	LA SPEZIA	2
ITALY	NAPLES	2
ITALY	RAVENNA	2
ITALY	SALERNO	2
ITALY	TARANTO	1
ITALY	TRIESTE	1
ITALY	VENICE	2
MALTA	MARSAXLOKK	1
MALTA	VALETTA	1
SPAIN	ALGECIRAS	2
SPAIN	ALICANTE	1
SPAIN	BARCELONA	5
SPAIN	CADIZ	1
SPAIN	CARTAGENA (SPAIN)	1
SPAIN	SEVILLE	1
SPAIN	TARRAGONA	1
SPAIN	VALENCIA	4
TURKEY	ANTALYA	1
TURKEY	IZMIR	1
TURKEY	MERSIN	1

Table 18: 20 of the world's top container ports in throughput in 2006

Country	Port	No. of terminals studied
USA - E	NEW YORK	7
HONG KONG	HONG KONG	6
PRC	GUANGZHOU	2
PRC	NINGBO	3
PRC	QINGDAO	2
PRC	SHANGHAI	7
PRC	SHENZHEN	9
PRC	TIANJIN/XINGANG	4
S KOREA	BUSAN	9
TAIWAN	KAOHSIUNG	15
U A E	DUBAI	2
BELGIUM	ANTWERP	11
GERMANY	BREMERHAVEN	4
GERMANY	HAMBURG	6
NETHERLANDS	ROTTERDAM	9
MALAYSIA	PORT KELANG	2
SINGAPORE	SINGAPORE	6
USA - W	LONG BEACH	7
USA - W	LOS ANGELES	7

We have collected, for the 165 terminals, physical information on the maximum berth depth, quay length, yard space, crane spacing, and number of gantry cranes, as inputs. Maximum berth depth, Quay length and Yard space represent infrastructure; Crane spacing and Number of gantry cranes represent the equipment category.

Figure 16: Container terminal inputs information and their approximate representation



In addition to the five physical inputs, there are two operational characteristics: (1) terminal type, which is either container or multi-purpose terminal, and (2) operation type, which is either global terminal or local terminal operation. The output of terminals is throughput in terms of TEU, which is the same as the output of port level data in Chapter 4. Table 19 below summarises the considered variables in this chapter.

Table 19: Variable specification for terminal level data

Output	y	TEU	number	
Inputs	x_1	Max Berth Depth	metre	
	x_2	Quay Length	metre	
	x_3	Yard Space	hectare	
	x_4	Number of Gantry	number	
	x_5	Crane Spacing	metre	
Exogenous factors	z_1	Terminal Type	binary	0=container terminal 1=multi-purpose
	z_2	Operation Type	binary	0=global terminal 1=local terminal

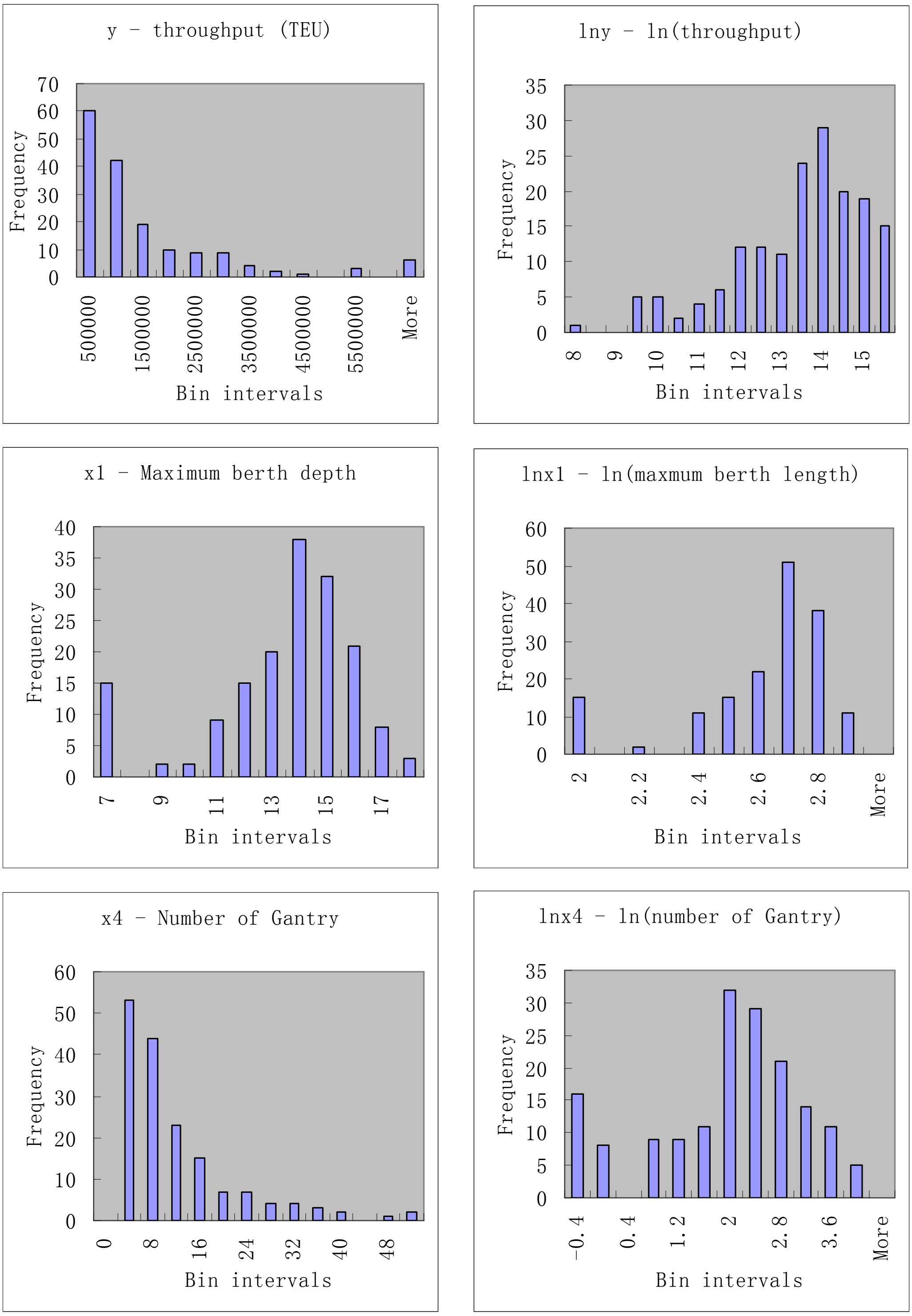
The descriptive statistics of the six continuous variables, one output and five inputs, is shown in Table 20. We can observe that Max Berth Depth has a negative skewness and the rest of the continuous variables have positive skewness, which means that relative to the overall range exhibited by the sample, most ports fall in the relatively smaller port size category, when measured by quay length, yard space, gantry cranes, and crane spacing. The distribution of berth depth exhibits the opposite characteristics, i.e. negative skewness, with only very few sample ports shallower than the median. The histograms of y (output), x1 (a negative skewed input) and x4 (a positively skewed input) are shown in Figure 17. The horizontal axis represents the value of the variable broken into intervals, the vertical axis indicates the number (frequency) of observations occurring within these certain intervals.

Table 20: Descriptive statistics of terminal level data

Variables	y	x_1	x_2	x_3	x_4	x_5
	Throughput	Max Berth Depth	Quay Length	Yard Space	Number of Gantry	Crane Spacing
Mean	1264682	13.24	1284.33	49.34	10.19	188.65
Standard Deviation	1548528	2.609	1171.277	43.264	10.087	213.995
Skewness	2.155	-1.072	4.432	1.757	1.790	5.389
Range	7686825	11.2	11142	234.8	51.5	1811
Minimum	2840	6.8	150	1.2	0.5	39
Maximum	7689665	18	11292	236	52	1850
Confidence Level(95.0%)	238035.6	0.4	180.0	6.7	1.6	32.9

The logged values of these three variables are also shown, because we use the functional forms Cobb-Douglas and Translog in this research, and both employ the natural log of the original value. We can observe that log changes positive skewness to negative and does not change the negative skewness very much.

Figure 17: Histograms of selected variables and their logged value histograms



As demonstrated in Chapter 5, by evaluating the logarithm of the continuous variables, this produces a negatively skewed distribution. Nevertheless, this is adequately distributed for use in Cobb-Douglas and Translog functional forms. In addition to the five continuous physical input variables, we include two exogenous variables on operational characteristics. How these two exogenous variables influence terminal efficiency and productivity is the focus of our analysis.

Factor 1: Terminal type

A port might handle three types of cargo: bulk, container and general cargo. Bulk cargo is unpacked homogeneous cargo, which is usually dropped or poured. Container cargo are heterogeneous goods which are moved in International Standard Organisation (ISO)-specified steel/aluminum boxes that can be lifted or rolled by equipment. General cargo constitutes the myriad of goods which are neither liquid nor bulk, nor containerisable. Container terminals specialise in handling containers only, whereas multi-purpose terminals can handle all three kinds of cargo. In this chapter we examine container terminals versus multi-purpose terminals. The estimated parameter on z_1 can be used to infer the incremental change of TEU output in moving from multi-purpose to container-only terminal of similar dimensions and equipment levels. Because the output TEU in this study measures only containerised cargo, we omit bulk and general cargo handled by multi-purpose terminals. Within this context, in the analysis we aim to test the following hypothesis: container terminals are more efficient than multi-purpose terminals, *ceteris paribus.*

Factor 2: Operation type

Container terminal operators can be classified as either local terminal or global terminal operators. Terminal operators who operate at more than one port are defined as global terminal operators. Our database is based on the Drewry regional classification (2006)：North America, North Europe, South Europe, Far East, South East Asia, Middle East, Caribbean, Central America, South America, Oceania, South Asia, Africa, and Eastern Europe. The estimated parameter on z_2 can be used to infer the incremental change of TEU output in moving from local to global terminal operator of similar dimensions and equipment levels. We assume that global terminal operators can share their experience of different ports in order to achieve an operating advantage and achieve higher efficiency. We therefore hypothesise that global container terminal operators are more efficient than local terminal operators, *ceteris paribus*.

Table 21: Correlation between the variables

	y	x1	x2	x3	x4	x5	z1	z2
y	1							
x1	0.311933	1						
x2	0.586325	0.266779	1					
x3	0.609693	0.252674	0.536385	1				
x4	0.871851	0.347002	0.661228	0.645013	1			
x5	-0.23602	-0.05224	0.094656	-0.08019	-0.28035	1		
z1	-0.33897	-0.39007	-0.14709	-0.25492	-0.35852	0.453724	1	
z2	-0.07795	-0.17212	-0.03954	-0.17774	-0.07387	0.019093	0.199248	1

Table 22: R-squared values between the variables

	y	x1	x2	x3	x4	x5	z1	z2
y	1							
x1	0.097302	1						
x2	0.343777	0.071171	1					
x3	0.371725	0.063844	0.287709	1				
x4	0.760124	0.12041	0.437222	0.416041	1			
x5	0.055703	0.002729	0.00896	0.00643	0.078597	1		
z1	0.114902	0.152155	0.021637	0.064983	0.128538	0.205865	1	
z2	0.006077	0.029624	0.001564	0.031591	0.005456	0.000365	0.0397	1

The correlations between each pair of variables are displayed in Table 21 and the r-squared values are displayed in Table 22. The dependent variables and independent variables are reasonably correlated. Quay Length (x2), Yard Space (x3) and Number of Gantry (x4) have relatively strong correlation with the throughput (y). Among the five input variables, Quay Length (x2), Yard Space (x3) and Number of Gantry (x4) are correlated to each other at ratio half, which is to be expected, given that aspects of terminal infrastructure and equipment increase broadly in proportion. The environmental factor, Operation Type, does not have a strong correlation with output or the other variables, which might be surprising, given that the global terminal operators may *a priori* be expected to be concentrated among the larger, better-equipped terminals.

There is one significant limitation of Drewry data is that the dataset only record the latest information of the ports and terminals, but do not record the change. Therefore no penal data is available for the analysis of time related effects.

6.3 Model specification

In order to analyse the impacts of terminal and operation type on terminal productivity and efficiency, we structure 22 different model specifications (see Table 23). The four rows in Table 23 illustrate the different factor-parameters involved in the models. The first row of models with five physical (continuous) inputs represents the basic models. The second and third rows of models include one management characteristic (binary variable), namely Terminal Type or Operation Type, respectively, in addition to the five physical inputs. The last row of models includes the five physical inputs as well as the two management characteristics.

Table 23: Summary of the models for terminal level efficiency analysis

Model specification / Factor parameters	Cobb-Douglas			Translog		
	Net effect model		*Gross* effect model	*Net* effect model		*Gross* effect model
	Half Normal	Truncated Normal	Truncated Normal	Half Normal	Truncated Normal	Truncated Normal
5 continuous inputs (basic model)	Model 2.1.1.1	Model 2.1.1.2		Model 2.2.1.1	Model 2.2.1.2	
5 continuous inputs, and terminal type	Model 2.1.2.1	Model 2.1.2.2	Model 2.1.2.4	Model 2.2.2.1	Model 2.2.2.2	Model 2.2.2.4
5 continuous inputs, and operation type	Model 2.1.3.1	Model 2.1.3.2	Model 2.1.3.4	Model 2.2.3.1	Model 2.2.3.2	Model 2.2.3.4
5 continuous inputs, terminal type, and operation type	Model 2.1.4.1	Model 2.1.4.2	Model 2.1.4.4	Model 2.2.4.1	Model 2.2.4.2	Model 2.2.4.4

The rows in Table 23 specify the variables involved in each model, and the columns depict different assumptions about each model. The first assumption category is the functional form used for the deterministic part of the model. We consider two forms:

Cobb-Douglas and Translog. The second category is *net* effect and *gross* effect models, which is the same as the model specification used in Chapter 4. The *net* effect model accounts for the impact of exogenous factors in the production technique, and consequently impacts on production efficiency, while the *gross* effect model accounts for the impact of exogenous factors on the production efficiency, but does not affect the production technique. The third assumption category in Table 23 illustrates the distribution assumption imposed on the random term. Below are the model specification examples for both Cobb-Douglas and Translog for the deterministic part, and three different error distribution assumptions.

Model 2.1.4.1 is specified as

$$\ln y^i = \alpha_0 + \sum_{n=1}^{5} \alpha_n \ln x^i{}_n + \delta_1 z^i{}_1 + \delta_2 z^i{}_2 + v^i - u^i \quad \text{n = 1, 2, … 5.} \tag{1}$$

Where

$y^i{}_t$	is the output obtained by the i-th firm at the t-th time period;
$x^i{}_{nt}$ and $x^i{}_{mt}$	are the inputs by the i-th firms at the t-th time period, n, m = 1, 2, … 4;
$z^i{}_1$ and $z^i{}_2$	are the exogenous variables of the i-th firm;
α_0, α_n, δ_1, and δ_2	are the model parameters;
v^i	are the random errors and assumed i.i.d., $N(0, \sigma_v^2)$;
u^i	are non-negative random variables and assumed i.i.d., $\lvert N(0, \sigma_u^2)\rvert$;

Model 2.2.4.2 is specified as

$$\begin{aligned} &\ln y^i{}_t = \alpha_0 + \sum_{n=1}^{5} \alpha_n \ln x^i{}_{nt} + \frac{1}{2}\sum_{n=1}^{5}\sum_{m=1}^{5} \alpha_{nm} \ln x^i{}_{nt} \ln x^i{}_{mt} + \delta_1 z^i{}_1 + \delta_2 z^i{}_2 + v^i{}_t - u^i{}_t \\ &\mathrm{u}^i{}_t = \mathrm{u}^i \exp(-\eta(\mathrm{t} - \mathrm{T})) \\ &\mathrm{n, m} = 1, 2, \ldots 5 \\ &\mathrm{t} = 1, 2, \ldots \mathrm{T} \end{aligned} \tag{2}$$

Where

y^i_t	is the output obtained by the i-th firm at the t-th time period;
x^i_{nt} and x^i_{mt}	are the inputs by the i-th firms at the t-th time period, n, m = 1, 2, … 5;
z^i_1 and z^i_2	are the exogenous variables of the i-th firm;
α_0, α_n, α_{nm}, δ_1, and δ_2	are the model parameters;
v^i_t	are the random errors and assumed i.i.d., $N(0, \sigma_v^2)$;
u^i_t	are non-negative random variables and assumed i.i.d., as truncations at zero of the $N(\mu^i, \sigma_u^2)$;
η	is a scalar parameter;
t = T = 1	since we consider cross-sectional data for the year 2006.

Model 2.2.4.4 is specified as

$$\begin{aligned}
&\ln y_t = \alpha_0 + \sum_{n=1}^{5} \alpha_n \ln x_{nt} + \frac{1}{2}\sum_{n=1}^{5}\sum_{m=1}^{5} \alpha_{nm} \ln x_{nt} \ln x_{mt} + v_{nt} - u_{nt} \\
&u_{nt} \sim \mathrm{N}(\mathrm{m}_{\mathrm{nt}}, \sigma_{\mathrm{u}}^{2}) \\
&m_{nt} = \delta_0 + z_1\delta_1 + z_2\delta_2 \\
&n, m = 1,2,...5 \\
&t = 1,2,..T
\end{aligned} \tag{3}$$

Where

y^i_t	is the output obtained by the i-th firm at the t-th time period;
x^i_{nt} and x^i_{mt}	are the inputs by the i-th firms at the t-th time period, n, m = 1, 2, … 5;
z^i_1 and z^i_2	are the exogenous variables of the i-th firm;
α_0, α_n, α_{nm}, δ_0, δ_1, and δ_2	are the model parameters;
v^i_t	are the random errors and assumed i.i.d., $N(0, \sigma_v^2)$;
u^i_t	are non-negative random variables and assumed i.i.d., as truncations at zero of the $N(m^i_t, \sigma_u^2)$;
t = T = 1	since we consider cross-sectional data for the year 2006.

In the next section we examine the results of the analysis by looking first at the statistical estimation of our models and then the results on terminal efficiency, according to the two exogenous factors.

6.4 Estimation results

The parameter estimation for all models can be found in Table 24 (Cobb-Douglas models) and Table 25 (Translog models). As indicated in Chapter 4, Translog is more flexible than Cobb-Douglas, and can represent more complicated production techniques, but requires greater numbers of observations than Cobb-Douglas. In our terminal level data the likelihood-ratio (LR) test suggests that Translog models are favourable; therefore 165 observations are sufficient for the use of the Translog functional form estimation. However, more observations would improve some of our estimation results. For all Cobb-Douglas models the model performance is reasonable and gives the expected results, although the same cannot be said for all Translog models. Therefore, it would be interesting to explore whether more observations would make the result of the Translog models as predictable as those of Cobb-Douglas.

When we compare net effect and gross effect models, the latter are preferable for both Cobb-Douglas and Translog models. *Net* effect models assume that port management characteristics affect the production technique directly, and subsequently influence port efficiency indirectly. *Gross* effect models assume that port management characteristics do not affect the production technique, but rather affect the efficiency of the port directly. The estimation results confirm that the exogenous factors, terminal type and operational type, influence efficiency directly rather than through the production technique.

Table 24: Estimation result of Cobb-Douglas models for terminal level efficiency analysis: (The number in grey is the t value)

Model number	2.1.1.1	2.1.1.2	2.1.2.1	2.1.2.2	2.1.2.4	2.1.3.1	2.1.3.2	2.1.3.4	2.1.4.1	2.1.4.2	2.1.4.4
Intercept	**10.55**	**10.62**	**10.39**	**10.38**	**10.80**	**10.51**	**10.54**	**10.69**	**10.38**	**10.48**	**10.92**
	9.93	**12.05**	**11.68**	**13.30**	**10.97**	**9.38**	**10.76**	**11.35**	**12.22**	**12.59**	**11.37**
Max Berth Depth	0.34	0.30	0.17	0.16	0.04	0.34	0.35	0.29	0.24	0.20	0.01
	1.30	1.39	0.70	0.74	0.15	1.27	1.46	1.20	0.97	0.94	0.06
Quay Length	**0.98**	**0.89**	**1.04**	**1.00**	**0.92**	**1.01**	**0.92**	**0.90**	**1.06**	**1.01**	**0.93**
	5.60	**5.48**	**7.04**	**7.53**	**6.80**	**6.19**	**5.97**	**6.80**	**7.22**	**7.56**	**7.03**
Yard Space	0.17	0.20	0.05	0.04	0.09	0.20	0.21	0.16	0.09	0.08	0.07
	1.60	1.83	0.45	0.40	1.01	1.72	1.91	1.51	0.84	0.91	0.79
Number of Gantry Cranes	0.05	0.11	0.03	0.06	0.08	0.00	0.05	0.10	-0.02	0.00	0.08
	0.43	0.91	0.33	0.79	0.87	0.03	0.54	1.05	-0.16	0.05	0.91
Crane Spacing	**-0.92**	**-0.85**	**-0.77**	**-0.73**	**-0.71**	**-0.96**	**-0.91**	**-0.86**	**-0.84**	**-0.80**	**-0.73**
	-5.35	**-4.99**	**-4.80**	**-5.32**	**-4.30**	**-5.65**	**-5.91**	**-5.51**	**-4.79**	**-5.59**	**-4.69**
Terminal Type			**-0.87**	**-0.84**	**4.48**				**-0.81**	**-0.78**	**4.09**
			-5.75	**-6.45**	**2.46**				**-5.21**	**-5.94**	**2.63**
Operator Type						0.13	0.12	18.50	0.14	0.13	**1.00**
						0.96	1.12	1.16	0.98	1.36	**2.05**
sigma-square	**2.10**	**6.35**	**1.83**	**5.90**	**2.95**	**2.22**	**6.75**	31.23	**1.94**	**6.45**	**2.77**
	6.36	**3.40**	**7.01**	**2.38**	**2.13**	**6.38**	**3.31**	1.09	**6.83**	**2.27**	**2.30**
γ	**0.95**	**0.98**	**0.97**	**0.99**	**0.97**	**0.97**	**0.99**	**1.00**	**0.98**	**0.99**	**0.97**
	29	**75**	**43**	**110**	**57**	**36**	**118**	**220**	**50**	**149**	**55**
μ	zero	**-4.99**	zero	-4.82	-2.92	zero	-5.16	-45.80	zero	-5.06	-3.13
		-2.92		-1.85	-1.23		-2.64	-1.04		-1.83	-1.39
log likeli	-205.73	-200.61	-190.83	-187.51	-179.37	-205.28	-200.10	-195.82	-190.31	-186.82	-177.95

Table 25: Estimation result of Translog models for terminal efficiency analysis

Model number	2.2.1.1	2.2.1.2	2.2.2.1	2.2.2.2	2.2.2.4	2.2.3.1	2.2.3.2	2.2.3.4	2.2.4.1	2.2.4.2	2.2.4.4
Intercept	-9.39	1.57	**8.62**	**6.70**	-14.53	**-21.78**	0.75	-10.71	**8.11**	**5.69**	-14.46
	-0.79	0.80	**9.07**	**3.25**	-1.65	**-3.87**	0.40	-1.23	**8.31**	**2.67**	-1.72
Max Berth Depth	9.19	2.27	**4.63**	**5.61**	8.35	**12.72**	**2.50**	8.19	**4.60**	**5.97**	**9.41**
	1.54	1.79	**8.03**	**3.47**	1.81	**6.29**	**2.09**	1.88	**5.49**	**3.76**	**2.17**
Quay Length	1.12	-0.48	**-4.08**	**-2.49**	2.17	**4.66**	-0.18	1.47	**-3.08**	**-2.04**	2.47
	0.40	-0.60	**-6.25**	**-3.35**	0.87	**2.70**	-0.22	0.64	**-4.32**	**-2.63**	0.94
Yard Space	1.07	1.34	**3.93**	0.32	0.34	0.93	1.23	1.23	**2.27**	0.32	1.16
	0.65	1.40	**5.52**	0.33	0.20	0.90	1.35	0.84	**2.55**	0.35	0.70
Number of Gantry Cranes	1.22	**1.98**	**2.02**	**3.15**	1.25	-0.76	**1.84**	0.63	**2.18**	**2.85**	0.03
	0.60	**2.62**	**5.86**	**4.15**	0.58	-0.91	**2.38**	0.35	**3.41**	**3.53**	0.01
Crane Spacing	1.48	**2.11**	**1.62**	**1.73**	2.84	0.76	**2.00**	1.97	**1.52**	1.43	1.76
	0.62	**2.05**	**5.77**	**2.34**	1.05	0.98	**2.27**	0.90	**2.04**	1.91	0.60
BerthDepth*QuayLength	-0.62	-0.38	-0.25	-0.35	-0.98	**-1.22**	-0.33	-0.72	-0.08	-0.32	-1.26
	-0.84	-0.75	-1.05	-0.69	-1.36	**-2.50**	-0.62	-1.03	-0.17	-0.64	-1.67
BerthDepth*YardSpace	-0.12	-0.10	-0.05	0.22	0.01	-0.33	-0.22	-0.09	0.04	0.15	0.07
	-0.29	-0.36	-0.20	0.72	0.03	-1.03	-0.70	-0.28	0.11	0.49	0.20
BerthDepth*NumberOfGantCrane	0.03	-0.06	0.35	-0.10	0.24	**0.76**	-0.02	0.06	0.06	-0.06	0.38
	0.07	-0.21	1.69	-0.35	0.57	**4.13**	-0.06	0.14	0.20	-0.20	0.84
BerthDepth*CraneSpacing	-0.04	-0.01	0.27	-0.13	-0.09	0.48	-0.12	-0.18	-0.02	-0.15	0.13
	-0.04	-0.02	0.91	-0.22	-0.12	0.90	-0.20	-0.25	-0.04	-0.26	0.16
QuayLength*YardSpace	0.12	0.11	**-0.39**	-0.01	-0.15	-0.05	0.15	0.05	-0.17	0.03	-0.27
	0.36	0.39	**-4.24**	-0.03	-0.47	-0.22	0.55	0.17	-0.68	0.14	-0.86
QuayLength*NumberOfGantCrane	-0.13	-0.28	**0.44**	0.13	0.31	-0.09	-0.19	-0.04	0.14	0.15	0.47
	-0.28	-0.91	**2.53**	0.41	0.84	-0.25	-0.63	-0.07	0.44	0.48	1.30
QuayLength*CraneSpacing	0.33	0.19	**1.56**	0.94	0.53	-0.17	0.28	0.26	0.90	0.94	0.69
	0.48	0.36	**6.76**	1.85	0.97	-0.29	0.54	0.36	1.72	1.87	1.29
YardSpace*NumberOfGantCrane	-0.06	0.00	0.07	0.10	-0.09	0.11	-0.02	-0.05	0.02	0.07	-0.18
	-0.24	0.01	0.97	0.58	-0.39	0.74	-0.13	-0.20	0.14	0.40	-0.82
NumberOfGantCrane*CraneSpacing	-0.16	-0.14	**-0.22**	-0.03	0.08	0.17	-0.12	-0.12	-0.15	-0.05	-0.05
	-0.50	-0.54	**-3.56**	-0.14	0.26	0.93	-0.47	-0.40	-0.61	-0.20	-0.16
YardSpace*CraneSpacing	-0.09	-0.04	**-1.09**	-0.72	-0.66	-0.17	-0.12	-0.11	-0.59	-0.69	-0.65
	-0.19	-0.12	**-11.62**	-1.86	-1.75	-0.56	-0.31	-0.22	-1.55	-1.84	-1.66
1/2(BerthDepth)^2	-1.65	0.55	**-2.00**	-1.30	-0.54	**-2.71**	0.71	-0.71	-1.64	-1.39	-0.84
	-0.72	0.55	**-3.37**	-1.19	-0.31	**-2.56**	0.74	-0.41	-1.87	-1.32	-0.50
1/2(QuayLength)^2	-0.14	0.15	-0.28	-0.14	-0.28	-0.01	-0.03	-0.09	-0.05	-0.24	-0.31
	-0.19	0.26	-0.92	-0.26	-0.50	-0.02	-0.05	-0.13	-0.10	-0.45	-0.57
1/2(YardSpace)^2	-0.17	-0.29	-0.01	-0.23	0.16	-0.19	-0.26	-0.15	-0.10	-0.21	0.34
	-0.58	-1.87	-0.11	-1.54	0.48	-0.95	-1.63	-0.47	-0.66	-1.49	1.04
1/2(NumberOfGantryCranes)^2	0.50	0.49	**-0.17**	0.02	0.05	0.25	0.43	0.40	0.05	0.02	0.07
	1.58	1.83	**-1.96**	0.08	0.19	1.33	1.57	1.21	0.19	0.09	0.25
1/2(CraneSpacing)^2	-0.67	-0.64	**-2.13**	**-1.36**	-1.14	-0.32	-0.68	-0.61	**-1.29**	**-1.29**	-1.18
	-0.96	-1.11	**-22.27**	**-2.38**	-1.87	-0.64	-1.18	-0.84	**-2.19**	**-2.32**	-1.92
Terminal Type			**-0.84**	**-0.82**	8.01				**-0.78**	**-0.77**	5.90
			-14.94	**-4.82**	1.46				**-5.05**	**-4.53**	1.83
Operator Type						**0.36**	0.15	17.47	0.19	0.12	1.83
						4.20	1.18	1.06	1.70	1.07	1.37
sigma-square	**1.81**	**5.66**	**1.66**	**5.14**	5.14	**2.15**	**5.90**	33.63	**1.80**	**5.45**	4.09
	6.33	**3.70**	**16.87**	**3.33**	1.31	**17.30**	**4.12**	0.96	**256.33**	**3.32**	1.60
gamma	**0.97**	**0.99**	**1.00**	**0.99**	**0.99**	**1.00**	**0.99**	**1.00**	**1.00**	**0.99**	**0.99**
	40	**101**	**224109**	**109**	**90**	**9150992**	**150**	**453**	**114423**	**122.94**	**94**
mu	zero	**-4.73**	zero	**-4.51**	-7.78	zero	**-4.83**	-47.47	zero	**-4.65**	-6.27
		-3.13		**-2.97**	-1.04		**-3.80**	-0.94		**-2.83**	-1.25
log likeli	-187.99	-181.51	-170.01	-172.27	-160.95	-183.98	-180.49	-175.30	-168.40	-171.61	-159.18

Model 2.2.2.4 is the best performing model in Translog form and Model 2.1.2.3 is the best performing model in Cobb-Douglas form; their variable specifications include five physical inputs and one environmental factor, Terminal Type, with a Truncated Normal distribution assumption for the random part of the model. The efficiency indices discussed below are generated by Model 2.2.2.3 because Translog models are generally preferable for this dataset.

The sign for the parameter of Crane Spacing conflicts between the Cobb-Douglas (Model 2.1.2.3) and the Translog model (Model 2.2.2.3). However, an unstable result for this parameter is not surprising. In fact, Crane Spacing indicates the density of the container handling machines and reflects the usage of available space, whereby the higher the usage and the lower the Crane Spacing, the better it is; Crane Spacing also reflects the potential for extending handling capacity, and thus attracting future container traffic within a relatively short period of time. Translog allows for the calculation of interaction between variables, but Cobb-Douglas does not, so it is not clear whether the change of sign is due to the nature of the variable or to the choice of functional form. It would be reasonable to assume that both are the cause and that the change of sign indicates that this variable requires more sophisticated modelling. An interesting question is whether, with panel data, we can demonstrate how this variable would affect the output over time.

The signs of parameters for other inputs are consistent between Cobb-Douglas and Translog models and between the *net* effect and *gross* effect models. All are positive in both Cobb-Douglas and Translog models. Among them, Quay Length, Yard Space and Number of Gantry Cranes were expected to have a positive sign, as a generally bigger terminal can be expected to exhibit greater throughput. In contrast, the parameter of Max Berth Depth was expected to exhibit an unstable parameter sign. The reason for this expectation is that when Berth Depth exceeds the requirement for ships, it is not important if the water is deeper. Berth Depth in our dataset ranges between 6.8 and 18 metres; the depth of the Panama Canal is 12.5-13.7 metres; so fully loaded super-panamax container ships would be unable to access shallow water terminals. However, the parameter for Berth Depth is positive in all the models, which implies that deep water contributes to the attraction of container traffic. The signs and values of parameters further indicate practical production information of the container port industry in the North Mediterranean Sea area.

The environmental factors

Factor 1: Terminal Type (container/multiple terminal). In the *net* effect models (Models 2.2.2.1 and 2.2.2.2) the parameter's sign of Terminal Type is negative, while in the *gross* effect model (Model 2.2.2.4) the sign is positive (see Table 24 and Table 25). This opposite parameter sign indicates a consistent result; the net effect models account for the factor terminal type in the deterministic part the same as 'input', while gross effect models take the factor in the random inefficiency term; thus input contributes to the output positively and inefficiency contributes to the output negatively. The opposite sign actually indicates the consistency of the result. In our case the result shows that container-only terminals are more productive than multi-purpose terminals and this meets our expectation for factor 1.

Factor 2: Operation Type (global/local operator). In both the net effect models (Models 2.2.2.1 and 2.2.2.2) and the gross effect model (Model 2.2.2.4), the parameter's sign of Operation Type is positive (see Table 24 and Table 25). Following the same interpretation as in factor 1, this uniformity in the sign of Operation Type parameter shows, however, inconsistency in the results. We therefore fail to meet the expectation that global container terminal operators are better than local operators.

When we compare these two management factors, Terminal Type improves the model performance significantly, but Operation Type does not. The inconsistency of the parameter sign and overall model performance illustrate that Terminal operator type does not play a key role in our dataset.

Efficiency indices

In this section we examine different efficiency indices. In Tables 24- 26 we show the selected terminals within the entire dataset in relation to total, scale, and technical efficiencies. Although the Operator Type is insignificant in our dataset, it is still listed in efficiency indices tables, because the emergence of global terminal operators is a profound institutional change in container ports and terminals since the 1990s.

Table 26: Selected top 10 terminals in total efficiency in model 2.2.2.4

No.	Port	Terminal	Scale Effi.	Tech Effi.	Total Effi.	Rank	Operator
76	SHENZHEN	Chiwan Nanshan Development Group	1.00	0.90	0.90	(1)	local
69	SHANGHAI	Shanghai East Container Terminal (Waigaoqiao Phase 4)	1.00	0.89	0.89	(2)	global
73	SHANGHAI	SIPG Zhendong Container Terminal (phase 2)	0.97	0.92	0.89	(3)	local
72	SHANGHAI	Shanghai Shengdong International Cont. Term.Phase 1	0.99	0.88	0.87	(4)	global
107	KAOHSIUNG	Terminal 5 (APM Terminals)	0.98	0.87	0.86	(5)	global
101	KAOHSIUNG	Terminal 3 (APL: 68/69)	1.00	0.86	0.86	(6)	global
85	TIANJIN/XINGANG	Number 2 Container Terminal	0.94	0.91	0.85	(7)	local
63	NINGBO	Beilun No. 2 Container Company	0.94	0.89	0.84	(8)	local
70	SHANGHAI	Shanghai Mindong Cont. Term. (Waigaoqiao Phase 5)	0.98	0.85	0.83	(9)	global
151	SINGAPORE	Tanjong Pagar(PSA)	0.99	0.83	0.82	(10)	local

Table 27: Selected top 10 terminals in scale efficiency in model 2.2.2.4 [6]

No.	Port	Terminal	Scale Effi.	Rank	Tech Effi.	Total Effi.	Operator
84	TIANJIN/XINGANG	CSX Orient (Tianjin) Terminals	1.00	(1)	0.65	0.65	global
58	HONG KONG	Modern Terminals (Kwai Chung)	1.00	(2)	0.78	0.78	global
95	BUSAN	Pusan East Container terminal (PECT)	1.00	(3)	0.77	0.77	local
1	RIJEKA	Brajdica Container Terminal	1.00	(4)	0.17	0.17	global
156	LONG BEACH	Pier J Berths J232-234 (Interna. Transport Service,K Line)	1.00	(5)	0.55	0.55	global
28	VALETTA	Valetta Gateway Terminal	1.00	(6)	0.10	0.10	local
153	LONG BEACH	Pier C Berths C60-C62 (Matson)	1.00	(7)	0.58	0.58	global
69	SHANGHAI	Shanghai East Container Terminal (Waigaoqiao Phase 4)	1.00	(8)	0.89	0.89	global
88	BUSAN	Dongbu Busan Cont. Term. (Singamman term, Evergreen)	1.00	(9)	0.80	0.80	global
37	CADIZ	Reina Sofia	1.00	(10)	0.29	0.29	local

Table 28: Selected top 10 terminals in technical efficiency in model 2.2.2.4

No.	Port	Terminal	Scale Effi.	Tech Effi.	Rank	Total Effi.	Operator
73	SHANGHAI	SIPG Zhendong Container Terminal (phase 2)	0.97	0.92	(1)	0.89	local
46	IZMIR	container berths (13-16 / 17-19)	0.79	0.91	(2)	0.73	local
85	TIANJIN/XINGANG	Number 2 Container Terminal	0.94	0.91	(3)	0.85	local
76	SHENZHEN	Chiwan Nanshan Development Group	1.00	0.90	(4)	0.90	local
63	NINGBO	Beilun No. 2 Container Company	0.94	0.89	(5)	0.84	local
69	SHANGHAI	Shanghai East Container Terminal (Waigaoqiao Phase 4)	1.00	0.89	(6)	0.89	global
72	SHANGHAI	Shanghai Shengdong International Cont. Term. Phase 1	0.99	0.88	(7)	0.87	global
82	SHENZHEN	Yantian International Container Term (Phase 1,2 & 3)	0.78	0.88	(8)	0.69	global
107	KAOHSIUNG	Terminal 5 (APM Terminals)	0.98	0.87	(9)	0.86	global
91	BUSAN	Gamman Hutchison ContTerm (ex Gamman Hyundai BGCT	0.86	0.87	(10)	0.75	global

[6] The scale efficiency for the top 10 terminals only shows differences at six digits after the decimal point, so it appears that all the terminals in Table 27 have 100% scale efficiency.

When we consider the geographical area of the selected terminals, the geographical spread of the 165 terminals are: 65 in the Far East, 5 in the Middle East, 30 in North Europe, 45 in South Europe, and 21 in North America. We observe that in the total efficiency index (Table 26) the top 10 terminals are located in the Far East; in the scale efficiency index (Table 27), among the top 10 terminals, five are in the Far East, three are in the Mediterranean Sea area, and two are in North America; and in the technical efficiency index (Table 28), nine of the top 10 terminals are located in the Far East and one is in the Middle East. Terminals in the Far East (mainly P.R. China) dominate the top efficiency indices; this appears to indicate that geographic location of terminals plays a significant role in relation to their efficiency. As remarked in the introduction, the literature shows that the location of a port has become less important, but our analysis identifies that the geographical characteristic is still correlated with the efficiency of the terminals. The reasons for this correlation are due to two factors: the first relates to supply; the Far East, and especially China, is a main production hub as well as a main driver of international merchandise trade. Second, it is relatively cheap to enter into the Far East market rather than other regions. Significantly, the Far East region has the ability to offer service and hinterland connections that fit into the global supply chain network.

When we examine global terminal operators in the total efficiency index (Table 26), half of the top 10 terminals are operated by global terminal operators and half by local operators; in the scale efficiency index (Table 27), seven of the ten top terminals are operated by global terminal operators; in the technical efficiency index, half of the top 10 terminals are operated by global terminal operators. Global terminal operators appear to perform well on achieving scale efficiency but not on technical and total efficiencies; therefore, we cannot conclude categorically that global terminals are more efficient than local ones. Each terminal’s efficiency is affected by many factors in relation to its context, e.g. regulation, market trends, etc.

Although we recognise that global terminal operators do not appear to achieve higher efficiency than their local counterparts, the emergence of the global container terminal operator is still a phenomenon that cannot be ignored. The top global terminal operators have increased their market share dramatically over the past decade, and by 2005, the big five operators were handling 28% of the world's containers (see Table 29). This growth may be driven by various factors other than greater efficiency: improved access to capital, greater bargaining and reputational power with shippers, and the influence of principal investment funds seeking to acquire and consolidate such assets in recent years.

Table 29: The top 10 global terminal operators by 2005 throughput

Ranking	Operator	Million TEU	% Share
1	Hutchison Port Holdings (HPH)	33.2	8.3
2	PSA - Singapore Port Authority	32.4	8.1
3	APM Terminals	24.1	6.0
4	P&O Ports	21.9	3.3
5	DP World	13.3	2.5
6	Evergreen	11.5	1.7
7	Eurogate	11.4	1.6
8	COSCO	8.1	1.5
9	SSA Marine	6.7	1.4
10	HHLA	5.7	1.3

Source: Drewry Shipping Consultants, Annual Review of Global Terminal Operators (2006)

Table 30: Selected top 10 Mediterranean terminals in total efficiency in model 2.2.2.4

No.	Port	Terminal	Scale Effi.	Tech Effi.	Total Effi.	Rank	Operator
29	ALGECIRAS	Terminal 2000 (APM Terminals)	0.99	0.76	0.75	(35)	global
46	IZMIR	container berths (13-16 / 17-19)	0.79	0.91	0.73	(40)	local
47	MERSIN	2 container quays	0.94	0.75	0.71	(44)	global
22	SALERNO	Salerno Container Terminal (SCT)	1.00	0.67	0.67	(56)	global
44	VALENCIA	Valencia Container Terminal (Principe Felipe quay)	0.97	0.69	0.66	(58)	global
34	BARCELONA	TerCat	0.89	0.69	0.62	(68)	global
16	LA SPEZIA	Terminal de Golfo	0.98	0.63	0.62	(70)	local
14	GIOIA TAURO	Medcenter Container Terminal	0.78	0.77	0.60	(74)	global
9	THESSALONIKI	Pier 6	0.99	0.59	0.59	(76)	local
15	LA SPEZIA	La Spezia Cont. Term. (Molo Fornelli Berths 13-15 / 17-18)	1.00	0.57	0.57	(81)	global

Table 31: Selected top 10 Mediterranean terminals in scale efficiency in model 2.2.2.4

No.	Port	Terminal	Scale Effi.	Rank	Tech Effi.	Total Effi.	Operator
1	RIJEKA	Brajdica Container Terminal	1.00	(4)	0.17	0.17	global
28	VALETTA	Valetta Gateway Terminal	1.00	(6)	0.10	0.10	local
37	CADIZ	Reina Sofia	1.00	(10)	0.29	0.29	local
4	MARSEILLES-FOS	Fos Container Terminal - Seayard	1.00	(15)	0.15	0.15	global
36	BARCELONA	UTE Llevant	1.00	(17)	0.22	0.22	global
19	RAVENNA	Setramar Terminal	1.00	(21)	0.03	0.03	local
22	SALERNO	Salerno Container Terminal (SCT)	1.00	(22)	0.67	0.67	global
40	TARRAGONA	Tarragona Container Terminal (Moll D' Andalusia)	1.00	(26)	0.05	0.05	global
15	LA SPEZIA	La Spezia Cont. Term (Molo Fornelli Berths 13-15 / 17-18)	1.00	(31)	0.57	0.57	global
21	SALERNO	other berths	0.99	(37)	0.30	0.30	local

Table 32: Selected top 10 Mediterranean terminals in technical efficiency in model 2.2.2.4

No.	Port	Terminal	scale Effi.	Tech Effi.	Rank	Total Effi.	Operator
46	IZMIR	container berths (13-16 / 17-19)	0.79	0.91	(2)	0.73	local
14	GIOIA TAURO	Medcenter Container Terminal	0.78	0.77	(49)	0.60	global
29	ALGECIRAS	Terminal 2000 (APM Terminals)	0.99	0.76	(51)	0.75	global
8	PIRAEUS	Venizelos Container Terminal (Pier II)	0.61	0.75	(53)	0.46	local
47	MERSIN	2 container quays	0.94	0.75	(56)	0.71	global
39	SEVILLE	Muelle de Centenario	0.71	0.74	(62)	0.52	local
18	NAPLES	Molo Bausan terminal (CoNaTeCo)	0.80	0.70	(70)	0.56	global
34	BARCELONA	TerCat	0.89	0.69	(72)	0.62	global
17	NAPLES	Flavio Gioia terminal	0.40	0.69	(73)	0.28	local
44	VALENCIA	Valencia Container Terminal (Principe Felipe quay)	0.97	0.69	(75)	0.66	global

By looking at the specific regions of the Mediterranean Basin (Table 30, Table 31 and Table 32), we observe that global terminal operators are more dominant in the Mediterranean area than is the case elsewhere in the world. In the total efficiency index, seven of the top 10 Mediterranean terminals are operated by global terminal operators; amongst both scale and technical efficiency indices, each index has six of the top 10 terminals operated by global terminal operators.

The EU has made three (unsuccessful) attempts at an EU-wide port policy, focused on stimulating competitive provision of services in larger ports such as stevedoring, Ro-Ro- ramp provision, container services and even pilotage. Such attempts have met with failure as labour unions, port representations, service providers and other objectors have pointed to the unattractiveness of such a policy. Many EU states saw little need for a policy of this type, regarding competition between ports as sufficient, while in the UK for example, privatised ports meant such a policy could not be enforced, particularly as port service providers had often entered into long term non-competitive contracts (Roe, 2009).

However, other EU policy measures have had a far greater indirect effect on port ownership. The *Motorways of the Sea*, *TEN-T, Marco Plog I and II*, (discussed in the Chapter 8) programmes have added significantly to prospective future container traffic volumes, on top of that expected from a general increase in world trade.

Visibility over this increase has prompted the acquisition of terminal operations by global operators eyeing the potential for long term growth by serving a burgeoning market demand. This process has been accelerated by individual EU states pursuing privatisation programmes (Notteboom and Winkelmans, 2001), content to receive a share of the profitability achievable from expanded ports following private sector ownership and investment.

Empirical evidence exists to suggest that a monopolistic stevedore in one port can exploit economies of scale and scope when expanding operations over a number of ports ((Notteboom and Winkelmans, 2001). The container handling business in particular has demonstrated private operator's desire to capture the benefit of consolidation across the EU. For global terminal operators such as Hong Kong's Hutchsion Port Holdings (HPH), PSA corporation and P&O ports, building out an EU-wide network to include a presence in the Mediterranean, Hamburg-Le Havre range and the UK is seem as a essential strategic requirement. Owing to the importance of the Mediterranean as both a transhipment and gateway zone on the Europe-Asia trade route, it is unsurprising that we find high concentrations of global terminal operators here, alongside significant investment in the most efficiency container handling infrastructures.

6.5 Conclusions

This chapter has evaluated container terminal efficiency for 165 terminals globally. Our aim was to complement the container port analysis by examining container terminal operations and efficiency indices. We examined two exogenous factors that are expected to influence terminal efficiency. First, we have demonstrated that container terminals are more efficient than multi-purpose terminals. Our second finding is that, compared with local operators, the global terminal operators do not have a dominant position in the international maritime trade in terms of productivity and efficiency, which shows that the cross-country experience of global terminal operators appear not lead to superior output and efficiency. However, global terminal operators appear to be more predominant amongst the most efficient Mediterranean terminals relative to their presence amongst the top 10 most efficient terminals worldwide. Finally, following on these two results pertaining to terminal management, we have showed that management characteristics influence the terminal efficiency directly rather than through the production technique.

Although exogenous factors, such as. economic crises, regulation, trade agreements, and geopolitical features, impact on and are important to terminal efficiency as mentioned earlier, information was limited in the dataset; only the latest terminal information was available. Because of this data limitation, we therefore could not take temporary effects or time-related impacts into consideration, such as in the case of a terminal with a low efficiency level in the selected year (2006), because the terminal had just been set up during that year.

Chapter 7: Scale Efficiency Improvement

Two types of (in)efficiency, technical (TE) and scale (SE), are analysed in this research. Aforementioned in the literature review, DEA and SFA are the primary methods used in empirical studies to calculate TE, and SE is studied only by DEA approach in the prior container ports and terminals literature. One objective of this research is to fill the gap that SE has not been studied in the empirical SFA study of container ports and terminals' efficiency; in addition, to quantify how to improve SE. In this chapter we discuss how to improve SE after knowing the (in)efficiency level. The degree of TE and SE can be quantified by SFA models and has been calculated in Chapters 5 and 6. Technical inefficiency is present when the given resources (inputs) are not used in the optimal way, whereas we observe scale inefficiency when the input level is not optimal for the given input mix (combination); in other words, the resources are not combined in the most effective way.

The SFA models can quantify the degree of inefficiency for TE, but cannot evaluate how to improve the inefficiency. For SE, we can calculate how to correct the scale inefficiency through SFA models. In this chapter we discuss the two possible ways to improve SE: by adjusting the input level and the input mix. We examine terminals and ports in order to demonstrate how these two adjustments can improve SE.

7.1 Scale efficiency change by input level

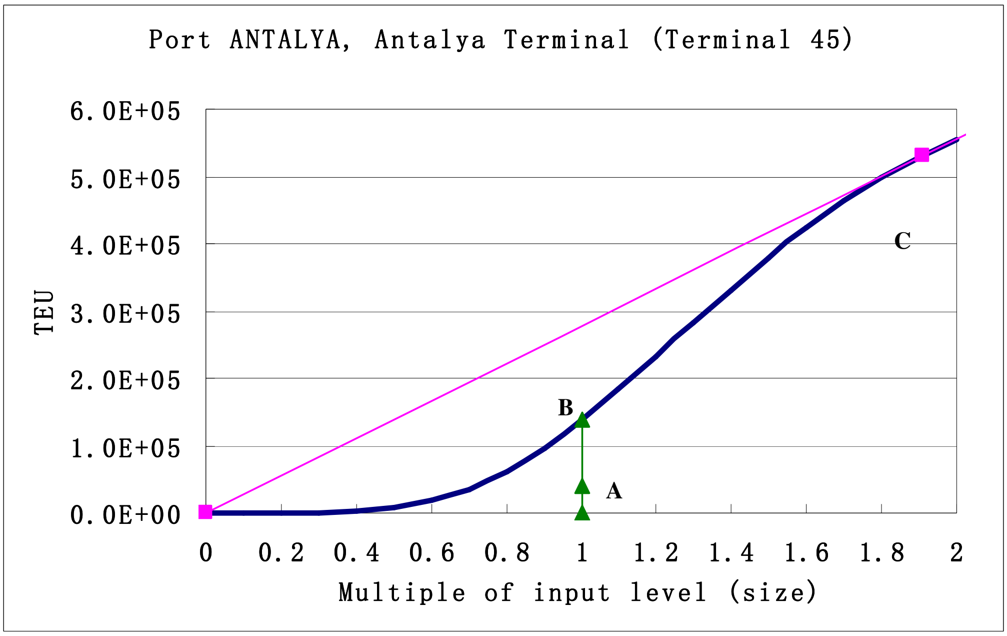
In order to show how to improve SE by changing the input level, we need to consider the concept of scale factor, t*. The SE is calculated through the comparison of the current size with the Most Productive Scale Size (MPSS), and scale factor, t* is used in order to estimate the MPSS (Chapter 4). The current observed size (input level) of the port or terminal is set to 1, and the optimal size (MPSS) is represented by t*. The value of t* is the scale that the port/terminal needs to reach, compared to its current size. If t* = 1, the optimal level is equal to the current observed input level; if t* = 3, the optimal input level is three times greater than the current observed input level; if t* = 0.5, the optimal input level is half of the current observed input level; so t* indicates how and how much to change the input level in order to obtain the scale optimal.

We use three examples to demonstrate how SE should be improved by the information given by t*; each example represents a typical scale status, *increasing*, *decreasing* and *constant* returns to scale. Increasing (decreasing) returns to scale in production means that an increase in resource use, by a certain percentage, results in an increase in output by more (less) than that percentage. Constant returns to scale in production means that an increase in resource usage, by a certain percentage, results in an increase in output by the same percentage.

Increasing returns to scale (IRTS) case

Terminal No. 45, Port ANTALYA, Antalya Terminal in Turkey, indicates that t* = 1.91, SE = 0.50, TE = 0.31, and overall efficiency is 0.15 (Appendix 13, terminal 45). The vertical axis in Figure 18 represents output in TEU; the horizontal axis represents size of the terminal, where 1 indicates current size. Point A on the vertical line is the actual observation point for terminal Antalya; the darker curve is the production technique frontier that terminal Antalya could achieve for its particular input mix (combination). Point B, where the vertical line and the frontier meet, represents the technical optimal that terminal Antalya could achieve at its current input level. The tangent point C, where the tangent meets the frontier, represents the optimal scale that terminal Antalya could achieve for its current input mix. For this case, the technical optimal point and the scale optimal point are not the same, therefore, two sources of inefficiency exist for this terminal, namely, technical inefficiency and scale inefficiency. The technical efficiency of 0.31 is measured as the relative distance between observation point A and technical optimal point B. Scale efficiency is 0.50, and is measured by the difference between the slope of technical optimal point B to origin point and the slope of scale optimal point C to origin point. In this case the terminal is experiencing increasing returns to scale; it therefore needs to increase its size to the level of point C in order to obtain its optimal scale; that is, it needs to enlarge to 1.91 of its current operating size (or input level).

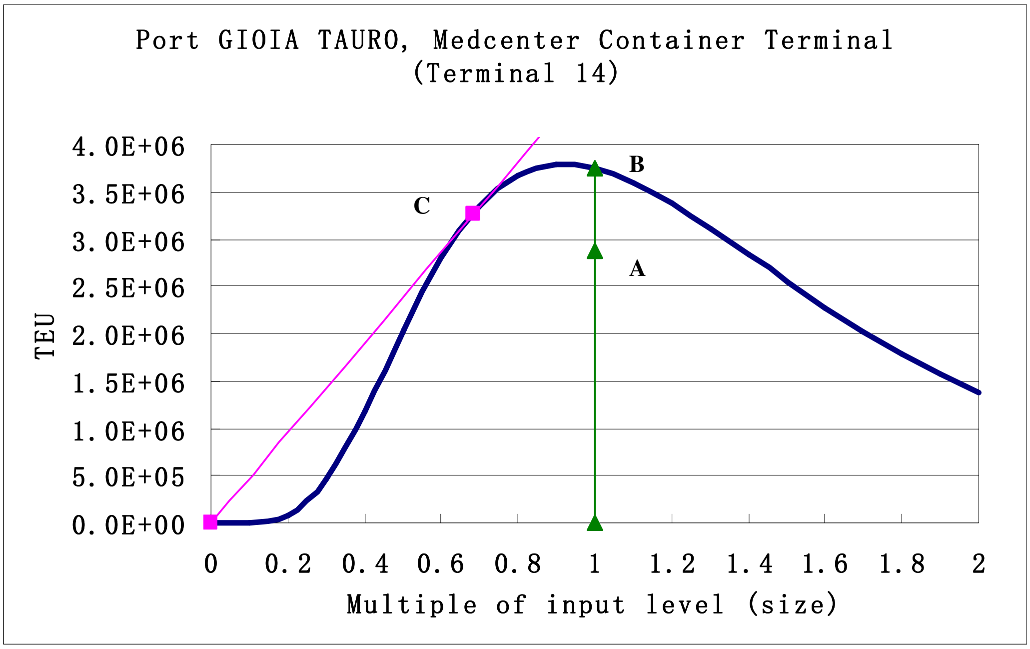
Figure 18: Terminal at increasing returns to scale level (Terminal 45)



Decreasing returns to scale (DRTS) case

Terminal 14, Port GIOIA TAURO, Medcenter Container Terminal in Italy, indicates that t* = 0.68, SE = 0.78, TE = 0.77, and overall efficiency is 0.60 (Appendix 13, terminal 14). Point A in Figure 19 on the vertical line is the actual observation point for the Medcenter Terminal. The darker curve depicts the production technique frontier that Medcenter Terminal could achieve for its particular input mix. Point B, where the vertical line and the production frontier meet, represents the technical optimal that Medcenter Terminal could achieve with its current input level. The tangent point C, where the tangent meets the frontier, represents the optimal scale that Medcenter Terminal could achieve for its current input mix. In this example the technical optimal point and the scale optimal point are also not the same, so in this case the terminal shows two sources of inefficiency. Technical efficiency is 0.77, measured as the relative distance between observation point A and the technical optimal point (B). Scale efficiency is 0.80, measured by the slope difference between the technical optimal point B and scale optimal point C. In this case, the Medcenter terminal is experiencing decreasing returns to scale and needs to decrease its size to the level 0.68 from its current level in order to obtain optimal scale size C.

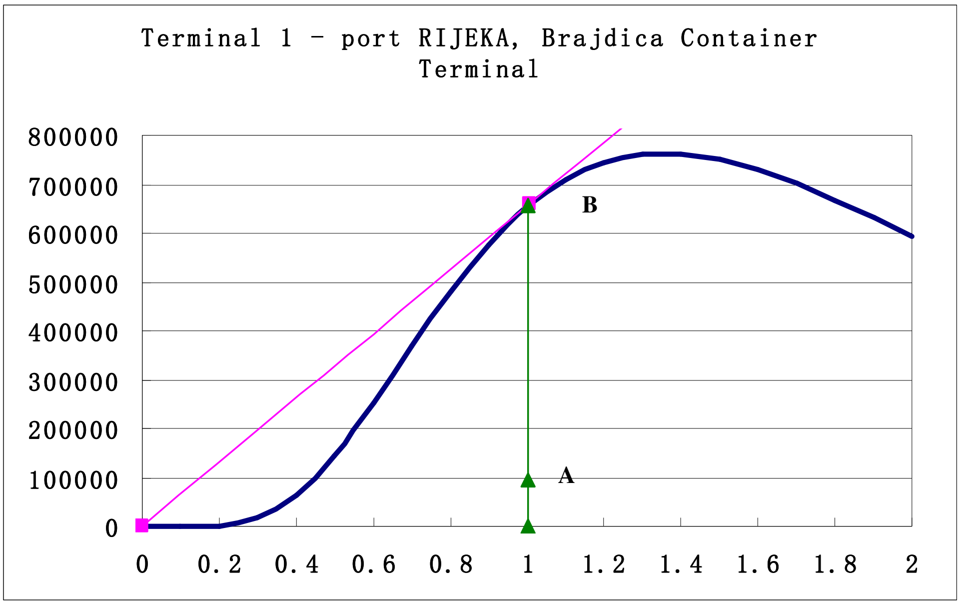
Figure 19: Terminal at decreasing returns to scale level (Terminal 14)



Constant returns to scale (CRTS) case

Terminal No. 1, Port RIJEKA, Brajdica Container Terminal in Croatia, indicates that t* = 1.01, SE = 1.00, TE = 17, and overall efficiency is 0.17 (Appendix 13, Terminal 1). Point A in Figure 20 on the vertical line is the actual observation point for this terminal; the darker curve is the production technique frontier that terminal Brajdica could achieve for its particular input mix. Point B, where the vertical line and the frontier meet, represents the technical optimal that Terminal Brajdica could achieve at its current input level. Tangent point C, where the tangent meets the frontier, represents the optimal scale that Terminal Brajdica could achieve for its current input mix. In this case the vertical line, tangent and frontier meet at the same point (B), indicating that Brajdica is already at its optimal scale, with a scale efficiency score of 100%. Moreover, Brajdica is experiencing constant returns to scale. The technical efficiency is measured by the relative distance of the observation point to its technical optimal point on the frontier. In this case technical efficiency is quite low. Therefore, the Brajdica Terminal needs to improve its production technique in order to improve efficiency.

Figure 20: Terminal at constant returns to scale level (Terminal 1)



In this section we have used terminal data to demonstrate typical returns to scale status. Port data can be analysed in the same way with the information on returns to scale status, scale efficiency and scale factor, t*. Some examples from port data are discussed below, and in Chapter 8 we analyse selected ports in the North Mediterranean Sea area.

We can summarise this section by observing that, when a terminal (or port) experiences constant returns to scale, the implication is that the terminal has reached its scale optical for its current input mix. In this case both the scale factor t* and SE score are equal to 1. When the port/terminal is not at the optimal size, t* can either be bigger or smaller than 1, whereas SE is always smaller than (or equal to) 1. A deviation of t* from 1 in any direction will cause SE to drop below 1. SE indicates how much more efficiency can be achieved, but does not indicate how to improve the efficiency. t* indicates how and how much change is needed in order to achieve scale optimal for the current input mix. Therefore, the combined information of t* and SE signals whether it is worthwhile to obtain the optimal by changing the input level, and this information can be obtained by examining the size elasticity of scale efficiency. In the next section we analyse examples from both terminal and port datasets with different sizes of elasticity of scale efficiency.

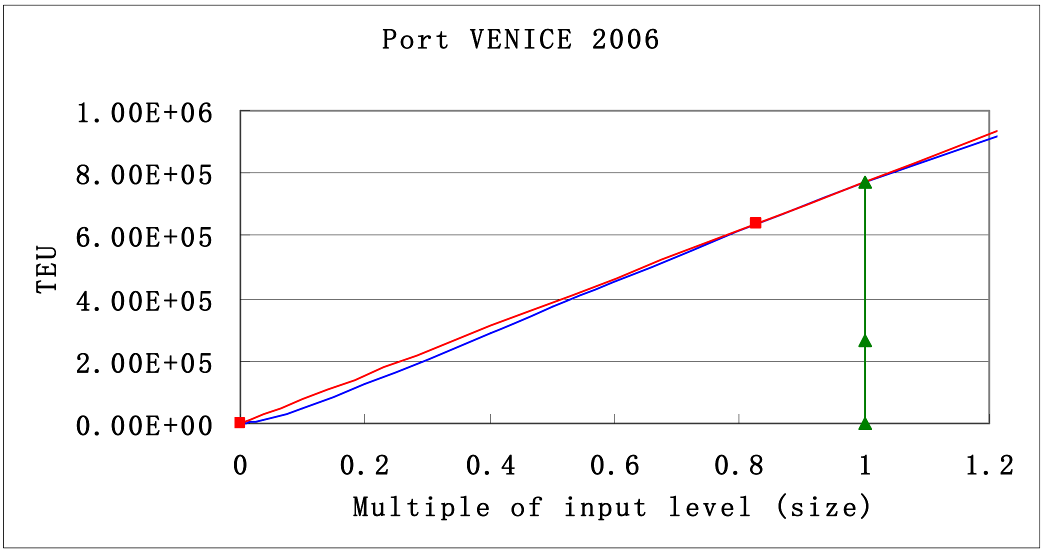
7.2 Elasticity of scale efficiency

There are two types of elasticity we can examine in this context: point elasticity and arc elasticity. Since our objective is to examine the relationship between current size and optimal size, we need to consider arc elasticity. The size arc elasticity of SE is represented by the ratio of the percentage change in SE to the percentage change in size (input level), and indicates how to effectively change the input level in order to achieve scale optimal, given a particular input mix.

We consider in our first example, a port with high size arc elasticity of scale efficiency: Port VENICE 2006 has t* = 0.83, SE = 0.99 (Appendix 13). t* < 1 indicates that Port VENICE 2006 has experienced decreasing returns of scale (
Figure 21). To obtain the scale optimal, the port needs to decrease the input level from its current level to 83% of its current level, thereby gaining 1% in scale efficiency. The size arc elasticity of scale efficiency for Port VENICE 2006 is -1340. The negative sign indicates decreasing economies of scale. In
Figure 21, we can also observe that the frontier and tangent are very close to each other, so the SE value does not change much in relation to the size (input level) adjustment. The SE value is almost invariant, so the determinate value is t*. We know that if t* is close to 1, the elasticity is large; if the value of t* is very far from 1, the

elasticity is small. In the case of Port VENICE 2006, t* = 0.83, thus resulting to a relatively large elasticity value.

Figure 21: High size arc elasticity of scale efficiency (Port VENICE 2006)

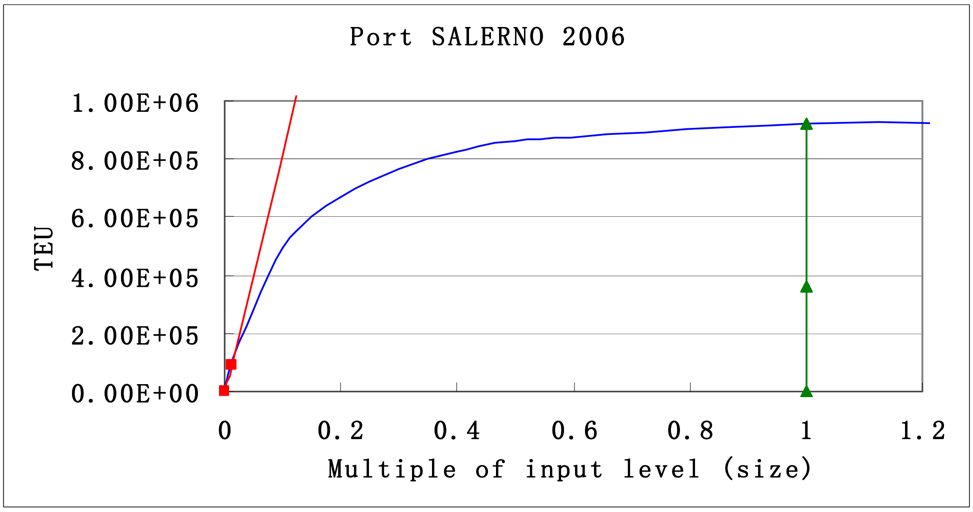


In our port dataset there are a few other ports with even larger elasticity, and all of those ports have very high SE scores as well. We can therefore observe an interesting situation: the higher is the value of SE, the closer to 1 is the value of t*, and the higher is the arc elasticity. We will next comment on our investigation of ports with low arc elasticity.

In our second example we examine a port with the least size elasticity of scale efficiency to the input level in port data. Port SALERNO 2006 has t* = 0.01, SE = 0.11 (Appendix 13). t* < 1 indicates that Port SALERNO 2006 has experienced decreasing economies of scale (Figure 22). In order to obtain the scale optimal, the input level needs to be decreased to 1% of its current level and thus 89% more scale efficiency could be gained. The elasticity of scale efficiency for Port SALERNO 2006 is -1.035. The frontier curve in Figure 22 has a very different shape from the frontier of Port VENICE 2006 (

Figure 21)[7]. In Figure 22 we notice that the curve deviates from the tangent as the size of Port SALERNO increases from the scale optimal point. The SE value is very small, therefore the scale efficiency is low. In this case the size arc elasticity of scale efficiency is also relatively small, which corresponds to the case of high arc elasticity.

Figure 22: Low size arc elasticity of scale efficiency (Port SALERNO 2006)



From our terminal level data, we next consider two examples with relatively high arc elasticity and which are experiencing increasing and decreasing returns to scale, respectively: Terminal 32, BARCELONA, Estibadora De Ponent Terminal indicates that t* =1.25, SE = 0.92. Terminal 33, BARCELONA TCB Terminal has t* = 0.80, SE = 0.92 (Appendix 13). By considering the value of t* (the horizontal axis in Figure 23), we observe that Terminal 32 needs to increase in size and Terminal 33 needs to decrease in size in order to obtain scale optimal. The values of SE for Terminals 32 and 33 are similar, 0.92, and the absolute values of their elasticity are also very close, 60 and -57, respectively. Other terminals in our dataset depict high arc elasticity values as well as very high SE values; we therefore observe in the terminal data the same situation as with port data, that higher SE values are associated with higher arc elasticity values.

[7] In Table 23, Port VENICE 2006, if we were to extend the graph, the frontier curve would eventually deviate from the tangent.

Figure 23: High size arc elasticity of scale efficiency (Barcelona Terminals)

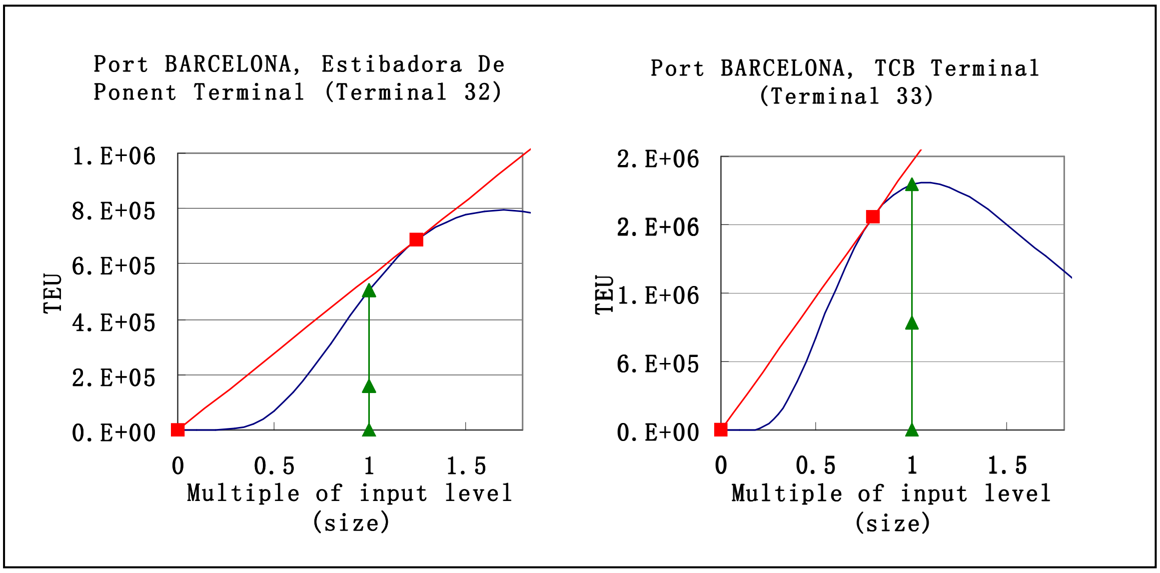
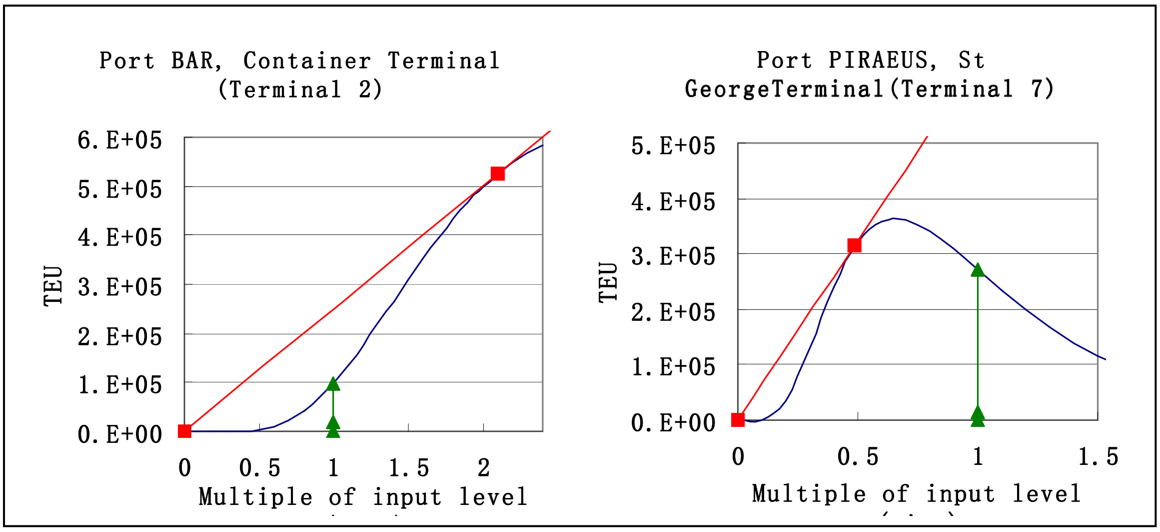


Figure 24: Low size arc elasticity of scale efficiency (Terminals Bar and Piraeus Grogre)



We consider two other examples from the terminal data that have relatively low arc elasticity and are therefore experiencing increasing and decreasing returns to scale, respectively: Terminal 2, Port BAR, Terminal Bar indicates that t* = 2.10, SE = 0.40; Terminal 7, Port PIRAEUS, Terminal St George indicates that t* = 0.49, SE = 0.42 (Appendix 13). The arc elasticities between the current size and optimal size are 3.34 for Terminal 2 and -3.53 for Terminal 7; both are relatively less elastic compared to Terminals 32 and 33 in our previous case. When we compare Figure 23 and Figure 24, Terminals 32 and 2 experience increasing returns to scale and their frontier curves have a similar shape. Terminals 33 and 7 experience decreasing returns to scale and their frontier curves have a similar shape. We can observe that terminals with their input levels closer to their scale optimal points have higher SE values and higher arc elasticity.

We have demonstrated in this section how to achieve optimal scale by examining the value of t*, and we have analysed the amount of investment needed to reach the optimal level for individual cases. Because the variables we consider in this research represent infrastructure and machinery of container ports and terminals, in order to achieve the scale optimal in the short-term, it is not feasible when the value of t* is big (small) to increase (decrease) the input level dramatically for two reasons. Firstly, the investment cycle of this kind of input is long-term; and secondly, a dramatic change with regard to some variables, e.g. terminal area, is not a choice in practice. We should therefore consider improving SE through other potential strategies, for example, by adjusting input mix (combination).

In practice, a port/terminal will not usually invest in all the variables simultaneously and proportionally. The investment is more likely to occur in certain factor(s), and that means the input mix for the port/terminals is modified. Through panel data we are able to examine the changes of input mix and SE value; therefore, in the following section we will use port data to analyse the impact of investment (the input mix change) on scale efficiency.

7.3 Efficiency improvements by input mix

An implicit condition is applied to all the efficiency analyses we have examined in the last section, that is, the input mix is constant. We have demonstrated in the previous sections that, using the information given by t*, we can improve the SE of ports/terminals, given a particular input mix. The shape of the frontier and the slope of the tangent remain the same during the course of changing input level (size). When the input mix changes, however, the graph representation will also change, which means that the shape of the frontier and the slope of the tangent will also both change.

The slope of the tangent of a port/terminal's total production frontier infers the optimal total productivity ratio that particular frontier curves (or input mix) could reach. In general, productivity can be defined as the ratio of aggregated outputs over aggregated inputs; thus the higher is the slope of tangent, the better is the productivity. We will next examine some panel ports information in this section in order to analyse the effect of input mix changes.

Let us consider Port LEGHORN (LIVORNO) in Italy. Between years 1998 and 2006, Port LEGHORN had sustained its level of investment every year except 1999 and 2002. Investment determines the input mix changes and this is captured by the SE and t* values observed in Table 33.

Table 33: Port LEGHORN years 1998 to 2006 efficiency index

Year	Port	t*	SE	TE	total eff.
2006	LEGHORN	0.160	0.695	0.311	0.216
2005	LEGHORN	0.161	0.696	0.296	0.206
2004	LEGHORN	0.424	0.924	0.280	0.259
2003	LEGHORN	0.507	0.951	0.265	0.252
2002	LEGHORN	0.434	0.927	0.251	0.232
2001	LEGHORN	0.434	0.927	0.236	0.219
2000	LEGHORN	0.430	0.926	0.222	0.205
1999	LEGHORN	0.116	0.604	0.208	0.125
1998	LEGHORN	0.116	0.604	0.194	0.117

In years 1998 and 1999, Port LEGHORN had the same values of SE and t* because the input mix was the same, and moreover, the frontier relative to these two years was also the same (see Figure 25). However, the TE values differ because the real outputs for the two years are different. We can observe in Figure 25 that two observation points are on the vertical line; the upper point represents output in year 1999 and the lower point represents output for year 1998. In years 2001 and 2002 we find the same situation: the frontier curve, tangent line, SE, and t* values are the same for two years, but TE values differ.

Figure 25: Port LEGHORN years 1998 and 1999 efficiency graphs – same input mix

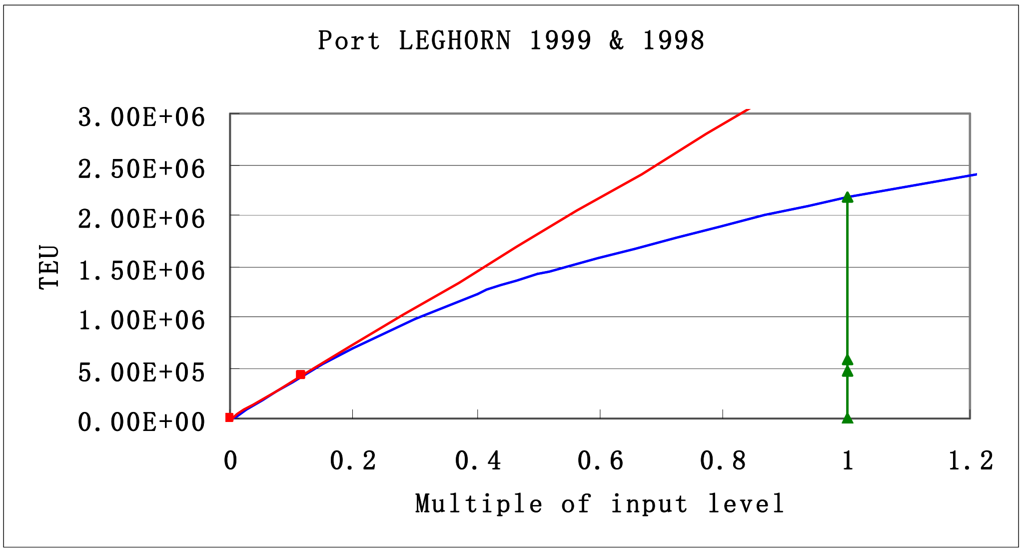
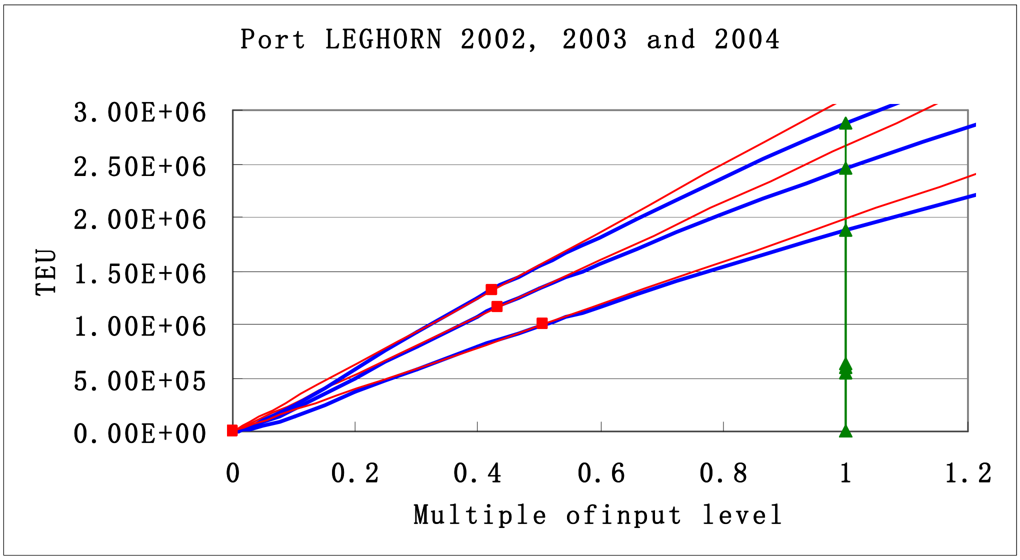


Figure 26: Port LEGHORN years 2002 - 2004 efficiency graphs – different input mix



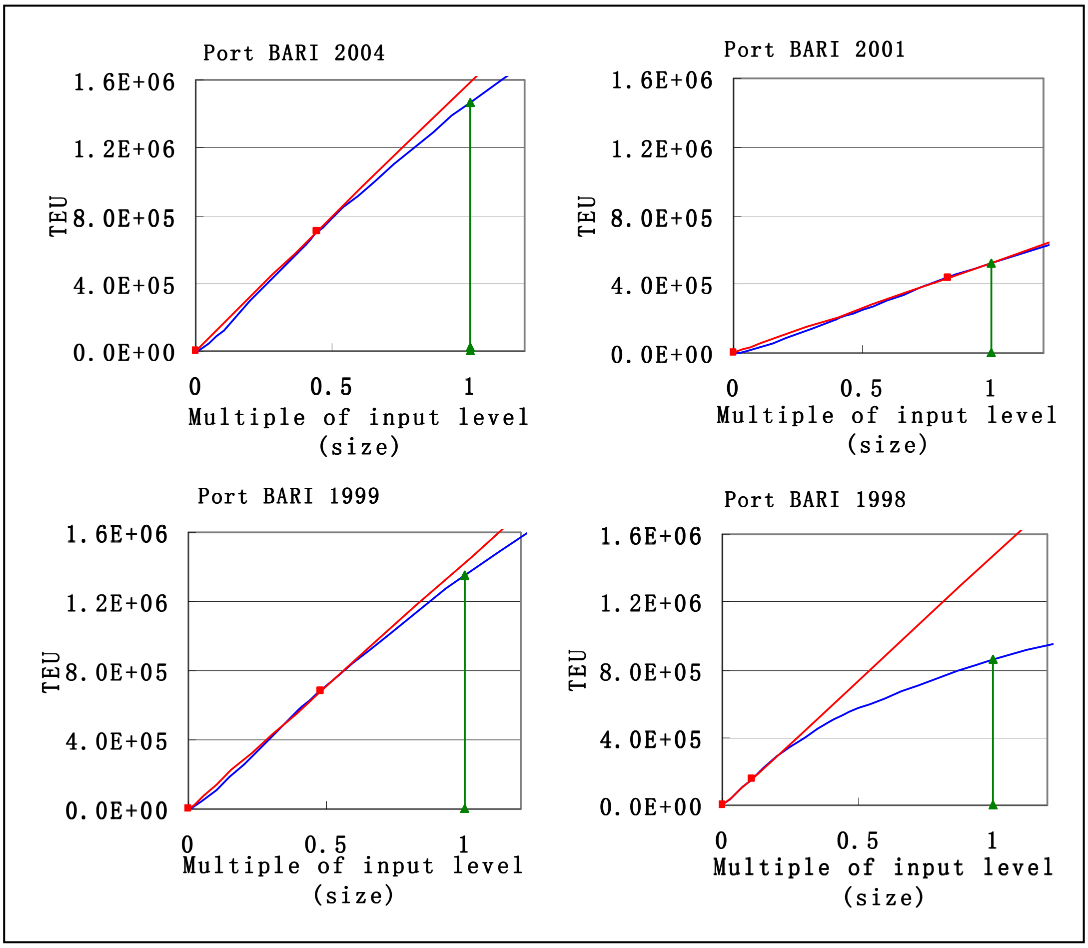
Between years 2002 and 2006, the input mix of Port LEGHORN changes every year, so the frontier curves, tangent lines, SE, and t* are all different in those years. For instance, let us compare three specific years 2004, 2003 and 2002. When the input mix is different, the frontiers should be drawn on separate graphs, but for demonstrational convenience, we deliberately put them on the same graph. In Figure 26, the vertical axis represents the output: port throughput in TEU; the horizontal axis represents the input level (size) of the port; the darker curves represent frontiers; the thinner lines next to the frontiers are the tangents to their respective frontiers, from top to bottom they are years 2004, 2002 and 2003. Different tangents infer different scale optimals that the port could achieve for the particular input mix for that year. In addition, different frontiers infer different technical optimals that the port could achieve for its particular input mix and level for that year. Hence Figure 26 indicates that, in year 2004, the technical optimal and the scale optimal have the highest values among the three years, although the values of technical and scale efficiency are not necessarily the highest among the three years.

We consider another port, the Port of BARI in Italy. Port BARI is a relatively smaller port than Port LEGHORN and the change in the inputs of BARI is, in turn, relatively larger than LEGHORN, which is reflected in the efficiency graphs: the position of the frontiers for BARI (Figure 27) changes more significantly than that of LEGHORN (Figure 26). Table 34 illustrates BARI's efficiency index from 2006 to 1998. We can see that in years 2006, 2005 and 2000, the port shares the same frontier and in years 2004, 2003 and 2002, it also shares the same frontier. In Figure 27 we have plotted the efficiency graph for selected years when input mix changed; they are years 2004, 2001, 1999, and 1998.

Table 34: Port BARI years 2006 to 1998 efficiency index

Year	Port	t*	SE	TE	total eff.
2006	BARI	0.456	0.935	0.012	0.011
2005	BARI	0.456	0.935	0.010	0.009
2004	BARI	0.445	0.931	0.008	0.007
2003	BARI	0.445	0.931	0.006	0.006
2002	BARI	0.445	0.931	0.005	0.005
2001	BARI	0.832	0.996	0.004	0.004
2000	BARI	0.456	0.935	0.003	0.003
1999	BARI	0.476	0.942	0.003	0.002
1998	BARI	0.108	0.585	0.002	0.001

Figure 27: Port BARI selected years efficiency graphs – different input mix



Among the four selected years, Port BARI has the highest value of scale efficiency in 2001 (Table 34), but in the same year, the slope of the tangent is the lowest (Figure 27). Here we want to emphasise the difference between SE and the slope of the tangent. The slope is the ratio of output to input for a single output and single input case; the higher the value of the ratio, the higher the port productivity, since it means that less input produces more output. We can find the 'best productivity' on that frontier by examining the slope. Analytically, the multiple outputs and inputs case is the same as the single output and input case: the slope is the ratio of output aggregation to input aggregation. The tangent indicates the highest slope within the possible production, which represents the best productivity for the given input mix, whereas SE indicates how good the current ratio is against the highest ratio (tangent).

In year 2001 Port BARI has the highest SE value, 0.99; and in year 1998 it has the lowest value of SE, 0.58. The low SE value in 1998 is not due to the low production ratio of that year, the production ratio in year 1998 is actually higher than in year 2001 (see Figure 27). The low SE value of year 1998 is because the ‘best practice’ (tangent slope) of year 1998 is high. In other words, the high SE value of Port BARI in year 2001 does not mean that the port is doing better than other years, but rather it is because the best possible production ratio or benchmark for that year is low.

The examples of Ports LEGHORN and BARI demonstrate that when input mix changes, the frontier, scale optimal (tangent), SE, and t* will all change. In Chapter 5 we showed that investment could cause TE to change, and this result can be identified by gross effect models. When investment occurs, TE scores may drop. If TE scores drop, it means that the capacity extension due to investment is larger than the container traffic growth. If TE scores keep increasing after investment, it indicates that the capacity increases but is less than the traffic growth. SE scores are also affected by investment, as we have demonstrated in this chapter. When all the inputs are invested proportionally, the SE scores increase or decrease, depending on whether the port/terminal is experiencing increasing or decreasing returns to scale. When the inputs are not invested in the same proportion, the tangent slope of the frontier will change and in turn change the SE score.

7.4 Conclusions

In this chapter we have examined two ways to improve the scale efficiency: adjustment of input level and input mix. The change in SE caused by input level changes was demonstrated through three examples from terminal data with increasing, decreasing, and constant returns to scale. We used the scale factor, t*, to indicate how SE can be improved by adjusting the input level in order to obtain the optimal scale for the particular input mix. The data indicates that the higher the value of SE, the higher the size arc elasticity of SE.

The change in SE caused by input mix changes was depicted through examples from port panel data. When input mix changes, the frontier, scale optimal (slope of tangent), SE, and t* will change as well. These changes are shown through efficiency graphs of the same port in different years.

Chapter 8: A comparative analysis of the efficiency of North Mediterranean container ports and terminals

8.1 Introduction

In the previous chapter we have studied the efficiency of container ports and terminals, respectively, based on two datasets. Although stemming from different data sources, the port and terminal datasets have been constructed by using the same sample of ports and their terminals, in order to compare and contrast results from both levels. Importantly, a container port is not merely the collection of its terminals, because a variety of agents with different objectives are involved in the operation. In order to address the complexity of multi-agent operation, our research focuses on the physical information of the container ports and terminals. However, because different exogenous factors are specified for container ports and terminals, we cannot compare the efficiency scores directly, but we can certainly compare the two analyses. In this chapter the objective is twofold: we first examine and compare the sensitivity of the models and the efficiency indices of ports and terminals; we then focus on the efficiency of the North Mediterranean Sea container ports and terminals.

Before we discuss the sensitivity of the indices it is necessary to re-examine the characteristics of port and terminal data. We acknowledge that the output and inputs used are limited by data availability. Output for both datasets is represented by the annual throughput in TEU, the standard measure of output for the container port and terminal industry. TEU measurements omit other goods that are handled in multi-purpose terminals; however, we were confronted by the fact that the information on other goods moved through container ports was not consistently available across ports.

Input specifications differ between the two datasets, but both represent the equipment and infrastructure required to handle containers in ports and terminals. Labour and cost information, however, was not available. Given the lack of input and output information, we construct exogenous factors into the dataset so that the data is more comprehensive and reflects port and terminal operations. The exogenous factors influence the efficiency and productivity of container handlings in ports and terminals, but nevertheless, they are not physical inputs. The port data is a panel data and the terminal data is a cross-sectional data. The exogenous variable applied in the port level analysis is the European trade volume with the rest of the world; this variable is time-series and cannot be applied to cross-sectional terminal level analysis. The exogenous variables that we apply in the terminal level analysis are terminal type (multi-purpose or container-only terminals) and operator type (global or local operators). These variables are not applicable to a port level analysis because most container ports will have *both* multi-purpose and container-only terminals, as well as global and local terminal operators.

Because it is a nine-year panel dataset, the port level analysis allows us to examine the efficiency trend and the effect of investment on the efficiency. The terminal level analysis would be strengthened if we could extend the analysis using panel data. Time-related factors cannot be evaluated for cross-sectional terminal analysis as we have mentioned before, but the terminal level dataset is nevertheless informative, because by including terminals from the world's top 20 container ports, we can benchmark the efficiency in relation to the global context.

8.2 Sensitivity of efficiency indices

Technical Efficiency (TE) and Scale Efficiency (SE) are Frontier Analysis concepts, whereby TE indicates the efficiency of a firm's production by comparing the industry optimal production for the given input mix and the given input level, whereas SE describes the efficiency of the current size (input level) for the given input mix. The analytical definitions have been given in Chapter 4. TE is measured by the ratio between the observed output and the best possible output. SE is measured by the slope difference between the point with most productive scale size (MPSS) and the TE point of the corresponding observation. Both MPSS point and TE point are on the frontier, and the difference between the slopes of these two points indicates the scale inefficiency.

From the mathematical point of view, the efficiency values are identified by the position and shape of the frontier, which are in turn determined by the data and model specifications. Various model specifications are applied to the data in order to estimate different positions and shapes of the frontier, and determine the efficiency score. We examine how the efficiency score changes in relation to the different model specifications. There are three sources of model specification that influence the position and shape of the frontier: choice of functional form, distribution assumptions of the error terms and variable specification. Table 35 summarises our selection of models in the port and the terminal analyses. The columns indicate the functional forms and error distribution assumptions, thereby representing the mathematical aspects of the models, and the rows indicate the variable specifications, thereby representing the empirical aspect of the models.

Table 35: Summary of the models for port and terminal level efficiency analysis

	Cobb-Douglas				Translog			
	Net effect			*Gross* effect	*Net* effect			*Gross* effect
	Half Normal (Cross-sectional)	Truncated Normal (Cross-sectional)	Truncated Normal (Panel B-C 1992)	Truncated Normal (Panel B-C 1995)	Half Normal (Cross-sectional)	Truncated Normal (Cross-sectional)	Truncated Normal (Panel B-C 1992)	Truncated Normal (Panel B-C 1995)
Models for Port Level Analysis (panel data)								
4 continuous inputs (basic model)			Model 1.1.1.3				Model 1.2.1.3	
4 continuous inputs, and time variable			Model 1.1.2.3				Model 1.2.2.3	
4 continuous inputs, time variable, trade volume			Model 1.1.3.3	Model 1.1.3.4			Model 1.2.3.3	Model 1.2.3.4
4 continuous inputs, time variable, logged trade volume			Model 1.1.4.3				Model 1.2.4.3	Model 1.2.4.4
Models for Terminal Level Analysis (cross-sectional data)								
5 continuous inputs (basic model)	Model 2.1.1.1	Model 2.1.1.2			Model 2.2.1.1	Model 2.2.1.2		
5 continuous inputs, terminal type	Model 2.1.2.1	Model 2.1.2.2		Model 2.1.2.4	Model 2.2.2.1	Model 2.2.2.2		Model 2.2.2.4
5 continuous inputs, operation type	Model 2.1.3.1	Model 2.1.3.2		Model 2.1.3.4	Model 2.2.3.1	Model 2.2.3.2		Model 2.2.3.4
5 continuous inputs, terminal type, operation type	Model 2.1.4.1	Model 2.1.4.2		Model 2.1.4.4	Model 2.2.4.1	Model 2.2.4.2		Model 2.2.4.4

* TE is calculated by all the models, SE is calculated only by shaded models.

8.2.1. The relationship between the functional form specification and the efficiency scores

Two functional forms are used in this research: Cobb-Douglas and Translog. TE can be calculated by both forms, but SE cannot be calculated by the Cobb-Douglas functional form due to its inherent mathematical feature (Chapter 4). In this section, therefore, we only examine TE score differences between Cobb-Douglas and Translog functional forms, *ceteris paribus*.

In the port level analysis TE scores generated by models using Cobb-Douglas and Translog functional forms have similar values with some deviations. Most TE score changes are less than 0.10, and there are a few changes (about 10%) which reach value 0.30. In the *net* effect models, Translog forms generate higher TE scores than their Cobb-Douglas counterparts for more than half the ports in the dataset. By constrast, in the *gross* effect models, Cobb-Douglas forms generate higher TE scores in most cases. It should be noticed that we compare four pairs of *net* effect models to calculate the differences in efficiency caused by functional form changes, but we have only one pair of *gross* effect models.

In the terminal level analysis the TE score follows the same trend when we use the two functional forms. Most TE score changes are less than 0.10, and less than 10% of the terminal changes reach value 0.30. We compare 11 pairs of model specifications, including eight pairs of *net* effect models and three pairs of *gross* effect models. In seven model pairs, the Translog forms generate larger numbers of high-TE scores than Cobb-Douglas. For the other four pairs, the situation is even: for half of the set, TE scores generated by Translog are higher than Cobb-Douglas and half of the set generated by Translog are lower than Cobb-Douglas. Both *gross* and *net* effects models show the same trend as just discussed.

Translog and Cobb-Douglas functional forms generate frontiers with different shapes; we therefore observe a deviation of TE score when calculated by these two forms. In relation to the positions of the observation and the frontier, the TE score can become larger or smaller when we change functional form. With regard to our port and terminal datasets, the Translog form tends to generate more high-TE scores than Cobb-Douglas.

8.2.2. The relationship between the distribution assumptions of error terms and the efficiency scores

Based on two basic distribution assumptions of the inefficiency term (u), Half Normal and Truncated Normal, four groups of models are used in this research. They include one Half Normal distribution model for cross-sectional data, one Truncated Normal distribution model for cross-sectional data, and two Truncated Normal distribution models for panel data (Battese and Coelli, 1992 and 1995; see Table 35).

In the port level analysis, the two error specifications for panel data are both Truncated Normal distribution, but they are specified in two different ways that has been analytically specified in Chapter 4. Three pairs of models can be compared for TE. TE scores change considerably between the two error specifications. The majority of the TE changes are within 0.10, but approximately a quarter of the total ports have TE score changes greater than 0.30. Therefore, there is no specific trend of the TE score changes, and the SE score changes cannot be examined because we can only calculate SE in one model (Model 1.2.1.3).

In the terminal level analysis we use three error specifications, two cross-sectional models and the Battese and Coelli (1995) panel data model. We only discuss the two cross-sectional models in this section; the Battese and Coelli model (1995) will be discussed with other panel data models in section 8.2.4. For the TE score, we can compare eight pairs of Half Normal and Truncated Normal models. The Truncated Normal models generate higher TE scores than the Half Normal for almost all the ports in the dataset, and the average TE value difference is 0.07. The same comparison for the SE scores shows the opposite result, although we can only compare one pair of models for the SE score. The majority of the SE scores generated by Truncated Normal models are smaller than the ones generated by Half Normal, and the average change is around 0.30.

8.2.3. The relationship between the variable specification (deterministic part) and the efficiency scores

The difference in variable specifications in this research emphasises the exogenous variables. The exogenous variables are included either in the deterministic (*net* effect models) or in the random part (*gross* effect models); we therefore have two types of variable specification changes. Given the basic models, we obtain the *net* effect models when the exogenous variables are added in the deterministic part of the model. Given the basic model, we obtain the *gross* effect models when the exogenous variables are included in the inefficiency term. We will next discuss the variable specification changes in the deterministic part of the model.

In the port level analysis, when we add the exogenous variable trading volume and the time variable in the deterministic part of the models, small changes occur in the TE score. These variation changes in the TE score are insignificant because the exogenous variable and the time variable are not port-specific variables. The trading volume between Europe and the rest of the world is a time series variable that changes every year but remains constant for all the ports in a specific year.

In our terminal level analysis, when we add the two exogenous variables, terminal type and operation type, in the deterministic part of the models, we observe considerable changes in the TE score. Different from the port analysis, the variables terminal type and operation type are terminal-specific binary variables; therefore the TE score more closely responds to their changes. A few terminals have a sizable change (0.30 TE score change or more), and the large majority of terminal efficiency changes remain under 0.10 in value.

8.2.4. The relationship between the variable specification (stochastic part) and the efficiency scores

In the case of the *gross* effect models, the exogenous variables determine the inefficiency term through the distribution function. The exogenous variables are considered to influence efficiency and in turn affect production, in contrast to the inputs that influence the production directly.

In the port level analysis, when we add the exogenous variable, i.e. trading volume, into the inefficiency terms, we observe significant changes in the TE scores. In the *gross* effect models, the TE index can capture the effects of the investment (Chapter 5). The influence on SE scores cannot be assessed here, because SE can only be calculated for Model 1.2.1.3. However by definition, when the distribution of the stochastic part of the model is fixed, SE is determined by the input level and input mix. For this case if no investment (change) occurs for any of the inputs, the SE scores for the same port in different years remain the same, even if the port outputs for different years are different. The changes of distribution of the stochastic part yields little change on SE scores as we have examined in section 8.2.2. We can therefore deduce that variable specification changes in the stochastic part of the model affects the SE score very little.

In the terminal level analysis, when we add the exogenous variables, we observe moderate changes in the TE and SE scores. The efficiency value changes for TE and SE are both around 0.05, and no discernible pattern of the changes is evident in relation to the efficiency indices.

We compare the TE and SE scores in different model specifications in order to explain the sensitivity of estimation results when we consider different SFA models. However, we cannot draw any conclusion on the sensitivity of the SFA approach in general. The comparison suggests that the distribution assumption for the error terms does not have significant influence on the efficiency score, whereas the choice of the functional forms in the deterministic part of the model has greater influence on the efficiency score. In the following sections we focus on the comparison of returns to scale status between port and terminal level analyses.

8.3 Comparison based on the returns to scale status between ports and terminals

Port and terminal level data allows us to make a very interesting comparison of the returns to scale status. The port level analysis contains 274 observations which form a panel dataset of 32 North Mediterranean Sea container ports for nine years, 1998 – 2006[8]. In our panel, 32 of the 274 observations experience *increasing returns to scale*, therefore, about 90% of the total observations in the sample show *decreasing returns to scale*.

The terminal level analysis contains 165 observations which comprises a cross-sectional dataset of 47 North Mediterranean Sea container terminals and 118 container terminals from the world's top 20 container ports based on throughput in 2006. For this sample 78 of 165 terminals (observations) experience increasing returns to scale, or about 50% of the total.

In Table 36 we illustrate the results of the 32 container ports from the first dataset and results from the 47 container terminals belonging to these ports in year 2006. All the ports are located in the North Mediterranean Sea area and Table 36 shows their returns to scale status. In year 2006, four of the 32 ports (observations) experience *increasing returns to scale*. For the 47 North Mediterranean Sea container terminals, 21 experience *increasing returns to scale*, which also represents about half of the total number of North Mediterranean Sea container terminals. In general, we observe a

[8] It is an unbalanced panel dataset where the information of ports Antalya, Cagliari, Izmir, Taranto are not available for certain years. There are 14 missing observations in total.

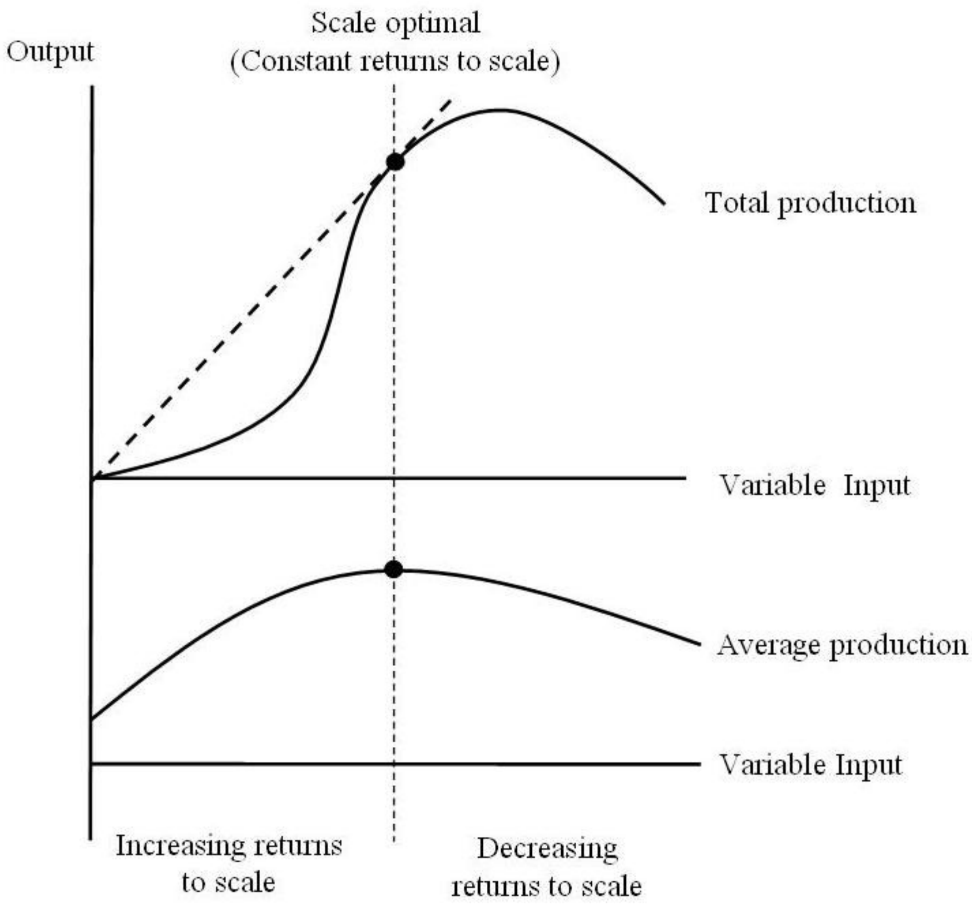
greater presence of *increasing returns to scale* at the terminal level, compared to the port level.

Table 36: Returns to scale status for North Mediterranean container ports and terminals

Country	Port	RTS	Terminal	No.	RTS
CROATIA	RIJEKA	decrease	Brajdica Container Terminal	1	**increase**
MONTENEGRO	BAR	**increase**	Container Terminal	2	**increase**
SLOVENIA	KOPER	decrease	3 container berths	3	**increase**
FRANCE	MARSEILLES	decrease	Fos Container Terminal - Seayard	4	decrease
			Mourepaine Container Terminal	5	decrease
	SETE	decrease	Container Terminal	6	decrease
GREECE	PIRAEUS	decrease	St GeorgeTerminal (Pier I)	7	decrease
			Venizelos Container Terminal (Pier II)	8	decrease
	THESSALONIKI	decrease	Pier 6	9	**increase**
ITALY	BARI	decrease	--	--	--
	CAGLIARI	decrease	Cagliari International Container Terminal	10	decrease
	GENOA	decrease	Messina Shipping Terminal - Ronco Pier	11	decrease
			SECH / Calata Sanita	12	**increase**
			Voltri Terminal	13	decrease
	GIOIA TAURO	decrease	Medcenter Container Terminal	14	decrease
	LA SPEZIA	decrease	La Spezia Container Terminal	15	decrease
			Terminal de Golfo	16	decrease
	LEGHORN	decrease	--	--	--
	NAPLES	decrease	Flavio Gioia terminal	17	**increase**
			Molo Bausan terminal (CoNaTeCo)	18	decrease
	RAVENNA	decrease	Setramar Terminal	19	decrease
			Terminal Contentori Ravenna (TCR)	20	**increase**
	SALERNO	decrease	other berths	21	decrease
			Salerno Container Terminal (SCT)	22	**increase**
	TARANTO	decrease	Taranto Container Terminal	23	decrease
	TRIESTE	decrease	Trieste Marine Terminal	24	decrease
	VENICE	decrease	Terminal Intermodale Venezia (TIV)	25	**increase**
			VECON (Banchina Emilia berths 25-27)	26	**increase**
MALTA	MARSAXLOKK	decrease	Malta Freeport (Terminal 1 & 2)	27	decrease
	VALETTA	**increase**	Valetta Gateway Terminal	28	decrease
SPAIN	ALGECIRAS	decrease	Terminal 2000 (APM Terminals)	29	decrease
			Terminales de Contendores de Algeciras	30	decrease
	ALICANTE	decrease	Berths 11	31	**increase**
	BARCELONA	decrease	Estibadora De Ponent	32	**increase**
			TCB Terminal de Contenidors de	33	decrease
			TerCat	34	decrease
			Terminal Port-Nou	35	decrease
			UTE Llevant	36	**increase**
	CADIZ	decrease	Reina Sofia	37	**increase**
	CARTAGENA	decrease	Santa Lucia	38	**increase**
	SEVILLE	**increase**	Muelle de Centenario	39	**increase**
	TARRAGONA	**increase**	Tarragona Container Terminal	40	**increase**
	VALENCIA	decrease	MSC Terminal (Muelle de Fangos)	41	**increase**
			Muelle de Levante Terminal (north end)	42	**increase**
			Muelle de Levante Terminal (south end)	43	**increase**
			Valencia Container Terminal (Felipe)	44	decrease
TURKEY	ANTALYA	decrease	general cargo / container berth	45	**increase**
	IZMIR	decrease	container berths (13-16 / 17-19)	46	decrease
	MERSIN	decrease	2 container quays	47	decrease

The status of *returns to scale* expresses important information: the different status is due to the different utilisation of variable inputs and fixed inputs. In Figure 28 we can observe the three different status of returns to scale. When a port/terminal experiences *constant returns to scale*, it indicates that its current size is optimal (scale optimal on Figure 28). When the current size of the port/terminal is smaller (larger) than the optimal size, the port/terminal experiences *increasing (decreasing) returns to scale*. Throughout the stage of *increasing returns to scale*, the utilisation of both variable inputs and fixed inputs is increasing with the quantity of variable inputs. In the stage of *decreasing returns to scale*, the utilisation of variable inputs begins to decline as the variable inputs quantity increases, and the utilisation of fixed inputs continues to increase at first and eventually decreases, while the variable inputs quantity increases. Hence, the *decreasing returns to scale* indicates that the fixed inputs begin to restrict the effect of the investment on variable inputs.

Figure 28: Increasing, decreasing and constant returns to scale



Source: Heathfield (1971)

Variable inputs represent the inputs that can be changed during the study period and the fixed inputs remain constant during the study period. In our study the variable inputs are the machinery as well as the infrastructure information of a container port/terminal, such as terminal area and quay length. Variable inputs are the inputs specified in the model, whereas fixed inputs are not captured by the model because they remain the same throughout the study. Therefore, the factors that confine the adjustment of variable inputs (infrastructure and machinery) are considered as the fixed inputs, e.g. available land for port use.

The key difference between increasing and decreasing returns to scale in practice is about the investment decision. For increasing returns to scale firm, more investment will increase the firm's productivity. For decreasing returns to scale firm, more investment will decrease the firm's overall productivity.

In order to expand their capacity, ports/terminals that show *increasing returns to scale* can therefore invest in the variable inputs. Ports/terminals that show *constant* and *decreasing returns to scale* cannot expand their capacity quickly by merely investing in the variable inputs because the fixed inputs are limiting their capacity expansion, thus fixed inputs must also be addressed in order to increase the capacity. As seen in Chapter 1, the world container port traffic is growing at an average rate of 12.2% per year. Against this background, *returns to scale* status would be more desirable for container ports and terminals because they can adapt quickly to the fast-growing demand for container handling.

As illustrated in Table 36, container terminals in the North Mediterranean Sea area appear to be better prepared than container ports to meet future growth in demand, since a greater proportion of terminals show *increasing returns to scale*, whereas most ports show *decreasing returns to scale*.

Even though the operation of container handling can be managed by port authorities and various private terminal operators, container ports as a whole are commonly considered to be public organisations. On the other hand, when container terminals are operated by private companies, the terminals are considered to be private organisations. Nowadays increasing numbers of container terminals are operated by private companies. Therefore, the result of the comparison analysis conducted here suggests that, in the container handling industry, the private sector is better able than the public sector to adapt to market demand.

Having examined and compared the *returns to scale* status for container ports and terminals in the North Mediterranean Sea, in the next sections we briefly review the port-related policy in the area and analyse particular individual ports and terminals.

8.4 Port-related policy in the North Mediterranean Sea

In our study we focus in particular on container ports and terminals located in the North Mediterranean Sea area. The ports under scrutiny are geographically concentrated but politically diversified, as we have ports that belong to the European Union (EU), ports in EU-candidate countries, and non-EU ports. The competition between ports is not only relative to port performance and efficiency, but also in many cases reflects differences in regulation and legislation, such as environmental regulation. When we talk about competition in the region we cannot undermine the dominant role played by the EU. The influence of the EU, which is a major economic and political entity, transcends the member states, for instance EU policies and legislations are enforced on member states but they also have a strong impact on neighbouring non-member countries. Within this context it is important to review port-related EU policies, projects and guidelines, in order to outline the maritime strategy in the North Mediterranean Sea area.

The *Trans-European transport network (TEN-T)* is part of the Trans-European

Network (TENs), which aims to promote an integrated single market as a key element for the creation of the internal market and for reinforcing economic and social cohesion. This includes the interconnection and interoperability of national networks, and the transport network is one of three categories, together with energy and telecommunications (European Parliament and Council, 1996; 2001 and 2004).

The policy objective of the TEN-T is to establish a single, multimodal network that enables safe and efficient traffic. Ports provide the link between sea transport and other modes of transport, and they form an important element of TEN-T. The European Commission has conducted a rough statistical survey[9] indicating that total expenditure in 439 TEN-T ports in the EU27 amounted to EUR 4.44 billion for the period 2004–2005. TEN-T assists EU ports on infrastructure upgrading and integration with other transport modes.

The *Marco Polo I and II* are EU funded programmes for projects supporting the shift of freight transport from the road to sea, rail and inland waterways and other more environmentally-friendly means. Since the start of the Marco Polo programme in 2003, more than 100 projects involving nearly 420 firms have received funding. The Marco Polo programme does not include funds dedicated to infrastructure projects, but rather only supports projects concerning freight transport services, thereby promoting the use of ports.

Short sea shipping has been actively promoted by the EU, because this form of transport mode has proved to be highly efficient in terms of environmental performance and energy efficiency, and the EU recognises its potential to solve road congestion problems affecting many areas of the European Continent (Medda and Trujillo, 2008). There are currently 22 Shortsea Promotion Centres (SPCs) operating in Europe. Short sea shipping has been prompted via various EU policies and

[9] It says rough because European Commission website stated that “as in a majority of ports the port services are provided by private operators, detailed investment information or long-term investment strategies were either not available or difficult to obtain. Therefore, the investment figures cannot be entirely relied upon.”

programmes, including TEN-T, Marco Polo, intermodal loading units, and especially motorways of the sea, a concept that has evolved from short sea shipping.

The *motorways of the sea* aims to improve existing maritime links and establish new intermodal maritime-based logistics chains for the goods transport between European member states. The motorways of the sea network is also supported by TEN-T policy and initiative in area can apply for funding under Marco Polo II grogramme. It aims to concentrate flows of freight on sea-based logistical routes and offer a door-to-door service in order to shift freight from long road distances to a combination of short sea shipping and other transport modes. Four corridors are designated as sea motorways and two are in the Mediterranean Sea, the Motorway of the Sea of south-east Europe (connecting the Adriatic Sea to the Ionian Sea and the Eastern Mediterranean, including Cyprus) and Motorway of the Sea of south-west Europe (western Mediterranean, connecting Spain, France, Italy and including Malta and linking with the Motorway of the Sea of south-east Europe, including links to the Black Sea). Through the concept of motorways of the sea, projects are being set up for private companies and member states to work together and create "floating infrastructures" on the Mediterranean Sea.

In addition to supporting its member countries, the EU also encourages cooperation with neighbouring non-EU countries. The *European Neighbourhood Policy* provides guidelines for closer integration of the EU transport system with neighbouring countries and proposes the Neighbourhood Investment Fund, which offers a suitable mechanism to encourage investment in the transport sector. This policy focuses on the main infrastructure for international transport and the legislation governing the use of these routes by different transport modes; it is expected to lead to common rules and regulations for the transport sector as a whole, and thus create an effective transport market involving the EU and its neighbours (European Commission, 2004).

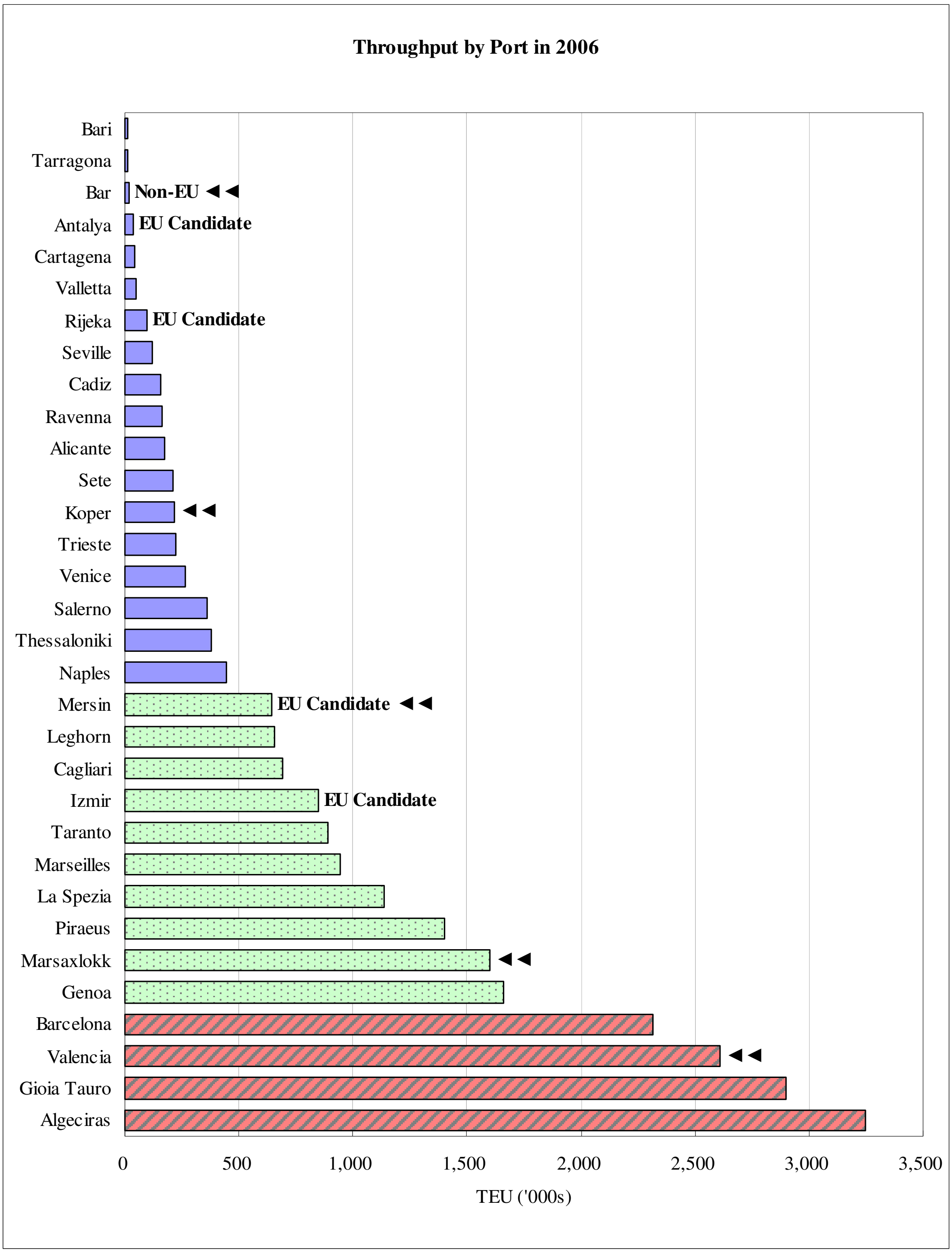
The aforementioned review of EU port-related strategy provides us with a picture of the port industry in the Mediterranean Sea area. The main policy features include: cohesion of the European and pan-European port and shipping market, integration of maritime transport with other transport modes, and an increase in market share of shipping in overall freight transport in order to reduce negative environmental impacts.

We have not explicitly analysed the impacts of EU policies on port competition; this will be the objective of a future study. However, in the next section we examine how EU strategies have influenced indirectly, e.g. through availability of funds, the efficiency and performance of the North Mediterranean ports and terminals.

8.5 Case studies in the North Mediterranean Sea

Our dataset is comprised of 32 North Mediterranean container ports, of which 27 are situated within the EU, four ports belong to EU-Candidate countries, and one is neither an EU nor an EU-candidate country. We consider the port size in terms of throughput in 2006, and observe that 18 ports have an annual throughput smaller than 500,000 TEU; 10 ports are medium size with annual throughput between 500,000 and 2,000,000 TEU; 4 ports have more than 2,000,000 TEU annual throughput in 2006. Figure 29 depicts these 32 ports on the basis of throughput, in which the four ports from Turkey and Croatia are 'EU-Candidate' and the Montenegro port is 'Non-EU'. We examine below five ports from each of the aforementioned categories related to the political structure and size of the ports in the region: Port BAR in Montenegro, a non-EU country, size small; Port MERSIN in Turkey, an EU-candidate country, size medium; and three EU Ports with size small, medium and large, respectively: Port KOPER in Slovenia, Port MARSAXLOKK in Malta, and Port VALENCIA in Spain.

Figure 29: Container ports in North Mediterranean Sea area by throughput 2006



Source: Containerisation International Yearbook (2007)

8.5.1. Non-EU port, size small - Port BAR in Montenegro

The North Mediterranean Sea is bordered by mainly EU and EU-candidate countries.

Therefore, non-EU ports are few in the region and their sizes are generally small. We have included only one in this research, Port BAR in Montenegro. The efficiency values of Port BAR from years 1998 to 2006 are shown in Table 37. Between 2000 and 2006 Port BAR received no investment (no input mix change); therefore, the production frontier and tangent of Port BAR during these years remained the same. The outputs during these years are different but very close (Figure 30).

Table 37: Efficiency index of Port BAR 1998-2006

Year	Port	t*	SE	TE	total eff.	Throughput
1998	BAR	0.83	1.00	0.03	0.03	6032
1999	BAR	4.43	0.79	0.03	0.02	9991
2000	BAR	1.14	1.00	0.04	0.04	9640
2001	BAR	1.14	1.00	0.04	0.04	5581
2002	BAR	1.14	1.00	0.05	0.05	9778
2003	BAR	1.14	1.00	0.05	0.05	8525
2004	BAR	1.14	1.00	0.06	0.06	11434
2005	BAR	1.14	1.00	0.07	0.07	12592
2006	BAR	1.14	1.00	0.08	0.08	18000

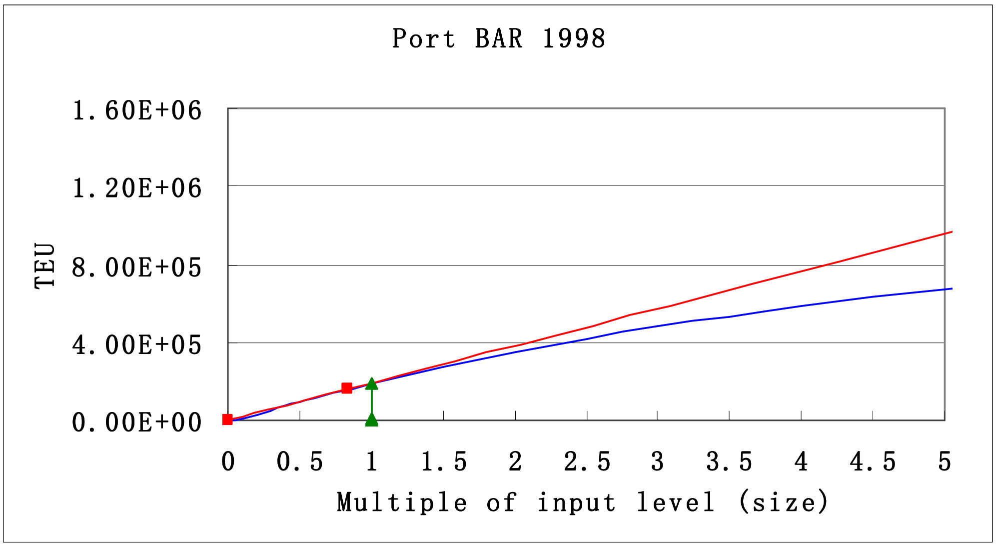
Table 38: Efficiency index of Port BAR and Terminal Bar in 2006

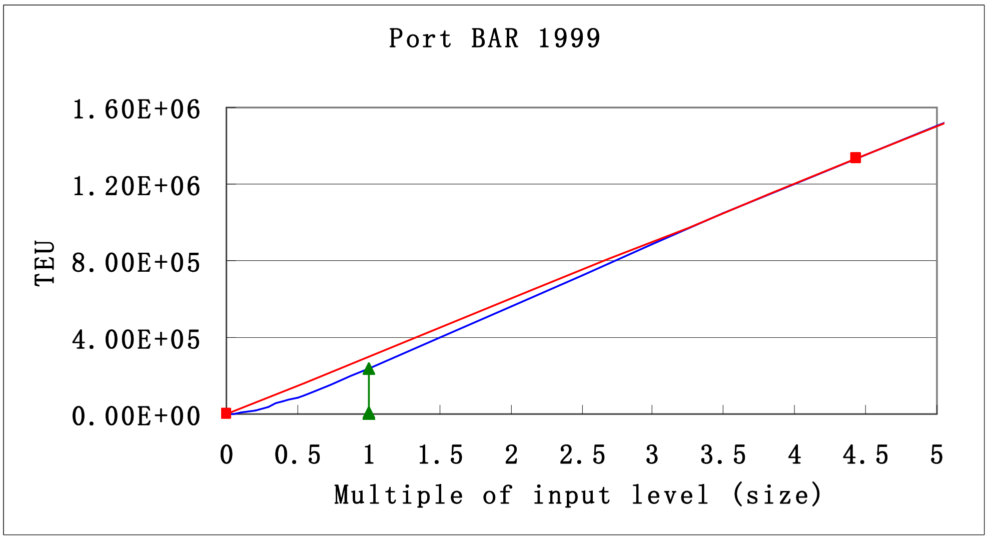
Year	2006	t*	SE	TE	total eff.	Throughput
Port	BAR	1.14	1.00	0.08	0.08	18000
Terminal	Bar	2.10	0.40	0.21	0.09	18000

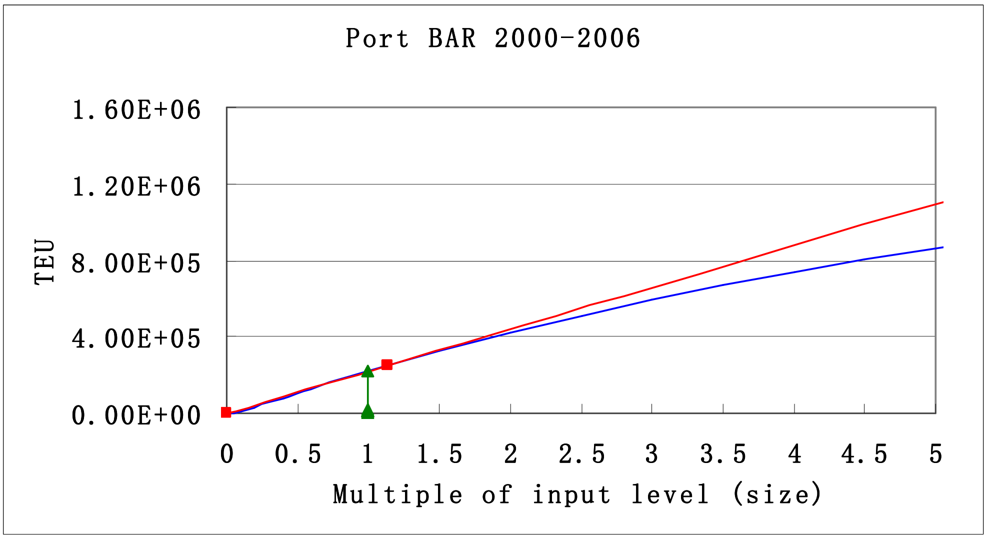
From Table 37 we notice that over the observation period, SE scores are very high, but TE scores are very low. The implication is that Port BAR has a satisfactory level of combination of resources (input mix); nonetheless, the port is not using its resources very efficiently. If we compare year 1999 with the years before and after, in year 1999 Port BAR has the steepest tangent and also the lowest SE score. From Figure 30, we can see that the SE score drops in 1999 because the optimal production ratio has increased (the slope of the tangent), but the observed production ratio has diminished. The low TE score, which means the port is technically inefficient, may be due to a number of reasons. A first explanation is that as a non-EU port it is not supported by EU policy schemes. The Port BAR operates in a small market and one which is significantly below its designed capacity; therefore, in order to improve the performance of Port BAR, the port has to acquire new markets, such as those in central Europe.

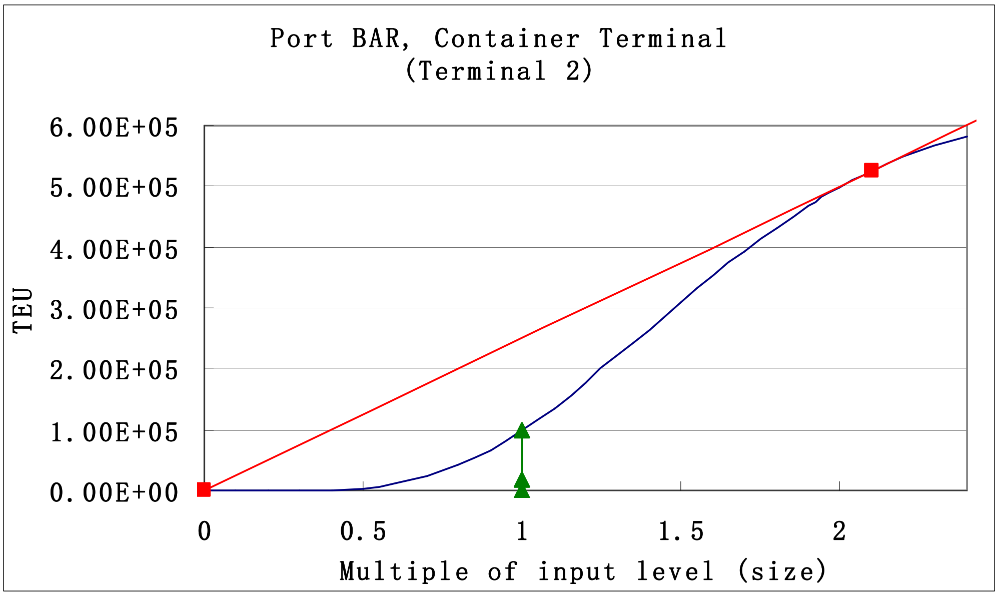
There is only one container terminal in Port BAR, so container traffic passing through the terminal is identical to that which passes through the port (Table 38). However, the inputs are different at the port and terminal levels, resulting in different TE and SE scores. The terminal TE score is larger than the port TE, given the same output. Therefore, the best possible output that can be achieved, given the current terminal inputs, is smaller than the best possible output that can be achieved, given the current port inputs (see the frontiers of Port BAR 2006 and Terminal Bar in Figure 30). The terminal SE score on the other hand is smaller than the port SE, and both show *increasing returns to scale*. When we observe the slopes of Port BAR 2006 and Terminal Bar in Figure 30, we see that the productivity ratio of the port does not have much room for improvement (SE is already very close to 1); in fact, it will begin to decline with the input level after reaching 1.15 of its current size. The productivity ratio of the terminal, however, has more room for improvement and the *increasing returns to scale* will be exhausted when the input level becomes larger than 2.1 of its current level. Hence, we can conclude that, for Port BAR, expanding the terminal input level from its current input mix is more effective than expanding the port input level.

Figure 30: Efficiency of Port BAR (1998-2006) and its terminal (2006)









8.5.2. EU-candidate port, size medium - Port MERSIN in Turkey

There are two EU-candidate countries in our dataset: Croatia and Turkey; we include four ports from EU-candidate countries in the study. We first examine Port MERSIN. Table 39 lists the efficiency information of Port MERSIN, and we can observe that the port has changed its infrastructure and facilities during the study period. This is reflected by the changes of t* and SE values.

Table 39: Efficiency index of Port MERSIN 1998-2006

Year	Port	t*	SE	TE	total eff.	Throughput
1998	MERSIN	0.13	0.63	0.23	0.15	241865
1999	MERSIN	0.13	0.63	0.25	0.16	251188
2000	MERSIN	0.11	0.60	0.26	0.16	175150
2001	MERSIN	0.08	0.51	0.28	0.14	189076
2002	MERSIN	0.08	0.51	0.29	0.15	363920
2003	MERSIN	0.07	0.45	0.31	0.14	467111
2004	MERSIN	0.09	0.53	0.32	0.17	532999
2005	MERSIN	0.09	0.53	0.34	0.18	596289
2006	MERSIN	0.09	0.53	0.35	0.19	643749

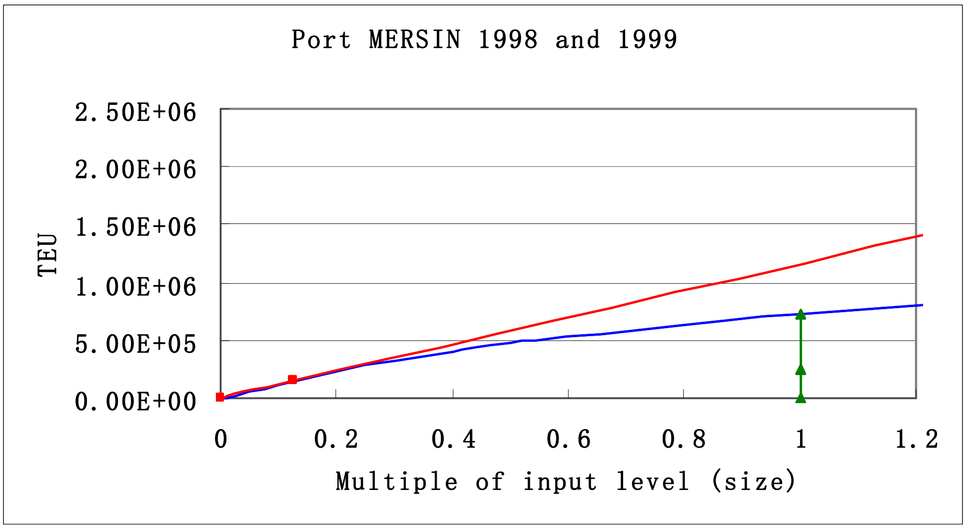
Table 40: Efficiency index of Port MERSIN and Terminal Mersin in 2006

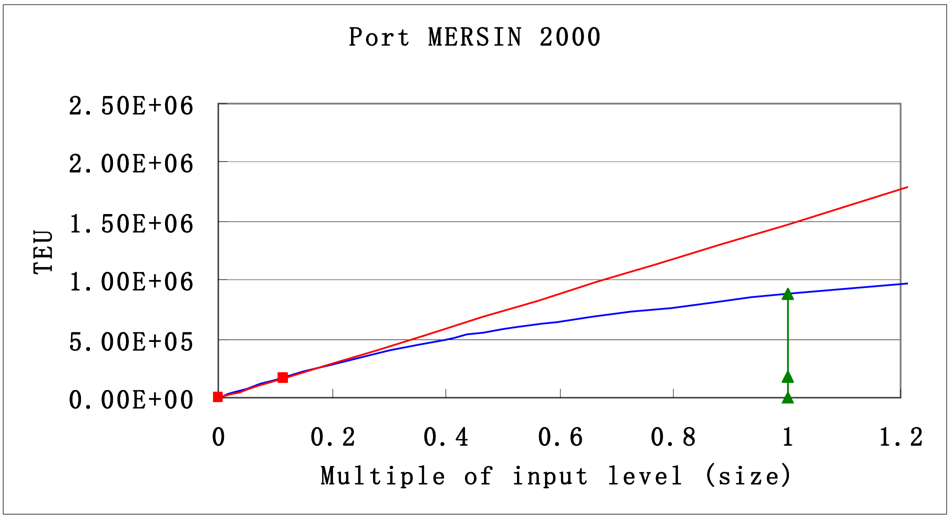
Year	2006	t*	SE	TE	total eff.	Throughput
Port	MERSIN	0.09	0.53	0.35	0.19	643749
Terminal	Mersin	0.83	0.94	0.75	0.71	643749

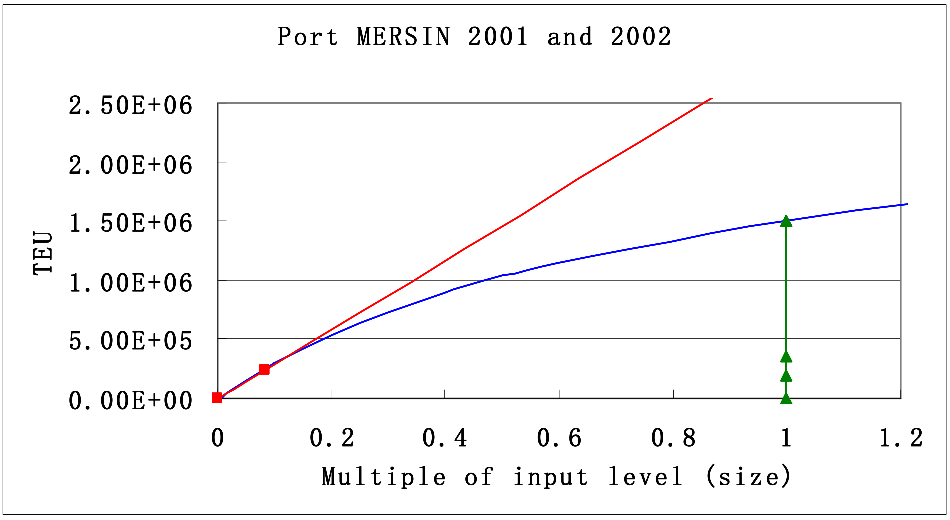
We observe that there was no change in inputs during years 1998 and 1999, so Port MERSIN has the same frontier for these two years. From 2000 (except 2002, which has the same input as year 2001), Port MERSIN expanded its handling capacity, but in 2004 the port reduced its handling capacity, and kept the same inputs for 2005 and 2006. The effect of increasing and decreasing handling capacity is shown by the position of the frontier. In Figure 31, the frontier curve and the tangent rise from the 1998/9 level every year (except 2002), they reach the peak in 2003 and drop again in 2004/5/6; in years 1998 and 1999 Port MERSIN shares a frontier, and in years 2001 and 2002 the port also shares one frontier.

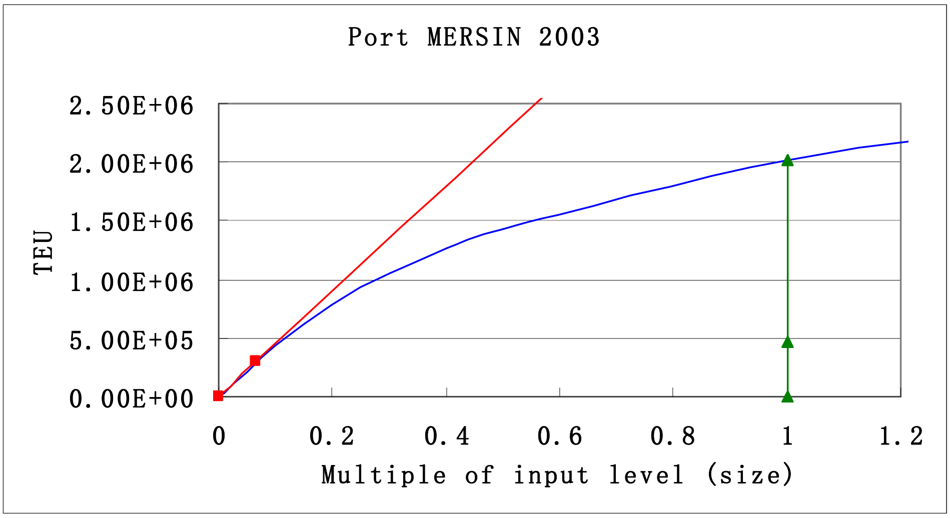
Port MERSIN has only one container terminal, so the output of the port and terminal is the same (Figure 34). The TE and SE scores of the terminal are higher than that of the port. Both port and terminal show *decreasing returns to scale*. As discussed in section 8.3, in a market where demand is growing, *decreasing returns to scale* status is not preferable, because in this status ports/terminals cannot expand their capacity rapidly by investing in the variable inputs (which includes the terminal area, berth length and machinery in our study). Other factors (fixed inputs), which are considered to constrain the variable inputs need to be examined and invested in, in order to expand their capacity.

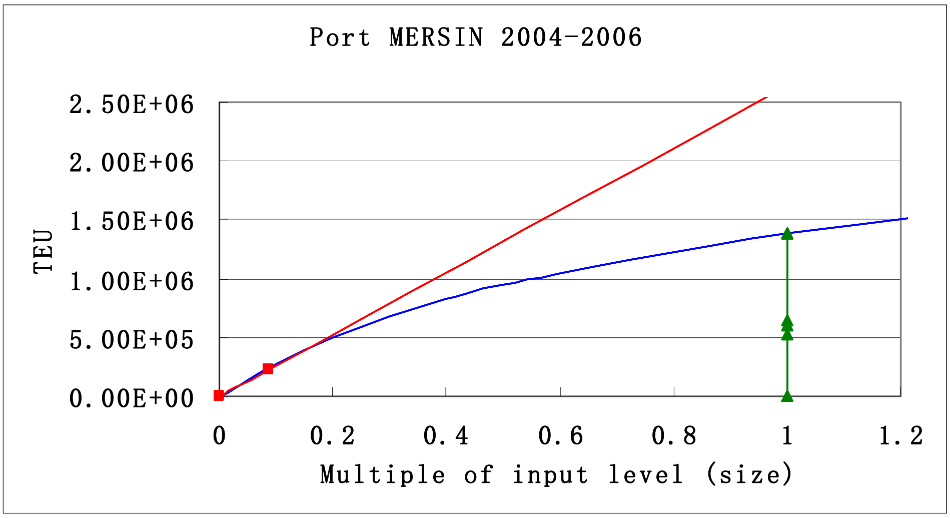
Figure 31: Efficiency of Port MERSIN (1998-2006) and its terminal (2006)

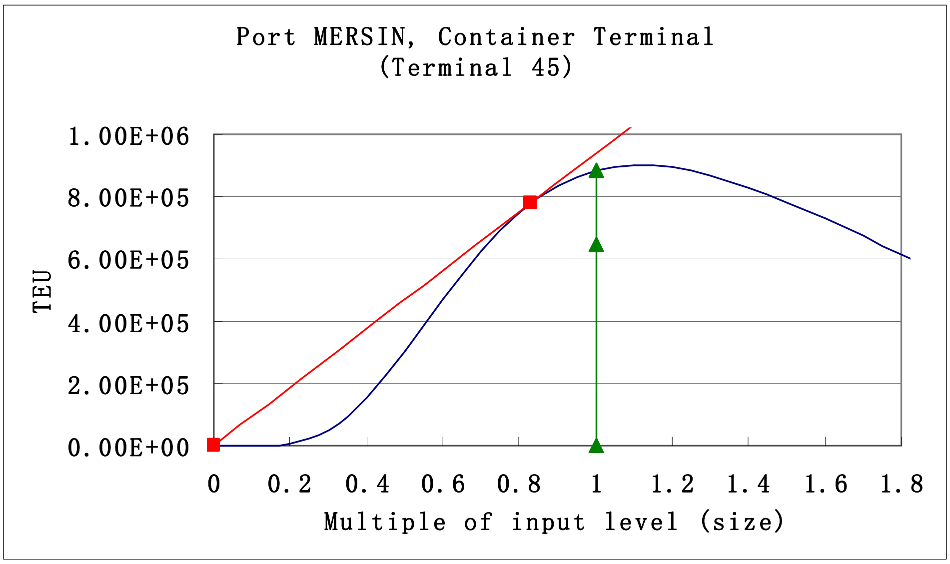












8.5.3. EU port, size small - Port KOPER in Slovenia

After considering the non-EU port and the EU-candidate port, we turn our attention to

EU ports. We first consider a small size port, Port KOPER, which has an annual throughput of less than 500,000 TEU. During our study period 1998-2006, Port KOPER invested in its infrastructure only between 1998 and 1999, by increasing 50 metres in berth length, extending 50,000 square metres in terminal area, and adding 1,500 more storage units. The handling capacity, however, remained constant. This is shown in the efficiency analysis: the SE and t* values for 1998 differ from other years, indicating that the input mix changes. All other years the SE and t* values remain constant, which indicates no input mix changes for those years (Table 41). Because there is no investment between 1999 and 2006, the frontier curve of Port KOPER stays the same for those years. The actual outputs for those years on the vertical line are not the same. Port KOPER had improved from 78,207 TEU in 1999 to 218,970 in year 2006. Consequently, the TE had improved from 0.14 to 0.25. This is depicted in Figure 32.

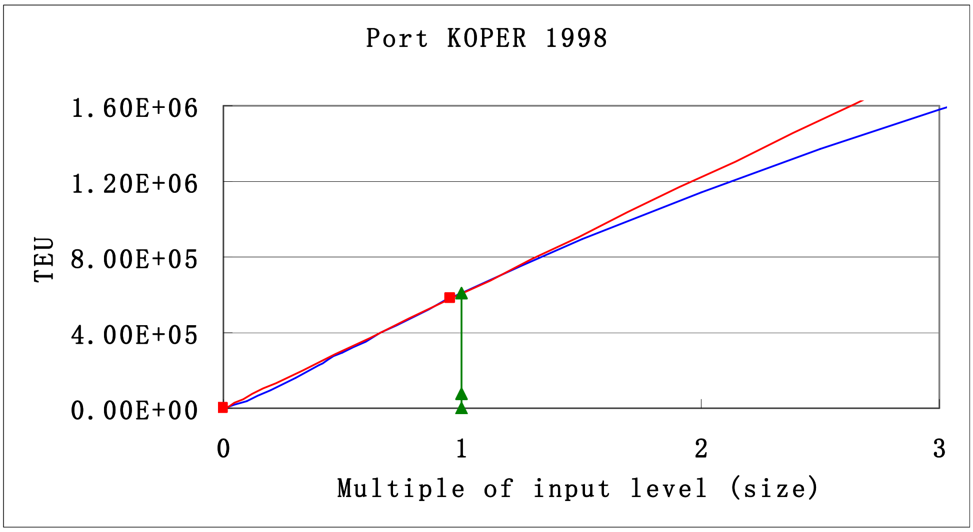
Table 41: Efficiency index of Port KOPER 1998-2006

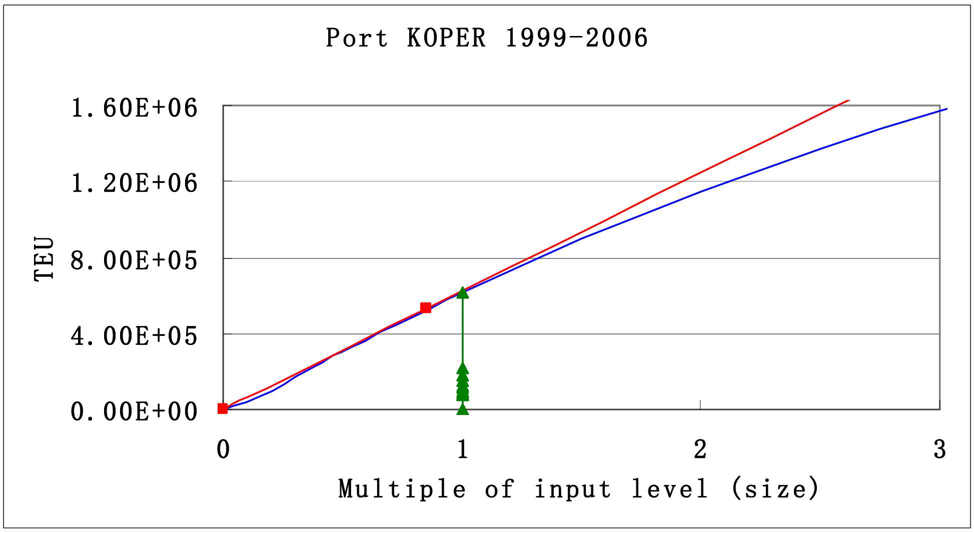
Year	Port	t*	SE	TE	total eff.	Throughput
1998	KOPER	0.95	1.00	0.14	0.14	72826
1999	KOPER	0.85	1.00	0.15	0.15	78204
2000	KOPER	0.85	1.00	0.16	0.16	85742
2001	KOPER	0.85	1.00	0.18	0.18	93187
2002	KOPER	0.85	1.00	0.19	0.19	114863
2003	KOPER	0.85	1.00	0.20	0.20	126237
2004	KOPER	0.85	1.00	0.22	0.22	153347
2005	KOPER	0.85	1.00	0.23	0.23	179745
2006	KOPER	0.85	1.00	0.25	0.25	218970

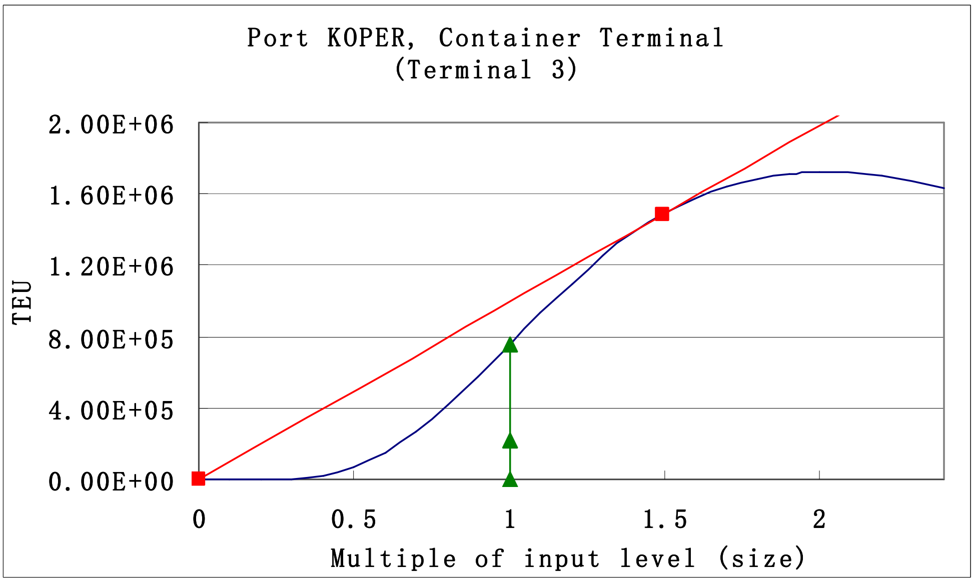
Table 42: Efficiency index of Port KOPER and Terminal Koper in 2006

Year	2006	t*	SE	TE	total eff.	Throughput
Port	KOPER	0.85	1.00	0.25	0.25	218970
Terminal	Koper	1.49	0.76	0.34	0.26	218970

Figure 32: Efficiency of Port KOPER (1998-2006) and its terminal (2006)







When we compare the port and terminal level efficiency analyses, Port KOPER shows *decreasing returns to scale* and the Koper container terminal shows *increasing returns to scale*. This finding indicates a divergence between the port and terminal operations. At the terminal level, the operator is able to expand the capacity relatively quickly when the market demand is growing. At the port level, the operator cannot respond to the market as fast as one may do at the terminal level. Although the SE score at the port level is high, indicating that the port is operating close to the optimal scale for their input mix, the terminal level operation can more easily adapt to the growing market.

8.5.4. EU port, size medium - Port MARSAXLOKK in Malta

Port MARSAXLOKK is a typical transshipment port in the Mediterranean Sea area. The Malta local market is very limited, but as a hub to western and central Europe, the port nevertheless handles a large volume of container traffic. Table 43 and Table 44 illustrate the efficiency information for both Port and Terminal MARSAXLOKK. The terminal throughput differs from the port throughput in Table 44. Because the data sources are different, it is possible to recognise inconsistencies. It is also likely that the port level data includes containers handled by non-primary container terminals, whereas terminal data does not include such traffic.

Table 43: Efficiency index of Port MARSAXLOKK 1998-2006

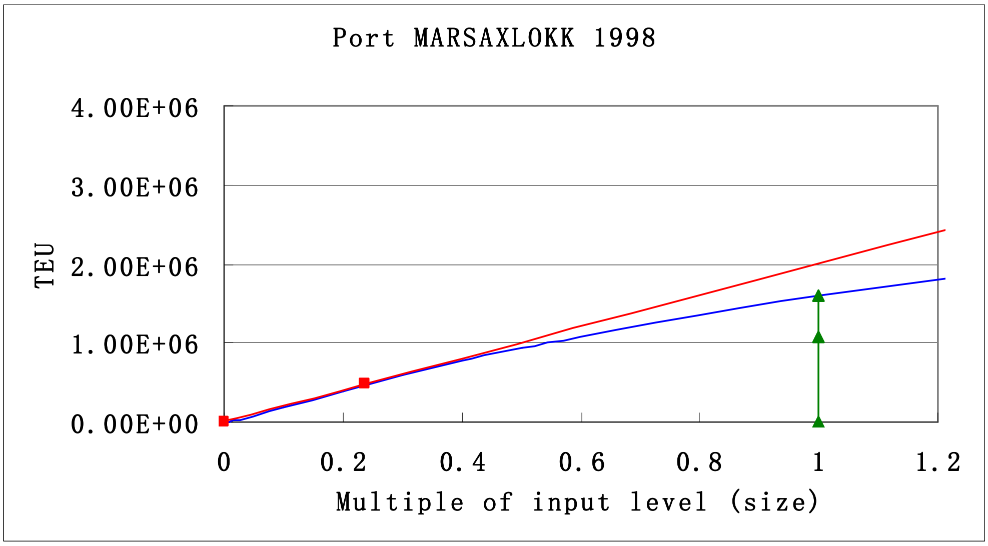
Year	Port	t*	SE	TE	total eff.	Throughput
1998	MARSAXLOKK	0.24	0.80	0.44	0.35	1071669
1999	MARSAXLOKK	0.11	0.59	0.46	0.27	1044972
2000	MARSAXLOKK	0.10	0.57	0.47	0.27	1033052
2001	MARSAXLOKK	0.10	0.56	0.49	0.27	1165070
2002	MARSAXLOKK	0.10	0.56	0.50	0.28	1244232
2003	MARSAXLOKK	0.10	0.55	0.52	0.28	1300000
2004	MARSAXLOKK	0.09	0.54	0.53	0.29	1461174
2005	MARSAXLOKK	0.10	0.55	0.55	0.30	1321000
2006	MARSAXLOKK	0.10	0.55	0.56	0.31	1600000

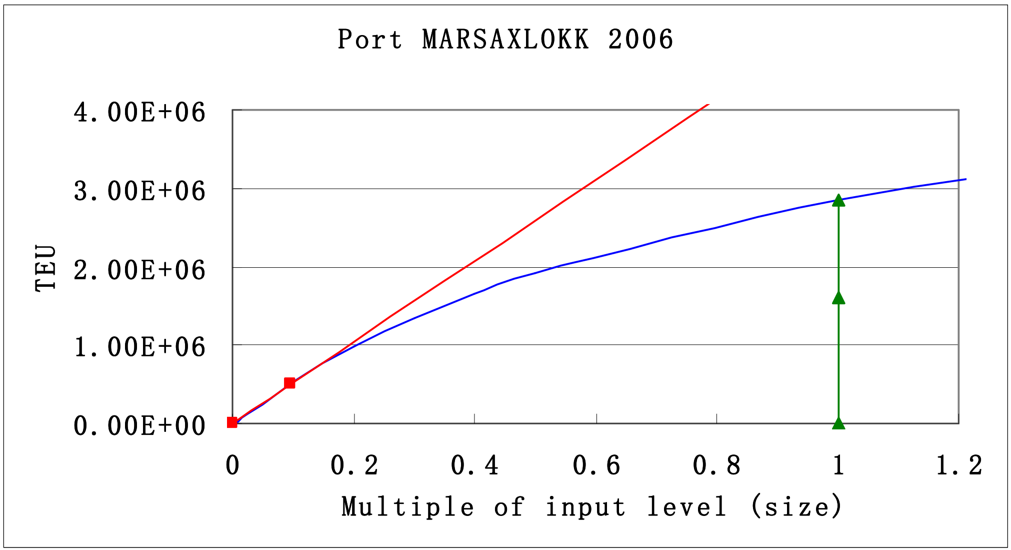
Table 44: Efficiency index of Port MARSAXLOKK and its Terminal Freeport in 2006

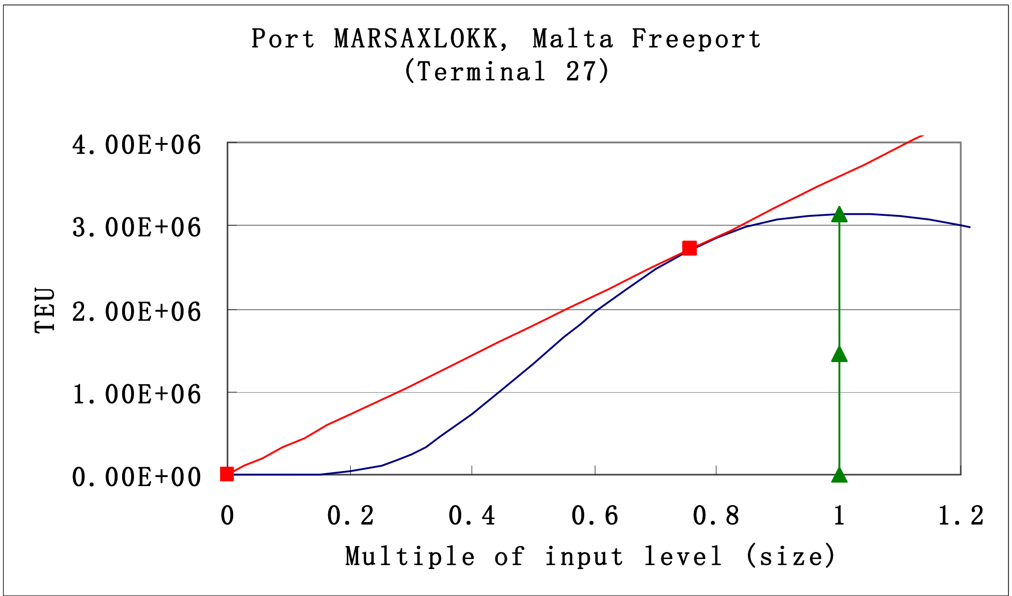
Year	2006	t*	SE	TE	total eff.	Throughput
Port	MARSAXLOKK	0.10	0.55	0.56	0.31	1600000
Terminal	Freeport	0.76	0.88	0.53	0.47	1450000

We observe that from 1998 to 2006, the SE score has decreased, but the slope of the tangent has increased (Figure 33), which means that the optimal production ratio between output and input has increased. Port MARSAXLOKK experiences *decreasing returns to scale* during the study period, and has changed its input mix, which in turn has improved the optimal production ratio. The implication is that if Port MARSAXLOKK wants to meet growing container traffic demand, it has to resolve the constraints posed by its fixed inputs, otherwise, more investment in the variables specified in the model will not lead to increased production capacity.

Figure 33: Efficiency of Port MARSAXLOKK (1998 and 2006) and its terminal (2006)







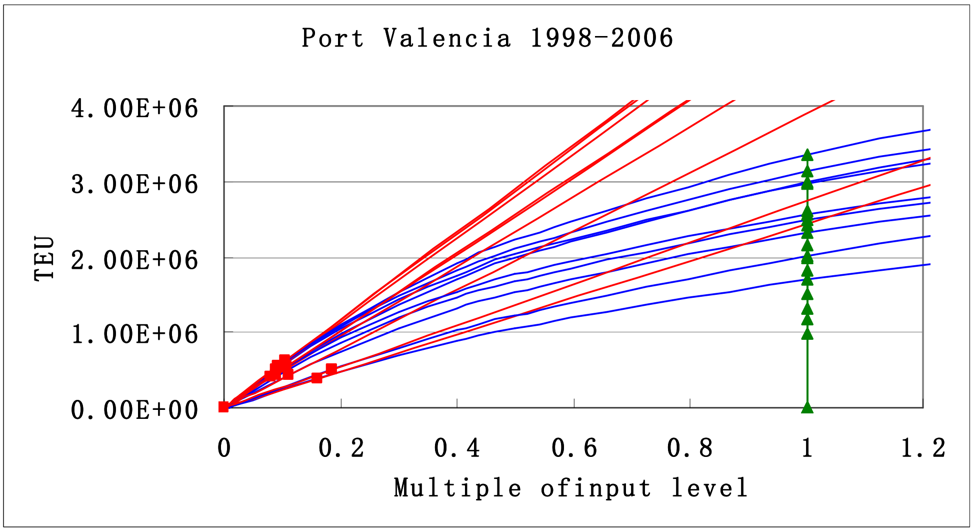
8.5.5.EU port, size large - Port VALENCIA in Spain

Port VALENCIA is one of the major Mediterranean Sea ports recording more than 2,500,000 TEU as throughput in 2006. Port VALENCIA updates its infrastructure and facilities every year, so the t* and SE values change every year (Table 45); the frontier for different years also changes every year (Figure 34). Over the study period the frontier curve of Port VALENCIA moves upwards every year, which indicates that the best practice (optimal technique) is improving. The TE also generally increases, indicating that Port VALENCIA has adapted to new production techniques and is relatively efficient over time. Conversely, the tangent slope of Port VALENCIA generally increases over time as well, which indicates that investment in the inputs has led to better resource combinations. However, we observe that the SE of Port VALENCIA is generally decreasing, which indicates that the real productive ratio does not change much: the SE value decreases as the best productive ratio increases. Moreover, Port VALENCIA shows *decreasing returns to scale* throughout the study period.

Table 45: Efficiency index of Port VALENCIA 1998-2006

Year	Port	t*	SE	TE	total eff.	Throughput
1998	Valencia	0.19	0.73	0.62	0.45	970758
1999	Valencia	0.16	0.70	0.63	0.44	1170191
2000	Valencia	0.08	0.50	0.64	0.32	1308010
2001	Valencia	0.11	0.59	0.65	0.39	1506805
2002	Valencia	0.09	0.54	0.67	0.36	1821005
2003	Valencia	0.11	0.58	0.68	0.39	1992903
2004	Valencia	0.11	0.58	0.69	0.40	2145236
2005	Valencia	0.09	0.55	0.70	0.38	2409821
2006	Valencia	0.09	0.53	0.71	0.38	2612139

Figure 34: Efficiency of Port VALENCIA (1998-2006)

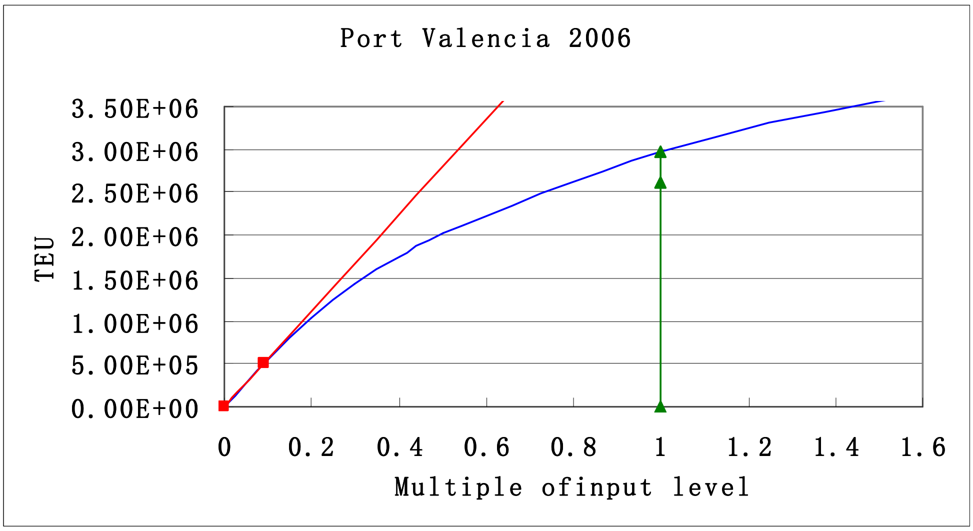


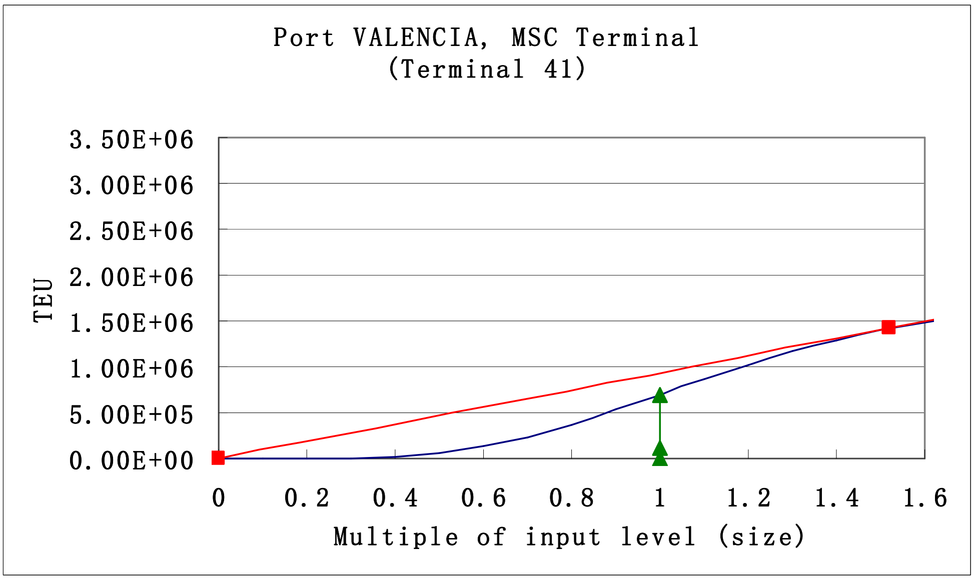
Port VALENCIA has four terminals. In order to compare the analyses of ports and terminals, we take the information of the port (panel data 1998-2006) for year 2006, when the terminal data is collected. Among the four terminals, Felipe is the biggest; it has similar features as the VALENCIA port and shows *decreasing returns to scale*. The three other smaller terminals show *increasing returns to scale*. For the port as a whole, and the Felipe terminal in particular, capacity expansion needs to address the variable and the fixed inputs. For the other three terminals, capacity expansion can be carried out relatively quickly, as they only need to invest in variable inputs in the near future.

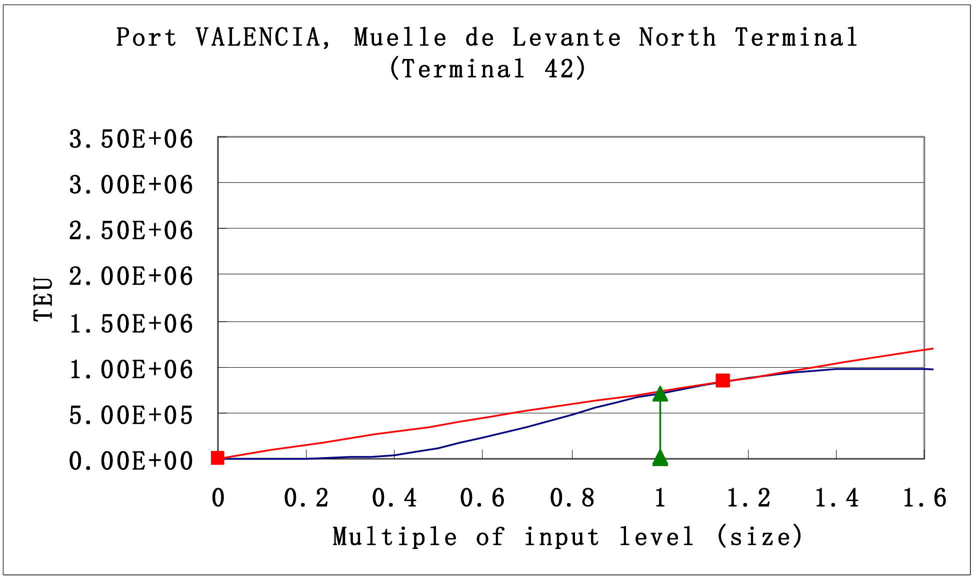
Table 46: Efficiency index of Port VALENCIA and its terminals in 2006

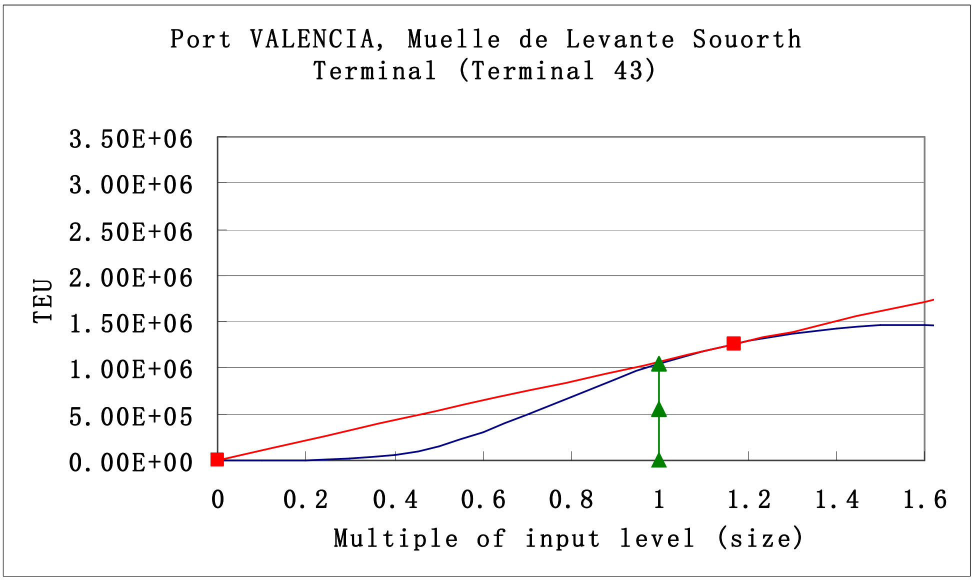
Year	2006	t*	SE	TE	total eff.	Throughput
Port	Valencia	0.09	0.53	0.71	0.38	2612139
Terminal	MSC	1.52	0.74	0.19	0.14	112685
Terminal	Muelle de Levante north	1.14	0.97	0.02	0.02	15000
Terminal	Muelle de Levante south	1.17	0.96	0.56	0.53	560000
Terminal	Felipe	0.87	0.97	0.69	0.66	1890000

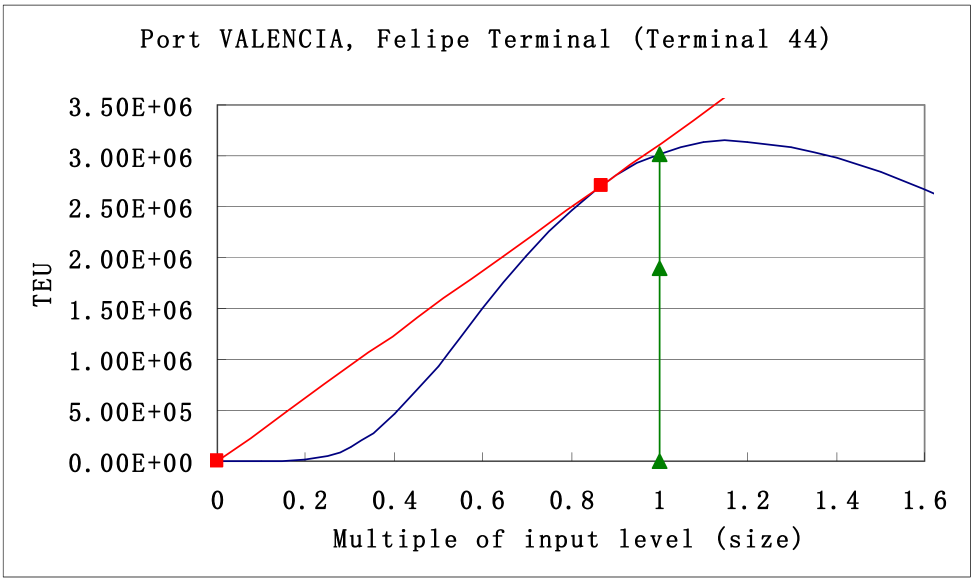
Figure 35: Efficiency of Port VALENCIA and its terminals (2006)




Port VALENCIA, MSC Terminal
(Terminal 41)
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
TEU
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Multiple of input level (size)


Port VALENCIA, Muelle de Levante North Terminal
(Terminal 42)
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
TEU
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Multiple of input level (size)


Port VALENCIA, Muelle de Levante Souorth
Terminal (Terminal 43)
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
TEU
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Multiple of input level (size)



8.6 Conclusions

In this chapter we have compared the efficiency of container ports and terminals in two distinct ways. First, we have examined the sensitivity of our efficiency evaluation in relation to different model specifications. Port and terminal level analyses reach the same conclusion: for our datasets the functional forms in the deterministic part of the model influence efficiency scores more than the distribution assumption in the random part of the model. TE is very sensitive to variable specification changes in the random part of the *gross* models. SE is very sensitive to variable specification changes in the deterministic part of the models. In order to explain this behaviour, we have to keep in mind that scale efficiency is defined as the ratio of productivity between the observed port/terminal size and the optimal size, whereas productivity is calculated by considering the input mix. Technical efficiency is defined as the ratio of the observed output and the optimal output, and the difference between the observed and the optimal output is represented by the random term inefficiency. Therefore, scale efficiency influences the shape of the possible production frontier and technical efficiency is related to the inefficiency term in the random part of the function.

We have then focused our discussion on the North Mediterranean Sea container ports and terminals. We found that in this area most container ports show *decreasing returns to scale* and, at the container terminal level, half of the terminals show *increasing returns to scale*. In the growing container handling market as is the case in the North Mediterranean sea area, *increasing returns to scale* is the preferred status because ports/terminals can invest in the (variable) inputs and expand their capacity reasonably quickly in order to meet increasing demand. In the examined region, for instance, container port traffic has been growing at an average annual rate of 12.2% for the past decade. Therefore, in our study, we find that container terminals can better adapt to this fast-growing market than container ports.

We have also surveyed EU port-related policies and strategies and analysed five representative ports with different political structures (EU, EU-candidate and non-EU countries) and different size groups (annual throughput under 500,000 TEU; over 500,000 but under 2,000,000 TEU; and over 2,000,000 TEU). However, at this research stage it is difficult to identify a specific behaviour and trend related to these different groups. In general we can observe that in the impact of the European Union policy in relation to port and terminal efficiency does not have a primary role within the context of our research study. Given the large EU investments in maritime policy and the economic dynamics of the area, this interesting topic will be a focus of my future research

Chapter 9: Conclusion

9.1 Research findings

In the literature we observed that container ports and terminals are often studied separately; different from the literature, this research analyses efficiency for both container ports and terminals, thus enabling us to compare and understand the differences between them. In thesis quantitative modelling of technical and scale efficiencies of container ports and terminals has been carried out by using the *Stochastic Frontier Analysis* method.

The majority of container ports and terminals in our North Mediterranean Sea dataset are technically inefficient: 90% of the container *ports* have a technical efficiency lower than 0.80; 95% of the container *terminals* have a technical efficiency lower than 0.80. The scale efficiency of the ports and terminals shows a different pattern: at the port level, 40% of all the ports have a scale efficiency larger than 0.80; but at the terminal level, 80% of all terminals have a scale efficiency larger than 0.80. In general we can conclude by observing that low technical efficiency values and relatively high scale efficiency values indicate that input level (the size of the port/terminal) is sufficient, but that container ports and terminals are not using their resources efficiently.

For our datasets, all the models indicate that the deviations from the best possible production performance (the frontier) are due mostly to technical inefficiency rather than statistical noise, which represents factors that are beyond the control of container ports and terminals

At the port level, most container ports show decreasing returns to scale, whereas at the terminal level more than half of the terminals show increasing returns to scale. These results, although counter-intuitive if we consider ports as a collection of terminals, highlight the importance of input mix in port and terminal operations. In particular as discussed in Chapter 8, within the context of the North Mediterranean Basin, increasing returns to scale is the preferred status because it determines an incentive to invest in the inputs in order to expand capacity and capture the benefits of increased traffic. The implication is that container terminals are better adapted than container ports to meet growing market demand.

We examine the impact on production and efficiency of three factors: trade volume (in US dollars), terminal type and operator type, and we model their impacts in two ways: we first assume that they influence production directly and then we assume that they influence technical efficiency directly. The comparison between the results of these two estimation assumptions enables us to understand how certain variables affect operations in a container port/terminal. The analysis indicates that the influence of trading volume on the production of container ports is more significant than its influence the technical efficiency, whereas terminal type and operator type have more significant direct influence on container terminal efficiency. Nevertheless, trading volume shows a positive effect on port technical efficiency as well as on output, since an increase in trading volume increases output and reduces technical inefficiency. Terminal type also has significant influence on the productivity and efficiency of container terminals. We show that container-only terminals are more productive than multi-purpose terminals with regard to handling containers. However, we demonstrate that operator type does not impact on the productivity and efficiency of container terminals and therefore that global container terminal operators cannot always be assumed to be preferable to local operators.

The annual percentage change in output due to technological change over time is negative in our panel data. This result was not predicted, as the container handling technique is not expected to deteriorate over time. The negative trend is due to other factors in the market and the main factor is overcapacity. Overcapacity is a common and necessary characteristic of container ports and terminals because productive headroom not only attracts more traffic to the port, but is also a signal of its reliability, a factor of paramount importance for port users. With generally expanding trading volumes and a volatile market, a bigger capacity reserve is a rational strategy, and the growing proportion of excess capacity is reflected in the 'negative' technique change in infrastructure efficiency.

Technical efficiency indicates how well the container port and terminal produces the output given the input recourses available to them. When capacity is greater than the market demand, the idle capacity is reflected in the technical inefficiency. We show in the analyses that technical efficiency is generally improving over time. In the *net* effect models of panel data, technical efficiency improves continuously. In the *gross* effect models when no investment occurs, the technical efficiency increases over time. However, when investment is applied, technical efficiency may or may not reduce in that year. The reduction of technical efficiency after investment indicates that the capacity expansion is larger than the growth of container traffic, whereas the continued increase of technical efficiency of investment in inputs indicates that container traffic growth is larger than the capacity expansion.

We find that technical efficiency is very sensitive to variable specification changes in the random part of the *gross* models and scale efficiency is very sensitive to variable specification changes in the deterministic part of the models. The functional forms in the deterministic part of the model influence technical and scale efficiency scores more than the distribution assumptions in the random part of the model affect technical and scale efficiency scores.

The most adequate models for port data were found to be the net effect models, whereas gross effect models are found to be most effective for the terminal data. However, the real strength of this multi-faceted modelling approach is in our ability to derive conclusions from a comparison of the results of different model specifications. This has allowed us to analyse whether certain factors influence production/output or affect efficiency, and has therefore allowed us to better understand inefficiency.

We also demonstrate through the cross-sectional data analysis how changing the size of the container port/terminal can improve the scale efficiency using increasing, decreasing and constant returns to scale, respectively. Moreover, through the panel data analysis, we show how the change in input mix (investment) may impact on the optimal productivity, and thus on the scale efficiency. This research fills a gap in which scale efficiency had previously only been studied by the Data Envelopment Analysis in the container port industry, and we also advance the literature not only by quantifying the degree of scale efficiency but also showing how to improve it by adjusting the input level.

9.2 Policy implications: the regional context

The North Mediterranean Sea area forms a natural laboratory for studying and understanding the port industry owing to its geographic location and unique political arrangements. In terms of location, the North Mediterranean Sea is the gateway to Asia-Europe trading traffic, one of the most significant global container trading routes (Medda and Carbonaro, 2007). Because there are eight European contries situated within our research zone, in addition to their nation-wide policy, the European Union also provides strong regional level regulation. The European Union has actively promoted the integration of trade and transport facilities throughout EU member countries and neighbouring countries (Notteboom, 2002). Many innovative and pioneering programmes were first initiated by the European Union in this region, e.g. Short Sea Shipping, (Trujillo et al., 2009) and these are now promoted on different continents.

In the discussion of this research we have shown that the main causes of inefficiency in container ports in the North Mediterranean Sea area are due to overcapacity and the effect of trade fluctuations. The impacts of trade fluctuations is a difficult problem to solve at the port and terminal levels, and only through a concerted planning structure can we diminish the negative effects. On the other hand, the inefficiency related to overcapacity can be ascribed to the port management. However, in the context of our regional focus, although overcapacity is controllable by the operator, its presence is often necessary to ensure reliability of the service.

The solutions for the overcapacity inefficiency and thus the possible policy implications differ in accordance with the maritime stakeholders. If we consider the port and terminal management, focus should be placed on improving operational flexibility in order to meet peaks in carrying demand and thus reducing levels of inefficiency induced by overcapacity. For governments, the implication is that measures must be put in place to assist port operators in coping with the extremes of trade fluctuations. As inefficiency of this type will be primarily evident during times of economic downturn, when ports retain idle productive capacity, governments may reduce inefficiency by implementing policy that aims to divert trade volumes to seaborne routes.

As we have shown in the previous chapters, global terminal operators, although they can draw from a cross-country experience, nevertheless in our context do not perform in a more efficient way than local operators. At this point our question is, why is the market share of global terminal operators increasing continuously (Van De Voorde and Vanelslander, 2008)? In the Mediterranean Basin the industrial strategy of global terminal operators in the last two decades has been to acquire local terminals with satisfactory efficiency levels (Notteboom, 1997). This strategy has paid off, because by following this type of acquisition, global terminal operators do not need to upgrade the operations and performance of the acquired terminals. The implication of this is that, over the long-term, the Mediterranean area will be dominated by strong global terminals in which investment will be directed towards efficiency improvements, thus constraining competition amongst terminals in the market. We therefore envisage a trend from a strong competitive market which exists at present in the Basin, towards an increasing development of dominant terminals with specialised operations.

In the Mediterranean Basin, the port organisation is usually under public sector ownership, whereas most container terminals are operated by private companies (Trujillo and Tovar, 2008). Our research found different returns to scale status for port and terminal levels, but interestingly, as has been discussed in the thesis, given their organisation and structure, terminals are more suitable to cope with the continuously growing container port traffic, particularly in the dynamic Mediterranean Sea region. The implication of the differential returns to scale between ports and terminals is that, in order to increase efficiency, it is necessary to implement greater coordination and partnerships between ports and terminals and between the public and private sector. Public port authorities should therefore encourage consolidation amongst private terminal operators within their ports, thus allowing terminals to expand their capacity to larger scales when necessary. In addition, the port authority must take into consideration the possibility that, by allowing the private terminal operator to gain sufficient scale, this may lead to monopolistic practices in the port, thus resulting in distorted competition practice.

9.3 Limitations of the research

In conducting this research we have encountered several limitations. The panel dataset includes container ports information from 1998 to 2006. Although this period also covers one global economic recession, it does not include the current economic downturn, which began at the end of 2007.

Another limitation of this research relates to the input variables: infrastructure and machinery information. These variables provide fundamental and necessary information about container port and terminal operations, but they do not capture the various physical configurations of ports and terminals. We were also unable to obtain labour information: such information would have enriched the analysis.

When we have discussed the output variable, annual throughput in TEU, the standard output measurement for container ports and terminals, we have observed that it omits other kinds of goods handled by multi-purpose terminals. If other output information had been available we could have applied the distance function in order to estimate the efficiency of multiple output container ports and terminals.

Finally, we were unable to obtain the cost information of operating container ports and terminals. Access to, for example, the disaggregated cost of handling different cargo, e.g. containers, rolling stock, bulk, non-containerised cargo, would have allowed us to estimate the efficiency in a much more detailed way.

9.4 Future research on port and terminal efficiency

A number of questions arising in this thesis require further study. We have demonstrated how to improve scale efficiency by adjusting input level (size), and have shown that scale efficiency is affected by the input mix. The information on how to change input level and input mix in order to achieve the maximum output for resource-constrained container ports and terminals is very useful for decision-makers. However, in our study, in relation to the input mix changes we cannot yet predict how to change the input mix in order to achieve optimal scale efficiency and furthermore, how the productivity ratio changes in relation to the input mix change. The comparison between pre-change and post-change of input mix of a container port cannot be made directly unless the cost information of all the inputs is available.

When the monetary value of inputs is available, we will then be able to quantify the changes across different input variables and compare the input mix change. If information on the input price is available, the input mix can be studied as allocative efficiency in frontier analysis; further research on this topic is necessary in order to obtain the optimal mix of inputs.

In this research we have studied global and local terminal operators. Another distinct classification of container terminal operators are carrier-operated terminals and pure terminal operators. Carrier-operated terminals are managed by liner companies, whereas pure terminal operators are merely managed by companies specialised in terminal operations. Nowadays one terminal is operated and often owned by many different companies with different proportions of ownership. For example, terminal Nuova Darsena di Levante in the Port of Naples, is owned by COSCO Container line, MSC, and the Fremura Group, and the operating owner is Terminale Levante. Therefore, the terminal is owned by two big shipping companies as well as a logistics company, and is operated by a pure terminal operator. Given the complexity of the operations management and ownership structure of container ports and terminals, the following questions emerge: Whether and how much will a shipping line benefit from being the owner of terminals? Whether and how much will the port benefit from the carrier-operated terminal arrangement? And finally, what are the effects of different ownership structures on container terminal efficiency and productivity? The investigation of these questions will be the focus of our future research.

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Appendix

Appendix 1: Estimated parameter values for port level data, Cobb-Douglas

Model No.	1.1.1.3	1.1.2.3	1.1.3.3	1.1.4.3	1.1.3.4
Intercept	9.94 (8.37)	9.88 (8.32)	2.40 (2.40)	-14.80 (1.44)	6.04 (9.75)
Berth length	0.18 (1.30)	0.19 (1.29)	0.72 (0.72)	0.20 (1.44)	0.26 (3.51)
Terminal area	-0.02 (0.26)	-0.02 (0.25)	0.17 (0.17)	-0.01 (0.18)	0.14 (2.05)
Storage	0.03 (0.99)	0.03 (0.97)	0.05 (0.05)	0.04 (1.15)	0.02 (1.36)
Handling capacity	0.48 (5.15)	0.49 (4.99)	0.58 (0.58)	0.49 (5.19)	0.70 (9.02)
Europe Trading Volume (z)			0.00 (0.00)	0.84 (2.41)	-0.00 (0.68)
Trand		-0.01 (0.40)	-0.04 (0.04)	-0.09 (2.30)	-0.05 (2.37)
sigma-squared (σ^2)	3.58 (1.34)	3.44 (1.30)	-3.12 (3.12)	3.43 (1.29)	24.10 (0.65)
Gamma(γ)	0.95 (23.00)	0.94 (21.60)	0.92 (0.92)	0.95 (22.10)	1.00 (176.00)
Mu(μ) or intercept of z	-0.12 (0.06)	-0.09 (0.04)	0.00 (0.00)	-0.20 (0.10)	-3.22 (0.26)
Eta(η)	0.04 (6.05)	0.04 (4.18)	0.00 (0.00)	0.04 (4.27)	
log likelihood function	-226.95	-226.88	-253.04	-224.00	-376.81

Appendix 2: The technical efficiency index from Model 1.1.1.3

Model 1.1.1.3: Cobb-Douglas functional form with **four inputs**

$$\ln y_{nt} = \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} \quad + v_{nt} - u_{nt}$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.91	0.91	0.92	0.92	0.92	0.93	0.93	0.93	0.93
Alicante	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.22	0.23
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.03	0.03	0.04
Bar	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03
Barcelona	0.54	0.55	0.56	0.58	0.59	0.60	0.61	0.62	0.63
Bari	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Cadiz	0.05	0.06	0.06	0.07	0.07	0.08	0.09	0.10	0.10
Cagliari	N/A	N/A	N/A	0.28	0.29	0.30	0.31	0.33	0.34
Cartagena	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.15
Genoa	0.56	0.57	0.58	0.60	0.61	0.62	0.63	0.64	0.65
Gioia Tauro	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.87	0.88
Izmir	0.54	0.55	0.56	0.57	0.58	N/A	0.61	0.62	0.63
Koper	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.21
La Spezia	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70
Leghorn	0.20	0.22	0.23	0.24	0.25	0.26	0.28	0.29	0.30
Marsaxlokk	0.53	0.54	0.55	0.56	0.57	0.59	0.60	0.61	0.62
Marseilles	0.34	0.35	0.36	0.37	0.39	0.40	0.41	0.43	0.44
Mersin	0.21	0.22	0.24	0.25	0.26	0.27	0.28	0.30	0.31
Naples	0.34	0.36	0.37	0.38	0.40	0.41	0.42	0.43	0.45
Piraeus	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.82	0.83
Ravenna	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Rijeka	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.05	0.06
Salerno	0.26	0.27	0.28	0.29	0.31	0.32	0.33	0.34	0.36
Sete	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.08
Seville	0.15	0.16	0.18	0.19	0.20	0.21	0.22	0.23	0.24
Taranto	N/A	N/A	N/A	N/A	0.38	0.40	0.41	0.42	0.43
Tarragona	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.07
Thessaloniki	0.27	0.28	0.29	0.31	0.32	0.33	0.35	0.36	0.37
Trieste	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14
Valencia	0.63	0.64	0.65	0.65	0.66	0.67	0.68	0.69	0.70
Valletta	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
Venice	0.26	0.28	0.29	0.30	0.31	0.33	0.34	0.35	0.36

Appendix 3: The technical efficiency index from Model 1.1.2.3

Model 1.1.2.3: Cobb-Douglas functional form with four inputs and **a trend variable**.

$$\ln y_{nt} = \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 t \quad + v_{nt} - u_{nt}$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.91	0.91	0.91	0.92	0.92	0.92	0.93	0.93	0.93
Alicante	0.14	0.15	0.16	0.17	0.18	0.19	0.21	0.22	0.23
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.03	0.04	0.04
Bar	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03
Barcelona	0.53	0.54	0.55	0.56	0.58	0.59	0.60	0.61	0.62
Bari	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Cadiz	0.05	0.05	0.06	0.07	0.07	0.08	0.09	0.10	0.11
Cagliari	N/A	N/A	N/A	0.28	0.29	0.30	0.32	0.33	0.34
Cartagena	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14	0.15
Genoa	0.55	0.56	0.58	0.59	0.60	0.61	0.62	0.63	0.64
Gioia Tauro	0.83	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.87
Izmir	0.54	0.55	0.56	0.58	0.59	N/A	0.61	0.62	0.63
Koper	0.12	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.21
La Spezia	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70
Leghorn	0.20	0.21	0.22	0.24	0.25	0.26	0.28	0.29	0.30
Marsaxlokk	0.52	0.53	0.55	0.56	0.57	0.58	0.59	0.60	0.62
Marseilles	0.33	0.34	0.36	0.37	0.38	0.40	0.41	0.42	0.44
Mersin	0.21	0.22	0.23	0.25	0.26	0.27	0.29	0.30	0.31
Naples	0.34	0.35	0.37	0.38	0.40	0.41	0.42	0.44	0.45
Piraeus	0.78	0.78	0.79	0.80	0.80	0.81	0.82	0.82	0.83
Ravenna	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Rijeka	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.05	0.06
Salerno	0.25	0.27	0.28	0.29	0.31	0.32	0.33	0.35	0.36
Sete	0.04	0.04	0.05	0.05	0.06	0.07	0.07	0.08	0.09
Seville	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25
Taranto	N/A	N/A	N/A	N/A	0.39	0.40	0.41	0.43	0.44
Tarragona	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.07
Thessaloniki	0.27	0.28	0.30	0.31	0.32	0.34	0.35	0.36	0.38
Trieste	0.07	0.08	0.09	0.10	0.10	0.11	0.12	0.13	0.14
Valencia	0.61	0.62	0.64	0.65	0.66	0.67	0.68	0.69	0.69
Valletta	0.13	0.14	0.15	0.16	0.18	0.19	0.20	0.21	0.22
Venice	0.26	0.28	0.29	0.30	0.32	0.33	0.34	0.36	0.37

Appendix 4: The technical efficiency index from Model 1.1.3.3

Model 1.1.3.3: Cobb-Douglas functional form with four inputs, a trend variable and **a NET exogenous variable**: EU trading volume.

$$\ln y_{nt} = \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 z + \alpha_6 t + v_{nt} - u_{nt}$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.852	0.852	0.852	0.852	0.852	0.852	0.852	0.852	0.852
Alicante	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.074	0.074	0.074
Bar	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Barcelona	0.277	0.277	0.277	0.277	0.277	0.277	0.277	0.277	0.277
Bari	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Cadiz	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
Cagliari	N/A	N/A	N/A	0.320	0.320	0.320	0.320	0.320	0.320
Cartagena	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171
Genoa	0.281	0.281	0.281	0.281	0.281	0.281	0.281	0.281	0.281
Gioia Tauro	0.526	0.526	0.526	0.526	0.526	0.526	0.526	0.526	0.526
Izmir	0.876	0.876	0.876	0.876	0.876	N/A	0.876	0.876	0.876
Koper	0.388	0.388	0.388	0.388	0.388	0.388	0.388	0.388	0.388
La Spezia	0.787	0.787	0.787	0.787	0.787	0.787	0.787	0.787	0.787
Leghorn	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161
Marsaxlokk	0.435	0.435	0.435	0.435	0.435	0.435	0.435	0.435	0.435
Marseilles	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234
Mersin	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Naples	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753
Piraeus	0.565	0.565	0.565	0.565	0.565	0.565	0.565	0.565	0.565
Ravenna	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156	0.156
Rijeka	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
Salerno	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510	0.510
Sete	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199
Seville	0.804	0.804	0.804	0.804	0.804	0.804	0.804	0.804	0.804
Taranto	N/A	N/A	N/A	N/A	0.375	0.375	0.375	0.375	0.375
Tarragona	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129	0.129
Thessaloniki	0.657	0.657	0.657	0.657	0.657	0.657	0.657	0.657	0.657
Trieste	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
Valencia	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340
Valletta	0.650	0.650	0.650	0.650	0.650	0.650	0.650	0.650	0.650
Venice	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734

Appendix 5: The technical efficiency index from Model 1.1.4.3

Model 1.1.4.3: Cobb-Douglas functional form with four inputs, a trend variable and **a NET exogenous variable**: **Logged** EU trading volume.

$$\ln y_{nt} = \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 \ln z + \alpha_6 t \quad + v_{nt} - u_{nt}$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.91	0.91	0.92	0.92	0.92	0.93	0.93	0.93	0.93
Alicante	0.14	0.16	0.17	0.18	0.19	0.21	0.22	0.23	0.25
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.03	0.04	0.04
Bar	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03
Barcelona	0.53	0.54	0.55	0.57	0.58	0.59	0.60	0.62	0.63
Bari	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Cadiz	0.05	0.06	0.06	0.07	0.08	0.08	0.09	0.10	0.11
Cagliari	N/A	N/A	N/A	0.29	0.30	0.31	0.33	0.34	0.36
Cartagena	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.16	0.17
Genoa	0.54	0.55	0.56	0.58	0.59	0.60	0.61	0.63	0.64
Gioia Tauro	0.83	0.83	0.84	0.84	0.85	0.86	0.86	0.87	0.87
Izmir	0.56	0.57	0.58	0.59	0.61	N/A	0.63	0.64	0.65
Koper	0.13	0.14	0.15	0.16	0.17	0.18	0.20	0.21	0.22
La Spezia	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71
Leghorn	0.19	0.21	0.22	0.23	0.25	0.26	0.28	0.29	0.30
Marsaxlokk	0.52	0.53	0.55	0.56	0.57	0.59	0.60	0.61	0.62
Marseilles	0.33	0.34	0.36	0.37	0.39	0.40	0.42	0.43	0.44
Mersin	0.21	0.22	0.23	0.25	0.26	0.28	0.29	0.30	0.32
Naples	0.37	0.38	0.40	0.41	0.42	0.44	0.45	0.47	0.48
Piraeus	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.83	0.83
Ravenna	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.18
Rijeka	0.02	0.03	0.03	0.03	0.04	0.05	0.05	0.06	0.06
Salerno	0.27	0.28	0.30	0.31	0.33	0.34	0.36	0.37	0.39
Sete	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.09	0.10
Seville	0.16	0.17	0.19	0.20	0.21	0.22	0.24	0.25	0.27
Taranto	N/A	N/A	N/A	N/A	0.39	0.41	0.42	0.44	0.45
Tarragona	0.03	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.08
Thessaloniki	0.28	0.29	0.31	0.32	0.34	0.35	0.37	0.38	0.39
Trieste	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
Valencia	0.60	0.61	0.62	0.63	0.65	0.66	0.67	0.68	0.69
Valletta	0.14	0.15	0.16	0.18	0.19	0.20	0.21	0.23	0.24
Venice	0.27	0.28	0.30	0.31	0.33	0.34	0.36	0.37	0.39

Appendix 6: The technical efficiency index from Model 1.1.3.4

Model 1.1.3.4: Cobb-Douglas functional form with four inputs, a trend variable and **a GROSS exogenous variable**: EU trading volume.

$$\ln y_{nt} = \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 t + v_{nt} - u_{nt}$$

$$m_{nt} = \delta_0 + z_t \delta_1$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.81	0.89	0.73	0.79	0.81	0.85	0.88	0.90	0.87
Alicante	0.30	0.25	0.39	0.48	0.50	0.56	0.61	0.42	0.48
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.05	0.09	0.12
Bar	0.02	0.05	0.02	0.01	0.03	0.02	0.03	0.04	0.06
Barcelona	0.41	0.39	0.45	0.48	0.52	0.60	0.67	0.64	0.55
Bari	0.00	0.01	0.00	0.01	0.02	0.03	0.03	0.02	0.02
Cadiz	0.05	0.05	0.11	0.10	0.11	0.17	0.13	0.17	0.20
Cagliari	N/A	N/A	N/A	0.32	0.38	0.32	0.54	0.54	0.73
Cartagena	0.82	0.84	0.14	0.09	0.13	0.13	0.09	0.12	0.14
Genoa	0.42	0.44	0.74	0.74	0.44	0.49	0.56	0.68	0.51
Gioia Tauro	0.72	0.63	0.72	0.71	0.78	0.81	0.78	0.79	0.78
Izmir	0.87	0.89	0.77	0.35	0.58	N/A	0.79	0.79	0.83
Koper	0.19	0.20	0.23	0.27	0.34	0.40	0.51	0.61	0.72
La Spezia	0.64	0.69	0.78	0.84	0.85	0.86	0.75	0.82	0.78
Leghorn	0.33	0.27	0.22	0.25	0.27	0.42	0.29	0.21	0.22
Marsaxlokk	0.81	0.57	0.45	0.56	0.61	0.60	0.63	0.64	0.74
Marseilles	0.26	0.30	0.46	0.38	0.43	0.47	0.54	0.53	0.57
Mersin	0.34	0.37	0.22	0.14	0.28	0.24	0.50	0.58	0.64
Naples	0.55	0.59	0.54	0.64	0.68	0.69	0.62	0.68	0.76
Piraeus	0.86	0.91	0.72	0.72	0.75	0.81	0.81	0.76	0.78
Ravenna	0.31	0.18	0.16	0.28	0.03	0.31	0.35	0.36	0.37
Rijeka	0.03	0.03	0.04	0.06	0.07	0.14	0.33	0.28	0.37
Salerno	0.28	0.31	0.59	0.57	0.72	0.77	0.61	0.76	0.72
Sete	0.06	0.08	0.06	0.07	0.07	0.08	0.74	0.76	0.81
Seville	0.38	0.43	0.56	0.63	0.65	0.68	0.73	0.76	0.80
Taranto	N/A	N/A	N/A	N/A	0.46	0.54	0.55	0.49	0.62
Tarragona	0.07	0.09	0.11	0.09	0.31	0.36	0.17	0.06	0.09
Thessaloniki	0.59	0.46	0.51	0.54	0.48	0.59	0.75	0.79	0.82
Trieste	0.09	0.16	0.10	0.14	0.13	0.09	0.15	0.19	0.22
Valencia	0.58	0.56	0.41	0.54	0.59	0.66	0.67	0.71	0.78
Valletta	0.64	0.65	0.70	0.64	0.70	0.74	0.82	0.84	0.80
Venice	0.47	0.47	0.50	0.60	0.65	0.71	0.74	0.76	0.73

Appendix 7: The technical efficiency index from Model 1.2.1.3

Model 1.2.1.3: Translog functional form with **four inputs**

$$\begin{aligned} \ln y_{nt} = {} & \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} \\ & + \alpha_5 \ln x_{1nt} \ln x_{2nt} + \alpha_6 \ln x_{1nt} \ln x_{3nt} + \alpha_7 \ln x_{1nt} \ln x_{4nt} + \alpha_8 \ln x_{2nt} \ln x_{3nt} + \alpha_9 \ln x_{2nt} \ln x_{4nt} + \alpha_{10} \ln x_{3n} \\ & + 1/2\alpha_{11} (\ln x_{1nt})^2 + 1/2\alpha_{12} (\ln x_{2nt})^2 + 1/2\alpha_{13} (\ln x_{3nt})^2 + 1/2\alpha_{14} (\ln x_{4nt})^2 \\ & + v_{nt} - u_{nt} \end{aligned}$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.89	0.89	0.89	0.90	0.90	0.91	0.91	0.91	0.92
Alicante	0.28	0.29	0.31	0.32	0.34	0.35	0.37	0.38	0.40
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.02	0.03	0.03
Bar	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.08
Barcelona	0.88	0.88	0.89	0.89	0.90	0.90	0.90	0.91	0.91
Bari	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Cadiz	0.04	0.05	0.05	0.06	0.07	0.07	0.08	0.09	0.10
Cagliari	N/A	N/A	N/A	0.23	0.25	0.26	0.28	0.29	0.31
Cartagena	0.11	0.13	0.14	0.15	0.16	0.17	0.19	0.20	0.21
Genoa	0.63	0.64	0.65	0.67	0.68	0.69	0.70	0.71	0.72
Gioia Tauro	0.85	0.86	0.86	0.87	0.87	0.88	0.88	0.89	0.89
Izmir	0.73	0.74	0.75	0.76	0.76	N/A	0.78	0.79	0.80
Koper	0.14	0.15	0.16	0.18	0.19	0.20	0.22	0.23	0.25
La Spezia	0.55	0.56	0.58	0.59	0.60	0.61	0.63	0.64	0.65
Leghorn	0.19	0.21	0.22	0.24	0.25	0.27	0.28	0.30	0.31
Marsaxlokk	0.44	0.46	0.47	0.49	0.50	0.52	0.53	0.55	0.56
Marseilles	0.35	0.37	0.38	0.40	0.41	0.43	0.44	0.46	0.48
Mersin	0.23	0.25	0.26	0.28	0.29	0.31	0.32	0.34	0.35
Naples	0.40	0.41	0.43	0.44	0.46	0.47	0.49	0.50	0.52
Piraeus	0.84	0.84	0.85	0.85	0.86	0.86	0.87	0.87	0.88
Ravenna	0.08	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16
Rijeka	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06
Salerno	0.24	0.26	0.27	0.29	0.30	0.32	0.33	0.35	0.36
Sete	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.07
Seville	0.70	0.71	0.72	0.73	0.74	0.75	0.75	0.76	0.77
Taranto	N/A	N/A	N/A	N/A	0.39	0.40	0.42	0.43	0.45
Tarragona	0.04	0.04	0.05	0.05	0.06	0.07	0.08	0.08	0.09
Thessaloniki	0.23	0.25	0.26	0.28	0.29	0.31	0.32	0.34	0.35
Trieste	0.06	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13
Valencia	0.62	0.63	0.64	0.65	0.67	0.68	0.69	0.70	0.71
Valletta	0.54	0.55	0.57	0.58	0.59	0.61	0.62	0.63	0.64
Venice	0.28	0.29	0.31	0.33	0.34	0.36	0.37	0.39	0.40

Appendix 8: The Technical efficiency index from Model 1.2.2.3

Model 1.2.2.3: Translog functional form with four inputs and **a trend variable**.

$$\begin{aligned}\ln y_{nt} &= \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 t \\ &+ \alpha_6 \ln x_{1nt} \ln x_{2n} + \alpha_7 \ln x_{1nt} \ln x_{3nt} + \alpha_8 \ln x_{1nt} \ln x_{4nt} + \alpha_9 \ln x_{2nt} \ln x_{3nt} + \alpha_{10} \ln x_{2nt} \ln x_{4nt} + \alpha_{11} \ln x_{3nt} \ln x_{4nt} \\ &+ 1/2\alpha_{12} (\ln x_{1nt})^2 + 1/2\alpha_{13} (\ln x_{2nt})^2 + 1/2\alpha_{14} (\ln x_{3nt})^2 + 1/2\alpha_{15} (\ln x_{4nt})^2 \\ &+ v_{nt} - u_{nt}\end{aligned}$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.88	0.89	0.89	0.90	0.90	0.90	0.91	0.91	0.92
Alicante	0.25	0.27	0.28	0.30	0.32	0.34	0.35	0.37	0.39
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.02	0.03	0.03
Bar	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07	0.08
Barcelona	0.87	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.91
Bari	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Cadiz	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11
Cagliari	N/A	N/A	N/A	0.23	0.25	0.27	0.28	0.30	0.32
Cartagena	0.12	0.13	0.15	0.16	0.18	0.19	0.21	0.22	0.24
Genoa	0.61	0.62	0.64	0.65	0.66	0.68	0.69	0.70	0.71
Gioia Tauro	0.84	0.85	0.85	0.86	0.87	0.87	0.88	0.88	0.89
Izmir	0.71	0.72	0.73	0.74	0.75	N/A	0.77	0.78	0.79
Koper	0.13	0.14	0.16	0.17	0.19	0.20	0.22	0.23	0.25
La Spezia	0.55	0.56	0.58	0.59	0.61	0.62	0.64	0.65	0.66
Leghorn	0.19	0.20	0.22	0.24	0.25	0.27	0.29	0.30	0.32
Marsaxlokk	0.43	0.45	0.47	0.48	0.50	0.52	0.53	0.55	0.56
Marseilles	0.34	0.36	0.38	0.40	0.41	0.43	0.45	0.47	0.48
Mersin	0.24	0.25	0.27	0.29	0.30	0.32	0.34	0.36	0.37
Naples	0.38	0.40	0.42	0.43	0.45	0.47	0.48	0.50	0.52
Piraeus	0.83	0.84	0.84	0.85	0.86	0.86	0.87	0.87	0.88
Ravenna	0.07	0.08	0.09	0.10	0.12	0.13	0.14	0.15	0.17
Rijeka	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.06
Salerno	0.24	0.25	0.27	0.29	0.30	0.32	0.34	0.35	0.37
Sete	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.07
Seville	0.67	0.68	0.70	0.71	0.72	0.73	0.74	0.75	0.76
Taranto	N/A	N/A	N/A	N/A	0.40	0.41	0.43	0.45	0.47
Tarragona	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.09	0.10
Thessaloniki	0.22	0.24	0.25	0.27	0.29	0.30	0.32	0.34	0.36
Trieste	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.13	0.14
Valencia	0.60	0.61	0.63	0.64	0.65	0.67	0.68	0.69	0.70
Valletta	0.48	0.50	0.51	0.53	0.54	0.56	0.58	0.59	0.60
Venice	0.26	0.28	0.30	0.32	0.33	0.35	0.37	0.39	0.40

Appendix 9: The technical efficiency index from Model 1.2.3.3

Model 1.2.3.3: Translog functional form with four inputs, a trend variable and **a NET exogenous variable**: EU trading volume.

$$\begin{aligned}\ln y_{nt} &= \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 z + \alpha_6 t \\ &+ \alpha_7 \ln x_{1nt} \ln x_{2nt} + \alpha_8 \ln x_{1nt} \ln x_{3nt} + \alpha_9 \ln x_{1nt} \ln x_{4nt} + \alpha_{10} \ln x_{2nt} \ln x_{3nt} + \alpha_{11} \ln x_{2nt} \ln x_{4nt} + \alpha_{12} \ln x_{3nt} \ln x_{4nt} \\ &+ 1/2\alpha_{13}(\ln x_{1nt})^2 + 1/2\alpha_{14}(\ln x_{2nt})^2 + 1/2\alpha_{15}(\ln x_{3nt})^2 + 1/2\alpha_{16}(\ln x_{4nt})^2 \\ &+ v_{nt} - u_{nt}\end{aligned}$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.91	0.92
Alicante	0.17	0.19	0.21	0.23	0.24	0.26	0.28	0.30	0.32
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.02	0.03	0.03
Bar	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.09
Barcelona	0.87	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.91
Bari	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02
Cadiz	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.12
Cagliari	N/A	N/A	N/A	0.25	0.26	0.28	0.30	0.32	0.34
Cartagena	0.15	0.17	0.18	0.20	0.22	0.24	0.25	0.27	0.29
Genoa	0.59	0.61	0.62	0.64	0.66	0.67	0.68	0.70	0.71
Gioia Tauro	0.84	0.85	0.85	0.86	0.87	0.87	0.88	0.89	0.89
Izmir	0.69	0.70	0.71	0.73	0.74	N/A	0.76	0.77	0.78
Koper	0.12	0.14	0.15	0.17	0.18	0.20	0.22	0.24	0.26
La Spezia	0.55	0.57	0.58	0.60	0.62	0.63	0.65	0.66	0.68
Leghorn	0.18	0.20	0.22	0.23	0.25	0.27	0.29	0.31	0.33
Marsaxlokk	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.55	0.57
Marseilles	0.34	0.36	0.38	0.40	0.42	0.43	0.45	0.47	0.49
Mersin	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.41
Naples	0.37	0.39	0.41	0.43	0.45	0.46	0.48	0.50	0.52
Piraeus	0.81	0.82	0.83	0.84	0.85	0.85	0.86	0.87	0.87
Ravenna	0.07	0.08	0.09	0.11	0.12	0.13	0.15	0.17	0.18
Rijeka	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.07
Salerno	0.23	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39
Sete	0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07
Seville	0.64	0.65	0.67	0.68	0.70	0.71	0.72	0.73	0.75
Taranto	N/A	N/A	N/A	N/A	0.42	0.43	0.45	0.47	0.49
Tarragona	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.10	0.11
Thessaloniki	0.21	0.23	0.25	0.27	0.29	0.31	0.33	0.35	0.37
Trieste	0.05	0.06	0.07	0.08	0.09	0.10	0.12	0.13	0.15
Valencia	0.58	0.60	0.62	0.63	0.65	0.66	0.68	0.69	0.71
Valletta	0.35	0.37	0.39	0.41	0.43	0.45	0.47	0.49	0.51
Venice	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.41

Appendix 10: The technical efficiency index from Model 1.2.4.3

Model 1.2.4.3: Translog functional form with four inputs, a trend variable and **a NET exogenous variable**: **Logged** EU trading volume.

$$
\begin{aligned}
\ln y_{nt} &= \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 \ln z + \alpha_6 t \\
&+ \alpha_7 \ln x_{1nt} \ln x_{2nt} + \alpha_8 \ln x_{1nt} \ln x_{3nt} + \alpha_9 \ln x_{1nt} \ln x_{4nt} + \alpha_{10} \ln x_{2nt} \ln x_{3nt} + \alpha_{11} \ln x_{2nt} \ln x_{4nt} + \alpha_{12} \ln x_{3nt} \ln x_{4nt} \\
&+ 1/2\alpha_{13} (\ln x_{1nt})^2 + 1/2\alpha_{14} (\ln x_{2nt})^2 + 1/2\alpha_{15} (\ln x_{3nt})^2 + 1/2\alpha_{16} (\ln x_{4nt})^2 \\
&+ v_{nt} - u_{nt}
\end{aligned}
$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.88	0.88	0.89	0.90	0.90	0.91	0.91	0.91	0.92
Alicante	0.17	0.19	0.21	0.23	0.24	0.26	0.28	0.30	0.32
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.02	0.03	0.03
Bar	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.09
Barcelona	0.87	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.91
Bari	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02
Cadiz	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.12
Cagliari	N/A	N/A	N/A	0.25	0.26	0.28	0.30	0.32	0.34
Cartagena	0.15	0.17	0.18	0.20	0.22	0.24	0.26	0.28	0.29
Genoa	0.59	0.60	0.62	0.64	0.65	0.67	0.68	0.69	0.71
Gioia Tauro	0.84	0.85	0.85	0.86	0.87	0.87	0.88	0.89	0.89
Izmir	0.69	0.71	0.72	0.73	0.74	N/A	0.77	0.78	0.79
Koper	0.12	0.14	0.15	0.17	0.18	0.20	0.22	0.24	0.26
La Spezia	0.55	0.56	0.58	0.60	0.62	0.63	0.65	0.66	0.68
Leghorn	0.18	0.20	0.21	0.23	0.25	0.27	0.29	0.31	0.33
Marsaxlokk	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.55	0.57
Marseilles	0.34	0.36	0.38	0.40	0.42	0.44	0.45	0.47	0.49
Mersin	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.41
Naples	0.37	0.39	0.41	0.43	0.45	0.47	0.49	0.51	0.52
Piraeus	0.81	0.82	0.83	0.84	0.84	0.85	0.86	0.87	0.87
Ravenna	0.07	0.08	0.09	0.11	0.12	0.13	0.15	0.17	0.18
Rijeka	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.06	0.07
Salerno	0.23	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39
Sete	0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07
Seville	0.63	0.65	0.66	0.68	0.69	0.71	0.72	0.73	0.74
Taranto	no	no	no	no	0.41	0.43	0.45	0.47	0.49
Tarragona	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.10	0.11
Thessaloniki	0.21	0.23	0.25	0.27	0.29	0.31	0.33	0.35	0.37
Trieste	0.05	0.06	0.07	0.08	0.09	0.10	0.12	0.13	0.15
Valencia	0.58	0.60	0.61	0.63	0.65	0.66	0.67	0.69	0.70
Valletta	0.35	0.37	0.39	0.41	0.43	0.45	0.47	0.49	0.51
Venice	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.39	0.41

Appendix 11: The technical efficiency index from Model 1.2.3.4

Model 1.2.3.4: Translog functional form with four inputs, a trend variable and **a GROSS exogenous variable**: EU trading volume.

$$\begin{aligned}\ln y_{nt} &= \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 t \\ &+ \alpha_6 \ln x_{1n} \ln x_{2n} + \alpha_7 \ln x_{1n} \ln x_{3n} + \alpha_8 \ln x_{1n} \ln x_{4n} + \alpha_9 \ln x_{2n} \ln x_{3n} + \alpha_{10} \ln x_{2n} \ln x_{4n} + \alpha_{11} \ln x_{3n} \ln x_{4n} \\ &+ 1/2\alpha_{12} (\ln x_{1n})^2 + 1/2\alpha_{13} (\ln x_{2n})^2 + 1/2\alpha_{14} (\ln x_{3n})^2 + 1/2\alpha_{15} (\ln x_{4n})^2 \\ &+ v_{nt} - u_{nt}\end{aligned}$$

$$m_{nt} = \delta_0 + z_t \delta_1$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.34	0.79	0.19	0.33	0.41	0.57	0.76	0.98	0.82
Alicante	0.87	0.12	0.21	0.30	0.35	0.45	0.57	0.49	0.64
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.04	0.07	0.11
Bar	0.04	0.02	0.04	0.03	0.06	0.06	0.10	0.14	0.23
Barcelona	0.11	0.09	0.11	0.13	0.17	0.22	0.28	0.25	0.18
Bari	0.06	0.00	0.00	0.00	0.02	0.05	0.05	0.03	0.04
Cadiz	0.02	0.02	0.04	0.05	0.06	0.11	0.10	0.14	0.19
Cagliari	N/A	N/A	N/A	0.14	0.18	0.20	0.38	0.37	0.75
Cartagena	0.50	0.63	0.11	0.06	0.09	0.11	0.08	0.13	0.17
Genoa	0.11	0.14	0.35	0.37	0.14	0.17	0.25	0.62	0.91
Gioia Tauro	0.99	0.14	0.19	0.22	0.31	0.40	0.34	0.42	0.44
Izmir	0.75	1.00	0.54	0.12	0.23	N/A	0.56	0.66	0.85
Koper	0.06	0.08	0.11	0.14	0.21	0.27	0.40	0.56	0.82
La Spezia	0.22	0.28	0.42	0.66	0.79	0.98	0.52	0.79	0.77
Leghorn	0.09	0.09	0.07	0.09	0.11	0.22	0.14	0.14	0.17
Marsaxlokk	0.35	0.18	0.13	0.20	0.26	0.26	0.30	0.36	0.52
Marseilles	0.06	0.08	0.20	0.14	0.19	0.23	0.32	0.32	0.39
Mersin	0.49	0.61	0.31	0.09	0.21	0.11	0.57	0.76	0.99
Naples	0.11	0.13	0.11	0.16	0.20	0.24	0.23	0.30	0.42
Piraeus	0.40	0.97	0.28	0.29	0.52	0.72	0.83	0.69	0.83
Ravenna	0.12	0.07	0.06	0.17	0.02	0.25	0.32	0.39	0.44
Rijeka	0.01	0.01	0.02	0.04	0.05	0.11	0.28	0.25	0.37
Salerno	0.18	0.23	0.43	0.47	0.76	1.00	0.42	0.72	0.75
Sete	0.02	0.03	0.02	0.02	0.03	0.03	0.40	0.72	1.00
Seville	0.12	0.16	0.24	0.31	0.38	0.46	0.60	0.74	0.95
Taranto	N/A	N/A	N/A	N/A	0.27	0.34	0.37	0.34	0.50
Tarragona	0.02	0.04	0.05	0.05	0.44	0.57	0.31	0.13	0.21
Thessaloniki	0.23	0.16	0.21	0.25	0.30	0.42	0.63	0.81	1.00
Trieste	0.02	0.06	0.03	0.05	0.05	0.05	0.09	0.13	0.17
Valencia	0.18	0.30	0.14	0.24	0.28	0.28	0.28	0.39	0.59
Valletta	0.14	0.17	0.21	0.21	0.28	0.36	0.52	0.66	0.62
Venice	0.15	0.17	0.21	0.29	0.38	0.49	0.60	0.72	0.75

Appendix 12: The technical efficiency index from Model 1.2.4.4

Model 1.2.4.4: Translog functional form with four inputs, a trend variable and **a GROSS exogenous variable**: **Logged** EU trading volume.

$$\begin{aligned}\ln y_{nt} &= \alpha_0 + \alpha_1 \ln x_{1nt} + \alpha_2 \ln x_{2nt} + \alpha_3 \ln x_{3nt} + \alpha_4 \ln x_{4nt} + \alpha_5 t \\ &+ \alpha_6 \ln x_{1n} \ln x_{2n} + \alpha_7 \ln x_{1n} \ln x_{3n} + \alpha_8 \ln x_{1n} \ln x_{4n} + \alpha_9 \ln x_{2n} \ln x_{3n} + \alpha_{10} \ln x_{2n} \ln x_{4n} + \alpha_{11} \ln x_{3n} \ln x_{4n} \\ &+ 1/2\alpha_{12} (\ln x_{1n})^2 + 1/2\alpha_{13} (\ln x_{2n})^2 + 1/2\alpha_{14} (\ln x_{3n})^2 + 1/2\alpha_{15} (\ln x_{4n})^2 \\ &+ v_{nt} - u_{nt}\end{aligned}$$

$$m_{nt} = \delta_0 + \ln(z_t)\delta_1$$

Port Name	1998	1999	2000	2001	2002	2003	2004	2005	2006
Algeciras	0.83	0.90	0.74	0.78	0.80	0.83	0.87	0.88	0.85
Alicante	0.81	0.32	0.50	0.59	0.62	0.66	0.70	0.51	0.56
Antalya	N/A	N/A	N/A	N/A	N/A	N/A	0.06	0.10	0.13
Bar	0.05	0.07	0.06	0.04	0.07	0.06	0.08	0.09	0.14
Barcelona	0.53	0.45	0.50	0.52	0.55	0.62	0.67	0.63	0.46
Bari	0.18	0.01	0.00	0.01	0.03	0.06	0.05	0.03	0.03
Cadiz	0.06	0.06	0.12	0.10	0.12	0.17	0.14	0.17	0.20
Cagliari	N/A	N/A	N/A	0.31	0.36	0.29	0.48	0.48	0.65
Cartagena	0.76	0.79	0.12	0.07	0.10	0.10	0.06	0.09	0.09
Genoa	0.47	0.50	0.77	0.64	0.44	0.47	0.54	0.77	0.87
Gioia Tauro	0.86	0.60	0.69	0.67	0.74	0.78	0.70	0.71	0.68
Izmir	0.90	0.91	0.81	0.42	0.66	N/A	0.82	0.82	0.84
Koper	0.25	0.25	0.28	0.32	0.40	0.45	0.55	0.64	0.73
La Spezia	0.65	0.69	0.77	0.83	0.83	0.84	0.72	0.82	0.74
Leghorn	0.33	0.27	0.16	0.18	0.19	0.30	0.19	0.22	0.23
Marsaxlokk	0.84	0.56	0.43	0.53	0.57	0.55	0.58	0.56	0.66
Marseilles	0.29	0.33	0.53	0.40	0.45	0.48	0.53	0.49	0.52
Mersin	0.71	0.73	0.42	0.17	0.34	0.24	0.59	0.65	0.70
Naples	0.52	0.55	0.56	0.63	0.66	0.66	0.57	0.62	0.70
Piraeus	0.86	0.91	0.58	0.56	0.78	0.82	0.82	0.74	0.75
Ravenna	0.35	0.18	0.17	0.28	0.03	0.30	0.33	0.33	0.33
Rijeka	0.04	0.03	0.04	0.06	0.08	0.14	0.31	0.27	0.35
Salerno	0.66	0.69	0.74	0.72	0.82	0.84	0.59	0.72	0.67
Sete	0.05	0.07	0.06	0.06	0.07	0.07	0.69	0.69	0.75
Seville	0.51	0.57	0.68	0.73	0.74	0.76	0.79	0.80	0.83
Taranto	N/A	N/A	N/A	N/A	0.50	0.54	0.53	0.46	0.57
Tarragona	0.08	0.10	0.12	0.08	0.64	0.68	0.34	0.13	0.17
Thessaloniki	0.66	0.55	0.59	0.62	0.46	0.58	0.77	0.81	0.82
Trieste	0.10	0.17	0.11	0.15	0.14	0.09	0.13	0.18	0.20
Valencia	0.58	0.70	0.48	0.60	0.64	0.60	0.56	0.65	0.74
Valletta	0.57	0.58	0.62	0.54	0.60	0.64	0.73	0.76	0.68
Venice	0.58	0.58	0.60	0.69	0.72	0.76	0.78	0.78	0.75

Appendix 13: Scale efficiency, technical efficiency and overall efficiency for terminal level data (models 2.2.2.4)

No.	Port	Terminal	Scale	Tech	overall
1	RIJEKA	Braidica Container Terminal	1.00	0.17	0.17
2	BAR	Container Terminal	0.40	0.21	0.09
3	KOPER	3 container berths	0.76	0.34	0.26
4	MARSEILLES-FOS	Fos Container Terminal - Seayard	1.00	0.15	0.15
5	MARSEILLES-FOS	Mourepaine Container Terminal	0.99	0.30	0.29
6	SETE	Container Terminal	0.88	0.06	0.06
7	PIRAEUS	St GeorgeTerminal (Pier I)	0.42	0.06	0.03
8	PIRAEUS	Venizelos Container Terminal (Pier II)	0.61	0.75	0.46
9	THESSALONIKI	Pier 6	0.99	0.59	0.59
10	CAGLIARI	Cagliari International Container Terminal	0.87	0.61	0.53
11	GENOA	Messina Shipping Terminal - Ronco Pier	0.95	0.50	0.47
12	GENOA	Southern European Container Hub (SECH) /	0.94	0.48	0.45
13	GENOA	Voltri Terminal	0.88	0.58	0.51
14	GIOIA TAURO	Medcenter Container Terminal	0.78	0.77	0.60
15	LA SPEZIA	La Spezia Container Terminal (Molo Fornelli	1.00	0.57	0.57
16	LA SPEZIA	Terminal de Golfo	0.98	0.63	0.62
17	NAPLES	Flavio Gioia terminal	0.40	0.69	0.28
18	NAPLES	Molo Bausan terminal (CoNaTeCo)	0.80	0.70	0.56
19	RAVENNA	Setramar Terminal	1.00	0.03	0.03
20	RAVENNA	Terminal Contentori Ravenna (TCR)	0.98	0.27	0.26
21	SALERNO	other berths	0.99	0.30	0.30
22	SALERNO	Salerno Container Terminal (SCT)	1.00	0.67	0.67
23	TARANTO	Taranto Container Terminal	0.95	0.56	0.53
24	TRIESTE	Trieste Marine Terminal	0.93	0.14	0.13
25	VENICE	Terminal Intermodale Venezia (TIV)	0.98	0.17	0.17
26	VENICE	VECON (Banchina Emilia berths 25-27)	0.89	0.33	0.29
27	MARSAXLOKK	Malta Freeport (Terminal 1 & 2)	0.88	0.53	0.47
28	VALETTA	Valetta Gateway Terminal	1.00	0.10	0.10
29	ALGECIRAS	Terminal 2000 (APM Terminals)	0.99	0.76	0.75
30	ALGECIRAS	Terminales de Contendores de Algeciras	0.97	0.48	0.47
31	ALICANTE	Berths 11	0.92	0.61	0.57
32	BARCELONA	Estibadora De Ponent	0.92	0.33	0.30
33	BARCELONA	TCB Terminal de Contenidors de Barcelona	0.92	0.51	0.47
34	BARCELONA	TerCat	0.89	0.69	0.62
35	BARCELONA	Terminal Port-Nou	0.95	0.10	0.10
36	BARCELONA	UTE Llevant	1.00	0.22	0.22
37	CADIZ	Reina Sofia	1.00	0.29	0.29
38	CARTAGENA	Santa Lucia	0.99	0.01	0.01
39	SEVILLE	Muelle de Centenario	0.71	0.74	0.52
40	TARRAGONA	Tarragona Container Terminal (Moll D'	1.00	0.05	0.05
41	VALENCIA	MSC Terminal (Muelle de Fangos)	0.74	0.19	0.14
42	VALENCIA	Muelle de Levante Terminal (north end,	0.97	0.02	0.02
43	VALENCIA	Muelle de Levante Terminal (south end, TCV	0.96	0.56	0.53
44	VALENCIA	Valencia Container Terminal (Principe Felipe	0.97	0.69	0.66
45	ANTALYA	general cargo / container berth	0.50	0.31	0.15
46	IZMIR	container berths (13-16 / 17-19)	0.79	0.91	0.73
47	MERSIN	2 container quays	0.94	0.75	0.71
48	NEW YORK	APM Terminals Port Everglade	0.99	0.49	0.49
49	NEW YORK	Global Marine Term	0.89	0.51	0.45
50	NEW YORK	Maher Terminals (Tripoli Street / Fleet	0.96	0.46	0.44
51	NEW YORK	New York Container Terminal (Howland	0.96	0.32	0.30
52	NEW YORK	Port Newark Container Terminal (PNCT)	0.95	0.71	0.67

53	NEW YORK	Red Hook Container Terminal	0.95	0.11	0.10
54	NEW YORK	South Brooklyn Marine Terminal	1.00	0.17	0.17
55	HONG KONG	COSCO-HIT Terminal-(Kwai Chung)	0.92	0.85	0.78
56	HONG KONG	CSX World Terminal - CT3 (DPW/PSA)	0.76	0.81	0.61
57	HONG KONG	HIT Terminals 4,6,7& 9	0.99	0.57	0.56
58	HONG KONG	Modern Terminals (Kwai Chung)	1.00	0.78	0.78
59	HONG KONG	Rivertrade Terminal	0.84	0.75	0.63
60	HONG KONG	Terminal 8W (Asia Container Terminals	0.97	0.75	0.73
61	GUANGZHOU	Guangzhou Xingang Container Terminal	1.00	0.80	0.80
62	GUANGZHOU	Nansha Container Terminal Phase 1	0.88	0.86	0.76
63	NINGBO	Beilun No. 2 Container Company	0.94	0.89	0.84
64	NINGBO	Ningbo Beilun International Container	0.97	0.71	0.69
65	NINGBO	Ningbo Daxie China Merchants International	0.94	0.33	0.31
66	QINGDAO	Qingdao Cosport International Container	0.53	0.66	0.35
67	QINGDAO	Qingdao Qianwan Terminal (Phase 2 & 3)	0.87	0.81	0.70
68	SHANGHAI	Shanghai Container Terminals (Bao Shan	0.98	0.79	0.77
69	SHANGHAI	Shanghai East Container Terminal	1.00	0.89	0.89
70	SHANGHAI	Shanghai Mindong Container Terminal	0.98	0.85	0.83
71	SHANGHAI	Shanghai Pudong International Terminal	0.98	0.65	0.64
72	SHANGHAI	Shanghai Shengdong International Container	0.99	0.88	0.87
73	SHANGHAI	SIPG Zhendong Container Terminal (phase	0.97	0.92	0.89
74	SHANGHAI	SIPG Zhendong Container Terminal (phase	0.98	0.71	0.70
75	SHENZHEN	Chiwan Container Terminal	0.96	0.79	0.76
76	SHENZHEN	Chiwan Nanshan Development Group	1.00	0.90	0.90
77	SHENZHEN	Da Chan Bay Container Terminal	0.54	0.80	0.44
78	SHENZHEN	Shekou Container Terminals Ltd - Phase I	0.93	0.87	0.81
79	SHENZHEN	Shekou Container Terminals Ltd - Phase II	0.95	0.52	0.49
80	SHENZHEN	Shekou Container Terminals Ltd - Phase III	1.00	0.31	0.31
81	SHENZHEN	Shenzhen Haixing Harbour Development	0.76	0.74	0.56
82	SHENZHEN	Yantian International Container Term (Phase	0.78	0.88	0.69
83	SHENZHEN	Yantian International Container Term	0.92	0.16	0.14
84	TIANJIN/XINGANG	CSX Orient (Tianjin) Terminals	1.00	0.65	0.65
85	TIANJIN/XINGANG	Number 2 Container Terminal	0.94	0.91	0.85
86	TIANJIN/XINGANG	Tianjin Container Terminal (Berths 21 &	0.25	0.49	0.12
87	TIANJIN/XINGANG	Tianjin Five Continental International Cont	1.00	0.78	0.78
88	BUSAN	Dongbu Busan Container Terminal	1.00	0.80	0.80
89	BUSAN	Gamman Global Terminal (BICT Gamman)	0.88	0.68	0.61
90	BUSAN	Gamman Hanjin Terminal (BICT Gamman)	0.94	0.78	0.74
91	BUSAN	Gamman Hutchison Container Terminal (ex	0.86	0.87	0.75
92	BUSAN	Hutchison Busan Container Terminal	1.00	0.80	0.80
93	BUSAN	Kamcheon Hanjin Terminal	1.00	0.71	0.71
94	BUSAN	Korea Express Pusan Container Terminal	0.86	0.78	0.67
95	BUSAN	Pusan East Container terminal (PECT)	1.00	0.77	0.77
96	BUSAN	UAM terminal	0.92	0.82	0.75
97	KAOHSIUNG	Terminal 1 (40-41)	0.94	0.22	0.21
98	KAOHSIUNG	Terminal 1 (42-43)	0.91	0.58	0.53
99	KAOHSIUNG	Terminal 2 (OOCL: 65/66)	0.88	0.87	0.76
100	KAOHSIUNG	Terminal 2 (Wan Hai: 63/64)	0.84	0.78	0.66
101	KAOHSIUNG	Terminal 3 (APL: 68/69)	1.00	0.86	0.86
102	KAOHSIUNG	Terminal 3 (Yang Ming: 70)	0.90	0.53	0.48
103	KAOHSIUNG	Terminal 4 (APM)	0.99	0.82	0.81
104	KAOHSIUNG	Terminal 4 (Evergreen: 115/116/117)	0.96	0.62	0.59
105	KAOHSIUNG	Terminal 4 (NYK: 121)	0.97	0.80	0.77
106	KAOHSIUNG	Terminal 4 (Yang Ming: 120)	0.79	0.57	0.45
107	KAOHSIUNG	Terminal 5 (APM Terminals)	0.98	0.87	0.86
108	KAOHSIUNG	Terminal 5 (Evergreen: 79/80/81)	0.99	0.75	0.75

109	KAOHSIUNG	Terminal 5 (Hyundai: 75)	0.75	0.76	0.57
110	KAOHSIUNG	Terminal 5 (KHB: 74)	0.91	0.28	0.26
111	KAOHSIUNG	Terminal 5 Berth 78 - Hanjin/Macquarie	0.91	0.78	0.71
112	DUBAI	Jebel Ali Terminal - 1	0.98	0.69	0.68
113	DUBAI	Port Rashid Terminal	0.98	0.84	0.82
114	ANTWERP	Antwerp Gateway (Deurganckdok East -	0.45	0.75	0.34
115	ANTWERP	Churchill Dock (Berths 402-428) & Unitload	0.68	0.27	0.19
116	ANTWERP	Churchill Docks (Berths 466-484, P&O)	0.19	0.54	0.10
117	ANTWERP	Delwaide Dock (Berths 732-748, P&O)	0.80	0.70	0.56
118	ANTWERP	Deurganckdok West (PSA/HNN)	0.69	0.27	0.18
119	ANTWERP	DPW 6th Harbour Dock / Hansa Dock	0.16	0.52	0.08
120	ANTWERP	Europa Terminal (Schelde Berths 855-869,	0.98	0.82	0.80
121	ANTWERP	Hesse-Noord Natie Terminal (Schelde berths	1.00	0.52	0.52
122	ANTWERP	MSC Home Terminal (Berths 702-730,	0.70	0.87	0.61
123	ANTWERP	Vrasenedok (1225-1231)	0.69	0.05	0.03
124	ANTWERP	Westerlund Bulk Terminal - BBI	0.45	0.03	0.01
125	BREMERHAVEN	Bremen Container Terminal (BLG)	0.83	0.03	0.03
126	BREMERHAVEN	Bremerhaven Container Terminal (Eurogate	1.00	0.40	0.40
127	BREMERHAVEN	MSC Gate (CT1)	0.95	0.75	0.71
128	BREMERHAVEN	North Sea Terminal (CT3 / CT3a)	0.99	0.83	0.82
129	HAMBURG	Altenwerder Container Terminal (CTA)	0.99	0.54	0.54
130	HAMBURG	Burchardkai Terminal (CTB)	0.82	0.77	0.63
131	HAMBURG	Buss Hansa Terminal (Oswaldkai Terminal)	0.83	0.58	0.48
132	HAMBURG	Eurogate Container Terminal Hamburg	0.98	0.66	0.64
133	HAMBURG	Tollerort Terminal	0.99	0.70	0.69
134	HAMBURG	Unikai Terminal	0.93	0.20	0.19
135	ROTTERDAM	APM Terminals (Maersk Delta, Maasvalakte	0.95	0.83	0.79
136	ROTTERDAM	ECT Delta (Maasvalakte)	0.75	0.75	0.57
137	ROTTERDAM	ECT Home	1.00	0.66	0.66
138	ROTTERDAM	Hanno / Uniport (Waalhaven Piers 6/ 7)	0.98	0.82	0.80
139	ROTTERDAM	Hanno Terminal (Waalhaven Pier 6)	0.84	0.29	0.24
140	ROTTERDAM	Morcon Terminal (Chemiehaven)	0.97	0.04	0.04
141	ROTTERDAM	Rotterdam Shortsea Terminal	0.96	0.78	0.75
142	ROTTERDAM	Steinweg (Botlek Terminal)	0.76	0.02	0.01
143	ROTTERDAM	Steinweg (Seinehaven)	0.67	0.04	0.03
144	PORT KELANG	Northport (prev. Klang Container Terminal)	0.86	0.67	0.58
145	PORT KELANG	Westport Kelang Multi Terminal (B07-B10)	0.89	0.70	0.62
146	SINGAPORE	COSCO-PSA Terminal (Pasir Panjang)	0.93	0.85	0.79
147	SINGAPORE	Brani (PSA)	0.97	0.82	0.79
148	SINGAPORE	Jurong Port (Jurong)	0.89	0.27	0.24
149	SINGAPORE	Keppel Terminal	0.96	0.78	0.75
150	SINGAPORE	Pasir Panjang (PSA)	1.00	0.45	0.44
151	SINGAPORE	Tanjong Pagar(PSA)	0.99	0.83	0.82
152	LONG BEACH	Pier A Berths A90-A94 (SSA for MSC / Zim)	1.00	0.49	0.49
153	LONG BEACH	Pier C Berths C60-C62 (Matson)	1.00	0.58	0.58
154	LONG BEACH	Pier E Berths E24-E26 (California United	0.99	0.65	0.64
155	LONG BEACH	Pier F Berths F6, F8, F10 (Long Beach	0.98	0.71	0.69
156	LONG BEACH	Pier J Berths J232-234 (International	1.00	0.55	0.55
157	LONG BEACH	Pier J Berths J243-J247, J266-J270 (Pacific	0.98	0.53	0.51
158	LONG BEACH	Pier T Berth 132-140 - Hanjin/Macquarie	1.00	0.48	0.47
159	LOS ANGELES	APM Terminals - Pier 400	1.00	0.68	0.68
160	LOS ANGELES	Evergreen: Berths 226-232	0.94	0.82	0.77
161	LOS ANGELES	Global Gateway South -Pier 300 (APL)	0.83	0.74	0.62
162	LOS ANGELES	Piers 100-102 (China Shipping)	0.55	0.82	0.45
163	LOS ANGELES	TraPac Terminal (MOL)	1.00	0.45	0.45
164	LOS ANGELES	West Basin Container Terminal: Berths	1.00	0.68	0.68

165	LOS ANGELES	Yusen Terminal (NYK): Berths 212-215	0.96	0.58	0.55