Productivity in the Container Port Business – Focus on the Mediterranean Range

Dissertation for the degree of doctor in applied economics at the University of Antwerp to be defended by

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Productivity in the Container Port Business – Case Study of the Mediterranean Range

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ABBREVIATIONS AND ACRONYMS

АРМ	AP Möller Terminals
BCC:	Banker, Charnes and Cooper
CAGR:	Compound Annual Growth Rate
CCR:	Charnes, Cooper and Rhodes
CI	Containerisation International
DEA:	Data Envelopment Analysis
DP World:	Dubai Ports World
FA:	Factor Analysis
GDP:	Gross Domestic Product
НРН	Hutchinson Ports Holding
IMF:	International Monetary Fund
KPI:	Key Performance Indicators
MAP	Minimum Average Partial
ML:	Maximum Likelihood
MSC:	Mediterranean Shipping Company
0&D:	Origin-destination
OECD:	Organization of Economic Co-operation and Development
PIN:	Price Index Numbers
PSA:	Port of Singapore Authority
SFA:	Stochastic Frontier Analysis

SMC Squared Multiple Correlation

- STS: Ship-to-Shore quay cranes
- TEU: Twenty-foot Equivalent Unit
- TFP Total Factor Productivity
- UNCTAD: United Nations Conference on Trade and Development
- yoy Year-on-year

EXPLANATORY NOTES

The word "throughput" is a measure of container handling activity. The two main categories of throughput are origin and destination, which are also often referred to as import and export, and transhipment. Every container shipped by sea is by definition an export container at the origin terminal and an import container at the destination terminal. A container that is transferred from one ship to another at some point during the journey is said to be transhipped, which gives rise to transhipment throughput at an intermediate terminal somewhere between the load terminal and the discharge terminal. Throughput includes the handling of imports, exports, empty containers and transhipments.

"Container ports (in the Mediterranean)" refers to all or part of the 36 selected container ports used in the empirical analysis in this dissertation.

References to "Appendix" or "Appendices" are to the appendices set out in the end of this document. The appendices are used where information which would normally make sense in the main body of the document is placed at the end of the document for reasons of clarity and improvement of text readability.

The word "capacity", in relation to container terminals, refers to the theoretical amount of throughput that a container terminal can handle in a year and is generally based on the size of the terminal's container stacking area and the capacity of its quay, which in turn is based on the length of the quay and the capacity of the ship-to-shore cranes that are available. Information on terminal capacity has been provided by port authorities and/ or terminal operators.

The term "Mediterranean Range" for the purposes of this document means the top-30 container ports located in the Mediterranean basin i.e. South Europe, North Africa and Near East as well as the additional 6 ports of Las Palmas, Santa Cruz de Tenerife, Sines, Casablanca, Algiers and Tangiers.

ABSTRACT

This thesis addresses the issue of container port productivity measurement and focuses on the ports of the Mediterranean. The Mediterranean has become a key region as a transhipment node for the world's largest container flows. This thesis considers the Mediterranean as a whole including recent port developments in Southern Europe, Middle East and North Africa.

There are two major questions addressed in this thesis. The first one is agreeing on a definition of what container port productivity means and to define a reduced number of key performance indicators. The analysis of the industry best practices and a review of academic literature on port productivity have established that handling, berth and terminal area productivity are key indicators of physical productivity of container ports.

The second question is to understand whether physical port productivity in the Mediterranean is driven by three different characteristics: port throughput, proximity to the shortest navigation route and by share of transhipment.

The methodological approach includes a multiple regression analysis considering fourteen explanatory variables. This empirical analysis is complemented by two other types of analysis, a grouping by key performance indicators and a grouping by time-series. To this end two datasets are used, a time-series dataset for 36 container ports in the Mediterranean range over a thirty-eight-year period, and a cross-sectional dataset for the same 36 container ports in the Mediterranean range.

The outcome of this research proves that size and the share of transhipment are the main drivers of physical port productivity, whereas the proximity of shortest navigational route does not come across as relevant. The two types of analysis were coherent on the robustness of the outcome.

The existence of a common definition and the identification of common indicators for container port productivity will lead to the possibility of more meaningful comparison amongst ports and to more informed decision making from the different clients, service providers, terminal operators, infrastructure owners, regulators and policy makers.

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The key to good communication is to find simplicity in complex matters. I hope to have achieved that in this dissertation.

To my Parents, Thank you for your unconditional love and unwavering support.

> *To my Husband and our Daughter, You make my life better and brighter every single day.*

1 INTRODUCTION

1.1 GENERAL DESCRIPTION OF THE CONTAINER PORT INDUSTRY

1.1.1 IMPORTANCE OF PORTS IN THE ECONOMY

Ports are busy, dynamic transportation hubs that are constantly adapting to meet the demands of global trade. They are places where communities, cities and regions meet global economic actors and forces. A port is more than a sea-land interface where cargo is loaded and unloaded; it is comprised of a network of activities beginning at the waterfront and extending to suburban warehouse distribution centres (Stopford, 2009).

Ports have always been at the centre of economic activity. Ports have been places of loading and unloading of goods, linking maritime transportation and hinterlands for various types of service providers, industry and trade. Ports are considered engines for economic development in regional and even national level, through employment, wages, rents and profits and taxes (Goss, 1990; Meersman, Van de Voorde & Vanelslander, 2010a).

The benefits associated with the infrastructure arise at various stages of its life cycle: construction, expansion and operation. During the construction or expansion phases the benefits of capital expenditure i.e. investment in infrastructure, largely reverts to the local and regional economy. The port operation generates direct employment for port operators, port authorities, port users, shippers and carriers, and other service providers such as shipping agents, ship repair, pilotage, towage, amongst others. The jobs generated by construction and operation of a port are direct benefits. It is recognized implicitly that these benefits would not exist in the region without the existence of the port (Talley, 2009).

Apart from direct and indirect benefits, a port can generate further benefits of third order, of perpetuity, as a result of improvements (infrastructure and quality of service) in the transport system in the region due to the existence of the port. For example, there may be improvements in road and rail links in the region, resulting in reductions in transit times for the movement of goods within the region, the increase in the frequency of collection and delivery, and improved accessibility to regional, national and international markets i.e. positive externalities. However, after a certain point the increase in goods movement to and from the port results in congestion on the roads, causing negative impact on the region (i.e. negative externalities). These impacts arise from the dynamic economic impact created by a port that is the port acts as a catalyst for further economic growth in the region (Monteiro, 2010).

1.1.2 INTERNATIONAL NATURE OF PORTS AND SHIPPING

Shipping is an inherently global industry with around 90% of world trade in volume being carried by sea. As world trade continues to grow, so does the shipping industry with the quantity of goods transported by sea increasin pout 50% in the last 15 years (measured in freight tonne/km).

Figure 1.1 illustrates the strong correlation between industrial activity, gross domestic product (GDP) growth, merchandise and seaborne trade. A contraction of economic activity in 2009 is followed by a V-shaped recovery in all indicators. Moreover, seaborne trade grows faster than both the industrial production and GDP, reflecting in particular the rapid expansion in container trade (UNCTAD, 2011).

Seaborne trade is highly correlated to the performance of the world economy: expanding when the economy is strong and contracting when the economic outlook is dim. Therefore, to estimate the demand for shipping services it is fundamental to look at trends in the economic sectors and activities that generate this demand, namely oil and gas, mining, agriculture and steel production.



FIGURE 1.1: INDICES FOR WORLD GDP, OECD INDUSTRIAL PRODUCTION INDEX, WORLD MERCHANDISE TRADE AND WORLD SEABORNE TRADE (1975-2012) (1990=100)

Source: (UNCTAD, 2012b)

The demand for port services is a derived demand i.e. results from the trade of goods between regions or countries. Thus, the increase or decrease in global and national economic activity has direct impact on demand in ports (Meersman, Van de Voorde & Vanelslander, 2002).

Globalization and strong global competition are the two main forces driving and shaping the development of the port sector. What is innovative in a globalized economy is the degree of interdependence between the actors and the possibility to choose anywhere in the world for inputs, intermediate or finished goods and services. The markets have become global and the same happened with the transport chains leading to the emergence of concepts such as integrated logistics and supply-chain management. These changes in demand patterns and new management concepts such as just-in-time imply a greater frequency and reliability in production and consequently of the supply chain and associated transport modes (Meersman, Van de Voorde & Vanelslander, 2011).

Ports function as nodes in integrated logistics networks and as such are critical to their success. In a highly competitive environment, the creation of added value is a way of ports to differentiate themselves from competitors, to better meet the needs of their customers and increase the volume of cargo handled. The choice of a port is directly related to its contribution in the global supply chain, in terms of the socalled generalized cost of transportation i.e. the total costs including the cost of transport in terms of time and reliability. Ports are therefore seen as elements of the transport chain, with the function of capturing value for itself and for the transport chain they integrate (Van de Voorde, 2011; Grosso & Monteiro, 2011).

This concept can be depicted in Figure 1.2 that illustrates the role of ports in the supply chains.



FIGURE 1.2: THE ROLE OF PORTS ROLE IN THE SUPPLY CHAIN

Source: adapted from (U.S. Department of Transportation, 2007)

Ports are a key link between international freight transportation and local or regional transport systems. Therefore, the productivity of a port might have a significant impact on a given region or country competitiveness. Port authorities are hence interested in increasing port performance and throughput. Port authorities' aim at maximising throughput and their success depends on their ability to compete with other ports that share a common hinterland and on dealing with growing pressure from shippers and shipping lines for lower port charges.

1.1.3 CONTAINER PORTS

Container shipping could lay claim to being the world's first truly global industry. Likewise it could claim to be the industry which, more than any other makes it possible for a truly global economy to work. It connects countries, markets, businesses and people, allowing them to buy and sell goods on a scale not previously thought possible.

By containerisation it is understood the way or process in stowing and forwarding cargoes by using containers (Paelinck, 2010). The advent of the container¹, dated from the 1960s, has changed profoundly the dynamics in the maritime industry and, consequently, port operations. The increasing level of containerization has developed the necessity for a new type of port terminal with very special characteristics, requiring adequate infrastructures and equipment, leading to heavy investments by ports.

The attractiveness of the container relies on the fact that it provides a standard cargo handling unit that is made available for shippers of all sizes at a low cost. Given that it is a standardised load unit it reduces the costly and lengthy handling procedures, which were part of the traditional cargo handling process, allowing for a shorter turnaround time. The goods are now loaded into a container at the origin and can progress throughout the supply chain until reaching its destination. All the logistics system has been upgraded to allow the efficient handling of the containerised cargo (Notteboom, 2004; Davidson, 2010).

It is common to refer to containerisation as a revolution. This process is still evolving and the degree of containerisation (in percentage of general cargo) is still increasing. In the major ports in the world the degree of containerisation is already above 90% but nonetheless, a further increase in the degree of containerisation is expected. This is explained due to two main reasons: an increasing number of commodities, namely dry bulk, are expected to be transported by container and the increasing importance of transhipment (Notteboom & Rodrigue, 2008).

¹ A container is a steel box of standardised dimensions of 8 feet square and 20 feet long (a TEU, Twenty Foot Equivalent Unit) or 40 feet long (two TEUs) (Paelinck, 2010).

Container trade is the fastest-growing maritime cargo segment growing at a compound annual growth rate of 8.2% between 1990 and 2010. This growth is driven largely by the increasing international division of labour and productivity gains within the sector. After stumbling briefly in 2009, world container port throughput increased by an estimated 13.3% to 531.4 million TEUs in 2010 (UNCTAD, 2011). It then went to an estimated increase of 5.9% to 572.8 million TEUs in 2011, the highest level ever of world container port throughput (UNCTAD, 2012b).

1.1.4 The Mediterranean range

1.1.4.1 DEFINITION OF RANGE

While there is no formal methodology that defines the extent of a port range, it is usual to consider factors such as access to a specific body of water, port proximity and hinterland as defining factors.

The Mediterranean Sea has historically and geographically grouped together countries and respective ports around its shores. The Mediterranean basin is the area around the Mediterranean Sea, and reaches three continents: Europe (south), Asia (near east) and Africa (north) (Abulafia, 2011).

Figure 1.3 shows the Mediterranean Sea, which by definition is limited by the Strait of Gibraltar to the West, the Suez Canal to the East and the Bosphorus Strait to the Northeast. Nevertheless, a more encompassing definition of the Mediterranean area of influence includes countries such as Portugal and the Atlantic coast of Morocco, as well as countries around the Black Sea, such as Romania. This latter definition is the one to be taken into consideration in the present dissertation.



FIGURE 1.3: MAP OF THE MEDITERRANEAN REGION

Note: This image is in the public domain for it is a screenshot from NASA's globe software World Wind using a public domain layer.

Traditionally in the port industry, the Mediterranean is not considere \bigcirc s an homogeneous range as there is little competition between ports, with each port catering essentially to its domestic hinterland. Globalization has reinforced the role of the Mediterranean in international maritime freight transport, nevertheless, traffic growth has mainly involved transit flows, with intra-Mediterranean flows representing less than a quarter of the total (Zallio, 2011).

The Mediterranean container ports can basically be divided into two categories (Lloyd's Marine Intelligence Unit, 2008):

- gateway ports serving a hinterland. For example, Genoa and Barcelona have been used primarily as gateway ports for national trade;
- transhipment hubs used by lines to tranship containers between east-west services and local feeder services. Gioia Tauro, Algeciras and Marsaxlokk are examples of hubs.

1.1.4.2 REASONS FOR THE FOCUS ON THE MEDITERRANEAN

The reasons for the focus in the Mediterranean are manifold. Firstly, the Mediterranean has a strategic geographical location that makes it one of the preferable transhipment areas in the world. It is located along one of the major shipping trade routes²: from Southeast Asia to Northern Europe and to America's West coast. Container traffic on the Europe-Asia route has been estimated at 20.3 million TEU in 2011, with 14.1 million TEU on the leg from Asia to Europe and 6.2 million TEU on the opposite direction (UNCTAD, 2012b).

Figure 1.4 shows the geographical location of the 36 container ports that were considered in this dissertation. These container ports handle over 90% of all container traffic in the Mediterranean and almost all of its transhipment traffic. The information related to the 36 ports constitutes the key building blocks of the port database. The white line shown on the map connecting the Gibraltar Strait with the Suez Canal is the shortest navigational route between the entry/ exit points of the Mediterranean Sea.

² The main shipping routes are east or westbound, located along a circum-equatorial corridor linking North America, Europe and Pacific Asia through the Suez Canal, the Strait of Malacca and the Panama Canal. The three major trade routes are Transpacific (Asia-USA), Europe-Asia and Transatlantic (Europe-USA).



FIGURE 1.4: MAP OF THE CONTAINER PORTS INCLUDED IN THE EMPIRICAL ANALYSIS

Source: own elaboration

Secondly, there is a significant increase in local origin and destination (O&D) traffic. Currently, around the Mediterranean there are significant and growing origin and destination markets in Southern Europe, North Africa and Middle East. The volume of goods transported by sea within the Mediterranean region has grown on average by 5% a year in the decade preceding the international economic crisis. The growth of container traffic was particularly high, expanding by over 10% a year (Zallio, 2011).

Thirdly, the market structure in the region is changing. In order to accommodate the increasing local and transhipment demand, an extensive hub-feeder container systems and short sea shipping networks have emerged in the Mediterranean since the mid-1990s. Earlier, Mediterranean ports were typically bypassed by vessels operating on liner services between the Far East and Northern Europe.

In fourth place, although globalization has strengthened the role of the Mediterranean in international maritime transport of goods, this port range is still one of the least studied regions, especially when compare with the Hamburg-Le Havre range, the Asia or North American ports.

1.1.5 The argument for productivity

Productivity measurement and improvement is important in all sectors, and so surely also in the transport and port sector. Port competition, competitiveness, economic performance and productivity are concepts which are linked to one another. Also productivity influences directly or indirectly the choice of port which is a key point. Regarding this topic, (Valleri & Van de Voorde, 1996) write:

The relationship between choice of port and performance appears a logical one. An increase in performance leads to an increase in cost-efficiency and as a result of this to a decrease in logistic costs and/or an increase in the quality of services provided (e.g. speed of transhipment and goods handling). Lower generalised costs, including out of pocket costs and time costs, strengthen the competitiveness of a port, or of the company set up there (Valleri and Van de Voorde, 1996, p. 131).

In the last decades the maritime transport suffered profound changes that have introduced increased competitiveness levels between ports and changed its organizational structure from a labour-intensive to capital-intensive industry (Trujillo & Nombela, 1999).

The trend has been towards a reduction in direct port employment and investment increase in technologically advanced cargo-handling equipment. The main factors underlying these changes are: the significant reduction in the cost of maritime transport, which allowed for the transport of products and raw materials at a worldwide scale; the trend towards containerisation in the maritime transport, and the changes in logistics and supply chain management, which have set new levels of efficiency in transport activities (Meersman, Van de Voorde & Vanelslander, 2008).

In an increasingly integrated world economy these changes have placed considerable demands on the transport chain, in particular on port facilities. Vessel operators, freight forwarders and logistics integrators demand adequate facilities and services to ensure the accurate, timely and cost efficient handling of cargoes. Most container ports no longer can rely on monopoly over the handling of cargoes in their hinterland, inter-port competition is fierce and such a competitive environment works as an encouragement to improve port productivity (Monteiro, 2007).

Container transportation in particular plays a key role in the process and the significance of container port and its productivity cannot be ignored. When comparing with traditional port operation the advent of the container allowed for heightened port productivity, mostly given the technical and economic advantages it possesses. Containerisation allows reaping economies of scale and of scope and so liner shipping companies are willing to deploy dedicated container ships and container ports are prepared to position efficient container handling systems (Cullinane, Song & Wang, 2005; Vanelslander, 2005).

There are two main factors shipping companies take into account when they decide to serve a port: i) the potential for attracting cargo (related to port throughput), and ii) the port's operational performance. The first factor is the control of the port (it depends on the industrial and service strength of its hinterland) but on the latter, ports can improve upon. In this context, port owners and terminal operators alike do feel the pressure to improve their port's productivity. This demands a continuous evaluation of the present situation, jointly with an effort to identify and implement potential improvements. In such context, container port productivity measurement and analysis is a necessary and powerful tool for port operators and their clients as well as port authorities and at a strategic level for local, regional and national governments.

The rationale for this thesis arises from the fact that traditional port productivity measurement techniques are not considered to be satisfactory to the container port industry for two major reasons. Either they are too complex to be easily implemented in the measurement and benchmarking of port productivity (DEA, PIN, SFA, etc.) and/ or do not have a common acceptance by the port stakeholders – port operators, shipping lines and others – and therefore lack practical usefulness in terms of pricing, operational efficiency, legal and regulatory framework, among other possible uses.

While promising and instructive, these essentially academic efforts have not yet been translated into day to day results useful to port planners or terminal managers.

1.2 WHAT IS PORT PRODUCTIVITY?

1.2.1 GENERAL ECONOMIC PRODUCTIVITY

As a technical concept in economic theory, productivity has more than one definition. Nonetheless, it is fair to say that all the definitions embrace the concept of getting more output from available resources i.e. inputs. A more efficient use of the resources such as labour, capital and materials results in an increase in productivity. Certainly, production can be increased in case more resources are utilized; however the supply of resources at any particular time is always limited. Therefore, productivity gains allow for more or better goods and services with the available resources (FHWA, 2004).

The generally accepted definition of productivity is the one put forward by (Porter, 2008).
"Productivity is the value of the output produced by a unit of labour or capital. Productivity depends on both the quality and features of products (which determine the prices that they can command) and the efficiency with which they are produced." (Porter, 2008, p. 176)

The concept of productivity defined as the ratio output per unit of input is an important concept that has been applied at various levels. At country level, has been argued that productivity is the only meaningful concept of competitiveness. At the firm level, productivity is often seen as a crucial factor impacting the firm's competitiveness (Porter, 2008).

1.2.2 PORT PRODUCTIVITY

The question of what is port productivity is not an easy one to answer given the lack of consensus on the subject. The concepts of port performance, productivity and efficiency have often been used interchangeably in the literature. According to (Valleri & Van de Voorde, 1996):

"Port competition, competitiveness, economic performance and productivity are concepts which are linked to one another. Only, it is not always clear which indicators show best the evolution of these concepts, and how everything should be measured." (Valleri and Van de Voorde 1996, p. 130)

Productivity in container ports is an often used argument to justify investments, promote the port and attract customers. However, the concept is not a straightforward one. It means different things for different people. The results of productivity measurement can affect the interests of port stakeholders: stevedores, unions, port authorities, shippers and governments, so there is an incentive for some to take advantage of the difficulties of measurement to promote their own interests.

In fact, it is generally acknowledged among economists that productivity is very difficult to measure given that quantifying an intangible quality is not a straightforward task. This seems to be particularly true in the container shipping industry. The data are hard to collect; publicly available productivity measurements

are not standardized and there are so many variables, even within a single terminal, that often similar productivity studies may produce differing conclusions.

This difficulty is expressed by (Dowd & Leschine, 1990):

"...the measurement of container productivity has more in common with a commercial art form than with science! The lack of uniformity in the data used for productivity measurement is enormous.... This lack of uniformity renders difficult valid comparison of the measurements of two terminals and the formulation of uniform standards for international, national, regional or portwide application." (Dowd and Leschine 1990, p.110)

This statement, although written over 20 years ago, is still accurate. However, despite the difficulties, industry players (shippers, terminal operators, port authorities, among others) have not refrained from measuring container port productivity. A report by (The Tioga Group, 2010) on behalf of the Cargo Handling Cooperative Program (CHCP), whose mission includes increasing cargo handling productivity and that is sponsored by United States Maritime Administration, states:

"Over the last 15 years, there have been numerous efforts in U.S., European, and Asian academic circles to model container port productivity. The primary technique employed has been Data Envelope Analysis (also referred to as Data Envelopment Analysis), but other econometric techniques have been tried as well. While promising and instructive, these efforts have not yet generated in results useful to port planners or terminal managers." (The Tioga Group, 2010, p.38)

Over time, the productivity of container ports has been measured using different approaches. The most common approach consists in the measurement of operational key performance indicators (KPIs) calculating productivity at each of the ports functional elements, for example, productivity at berth – in TEUs per meter berth; crane handling productivity – in TEUs per crane – or terminal area productivity in terms of TEU per terminal unit area. These types of measurements can be easily benchmarked against other container ports and terminals. For a comprehensive overview of literature on port productivity measurement, see Chapter 3.

In a KPI-based approach, a number of operational KPIs are put forward in order to measure container port productivity and eventually a number of solutions are

implemented to optimize the port performance – as measured by the KPIs under study. From the literature review done in Chapter 3, it is observed that industry discussions on container port productivity measures tend to converge on a relatively few metrics, namely:

- Physical productivity indicators:
 - annual TEU per berth length (per meter or foot of berth);
 - annual TEU per Ship-To-Shore (STS) crane;
 - annual TEU per terminal area (acre or hectare);
- Operative productivity indicators
 - crane moves (or TEU) per time period (hour or year);
 - vessel turnaround time (in hours or minutes);
 - berth utilization (in percentage);
- Labour productivity indicators
 - TEU or crane moves per man-hour.

In general, data on port layout, facilities and equipment is more commonly available, while operative data tend to be scarce and human resources data is often confidential and not publicly available. Also, data values for operative and labour productivity tend to vary depending upon the methodology used and assumptions made, which can vary from port to port.

Taking this into consideration, in the present thesis the focus is on the first three measures - annual TEU per berth length, annual TEU per STS crane, and annual TEU per terminal area. These can be designated as physical productivity indicators for container ports and will be considered as the dependent variables to be studied in the empirical analysis done in chapter 5 (see chapter 4 for detailed information on methodology and data collection). More precisely:

- **Handling Productivity** measured as annual throughput in TEU per STS quay crane i.e. throughput per number of STS quay cranes (TEU/crane);
- **Berth Productivity** measured as annual throughput in TEU per meter of container berth i.e. throughput per berth length (TEU/m);

 Terminal Area Productivity measured as annual throughput in TEU per container terminal area in hectare i.e. throughput per terminal area (TEU/ha).

This line of research has found resonance in a number of publications by multilateral institutions, notably the World Bank where port KPIs are used as a key criterion within the framework of safeguarding port performance. In this thesis, these three selected physical productivity indicators for container ports are analysed in order to assess the productivity of the three most critical elements of a port: its primary cargo handling equipment, the STS cranes; its berth, and; its terminal area.

1.3 The research process

In this sub-chapter the methodological planning of the current doctoral research is presented. The research process is illustrated in Figure 1.5.



Source: adapted from (Ethridge, 2004)

The following tasks are undertaken sequentially, as follows: identifying and setting the goal, elaborating the research questions, establish the research methodology, choice of sample and method of data collection, modelling and empirical work, with the subsequent interpretation of results. Finally, to present the findings, drawing conclusions and giving suggestions for further research.

1.3.1 Goal and research questions

Having selected the broad area of study (port and maritime economics), and identified a topic (container port productivity), the first step in defining the dissertation's research process involves setting the goal and formulating the research questions within the selected area of study.

The goal of the dissertation is threefold:

- to identify the trends influencing productivity in the container port industry (in Chapter 2);
- to understand what are the different concepts in measuring container port productivity in academic literature and industry expertise (in Chapter 3);
- to identify the main variables influencing port productivity in the Mediterranean specifically what influences physical productivity in container port (in Chapters 4 and 5).

The **research questions** that arise from the goal definition above are:

- 1. What is container port productivity and how is it measured?
- 2. What are the variables influencing container port productivity?
- 3. This leads to three questions that are going to be verified in the modelling and empirical work of the thesis, namely:
 - **Research question 1:** Is container port size correlated with container port productivity? Are bigger container ports more productive than smaller ones?
 - **Research question 2:** Is geographical centrality i.e. the proximity to the Mediterranean navigational centreline correlated to container port productivity?
 - **Research question 3:** Are ports with high transhipment shares more productive than non-transhipment ports?

1.3.2 RESEARCH METHODOLOGY

In this sub-chapter is described the research methodology i.e. the guideline system for addressing the research questions. Two types research were considered:

- Exploratory research: a type of research conducted for a problem that has not yet been clearly defined; it helps to determine the best research design, data collection method and selection of indicators. Exploratory research is most useful in the preliminary stages of a study and its main aim is to discover the important variables in a given situation and then to provide an accurate and valid representation of those variables.
- Causal research: the objective is to test hypotheses about cause-and-effect relationships through the use of multivariate data models. Given that the objective is to determine which variable(s) might be causing certain behaviour(s) i.e. whether there is a cause and effect relationship between variables, causal research is undertaken in order to understand the delicate relationships between variables that are important to container port productivity. Causal research is used to understand how changes in the independent variables (e.g., throughput, berth length, terminal area, etc.) affect the dependent another variable (e.g., container port productivity).

Chapter 2 entails an exploratory research on the topic of container port industry, focusing on the container port industry, its history and development, main trends, market structure and key players in the market.

Similarly to Chapter 2, exploratory research on the topic of measurement of productivity in container ports is carried out in Chapter 3. This activity is undertaken through an in-depth literature review that identifies previous studies on the topic, draws useful conclusions on methods to measure port productivity and working concept of container port productivity to be used in this thesis.

An important issue following from above is how to model data and how to approach the empirical analysis. Chapter 4 addresses the methodology for productivity measurement, and describes the type of data and sample to be used in the empirical analysis, what data was collected, which variables were selected, and how the data-collecting method was structured. This involved inevitably a compromise between the ideal and what was feasible.

In Chapter 5, the empirical analysis is presented and the results are interpreted. The data analysis techniques used in order to better understand the topic of container port productivity are: multivariate regression analysis, which is then complemented by a grouping analysis, where ports are group together according to certain criteria.

Chapter 6 draws conclusions and present policy implications.

1.3.3 CHOICE OF SAMPLE AND DATA COLLECTION

In this dissertation data are collected from various sources. Two data sets have been constructed. The first consists of a time series between 1970 and 2008 with container throughput per port, based on data retrieved from the database CI Online Liner Intelligence[®].

A second data set consists on a compilation of variables consisting of: port performance indicators, operational data, layout characteristics and macroeconomic indicators for a sample of 36 Mediterranean container ports. It includes 14 carefully selected variables for each of the 36 Mediterranean container ports for year 2008. These data were used to classify ports on the basis of several variables that are expected to influence the three selected physical productivity indicators for container ports. This step of the research process is addressed detail in Chapter 4 - methodology for productivity measurement.

1.3.4 MODELLING, EMPIRICAL WORK AND FINDINGS

In Chapter 5, the empirical analysis is presented and the results are interpreted. The data analysis techniques used in order to better understand the topic of container port productivity are: multivariate regression analysis, which is then complemented by a grouping analysis, where ports are group together according to certain criteria.

1.3.5 CONCLUSIONS

The overall conclusions of this dissertation are presented in Chapter 6, and the potential policy implications of the findings of the empirical analysis are discussed. Also, suggestions for further research are given.

1.4 SIGNIFICANCE AND ORIGINAL CONTRIBUTION

The significance and original contribution of the research in this dissertation is manifold. The first contribution is to consolidate and summarize the vast existing literature on container port productivity.

The second contribution is to validate the concept that the container ports in the Mediterranean range can be treated as one single geographic entity that by and large are facing the same market challenges over the last two decades. Rather than facing a geographical differentiation, the container ports in the Mediterranean range despite having heterogeneous characteristics can nonetheless be grouped into sets of container ports with similar characteristics and productivity levels.

The third contribution is to demonstrate that there are a number of key performance indicators that can serve as a measure of physical productivity of container ports and that can be applied to the Mediterranean range of ports.

In fourth place, in order to undertake a robust analysis, a unique tailor-made comprehensive database was compiled. This database is particularly meaningful given that previous research in this topic has been limited by the lack of comprehensive data and furthermore is limited in terms of geographical scope. This database consists of 14 variables, which were considered to be relevant (derived from the literature review). The database covers the top-36 container ports in the Mediterranean ranked by throughput in 2008.

Furthermore, the studies that focus on the Mediterranean container ports tend to be limited in scope; they use data from one single country, compare between two countries, or use only the Mediterranean ports in the European Union. This is mainly due to limitations in data availability and difficulties in collecting data for such a large and diverse group of ports, belonging to various countries and different continents. This thesis considers the Mediterranean in its totality, including south Europe, Middle East and North Africa.

Finally, this dissertation puts forward an innovative way to assess container port productivity based on simple yet validated and meaningful physical productivity indicators. It proposes to build a bridge between academia and industry, the former being known for the complex econometric models and the later for easy-to-use performance indicators that vary according to the entity measuring them and thus often lack consistency for inter-port comparability.

1.5 STRUCTURE OF THE DISSERTATION

This sub-chapter presents an outline of the dissertation and a brief overview of the content of the chapters. An illustration of the structure of the dissertation is depicted in Figure 1.6.

The present introductory chapter provides an overview of the study, addressing the rationale for the dissertation, goal and research questions as well as describing the research process. It sets the scene for the present doctoral research.

In Chapter 2 - The container port industry, outlines the major trends in the container port industry at worldwide level, namely the increasing level of containerization, the hierarchical system of hub and spoke applied to the port sector, the increasing average and maximum container ship size and the role of transhipment.

In Chapter 3 – Measurement of productivity in ports, is reviewed the literature on container port productivity covering a forty year period of both an academic and industry expertise. Additionally, in this chapter the evolution of how productivity has been measured since the emergence of the container port industry is presented. In this context, the main methodologies that have been used are evaluated, their advantages and drawbacks identified and the important variables to measure container port productivity are singled out. Lastly, is presented the

working definition of physical productivity of container ports to be used in this thesis.



FIGURE 1.6: STRUCTURE OF THE DISSERTATION

Source: Own composition

In Chapter 4 – Methodology for productivity measurement, are described the sampling strategy, methodology for the data collection and data treatment process. The variables are described and analysed in order to have a sense of the data. Furthermore, are introduced the different data analysis techniques used for the empirical data analysis.

In Chapter 5 – Empirical analysis, different yet complementary data analysis techniques are used in order to better understand the topic of container port productivity. Multiple regression analysis is done using a cross-section database with a sample of 36 Mediterranean container ports and 14 variables for the year 2008. The regression analysis models allow analysing the relationships between several variables know to influence port productivity (independent variables) and the container port productivity indicators (dependent variables). The regression analysis model indicates i) if the independent variables have a significant relationship with the dependent variable; and ii) the relative strength of different independent variables' effects on the dependent variable i.e. container port productivity.

This analysis is complemented by a grouping analysis where ports are grouped along different dimensions, using both the abovementioned cross-section database and a time-series database for container throughput for the same sample of ports.

In the final Chapter 6 – Conclusions and policy implications, are drawn conclusions and summarised the findings of the thesis, as well as, are presented potential policy implications and are given suggestion for further research.

2 THE CONTAINER PORT INDUSTRY

2.1 INTRODUCTION

Trends such as globalisation, containerisation, increasing vessel size and consolidation have reshaped the container port and shipping industry.

One of the reasons the container port become an industry in its own right is the flexibility and much lower handling costs of containers. The decrease in handling costs between non-containerised and containerised cargo is very significant. At US ports it was calculated that the handling cost per ton of cargo decreased from 5,85 USD to 0,15 USD per ton (Volk, 2002). This comparison was undertaken during the early days of containerisation when such comparison was still possible. At the time the difference equated to about 40 times; this change of scale has underpinned the very fast containerisation rate (Haralambides, 2004).

The flexibility and mechanisation of container handling also allowed for the increasing degree of containerisation. Another success factor in the industry was the structural changes in transportation (Volk, 2002). Not only did ports d to adapt to the efficient handling of containers, but this adaptation did extend to all transport modes, transport infrastructures, transport operations and associated information flow.

In this chapter is given an overview of the container port industry, its historical development and main characteristics and trends. Additionally, the impact of these trends is going to be assessed within the geographical scope of the Mediterranean area.

2.2 HISTORY AND DEVELOPMENT

World trade increased significantly after the Second World War and by 1950 most ports were suffering from congestion. Progress in naval engineering allowed the construction of bigger and faster vessels, as well as, more efficient cargo handling equipment. This gave way to unitization of cargo through the use of trowels, preslung systems and marine containers. The advent of the container has radically changed the dynamics of the port and maritime industry and by consequence of port operations. The use of standardised containers for freight transport was first introduced in the 1950s and has since expanded rapidly and consistently to emerge as the most dominant mode for the transport of break-bulk goods (see sub-chapter 2.5 for more information on continued growth in container trade).

otteboom and Rodrigue, 2008) argue that three major paradigm shifts have taken place within containerized freight distribution systems with each shift representing a specific functional and geographic diffusion.

The first is the introduction of the container and its diffusion within maritime transport systems, particularly from the mid-1960s when standardization resulted in common size and lashing systems. The efficiency of port transhipments improved and inland services, dominantly relying on trucking, began to be established.

The second is the diffusion of containerization within inland transport systems. For instance, the introduction of double-stacking rail services required the setting and redesign of inland container rail terminals in North America. The adoption of the container in Europe gained momentum when an intermodal transportation system started to emerge in the late 1970s. For example, the shift from conventional and highly irregular barge services to scheduled and reliable container services in the second half of the 1970s gave impetus to a fast containerization process along the Rhine basin up to the main ports of Rotterdam and Antwerp (Notteboom & Konings, 2004).

In the 1980s a new generation of ports was built, strongly influenced by containerization and intermodality. These ports have become integrated centres of transport, logistics and information technologies (IT), radically changing the traditional way ports operated.

A third paradigm shift is occurred in the end of the 00's and concerns intermodal operations and the functional diffusion of containerization within supply chains. This efficiency is mainly base on the reduction of the number of times a container is handled (Rodrigue & Notteboom, 2008).

The attractiveness of the container as a standardised load unit relies on the fact that it made low cost service available to shippers of all sizes. It reduces the costly and lengthy handling processes which used to be done to the cargo, allowing for significantly lower turnaround times. Goods are loaded into a container at the origin and can pass throughout the entire supply chain without the need for further handling until reaching its final destination. In the maritime transportation of cargo all the supply chain and associated logistics' systems have been optimised to allow the efficient handling of the containerized cargo.

The increased levels of containerization, the concentration of container cargo on a small number of intercontinental shipping routes and a reduced number of shipping lines operating on those routes has led to an increase in market share for a small number of more dynamic hub ports and hence gave origin to a new type of even more specialized container ports.

The emergence of the hub-and-spoke networks in the container liner industry in the 1980s has been widely referred to in shipping literature (World Bank, 2003; Freemont, 2007; Notteboom, 2004; Coulter, 2002). Figure 2.1 gives an overview of the maritime hub and spoke network.



FIGURE 2.1: MARITIME HUB AND SPOKE NETWORK

Source: (Frost, 2008)

The underlying hub-and-spoke concept states that the so called hub ports seek to consolidate regional cargo by connecting regional ports through feeder³ services to a main port - the hub, thus allowing shipping companies to take advantage of economies of scale by deploying larger vessels on long routes, such as in transoceanic transport.

The concept of hub and spoke network is intended to maximize the utilization of large containerships while providing market coverage to a maximum number of ports. This concept has changed global distribution patterns and for the first time in maritime history it implies a hierarchical separation amongst ports: hub ports connect to other hubs and the most convenient hub then connects to smaller surrounding ports.

A hub port must have the capacity to cater for the operational requirements of large container ships: water depth, berth length and capacity of terminal facilities, efficient handling of container operations, frequent feeder services availability and a good location (large hinterland and substantial intermodal connections).

Typically, hub ports have a mix of local and transhipment traffic but some ports have specialized almost exclusively in the transhipment business, which consises the unloading of feeder vessels, temporary storage of containers, and loading of

³ A feeder service is a short sea shipping service which connects at least two ports in order for the freight (generally containers) to be consolidated or redistributed to or from a deep-sea service in one of these ports.

large vessels and vice versa. Therefore, a transhipment port is a port where cargo is transferred from one vessel to another vessel without the cargo leaving the port. Usually, two types of operations are differentiated: i) relay transhipment, operations taking place between two mother ships; and ii) hub-and-spoke transhipment, operations between the mother ship and feeder vessel. This business model is only interesting as long as transhipment traffic is able to generate additional throughput and hence higher economic value.

The development of international trade, the logistics strategy of freight forwarders and the organization, network and 'architecture' of maritime routes by shipping lines currently shape the international maritime transport network, regardless of the modernisation efforts made by ports. A port's activity can be destabilized or consolidated by the shipping lines' choice of terminals or decisions to create, increase, reduce or withdraw stopovers at a certain port (Huybrechts, Meersman, Van de Voorde, *et al.*, 2002).

Nevertheless, ports are becoming increasingly important world players and active elements in the organization of the international transport network. Ports draw together a number of market players in maritime business such as shippers, freight forwarders, insurance companies, banks, stowage companies, customs, and road and railroad operators, among others. A port is, in fact, characterized by a significant number of complex inter-relationships between the owners and managers of port infrastructure, the intermediary users of port infrastructure comprising port service providers (stevedores) and transport operators (shipping lines); and the end users: the cargo owners, namely importers and exporters.

The goals of all these market players involved in port activities are seldom aligned and in most industry-related issues compromises must be reached between these stakeholders.

A port's most significant competitive advantages is its geographic location close to the biggest maritime routes linking major produced to consumption regions and the existence of other ports that compete for its catchment area and could be used as substitutes. With the improvements in the transport sector (road, railway and inland navigation infrastructure and vehicles), distances became shorter in relative terms and the ports catchment areas started to overlap (Macário & Viegas, 2009).

Analysing the shift in bargaining power from port to shipping companies requires understanding the patterns of scarcity. Up to a few decades ago, port infrastructures were relatively scarce. Building a port requires high investment and to make it attractive, large storage areas and efficient accessibilities were necessary. Traditionally, ports should be close to or near a large consumption region or an industrial centre in order to ensure high orig destination cargo traffic.

With the introduction of the hub and spoke system and ever bigger vessels, shipping companies turned the bargaining power to provide favour. Each vessel carries more cargo than before, but they serve fewer ports. So, the ports fight for the role of hubs.

Compared to the existing situation only a couple of decades ago, there are presently more ports and fewer clients who concentrate their services on fewer infrastructures, so the market power changed from ports to shipping lines. Nowadays, shipping lines can play ports against each other to obtain better conditions.

In previous decades, the port sector could be characterised as a fragmented industry composed of fairly independent actors with small presence in the market, where port authorities were seen as autonomous bodies and goods handlers competing with each other within the same port and often within the same terminal. The shipping industry had also a fragmented market structure with the largest shipping companies competing against each other and numerous smaller independent shippers with almost no market power.

The major world trends in the port industry, namely the increasing level of containerization, the hierarchical system of hub and spoke applied to the container port industry, the increasing average and maximum size of container ships, and the phenomenon of 'oligopolisation' of the players in this industry, are the drivers of the trend towards the industry's increased vertical and horizontal integration (Meersman, Van de Voorde & Vanelslander, 2010b).

Although these business trends are not new, they are still developing and gaining momentum. The level of containerization is expected to continue to increase in the following years. The size of vessels is also expected to grow although there is strong discussion until when is this further growth viable. The implementation of the 'hub and spoke' network, which is in a process of consolidation, is central for the container market dynamics. The increased co-operation and horizontal and vertical concentration in the maritime industry has a strong impact on the balance of power between the actors in the container sector.

2.3 EVOLUTION OF GDP AND WORLD TRADE

Historically, growth in world trade and in container traffic is related with GDP growth. While world trade has expanded between 3 to 5% per annum over the past 20 years, international trade has grown at an average of 9% whereas container traffic has grown by an average of between 8 to 12%, which equates to a GDP multiplier between 2.0 and 3.0 (UNCTAD, 2011).

Maritime freight, in particular, is sensitive to the wider macro-economic environment. It shows sensitiveness to factors such as: economic growth (declining with recession and increasing with expansion), globalization of world trade and variations in the industrial manufacturing base.



FIGURE 2.2: WORLD GDP AND WORLD TRADE 1990-2008 (% YOY)

As can be seen in Figure 2.2, that depicts the evolution of world GDP and world trade between 1990 and 2008, there is a strong correlation between the world's economic activity and container traffic throughput. Moreover, as can be observed in Figure 2.3, between 1980 and 2010 the average world container growth has had a compound annual growth rate (CAGR) of 9.4% whilst the world's GDP has grown with a 3.3% CAGR. This means that on average over the last 30 years the multiplier between growth in GDP and growth in container throughput has been of 2.85 (HPH Trust, 2012).

FIGURE 2.3: WORLD ECONOMIC GROWTH AND CONTAINER TRAFFIC 1980-2010 (% YOY)



It is relevant to note that growth in container throughput is also closely correlated with growth in world trade, as can be seen from Figure 2.4. The best fit trendline shows an elasticity of 0.75 between the growth in world trade and growth of container throughput i.e. for every 1% of growth in world trade, container throughput grows by 0.75. However, the best fit trendline intersects the y axis at 5% i.e. when world trade grows at 0% then container throughput still grows at 5%. For this range of values the growth in container throughput is always higher than growth in world trade except for one year, 2009 when for the first time ever container throughput declined by 9%.



FIGURE 2.4: CORRELATION BETWEEN WORLD TRADE GROWTH AND CONTAINER SHIPPING GROWTH (1990-2008)

In addition to the macro-economic drivers, the maritime and container port industries were subject to profound changes that led to a massive increase in throughput in the last decades. These changes were manifold. Some of the most important are: i) the significant reduction in the unit cost (cost per TEU) of maritime transport, which allowed for the increase in transport of products and raw materials at a worldwide scale; ii) the trend towards containerization in the maritime transport, and; iii) the changes in logistics and supply chain management, which have set new levels of efficiency in transport activities.

Even today, more and more different types of goods are being transported in containers. This happens primarily as a consequence of two factors – lower transport costs and the extended global reach of megacarriers – with both of these factors resulting in ever-greater volumes of container traffic.

Source: (Deutsche Bank Research, 2011) Notes: x-axis, world trade (% yoy); y-axis, container throughput (% yoy)

2.4 EVOLUTION IN MARITIME TRADE

The continuing international integration towards a globalised economic system enhances the importance of maritime transport and ports as connection points between sea and land trade. Globalization has changed the logistics sector, through the development of integrated transport chains. Today's global logistic organization pressures shippers worldwide to develop 'smooth' transport chains, in which the shipping lines and ports play an important role. Besides, economies of scale in the shipment of cargo have also led to the consolidation of distribution and logistics companies.

New trends in logistics and supply chain management, such as just-in-time production and delivery, or the tendency towards spatial concentration of production and of warehousing and distribution centres, imply that the critical factors in logistics and supply chains are: i) transportation time, reliability and predictability and ii) production costs.

In this context, the cost of transport is just a small part of the overall production and logistics cost. Modern transportation in logistics can be described as the links between the nodes, which are either factories, where the products are manufactured, or interfaces between modes, such as ports, warehouses or logistics centres. Benefiting from economies of scale from increasingly larger and more specialized ships, which require new infrastructures, or the adaptation of the existing ones (e.g. ports) and equipment has furthermore led to reduction in the transport cost.

As a result, globalization and liberalization of trade together with the developments in logistics and supply chain management are the background against which the transport industry has been evolving. The global shift in the location of manufacturing activities as well as changes in supply chain management has led to much bigger flows being handled by maritime shipping. Flows of raw materials handled by maritime shipping have adapted and emerging manufacturing clusters have seen a growth. It is however in container shipping that the growth of traffic flows is more visible. As exemplified on Figure 2.5, the new geography of production entails a new geography of distribution and its related flows.



FIGURE 2.5: CONTAINER TRADE FLOWS BETWEEN WORLD'S MACRO REGIONS 2009-2011

Source: own composition from (UNCTAD, 2012b)

The worldwide container trade flows are normally classified into two main groups: inter-regional trade and intra-regional trade. Inter-regional trade runs essentially along a circum-equatorial corridor linking North America, Europe and Pacific Asia through the Suez Canal, the Strait of Malacca and the Panama Canal. The three major trade routes are Transpacific (Asia-USA), Europe-Asia and Transatlantic (Europe-USA).

2.5 CONTINUED GROWTH IN CONTAINER TRADE

2.5.1 WORLD CONTAINER THROUGHPUT

Container throughput has had very significant growth rates in the last two decades. For instance, world container throughput grew at an annual average rate above 10% between 1990 and 2008. After the 2008 world financial crisis there was a drop in throughput, but in 2010 the sector had already recovered as can be seen in Figure 2.6.



FIGURE 2.6: EVOLUTION OF WORLD CONTAINER PORT THROUGHPUT 1990-2010 (MILLION



Historically, the drivers for the very high growth rates in container shipping are manifold. On the one hand the increasing international division of labour and the growing liberalisation of world trade. On the other, the share of semi-finished and finished products has risen over the last couple of decades and these constitute the ideal type of goods for shipping via container. Also, container vessels present advantages over traditional general cargo ships, namely the shorter loading and unloading times that significantly reduce turnaround times in the port, which translates into a reduction in transportation and handling costs.

In fact, the fastest growing r O = of maritime transport is container shipping, with world container throughput being likely to expand by an average of 7 to 8% per year until 2015. The increasing international division of labour and productivity gains within the sector remain the drivers behind this positive outlook on the container industry. Despite the optimistic position, some challenges need to be taken into account including rising fuel prices, stricter environmental regulation, protectionist tendencies, and capacity bottlenecks at ports (Deutsche Bank Research, 2011).

Figure 2.7 illustrates the evolution of container throughput and container trade since 1990 to 2011, and presents forecast until 2015. Note that port container throughput takes into account all handling activity, including transhipment operations and empty container movements, and that container trade covers only the number of laden containers that ultimately arrive at the destination port.



FIGURE 2.7: WORLD CONTAINER THROUGHPUT AND CONTAINER TRADE 1990-2015 (MILLION TEU)

Likewise, the number of containers has also increased significantly paralleling the importance of containerization for global trade. In twenty years the number of containers in use for maritime transport has grown more than fourfold from just under 7 million TEU in early 1991 to about 29 million TEU of containers by January 2011 (Deutsche Bank Research, 2011).

Source: (Deutsche Bank Research, 2011)

2.5.2 INCREASING DEGREE OF CONTAINERISATION

It is common to refer to containerization as a revolution. This process is still evolving and the degree of containerization measured as share of general cargo is still increasing.

In mature markets, such as the northern Europe/United States of America or the northern Europe/Far East markets, the process of change towards containerisation is more or less complete, and few, if any, non-containerised cargoes are left which are able of being containerised.

In fact, in the major ports of the world the degree of containerization is already above 90% (ISL, 2012) but nonetheless, a further increase in the degree of containerization is expected. This is explained by two main reasons: firstly, other types of commodities, namely dry bulk, can be transported cheaply by container, and secondly, the increasing importance of transhipment which allows reaching destinations without the need for dedicated services.

Containerization began by replacing the conventional system of handling break-bulk cargo in general cargo vessels or passenger vessels that handled express type shipments. These goods when handled individually were subject to a great deal of loss and damage. Firstly the most valuable cargos were containerised such as high end consumer goods that were prone to theft and subject to damage when handled. Ultimately, almost all consumer goods were containerized followed by most manufactured goods, such as parts. More recently, a growing quantity of commodities such as specialty grain and wood products are being shipped in containers (Rodrigue, 2012).

This increasing degree of containerisation was accompanied by a growth of the world's container vessel fleet in terms of the number of vessels as well as in the size of vessels. In recent years this growth still continues due to the strong increase in international trade (see Figure 2.8).

FIGURE 2.8: WORLD CONTAINER FLEET DEVELOPMENT AS OF JANUARY 1st, 1986 - 2012 (INDEX 1986 = 100)



2.5.3 DRIVERS OF CONTAINER TRADE

As mentioned previously in the comments to Figure 2.3, growth in container traffic has consistently surpassed economic activity and, in the period from 1980 to 2000, it has grown at an average rate almost three times above world GDP growth. Since the 1980s each decade has also witnessed different drivers of growth, which are summarised Table 2.1.

High container traffic growth rates were driven by a number of reasons: the shift in global manufacturing to South East Asia, especially to mainland China; the steady containerisation of break-bulk (general) cargo; the disintermediation of global supply chains, and induced demand, driven by practices such as transhipment.

Period	Key drivers	Impact on container traffic growth
1980-1990	Trade liberalization: GATT - General Agreement on Tariffs and Trade. Container trade predominantly between developed nations	CAGR: 8.0%
1991-2000	Greater global integration on container trade. New and emerging markets. Asian financial crisis	CAGR: 10.0%
2000-2008	China becomes WTO - World trade Organization member in 2001. United States recession	CAGR: 11.0%
2009	Global financial and economic crisis	Declined by 9.0% as compared to 2008
2010	Recovery: container volumes increase in several regions and major ports	Increased by 13.0% over 2009

TABLE 2.1: KEY DRIVERS OF CONTAINER TRADE

Source: (HPH Trust, 2012)

2.6 INCREASING VESSEL SIZE

2.6.1 WORLD CONTAINER FLEET

In parallel with the growth in container traffic, the expansion of transhipment activities and the increasing containerization rates, the container ship fleet has grown and is expected to continue to grow, both in absolute numbers and average ship size, in order to accommodate an increasing demand.

The other major factor that led to a considerable increase in vessel size is the shipping companies' drive for the reduction of transportation costs through the maximisation of economies of scale in order to be able to compete on price. Assuming that the major variables in maritime transportation remain constant, in particular the vessel cargo load factor, then significant economies of scale can be achieved by increasing vessel size.

Figure 2.9 depicts the evolution of the capacity of the container vessels by size, indicating the long-term trends in container ship fleet.

Beginning of year	Number of vessels	TEU capacity	Average vessel size (TEU)
1987	1 052	1 215 215	1 155
1997	1 954	3 089 682	1 581
2007	3 904	9 436 377	2 417
2008	4 276	10 760 173	2 516
2009	4 638	12 142 444	2 618
2010	4 677	12 824 648	2 7 4 2
2011	4 868	14 081 957	2 893
2012	5 012	15 406 610	3 074
Growth 2012/2011 (per cent)	2.96	9.41	6.26

FIGURE 2.9: LONG-TERM TRENDS IN THE CELLULAR CONTAINER SHIP FLEET

Source: (UNCTAD, 2012b)

Note: i) compiled from UNCTAD secretariat on the basis of data supplied by IHS Fairplay; ii) fully cellular container ships of 100 GT and above; iii) beginning-of-year figures, except those from 1987, which are mid-year figures.

As can be seen, the average box carrying capacity of container ships has reached 3,074 TEUs in 2012, which corresponds to an increase of 6.26% over the previous year.

Indeed, the cumulative capacity of the container ship fleet has closely followed the growth of containerized shipping. In 1998 shipping lines introduced the first ships whose size was greater than the dimensions imposed by Panama Canal. These were the so-called post-Panamax, with capacities above 4,000 TEU. Maersk, MSC and CMA-CGM are nowadays operating vessels with a capacity in excess of 14,000 TEUs. Table 2.2 shows the container shipping capacity breakdown as of July, 1st 2012.

Size ranges	Ships	Total
(TEU)	(#)	(TEU)
10,000 - 18,000	150	1,915,872
7,500 – 9,999	308	2,663,673
5,100 - 7,499	471	2,889,031
4,000 - 5,099	728	3,289,616
3,000 - 3,999	312	1,067,044
2,000 – 2,999	684	1,742,054
1,500 - 1,999	590	1,001,552
1,000 - 1,499	699	821,192
500 - 999	787	586,371
100 - 499	225	73,801
Total	4,954	16,050,206

TABLE 2.2: CONTAINER SHIPPING CAPACITY BREAKDOWN FLEET AS OF JULY 1ST, 2012

Source: (BRS, 2012)

Moreover, not only the larger size container ships are increasing in size, but also feeder vessels are following this trend and growing proportionately. Ultimately, the question of the limit to vessel size depends not on technical issues -as technically there are no strong limitations to increases in vessel size- but from commercial issues and port capabilities, in particular water depth at ports will be the limiting factor. A timeline perspective of the evolution of the container ship is depicted in Figure 2.10.

FIGURE 2.10: THE EVOLUTION OF THE CONTAINER SHIP



Source: (VanderMey, 2012)

2.6.2 IMPACT ON PORTS

The trend for ever-increasing vessel sizes does not come without challenges. In fact, three major issues arise as a consequence: i) maritime accessibilities: dredging of ports and access channels, ii) port superstructure: investing in cargo handling equipment in order to be able to cope with increasing volumes and the wider beam, and iii) port infrastructure: make the necessary arrangements to store, handle and move cargo onwards by road, rail, barge, or feeder ships.

As a result, the increasing vessel size has had significant impact on ports, pressuring for larger, deeper and more performing ports. Modern liner vessels are larger, more sophisticated and more capital intensive. Productivity and efficiency of ports have a strong influence on the ability of shipping companies to exploit economies of scale related to the vessel. In effect, carriers must ensure that these gains in the sea leg are not lost by the costs of additional time in port (loading, unloading, etc.).

The increase in vessel size also led to a new hierarchy of ports, where the differentiation is increasingly based on their ability to receive the larger vessels and handle efficiently their increasing container capacity. Only the larger, deeper and better equipped ports are able to receive the new generations of container vessels, while other less capable ports are increasingly being relegated to feeder operations. Hence, the increasing vessel size contributed to the creation and development of the so-called hub-and-spoke type network (Monteiro, 2005).

In short, the option for larger container ships is fairly straightforward from the shipper or shipping line perspective given the economies of scale that translate into lower unit costs per TEU carried. However, this trend towards an increased size in container ships places tremendous pressure on ports and terminals when it comes to infrastructure (quay and terminal area) and superstructure (crane) investments. It is also noteworthy that the larger the size of the ship, the lower the number of ports that are able to handle those vessels.

When looking at the world map it is easy to understand where the main hubs are located. The Port of Singapore in Southeast Asia is by far the largest, with an annual turnover of about 30 million TEUs. The region around the Strait of Gibraltar covering the south of Portugal, Spain and northern Morocco is also a prime location at the intersection of Atlantic and Mediterranean routes.



FIGURE 2.11: WORLD CONTAINER ROUTES AND MAIN HUB AREAS

Source: (Port Strategy, 2011)

2.7 THE ROLE OF TRANSHIPMENT

2.7.1 DEVELOPMENT OF TRANSHIPMENT

As mentioned above, the growth in world container throughput is to a large extent due to the growth of transhipment⁴ activities. Initially, transhipment was used as a means of serving smaller ports where mainline vessels were not able to call. So, these larger ships would stop at a regional hub port, where containers would be transhipped onto smaller feeder vessels that in turn would carry the containers to its final destinations and vice versa.

However, in the 1990s the major shipping lines started to tranship containers between mainline vessels in order to increase service options and reduce overall network cost. These developments led to an increase in the use of transhipment. In fact, the incidence of transhipment worldwide has increased from around 11% in 1980 to an estimated 28.5% of total container port throughput in 2009, as can be depicted in Figure 2.12.



FIGURE 2.12: TRANSHIPMENT SHARE (AS % OF TOTAL CONTAINER PORT THROUGHPUT)

⁴ The transhipment of containers at a container port or terminal can be defined as the number of containers (in TEU) of the total container flow that is handled at the port or terminal and transferred to another ship to reach their destinations.

2.7.2 TRANSHIPMENT ACTIVITIES

Transhipment activities do not take place uniformly at ports around the globe. In fact they are mostly concentrated in per located along the circum equatorial route as illustrated in Figure 2.13. Even though transhipment activities are dynamic in nature and are a function of the ship-owners strategies, this Figure gives a good visual of the position of the world's largest transhipment ports.



FIGURE 2.13: WORLD LARGEST TRANSHIPMENT PORTS

Source: (Rodrigue, Comtois & Slack, 2009)

The most important transhipment activities are concentrated in Southeast Asia, the Mediterranean region and the Caribbean. There can be a strong competition for the choice of port or container terminal, since the transhipment activity can be taken by any another port in the region with low switching costs. The ability to be able to easily switch between ports is a determinant factor for the increased competition between ports.

The significant increase in capacity of the Panama Canal, which is being undertaken, contributes to the development of the circum equatorial route and is likely to expand the opportunities for transhipment operations. Transhipment ports connect regional port systems, to transoceanic and to circum equatorial routes, mainly through hub-and-spoke services.

In fact, many large ports around the world operate essentially as dedicated transhipment hubs, handling relatively little local origin and destination (O&D) traffic and operate for the most part as hubs for global container shipping companies. Figure 2.14 shows the main transhipment ports in the world and the importance of transhipment for those ports.



FIGURE 2.14: TOP-20 TRANSHIPMENT PORTS 2009 (MILLION TEU) AND TRANSHIPMENT SHARE (%)

Source: (Deutsche Bank Research, 2011)

Of the world's top-20 transhipment ports, four of them are located in the Mediterranean: Algeciras, Gioia Tauro, Port Said and Marsaxlokk and all of them have a transhipment share of 90% or above.

Usually, if a port has a transhipment share dominant percentage of transhipment cargo, namely above 55%, it is considered a transhipment port. In case the transhipment share is consistently above 80%, it can be classified as dedicated

transhipment hub. Other ports with a significant transhipment throughput are not dedicated transhipment hubs as they have other core activities. For example Chinese ports such as Guangzhou, Shanghai and Shenzen have transhipment shares below 50% as they are mostly dedicated to export traffic. In the same way, large ports as Rotterdam and Hamburg also have considerable transhipment traffic, but with reduced share of total traffic as they are mostly import and export interfaces for the northern European markets.

The emergence of large transhipment hubs along the circum-equatorial route has fostered the utilisation of very large container ships along this route as well as the north-south routes to northern Europe. The economies of scale due to the utilisation of large ships become bigger as distances increase. The increasing number of transhipment hub ports also allows smaller ports to have better service as feeder vessels have more service choice making it possible to create feeder services that would be otherwise impossible. Smaller ports or ports located away from the circum equatorial route are then served with through feeder ships.

The increasing degree of containerization and vessel size together with growing volumes of cargo with different origin and destination have fostered the use of the 'hub and spoke' network for shipping.

Large container ships are capital intensive assets, which require the smallest possible number of ports of call in their operation, so as to optimize their lower unit cost base. Hence, at hub ports a significant volume of containers is unloaded and then forwarded by smaller feeder vessels to their final destinations. These are complex operations that require the optimization of the logistics process. The implementation of the hub-and-spoke network concept in a shipper's fleet has the advantage of reducing overall transport time and fuel costs, while increasing the productivity at the larger container port terminals and leading to highly predictable schedules.
2.8 CONSOLIDATION OF CONTAINER TERMINAL OPERATORS

The increasing financial and economic integration of world economies and the increasing need for private investment in transport infrastructures allowed for the emergence of large multinational corporations managing transport infrastructure assets in many countries in the world. Global container terminal operators follow a similar trend regarding the management of container port terminal assets.

Indeed, after the growth in tenders for container port terminal concessions in the 1980-90s, there was a trend towards greater consolidation in the container port terminal industry. This consolidation process has been driven essentially by: i) the demand for higher efficiency to serve vessels of increasing size requiring larger investments in cranes, quay depth, terminal area and IT; ii) the need to counterbalance the greater bargaining power of the largest shipping lines and market alliances, and lastly iii) the vertical concentration among shipping companies, logistic providers and hinterland transporters who are also interested in getting control of terminals.

Moreover, the advent of containerization and technological improvements in cargo handling also contributed to the consolidation of container terminal operators. In order to be able to invest in what is now a capital intensive industry, this sector, which was previously fragmented into a large number of small companies, has been restructuring and consolidating into a few global and regional operators which are able to do the required heavy investments in costly infrastructure and equipment.

Four major global container port and terminal operators dominate the industry. They have, in 2012, equity shareholdings in 177 dedicated port container terminals worldwide. According to ranking by throughput, these operators are: the Port of Singapore Authority (PSA), Hutchinson Ports Holding (HPH) from Hong-Kong, APM Terminals (controlled by Maersk, Denmark) and Dubai Ports World (DP World). Their container terminal assets under management are geographically diversified and as expected located, in its majority, along the circum-equatorial route and in the major export and import markets. The main focus of HPH and PSA is South Asia and the Middle East, due to their geographic origins. DP World is well represented worldwide and APMT has a portfolio with a strong North American emphasis. In the Mediterranean region, in 2012 the four global container port operators have presence in 19 container terminals under their management. The distribution is as follows:

- PSA has operations in four locations: Sines, Mersin, Genoa and Venice;
- HPH manages four terminals in: Barcelona, Taranto, Alexandria and El Dekhelia;
- APM Terminals has operations also in six locations: Algeciras, Port Said, Tangier, Cagliari, Constantza and Gioia Tauro; and
- DP World has operations in five locations: Algiers, Djen-Djen, Marseille-Fos, Constanta and Tarragona.

Figure 2.15 illustrates the worldwide location of container terminals that are managed by the so called global terminal operators already mentioned APM Terminals, DP World, HPH and PSA.



FIGURE 2.15: GEOGRAPHICAL LOCATION OF CONTAINER TERMINALS MANAGED BY GLOBAL TERMINAL OPERATORS

Source: (Rodrigue, Comtois & Slack, 2009)

Table 2.3 shows the equity market share of the leading container terminal operators.

It clearly shows that in 2011, PSA International was the market leader, with 8.1% share of world's maritime container cargo throughput. It also shows that the top-4 players have a share of almost 30% of the market; however the remainder of the industry is quite fragmented.

2006		2009		2011				
Operator	m TEU	share	Operator	m TEU	share	Operator	m TEU	share
PSA	41.2	9.3	PSA	45.0	9.5	PSA	47.6	8.1
APMT	32.4	7.3	НРН	32.2	6.8	НРН	43.4	7.4
НРН	30.8	7.0	DP World	31.5	6.7	DP World	33.2	5.6
DP World	26.2	5.9	APMT	31.1	6.6	APMT	32.0	5.4
Evergreen	8.1	1.8	Cosco Pacific	10.9	2.3	Cosco Pacific	15.4	2.6
Cosco Pacific	7.9	1.8	MSC	8.2	1.7	Terminal Inv. Lmtd	12.1	2.1
Eurogate	6.6	1.5	Evergreen	7.2	1.5	China Ship. Term. Dev	7.8	1.3
HHLA	6.0	1.4	SSA Marine	6.3	1.3	Evergreen	6.9	1.2
OOCL	4.8	1.1	Eurogate	6.1	1.3	Eurogate	6.6	1.1
APL	4.6	1.0	CMD_CGM	4.6	1.0	HHLA	6.4	1.1
Тор 10	168.6	38.1	Тор 10	183.1	38.7	Тор 10	211.4	35.9

TABLE 2.3: TOP 10 GLOBAL CONTAINER TERMINAL OPERATORS EQUITY BASED THROUGHPUT

Source: based on Drewry Maritime Research (2007, 2010, 2012)

Note: Figures include all terminals in which 10% plus shareholdings were held. Figures do not include operations at common-user terminals.

The recent downturn in trade and cargo volumes at ports worldwide along with the fierce competition for market share will compel terminal operators to look closely at their existing operations and equipment, and to ask whether they are really efficient, and what can be done to improve productivity.

2.9 THE MEDITERRANEAN CONTAINER MARKET

Traditionally, routes along the Mediterranean have played an important role in connecting Asia to Europe and the countries along its shores. However, in the more recent past Mediterranean ports were known for high costs, low productivity and outdated infrastructure. The era of containerization urged the old Mediterranean ports to adapt and to find a new role. Shipping lines in particular have been demanding better performance from ports and more investment in equipment and facilities to ensure the accurate, timely and cost efficient handling of cargo.

Up to a few decades ago, there was no effective competition among ports in the Mediterranean. However, this did not impact negatively on shipping operations since most ports in the Mediterranean were by and large monopolistic in their catchment area (Musso, 1999).

Significant changes have occurred in the last decades and now some ports in this region are amongst the largest in the world (namely, Gioia Tauro, Algeciras, Barcelona, Valencia, Port Said and Marsaxlokk). However, the need for further improvement still exists and not all ports have risen up to the challenge. Various ports in the Mediterranean still operate in a context of ill-defined incentive frameworks, labour issues, and lacking accountability which hamper competition and undermine efficiency. Although these problems exist more or less worldwide, reforms in the Mediterranean ports are lagging behind other regions in Europe such as the Hamburg-Le Havre range, Latin America or the Baltic Sea (Musso, Piccioni & Van de Voorde, 2012).

	1990	1995	2000	2005	2008	
EU27	41,885	47,970	54,719	62,218	66,700	EU27
EU15	39,616	45,468	51,490	57,995	61,521	EU15
EU12	2,269	2,502	3,229	4,223	5,179	EU12
EL	190	421	615	1,047	1,120	EL
ES	4,976	6,962	9,049	11,432	13,515	ES
FR	6,824	8,275	9,766	10,798	11,042	FR
IT	6,193	6,435	6,478	6,542	6,629	IT
СҮ	120	167	257	276	257	СҮ
РТ	316	687	1,482	2,341	2,623	РТ
RO	113	113	113	228	281	RO
SI	228	293	427	569	696	SI
HR	291		411	792	1,043	HR
МК	83			216	237	мк
TR	281		1,773	1,775	2,010	TR

TABLE 2.4: EUROPEAN UNION MEDITERRANEAN COUNTRIES AND CANDIDATE COUNTRIESMOTORWAY LENGTH 1990-2008 (IN KM)

Source: (European Commission, 2011)

The liberalization of sea, road and railway transport within the EU and a simultaneous increase in the amount and quality of landside transport infrastructure (see Table 2.4) has had an impact in ports. As a result, ports no longer rely on dedicated catchment areas, as cargo can be moved landside at much lower cost. This has led to an overlap of ports catchment areas and increasing competition for hinterland markets.

Moreover, significant economies of scale have arisen from the use of much larger container ships. In order to be profitable, the Panamax and Post-panamax containerships can only serve a limited number of ports by service. These changes have led to a profound redesign of the route network operated by container ships, especially due to the fact that some of the existing ports have neither the layout nor the water depths to accommodate these ships.







As can be seen in Figure 2.16, Mediterranean ports are split in two groups with different characteristics. One group gathers the fast growing high throughput ports (highlighted in green) and the other represents those ports with low growth and low throughput (highlighted in red). The 'green group' is composed by container ports that, it can be assumed, are fighting fiercely for market share in the Mediterranean. The 'red group' is not in this race and its traffic is composed mainly of O&D traffic. This may be due to several reasons, however, one of the most significant is that there is limited capacity in those ports and the construction of new infrastructure is very difficult if not impossible in traditional ports, often limited by the urban development. A good example of this reasoning is the case of the port of Lisbon.

This analysis raises several issues: the Mediterranean container market is a developing and dynamic market. It is growing at considerable rate and there are a number of ports with above-average growth rates. This growth comes essentially

from transhipment traffic as those ports have long reached high containerization levels and their hinterland is non-existent or growing at much lower rates.

In order to maintain growth, there will be competition for transhipment traffic in the short and medium term, while growth rates are far above those of O&D traffic. Later in the document, the productivity of those ports will be analysed and the factors driving productivity will be identified.

2.10SUMMARY

The world economy has become progressively more integrated in the last decades and therefore the global logistics supply chains, in particular container port facilities, face increasing demands. Indeed, various players in the port sector, namely terminal operators, shipping lines, port authorities and shippers have been facing new challenges, such as the greater degree of containerization, the increasing vessel size, and the development of the hub and spoke system and the tendency towards higher co-operation among several market players. These developments together with the enormous growth in container traffic have contributed to a changing business environment with stronger competition.

The economies of scale enabled by larger ships and a move towards hub and spoke transhipment has created possibilities for larger feeder vessels to operate, thereby generating economies of scale in ship size, and in turn lowering the overall cost of transhipment. Not only does this help to reduce costs for intercontinental traffic, it also helps to reduce costs for intra-regional business as well.

The economies of scale described above have led to a dramatic fall in the cost of maritime transport, turning container shipping into a commodity business. Commodity-type businesses compete primarily on the basis of price. As any other commodity business, container shipping is normally characterized by high assetintensity, significant capital expenditures in relation to assets (vessels), low profit margins and intense competition. This is why the issue of container port productivity has such relevance as it is a key differentiator in terms of the choice of a port, since a port with higher productivity is more attractive to shipping lines. In fact, the implementation of the hub-and-spoke concept made journeys longer and ports substitutable for one another. This weaker bargaining position of port regarding other players pushes them to compete through lower cost and increased productivity. It requires a reduction in queuing times (supply of berths) and operating times (loading and unloading), which results usually in ports investing in more capacity (infrastructure and superstructure).

The implementation of the 'hub and spoke' concept to shipping routes allows maximizing the use of large container vessels and provides market coverage to a maximum number of ports. With this system the routes are divided into shorter spokes and the focus is on optimizing the whole transport chain.

The increasing level of containerization has developed the necessity for a new type of port terminal with very special characteristics, requiring dedicated infrastructure and equipment, leading to a cycle of considerable capital expenditure in ports with considerable general cargo volumes.

The market dynamics in the container port business have shifted: shippers have become larger and stronger, shipping lines have also increase their market power and are increasingly involved in terminal operations. Terminal operators have seen their bargaining power reduced in benefit of other actors. These world trends have a deep impact on the in the industry stakeholders and their ability to adjust to these developments will influence strongly the dynamics of market competition.

This is also true for the Mediterranean container port industry, which is presently in the middle of a process of transformation and development. There is fierce competition among ports in the Mediterranean range and this competition takes places in an ever changing, dynamic environment.

3 MEASUREMENT OF PORT PRODUCTIVITY

Measuring and understanding productivity is essential in any industry and the container port industry is no exception, whether it is the measuring of achievements against set goals or against the competition. In this chapter a comprehensive review of the literature on the topic of port productivity measurement is undertaken, covering academic journals, technical magazine articles, books and reports. The purpose is reviewing the academic and industry literature to determine how container port productivity could and should be measured.

In this dissertation, the focus is on port economics, namely productivity measurement in container ports.

3.1 SETTING THE SCENE

In this section is given an overview of the economic literature on port economic topics; is presented the scope of the review of literature, indicating the focus on container port productivity measurement; and lastly is given an overview of the most common measurement approaches available.

3.1.1 PORT ECONOMICS

As noted in previous chapters, it is argued that ports constitute one of the backbones of a thriving economy. Nevertheless, it can be reasoned that it took some time for the port industry to be duly recognised in the economics field. The earliest studies on port economics date back to the 1920's and for five decades the first academic manuals on port economics as an independent subject matter were far and sparse (Cunningham, 1926; Bown, 1953; Connor & Boyd, 1966; Goss, 1967; Bown, 1967).

In the 1970's a surge of books and other publications on port economics and economic impact analysis were published (Peston & Rees, 1971; Port Authority of

Portland, 1971; Oram & Baker, 1971; Ryan & Adams, 1973; Abrahamsson & Vardi, 1973; UNCTAD, 1976, 1977; Port Authority of New York and New Jersey, 1977; Bennathan & Walters, 1979). From that point onwards, the literature on ports broadened and started to deal with several topics which Table 3.1 presents a non-exhaustive overview.

As can be seen, in the last three decades or so, there has been a growing amount of work, both practical and theoretical on port economics. For the purpose of the present thesis, attention is now given to studies analysing the efficiency and productivity of the port sector.

Factors	Authors and dates			
Investment and planning	(Shneerson, 1981, 1983; Bobrovitch, 1982; Goodman, 1984; Meersman, Steenssens & Van de Voorde, 1997; Dewulf, Van de Voorde & Yzewyn, 1992; Bennathan & Walters, 1979)			
Privatization	(Trujillo & Nombela, 1999; Fernández, De Cea & Fernández, 1999; Baird, 2002; Monteiro, 2003; Tongzon & Heng, 2005)			
Competition	(Slack, 1985; Heaver, 1995; Veldman & Bückmann, 2003; Monteiro, 2005; Langen, 2007; Yip, Sun & Liu, 2009; Meersman, Van de Voorde & Vanelslander, 2002, 2010b, 2011)			
Costs and economies of scale	(Reker, Connell & Ross, 1990; Martínez-Budría, 1996; Jara-Díaz, Cortés, Vargas, <i>et al.</i> , 1997; Tsion & Loizides, 2001; Clark, Dollar & Micco, 2002; Sánchez, Hoffmann, Micco, <i>et al.</i> , 2003; Clark, Dolla & Micco, 2004; Meersman, Monteiro, Pauwels, <i>et al.</i> 2006; Meersman, Monteiro, Onghena, <i>et al.</i> , 2006; Meersman, Monteiro, Pauwels, <i>et al.</i> , 2007; Tovar, Jara-Díaz & Trujillo, 2007)			
Port selection criteria	(Dalenberg, Daley & Murphy, 1992; D'Este & Meyrick, 1992; Daley & Murphy, 1994; Malchow, 2001; Malchow & Kanafani, 2001, 2004; Song & Yeo, 2004; Lirn, Thanopoulou, Beynon, <i>et al.</i> , 2004; Grosso & Monteiro, 2008, 2011)			
Performance, efficiency and productivity	(UNCTAD, 1976, 1987; De Monie, 1987; Chung, 1993; Saundry & Turnbull, 1999; De Langen, 2003; Marlow & Paixão Casaca, 2003; Talley, 1994; Marconsult, 1994; Valleri & Van de Voorde, 1996; Turner, Windle & Dresner, 2004; Bichou & Gray, 2004; Estache, Perelman & Trujillo, 2005; Monteiro 2007; Ducruet, Lee & Song, 2011)			

TABLE 3.1: OVERVIEW ECONOMIC LITERATURE ON PORT ECONOMIC TOPICS

Source: own composition

3.1.2 Scope of the literature review

The present dissertation concentrates on the topic of productivity and specifically on container port productivity. With the widespread adoption of the container as the standard maritime load unit for bulk cargo in the shipping industry since the mid-1970s, literature on productivity of container ports has emerged (see Table 3.1). Containerization by its very nature allowed for more efficient handling of the cargo, nevertheless, the shipping lines continuous search for productivity gains encouraged the measurement and optimisation of container ports and the productivity measurement of container terminals.

The literature on container terminal productivity measurement is quite diverse, including studies and research reports, magazine and journal articles, academic papers and articles as well. A significant challenge is to stay on key since there is a related and often intertwined literature on port choice criteria, port competition, regulation and port privatization. Nevertheless, the present review of the literature on container port productivity aims to cover the last 30 years since its inception and covers the efforts made by the industry (inside perspective) and academic circles and international or government institutions (outside perspective).

3.1.3 MEASUREMENT APPROACHES

A variety of ways of measuring container port productivity and efficiency exist in the literature. Nevertheless, two major lines of academic research on the topic of port productivity measurement can be identified: a key performance indicator based approach and an efficiency-based approach to the delivery of port services.

In the key performance indicators based approach, a number of KPIs is put forward in order to measure port productivity and came up with a number of solutions to optimize the port performance – as measured by the KPIs under study.

This line of research has found resonance in a number of publications by multilateral institutions, notably the UNCTAD (UNCTAD, 1976, 1987; De Monie, 1987; UNCTAD, 2012a) where port KPIs are used as key criteria within the framework of guaranteeing the port performance. This often happens in the context

of port privatization and/ or concessions. Sub-chapter 3.2.2 deals with this line of research in greater detail.

Within the efficiency approach, the main techniques utilised to measure port productivity are: Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). These methods differ in the type of data required, the type of measures applied, and the assumptions made regarding production function and economic behaviour of the decision makers. This efficiency-based approach is reviewed with more depth in sub-chapter 3.2.3.

As a general tendency, the industry focuses on performance indicators, and the academia uses predominantly the technique of data envelopment analysis, but other econometric techniques, such as stochastic frontier analysis and variants have been widely tried as well.

Given its practical use in the port industry a brief overview of the literature on best practices in terminal operations is undertaken. These studies often focus on terminal operational improvements, usually related to crane productivity, the role of automation and technology. This review is undertaken in sub-chapter 3.2.4.

The following studies have undertaken surveys of the literature on the area of productivity and efficiency measurement: (Coelli, Estache, Perelman, *et al.*, 2003; Estache, Perelman & Trujillo, 2005) focusing on infrastructure regulation, (The Tioga Group, 2010) focusing on container terminal productivity and (González & Trujillo, 2008a) focusing on efficiency measurement.

As a final note, it is worth mentioning three other lines of research, which although not in line with the topic of this thesis, are related to the subject of productivity.

- a line of research that focuses on qualitative indicators and indirectly measures port productivity as the type and quality of relationship between the different port stakeholders, in particular between the terminal operators and their main clients, the shipping lines (Fulginiti & Perrin, 2005; Goss, 1993; Isbell, 2005);
- studies with an engineering approach that use simulations and queuing theory, taking into account the potential result that the firm has not exploited and may be used as a source for increasing its productivity (Chen, Hsu & Huang, 2003; Casaca, 2005; Goodchild & Daganzo, 2005, 2007;

Chen, 1999; Choi, 2005; Dragovic, Park & Radmilovic, 2006; Imai, Nishimura, Hattori, *et al.*, 2007; Jeon & Park, 2005; Hofseth, Heisey, Males, *et al.*, 2006).

 studies on best practices in terminal operations, mostly focused on technology and capacity. A few of these studies focus specifically on crane productivity (Ward, 1998; Goussiatiner, 2007, 2009); others discuss the conceptual role of automation (Ranstrom, 2005; McCarthy, 2006), (SY & CG LLC., 2001a, 2001b, 2001c) analysed productivity issues at intermodal transfer facilities linking port and surface transportation; and (Schmidmeir, 2006; Taro, 2006; Tarkenton, 2005) all regard technology as an enabler of best practices and give recommendations on how to achieve higher productivity.

3.2 PERFORMANCE INDICATOR-BASED APPROACH: KPIS

Despite having started relatively recently, there is already a vast literature dealing with the performance indicator based approach of assessing port productivity. A possible categorisation of this literature is studies focusing on single, partial and/or total factor productivity indicators.

A single productivity indicator is the ratio of a measure of a single output quantity to the quantity of a single factor input. The input factor is usually related to the resources labour, land or capital. As for the output factor is normally related to throughput. A partial productivity indicator is similar to that of a single productivity indicator, however seeks to compare a group of outputs to a group of inputs. For both measurements, the idea is to capture a change in productivity prompted respectively by a single factor or by a group of factors. Considerable part of the traditional port productivity literature belongs to single and partial factor productivity measurement, namely (Bendall & Stent, 1987; De Monie, 1987; Frankel, 1991; Fourgeaud, 2000; Talley, 1988; UNCTAD, 1976, 1987) as well as most industry publications such as ports' statistics, trade journals, and market reports.

Total Factor Productivity (TFP) indicators incorporate multiple inputs and outputs through the use of aggregated index methods or estimated indices from specified

cost or production functions. The concept behind total factor productivity is to synthesise a productivity index by assigning weights that reflect the relative importance of its cost and production components. A TFP index can be constructed directly from output and input data such as price, cost and revenue shares. However, when these data are not available, it is possible to estimate the weights from econometric cost or production functions.

Research using total factor productivity indicators were undertaken by (Kim & Sachish, 1986; Talley, 1994; Sachish, 1996; Lawrence & Richards, 2004; De, 2006). In (Kim & Sachish, 1986), the composed TFP index consisted of labour and capital expenditure as input and throughput in metric tonnes as output. (Talley, 1994) suggests a TFP index using a shadow price variable. (Sachish, 1996) refers to a weighting mechanism of partial productivity measures. (Lawrence & Richards, 2004) developed a decomposition method for the Törnqvist index to investigate the distribution of benefits from productivity improvements in an Australian container terminal. (De, 2006) assesses total factor productivity growth of the Indian port sector.

Another way of categorising these studies on port productivity is according to areas of research: (Bendall & Stent, 1987; Tabernacle, 1995; Ashar, 1997) focus on cargo-handling productivity at berth; (Talley, 1988) concentrates on comparing actual with optimum throughput over a specific time period, (UNCTAD, 1976; De Monie, 1987; UNCTAD, 1987; Frankel, 1991; Chung, 1993) suggest set of productivity indicators for ports, and quite a few studies address container terminal productivity (BTE, 1984; Ashar, 1985; Committee on Productivity of Marine Terminals, 1986; Dowd & Leschine, 1990; Productivity Commission, 2003; Le-Griffin & Murphy, 2006; The Cornell Group, 2007; Beškovnik, 2008; The Tioga Group, 2010).

Chronologically, among the earliest studies were those undertaken by UNCTAD, the United Nations Conference on Trade And Development and the principal organ of the United Nations General Assembly dealing with trade, investment, and development issues. In (UNCTAD, 1976) port authorities are advised on the collection and use of a set of performance indicators, concerning both operational and financial aspects of port operation. The decision which indicators to maintain depends on the port authority particular requirements and set of performance indicators differs according to cargo category. This study includes an application of a set of indicators to the port of Piraeus (see Table 3.2).

Summary of Financial Indicators	Units
tonnage worked	tons
berth occupancy revenue per ton of cargo	monetary units/ton
cargo-handling revenue per ton of cargo	monetary units/ton
labour expenditure per ton of cargo	monetary units/ton
contribution per ton of cargo	monetary units/ton
total contribution	monetary units
Summary of operational indicators	Units
arrival late	ships/day
waiting time	hours/ship
service time	hours/ship
turn-round time	hours/ship
tonnage per ship	tons/ship
fraction of time berthed ships worked	
number of gangs employed per ship per shift	gangs
tons per ship-hour in port	tons/hour
tons per ship-hour at berth	tons/hour
tons per gang-hour	tons/gang-hour
fraction of time gangs idle	

TABLE 3.2: SUMMARY OF FINANCIAL AND OPERATIONAL INDICATORS

Source: (UNCTAD, 1976)

(Suykens, 1983) discusses cargo-handling productivity in European seaports and various factors which may influence it. It concludes on the importance of organization of dock labour, port physical lay-out, type and extent of use of technical equipment. Also, that big differences exist in port productivity between continental European ports and possibly the main reason is port's response to changes. It includes an application to the port of Antwerp concerning cargo handling productivity.

Another significant addition to the field was the work of Bureau of Transport Economics, Australia. In (BTE, 1984) was done a survey of port productivity focusing on vessel time in port, noting that differences in vessel sizes and types affected terminal performance. The study compared two container terminals at Port Jackson, and took the unusual step at the time, of breaking down vessel time into the process of the vessel in a port: time waiting to berth, time at berth, time working the vessel, and time lost to delays for various reasons.

(Bureau of Industry Economics, 1993, 1995; Productivity Commission, 1998) continue the efforts of productivity measurement and monitoring in the Australian waterfront. However, both of these organisations developed their own measures of waterfront productivity⁵. (Productivity Commission, 2003) contains a detailed discussion of net versus gross crane rates (lifts per hour). It is noted that the definition of delays and non-working time, which constitute the difference between gross and net crane hou differs from port to port. This difference may make lifts per gross crane hour more reliable although a less precise basis of comparison than lifts per net crane hour.

(Ashar, 1985) was another early contributor, observing that the new container terminals being built at the time were larger versions of older terminals without innovations designed to increase productivity. The author introduces the Terminal Management System that had been developed and applied at the Port of Seattle. The idea is to collect operational data from container terminals and analyse and monitor through a set of productivity indicators, namely: TEU per gross terminal acre, TEU per container yard acre, vessel shifts per berth, moves per crane, and moves per crane-hour. These five measures illustrate an important distinction between the productivity of resources when employed (e.g. container moves per crane hour) and the overall utilization of terminal resources (e.g. annual container moves per crane).

(Committee on Productivity of Marine Terminals, 1986) provided a profile of terminal productivity measures and made a strong case for standardizing, collecting, and publishing such measures as a management tool and a spur to improved productivity. Table 3.3 shows the indicators used to measure terminal productivity.

⁵ For an overview of the historical background to the development of Australia's system of uniform measurement of container port performance see (Hamilton, 1999).

Element of terminal	Indicator of productivity				
Crane	Net crane productivity	moves/(gross gang hours- downtime)			
	Gross crane productivity	moves/gross gang hours			
Berth	Net berth utilization	annual container vessel shifts/container berths			
Yard	Yard throughput	annual TEU/gross acres			
	Yard storage productivity	TEU capacity/net storage acre			
Gate	Net gate throughput	container per hour/lanes			
	Gross gate throughput	equipment moves per hour/lanes			
	Truck turnaround time	total truck time in terminal/# trucks			
Gang	Gross labour productivity	# moves/man-hours			

TABLE 3.3: INDICATORS OF TERMINAL PRODUCTIVITY

Source: (Committee on Productivity of Marine Terminals, 1986)

Following a different approach (De Monie, 1987) argued that port productivity should be measured with respect to: i) duration of a ship's stay in port, ii) quality of cargo-handling, and iii) quality of service to inland transport vehicles. The author, similarly to (BTE, 1984), breaks down vessel time in port into several components, of which total time at berth and operational (working) time at berth are the most relevant for terminal productivity.

(Chung, 1993) provides a discussion of port indicators applicable to other types as well as container ports. Those applicable to container ports include: i) average vessel turn time; ii) TEU per crane hour, iii) cargo dwell time, and iv) berth occupancy rate.

Based on (Marconsult, 1994), which analyses productivity and handling costs of containers for the most important European ports, (Ashar, 1997) argues that an all-inclusive port cost per move is a more relevant measure than moves per hour when it comes to competition between ports. The underlying idea is that a cost per hour should be limited to moves per hour to account for the non-cash cost of vessel time.

(UNCTAD, 1999) suggests two categories of port performance indicators: macro performance indicators quantifying aggregate port impacts on economic activity, and micro performance indicators evaluating input/output ratio measurements of port operations.

Port/terminal	Throughput (TEU, 2004)	Throughput/ acre	Throughput/ crane	Throughput/ quay length
Los Angeles	7,321,440	4,342	106,108	229
Long Beach	5,779,852	4,501	84,998	210
Hong Kong	13,425,000	19,070	156,105	480
Singapore	20,600,000	24,582	174,576	523
Rotterdam	8,300,000	7,168	89,247	251
Antwerp	6,063,746	5,041	97,802	196
Hamburg	7,321,479	7,285	126,232	304
Tacoma	1,798,000	3,519	81,727	190
Klang	5,243,593	13,549	119,173	339
Houston	1,440,478	5,762	120,040	240

TABLE 3.4: PRODUCTIVITY MEASURES OF SELECTED LEADING CONTAINER TERMINALS

Source: (Le-Griffin & Murphy, 2006)

(Le-Griffin & Murphy, 2006) conduct an analysis of the productivity of the ports of Los Angeles and Long Beach in comparison with other leading container ports. Table 3.4 shows the utilized productivity measures.

(Blonigen & Wilson, 2006) propose fferent method for measuring overall port efficiency using trade data. This approach uses port charges, derived from trade sources, and performs a regression analysis on factors such as distance, weight, and trade balance. The result is an index of cost efficiency, but it is not directly related to terminal design or operating factors under management control. This approach could best be employed in high-level benchmarking, which would then be followed by more detailed analysis of terminal operating variables.

(Hanam Canada Corporation, 2007) undertakes a review of expansion plans at North America Pacific coast ports and provides comparison of productivity indicators, as can be seen in Table 3.5. Container storage capacity is considered separately as can be seen in Table 3.6 and the sample of ports is not exactly the same.

Port	mTEU/ year/ terminal	mTEU/ berth	mTEU/ crane	mTEU/ hectare	Hours/ year	Lifts/ hour	Useful excess capacity
Deltaport	1,078	539	180	17	3,188	24	0.2
Los Angeles	1,169	273	106	12	6,096	23	0.8
Long Beach	896	184	80	12	6,096	25	1.2
Balboa	500	250	167	59	8,760		0.2
Manzanillo	450	225	113	38	8,592		0.4
Seattle	556	185	72	9	2,146	22	0.2
Vancouver	504	252	92	17	3,188	19	0.4
Lazaro	375	375	188	25	8,760		0.1
Oakland	347	128	76	9	2,322	23	1.0
Tacoma	310	172	65	7	2,045	25	1.5
Surrey	200	100	50	7	2,250		0.0
Portland	196	65	28	4	2,146		0.0
Ensenada	109	109	27	8	8,760		0.0
Average	657	276	121	12	3,650		6.0

TABLE 3.5: PORT PRODUCTIVITY INDICATORS COMPARISONS

Source: (Hanam Canada Corporation, 2007)

Port/ terminal	Hectares	Storage Grounded TEUs	Storage Total TEUs	TEU/ acre
Cal United, Long Beach	38	14,400	43,200	1,135
Seaside, Oakland	23	5,898	17,694	762
Hutchinson Ensenada, Mexico	13		6,500	507
Pacific Container, Long Beach	102	15,317	45,951	450
SSAT, Long Beach (Matson)	28	4,000	12,000	427
Centerm, Vancouver	29		12,000	410
TSI, Delta	64		24,000	375
SSAT, Long Beach	68		24,000	352
APM Terminals, Tacoma	54	4,700	14,100	260
Terminal 6, Portland	80		7,700	97

TABLE 3.6: CONTAINER STORAGE CAPACITY

Source: (Hanam Canada Corporation, 2007)

Port/ terminal	# terminals	mTEU/ berth	mTEU/ crane	lifts/ crew/ hour	container dwell days
Long Beach	7	185	81	25	3
Vancourver	2	513	186	24	4
Delata	1	476	159	24	3
Los Angeles	7	262	102	23	3
Seattle	3	183	71	22	3
Oakland	7	127	75	23	3
Tacoma	5	162	61	25	3
Average	6	214	89	24	3

TABLE 3.7: PORT PRODUCTIVITY INDICATORS COMPARISONS

Source: (Hanam Canada Corporation, 2008)

In (Hanam Canada Corporation 208) quantitative competitiveness indicators, such as industry structure, service quality, environmental sustainability, innovation, prices, and profitability are analysed. Of relevance to this thesis, is the productivity indicators collected, that can be seen in Table 3.7. Unfortunately, the sample of points once again not the same as in the previous report and the indicators used also differ even if only to some extent, which limits comparability.

It is worth mentioning the initiative taken by Transport Canada concerning the development of a supply chain performance monitoring program, including the development and implementation of utilisation indicators across Canada's major seaports (Olivier, 2009; Transportation Canada, 2012).

The first phase of the project sought to implement metrics at container facilities, while bulk facilities were addressed in a subsequent phase due to methodological complexities related to bulk operations. Table 3.8 shows the port utilisation indicators developed for container ports. All metrics focus on operational aspects of port facilities.

Number	Indicator	Unit		
1	Truck turnaround time	Minutes		
2	Vessel turnaround time	Hours or seconds/ TEU		
3	Average vessel call size	TEU		
4	Berth Utilization	TEU/ metre of workable berth		
5	Container dwell time	Days		
6	Gross port productivity	TEU/ hectare		
7	Gross crane productivity	TEU/ gantry crane		

 TABLE 3.8: PORT UTILIZATION INDICATORS FOR CONTAINER FACILITIES

Source: (Transportation Canada, 2012)

(Ministry of Transport, 2011) looks at container productivity data from six ports representing over 90% of container traffic through New Zealand ports. It also compares this data with productivity results from Australian and other international ports. It concludes that, although there is room for improvement, container productivity at the six New Zealand ports appears adequate. Interesting to note

that the data in this study is based on container productivity measures as defined by the Bureau of Infrastructure, Transport and Regional Economics in Australia:

- quantity of containers;
- crane rate (number of containers a crane lifts on and off a container ship in an hour);
- ship rate (the number of containers moved on and off a container ship in an hour);
- vessel rate (the number of containers moved on and off a container ship in an hour of labour).

3.3 EFFICIENCY-BASED APPROACH

A number of methods have been proposed for measuring efficiency having in common the frontier concept i.e. efficient units are those operating on the cost or production frontier, while inefficient ones operate either below the frontier (in the case of the production frontier) or above the frontier (in the case of the cost frontier). The literature on frontier models begins with (Farren, 195, proposed framework, which was later widely accepted, for analysing economic efficiency in terms of palised deviations from an idealised frontier isoquant.

Concerning the different techniques utilized to derive the specification of the frontier model, differences exist. Statistical or non-statistical methods may be used, with the former making assumptions about the stochastic properties of the data, while the latter does not. Also, a distinction can be made between parametric and non-parametric methods.

The parametric approach imposes a particular functional form and employs econometric techniques where efficiency is measured relative to a frontier production function which is statistically estimated. Often named stochastic frontier analysis (SFA), it is assumed that the boundary of the production possibility set can be represented by a particular functional form with constant parameters.

The non-parametric approach does not impose a particular functional form and revolves around mathematical programming techniques. Also known as data

envelopment analysis (DEA), it focuses on the regularity assumptions of the production possibility splitself and does not postulate a particular functional boundary.

DEA	SFA					
Simil	Similarities					
Both require data on input and outpu	t quantities used by a sample of firms.					
Then the frontier is fitted over these or measured as the distance betweer fror	data points and technical inefficiency is each data point and the estimated ntier.					
Diffe	rences					
Uses linear programming methods to construct frontier	Uses methods similar to regression methods but more complex					
Assumes data are free of noise	Attempts to account for effects of data noise (data errors, omitted variables, etc.)					
Doesn't allow for standard statistical tests.	Can use standard statistical tests to test the significance of variables included in the model					
Need not specify a functional form for the production frontier.	Must select a functional form.					
Easier to calculate using available software	Less easy to calculate					
Has been more popular because DEA methods are easy to draw on diagrams, easy to calculate and until recently SFA couldn't accommodate multiple outputs.	Can now easily accommodate multiple outputs using a multi-output production function, known as a distance function.					

TABLE 3.9: COMPARISON OF METHODS FOR EFFICIENCY MEASUREMENT

Source: adapted from (Coelli, Estache, Perelman, et al., 2003)

Both parametric and non-parametric frontier methods allow the estimating of production and cost frontiers, deriving ratios of relative efficiency within a given group of units and using cross-section and panel data. The basic difference is that SFA draws on econometric methods and DEA is a non-parametric technique based on linear programming.

3.3.1.1 PARAMETRIC METHODS: SFA TECHNIQUE

Among the proposed methods for measuring efficiency using the frontier concept, the first one is econometric modelling. Stochastic frontier analysis is the most common approach among these models. SFA has its origins in the stochastic production frontier models introduced independently by (Aigner, Lovell & Schmidt, 1977; Meeusen & van den Broeck, 1977). When recurring SFA technique actual to optimum output is usually compared by means of the efficient frontier concept. From the literature review it is noticeable that most authors consider the studies based on econometric techniques to have a stronger background in economics than the non-parametric techniques, which gives more credibility of the conclusions drawn.

Table 3.10 gives an overview of the literature on application of stochastic frontier analysis to ports, indicating the author, the objective of the work, a description of the data used, an indication of the model and its functional form, and a brief description of the main conclusion per study.

This technique has been applied to ports and used for assessing port productivity both within a single country (Liu, 1995; Baños-Pino, Coto-Millan & Rodriguez, 1999; Coto-Millan, Baños-Pino & Rodríguez-Álvarez, 2000; Estache, Gonzalez & Trujillo, 2001; De & Ghosh, 2002; Barros, 2005; González & Trujillo, 2008b) and across different countries (Notteboom, Coeck & Van den Broeck, 2000; Song, Cullinane & Roe, 2001; Cullinane, Song & Gray, 2002; Han, 2002; Cullinane & Song, 2003; Song & Han, 2004; Tongzon & Heng, 2005; Tovar, Jara-Díaz & Trujillo, 2007).

Also relevant the diversity of purposes for these works, ranging from analysing the relation existing between type of ownership and port efficiency (see (Liu, 1995; Song, Cullinane & Roe, 2001; Cullinane, Song & Gray, 2002; Cullinane & Song, 2003; Tongzon & Heng, 2005), assessing the results of port reforms (Estache, Gonzalez & Trujillo, 2001; González & Trujillo, 2008b), ranking ports according to efficiency levels (Notteboom, Coeck & Van den Broeck, 2000; Coto-Millan, Baños-Pino & Rodríguez-Álvarez, 2000; Tovar, Jara-Díaz & Trujillo, 2007) and considering determinants of terminal efficiency (Han, 2002; Song & Han, 2004).

The main argument against the use of parametric models for port productivity measurement arises from the deterministic requirement of a functional specification, which does not allow for relative comparisons with the best multi-factor practice. Also, according to (Kim & Sachish, 1986) parametrical approaches may not be suitable for international port comparisons since the structure of port production may limit the econometric estimation of a cost or production function to the level of a single port or terminal.

Reference	Objectives	Data description	Model(S)	Functional form	Conclusions
(Liu, 1995)	Assess efficiency differences between public and private ports	Panel data; 28 UK ports; 1983-1990	Stochastic production function	Translog	Concludes differences in efficiency between private and public ports are negligible
(Baños-Pino, Coto- Millan & Rodriguez, 1999)	Estimate the degree of overutilization of quasi- fixed inputs using 2 alternative methods: the cost function and the input distance function	Panel data; 27 Spanish ports; 1985-1997	Stochastic cost function; distance function	Translog	Both methods identify overcapitalization but magnitude and significance differs according to method used; concluded that distance function is more appropriate
(Notteboom, Coeck & Van den Broeck, 2000)	Assess productivity of European container terminals	Cross-section data; 36 European container terminals; 1994	Stochastic production frontier	Cobb-Douglas	Hub ports generally more productively efficient than feeder ports; intra-port competition influences positively the terminal productivity within the port
(Coto-Millan, Baños-Pino & Rodríguez-Álvarez, 2000)	Estimate a translog cost frontier for the Spanish ports	Panel data; 27 Spanish ports; 1985-1989	Stochastic cost function	Translog	Most efficient ports are smallest in size and managed centrally; detected pres bood of economies of scale and lack of technical progress
(Estache, Gonzalez & Trujillo, 2001)	Estimate a Cobb-Douglas and translog production frontier for Mexican ports	Panel data; 14 Mexican ports; 1996-1999	Stochastic production function	Translog and Cobb-Douglas	Reforms have resulted in significant improvements in the performance of ports on average

TABLE 3.10: SURVEY OF LITERATURE ON APPLICATION OF STOCHASTIC FRONTIER ANALYSIS TO PORTS

(Song, Cullinane & Roe, 2001)	Assess the practical impact of port privatization policies upon the economic performance of the sector	Cross-section and panel data; 2 Korean and 3UK container terminals	Stochastic production frontier	Cobb-Douglas	Greater private participations does not seem to by rucial factor influencing efficiency levels in these 5 terminals
(Cullinane, Song & Gray, 2002)	Analyses the administrative and ownership structures of the major container ports in Asia	Cross-section and panel data; 15 Asian countries; 1989-1998	Stochastic production function	Cobb-Douglas	Size of a port is closely correlated with its efficiency; exists some support for claim that private sector improves economic efficiency
(De & Ghosh, 2002)	Study performance of Indian ports in terms of labour productivity in relation to capital coefficients	Cross-section; 12 Indian ports; 1981-1982 and 2000-2001	Time varying production function	Cobb-Douglas	Increases in capital use in India's ports led to productivity improvements
(Han, 2002)	Test empirical estimation to identify the determinants of port performance and efficiency	Panel data; 38 Asian container terminals; 1993- 1999	Production function	Cobb-Douglas	Among the determinants of terminal efficiency, yard throughput and berth surface are the dominant contributors
(Cullinane & Song, 2003)	Assess the impact of privatization and deregulation policies in Korean ports and using UK ports as a benchmark	Cross-section and panel data; 2 Korean and 3 UK container terminals	Stochastic production frontier	Cobb-Douglas	Degree of private participation in port terminal is positively related to productive efficiency; privatization and deregulation policies led to increased productivity

(Song & Han, 2004)	Use a quantitative approach to determine port performance	Cross-section data; 38 Asian container terminals; 1993- 1999; 2000	Simultaneous equations	Cobb-Douglas	Port performance is significantly influenced by berth utilisation
(Tongzon & Heng, 2005)	Investigate the relationship between port ownership structure, port size and technical efficiency	Cross-section data; 25 world container ports; 1999	Stochastic production function; regression model	Cobb-Douglas	Port authorities should limit private sector participation to "landowner and operator" and take over regulatory function
(Barros, 2005)	Analyse the extent of technical change and technical efficiency in Portuguese seaport costs	Panel data; 10 Portuguese ports; 1990-2000	Stochastic cost function	Translog	High degree of waste in the use of resources, despite the fact that technical change contributed to a reduction of costs
(Trujillo & Tovar, 2007)	Estimate technical efficiency of European Port Authorities	Cross-section data; 22 European ports; 2002	Stochastic distance function	Cobb-Douglas	Average port efficiency in 2002 was estimated to be around 60%, denoting that ports could have handled 40% more traffic with the same resources
(González & Trujillo, 2008b)	Analyse the extent to which port reforms that took place in the 90's had an impact on the efficiency of the Spanish container ports.	Panel data; 9 Spanish ports; 1990-2002	Stochastic distance function	Translog	Significant movement of the efficiency within ports over time as a result of reforms

Source: own composition

3.3.1.2 NON-PARAMETRIC METHODS: DEA TECHNIQUE

Among the non-parametric frontier models, DEA is the most known. This technique for measuring technical efficiency was originally developed by (Charnes, Cooper & Rhodes, 1978), the so so-called CCR. This model assumes constant returns to scale, which is inappriate to several sectors including ports. Later (Banker, Charnes & Cooper, 1984) introduced the assumption of variable returns to scale. This model is known in the literature as the BCC model.

The DEA technique uses output data (in most cases annual TEU) and a selection of dependent variables to generate a "DEA Score" for each production unit (in this case a port or terminal). The best scores define a data envelope akin to an economic production frontier. Less favourable scores indicate relatively inefficient resource use, unrealized economies of scale, or other shortfalls.

In recent years, DEA has been more and more employed as a methodology for assessing productivity in the port sector. A reason may be that DEA has, over the traditional techniques, the advantage of allowing taking into consideration multiple inputs and outputs, which is very useful for a complex sector such as ports. Some papers are genuine applications of DEA to ports, while others are more a theoretical explanation of applying this technique to the port sector. Table 3.11 presents a survey of the literature on applications of mathematical programming methods to the port sector. The table indicates per reference, the objective of the study, description of the data used, inputs, outputs and briefly states the main conclusions.

Among the applications listed, that of (Roll & Hayuth, 1993) should be treated as a theoretical exploration of applying DEA to the port sector, rather than as a genuine application. This is because no genuine data were collected and analysed.

As can be seen, DEA applications in ports are quite recent. Some applications attempt to aggregate port operations (Barros & Athanassiou, 2004), others address a single port function (Cullinane, Song, Ji, *et al.*, 2004), a few studies complement DEA with a second-stage analysis (Bonilla, Medal, Casasús, *et al.*, 2002; Turner, Windle & Dresner, 2004).

Considering the geographic location, some studies have been conducted using DEA applied to ports in order to compare efficiency of ports in European countries (Martinez-Budría, Diaz-Armas, Navarro-Ibañez, *et al.*, 1999; Bonilla, Medal, Casasús, *et al.*, 2002; Barros, 2003; Barros & Athanassiou, 2004; Barros, 2006; Cullinane & Wang, 2006); in Asian countries (Park & De, 2004; Barros & Managi, 2008; Hung, Lu & Wang, 2010), in Australia (Poitras, Tongzon & Li, 1996; Tongzon, 2001), in East African and Middle Eastern countries (Al-Eraqi, Mustafa, Khader, *et al.*, 2008), in North America (Turner, Windle & Dresner, 2004) and South America (Rios & Maçada, 2006). Still some authors use for their study samples of world ports (Valentine & Gray, 2001; Wang, Song & Cullinane, 2003; Cullinane, Song, Ji, *et al.*, 2004; Cullinane, Song & Wang, 2005; Herrera & Pang, 2008).

Author(s)	Objective	Data description	Inputs	Outputs	Conclusions
(Roll & Hayuth, 1993)	To theoretically rate the efficiency of ports	Cross-section data; hypothetical numerical example of 20 ports	Manpower; capital; cargo uniformity	Cargo throughput; level of service; users' satisfaction; ship calls	DEA can be useful in assessing relative efficiency of various ways of organizing port services with limited available data
(Poitras, Tongzon & Li, 1996)	Provide an efficiency ranking for five Australian and eighteen other international container ports	Cross-section data; 5 Australian and 18 world ports; 1991	Container mix; stevedoring delays; TEUs per Crane hour; # ship calls; port charges; average # of TEUs per ship call	TEUs per berth hour; # TEUs year	Main contribution is methodological; it demonstrates that DEA provides a viable method of evaluating relative port efficiency
(Martinez- Budría, Diaz- Armas, Navarro- Ibañez, <i>et al.</i> , 1999)	To examine the relative efficiency of ports and efficiency evolution of an individual ports	Panel data; 26 Spanish ports; 1993- 1997	Labour expenditures; depreciation charges; other expenditures	Total cargo moved through docks: revenue obtained from rent of port facilities	Classified ports into 3 groups: high, medium and complexity ports; conclude that ports of high complexity are associated with high efficiency, compared with medium and low efficiency found in other groups of ports
(Tongzon, 2001)	Specify and empirically test the various factors which influence the performance and efficiency of a port	Panel data; 4 Australian and 12 international container ports; 1996	<pre># cranes; # container berths; # tugs; terminal area; delay time; # port authority employees</pre>	Cargo throughput; ship working rate	A port's operational efficiency does not depend only on size and function (hub vs feeder); sources of inefficiency are under-utilization of labour, container berth and terminal area

TABLE 3.11: SURVEY OF LITERATURE ON APPLICATION OF DATA ENVELOPMENT ANALYSIS TO PORTS

(Valentine & Gray, 2001)	Determine whether there is a particular type of ownership and organisational structure that leads to a more efficient port	Panel data; 31 world container ports; 1998	Berth length; assets	# containers; total throughput	Organisation theory and ownership structure can be incorporated into a conceptual model of the port industry that can in itself enable a simple comparison of the efficiency of differing patterns to be made
(Bonilla, Medal, Casasús, <i>et</i> <i>al.</i> , 2002)	Study commodities' traffic efficiency in Spanish port system	Panel data; 23 Spanish ports; 1995- 1998	Solid bulk, liquid bulk, general and container traffic	Port equipment	Spanish port system presents some inefficiencies and big differences in the results; results show that small variations in data generate big changes
(Barros, 2003)	Analyse Portuguese port authorities, propose framework for evaluation of seaports and rationalisation of their operational activities	Panel data; 6 Portuguese port authorities; 1999- 2000	# workers port authority; book value of assets	Ships, movement of freight, gross tonnage, market share, break-bulk cargo, containerised cargo, roll-on/roll-off (ro/ro) traffic, dry bulk, liquid bulk and net income.	An organisational governance environment, with account- ability, transparency and efficiency incentives that explicitly oblige the seaports to achieve efficiency in their operational activities, is needed to overcome the deficits in technical and allocative efficiencies observed in the seaports analysed
(Wang, Song & Cullinane, 2003)	Evaluate efficiency of world's most important container ports and terminals using two alternative techniques: DEA and Free Disposal Hull (FDH) Model	Cross-section data; 57 world terminals and ports; 1999	Quay length; terminal area, # gantry cranes; # yard gantry cranes; # straddle carriers	Container throughput	Available mathematical programming methodologies lead to different conclusions; availability of panel data, rather than cross-sectional data would greatly improve the validity of the efficiency estimates

(Barros & Athanassiou, 2004)	Compare seaport efficiency of two European countries, Greece and Portugal, using DEA	Panel data; 4 Portuguese and 2 Greek port authorities; 1998- 2000	# workers port authority; book value of assets	Ships, movement of freight, total cargo handled (dry and liquid cargo, unloaded and loaded) and containers (loaded and unloaded)	Majority of the seaports are efficient with the sole exception of Thessaloniki; scale economies should be the principal target for adjustment
(Cullinane, Song, Ji, <i>et al.</i> , 2004)	Apply DEA windows analysis to a sample of the world's major container ports in order to deduce their relative efficiency	Panel data; 25 world container ports; 1992-1999	Quay length; terminal area, # gantry cranes; # yard gantry cranes; # straddle carriers	Container throughput	Estimates of container port efficiency fluctuate over time; existing programming methods for estimating efficiency are inadequate in capturing the long-term increased efficiency and competitiveness that accrue from significant investments
(Park & De, 2004)	Reviews approaches to performance measurement and provide an examination of the applicability of alternative (four-stage) DEA to seaport efficiency measurement	Cross-section data; 11 Korean ports; 1999	Berthing capacity; cargo handling capacity	Cargo throughput; # ship calls; revenue; customer satisfaction	Suggest new approach for measuring seaport efficiency: four-stage DEA method, showing the multi- stage efficiency according to the characteristics of inputs and outputs
(Turner, Windle & Dresner, 2004)	Create efficiency score using DEA and examine determinants of port productivity using regression	Panel data; 26 US and Canadian container ports; 1984-1997	Terminal area; quay length; # container cranes	Container throughput	Larger ports are more efficient (size matters); railroad is significant determinant in port productivity; strike days and leasing are not significant; port- specific fixed effect not found

(Cullinane, Song & Wang, 2005)	Compare estimates of performance container ports applying DEA and Free Disposal Hull (FDH)	Cross-section data; 57 world terminals and ports; 1999	Quay length; terminal area, # gantry cranes; # yard gantry cranes; # straddle carriers	Container throughput	Confirms that DEA and FDH tend to give significantly different results; so, choice of methodology matters (Identical to Cullinane et al 2003)
(Barros, 2006)	Evaluate performance of Italian seaports combining operational and financial variables	Panel data; 24 Italian ports; 2002-2003	# workers port authority; book value of assets; operational costs	Liquid bulk; dry bulk; # ships; passengers; containers; sales	Examined ports display relatively high-managerial skills, being VRS-efficient for the most part; there are also inefficient seaports that do not display equivalent scale efficiency i.e. dimension acts as a restriction on the efficient performance of small seaports
(Cullinane & Wang, 2006)	Measure efficiency of container terminals in Europe using DEA; consider scale properties and geographical influence	Cross-section data; 69 European container terminals; 2002	Terminal length; terminal area; # equipment	Container throughput	Significant inefficiency exists for most terminals; some terminals are scale efficient but most exhibit increasing returns to scale; average efficiency of terminals located in different regions differs to large or small extent
(Rios & Maçada, 2006)	Analyse the relative efficiency of operations in container terminals of Mercosur	15 Brazilian, 6 Argentinean and 2 Uruguayan container terminals; 2002- 2004	<pre># cranes; # berths; # employees; terminal area; # yard equipment</pre>	TEUs handled; average # of containers handled per hour/ship	60% of the terminals were efficient in the 3-year period

(Al-Eraqi, Mustafa, Khader, <i>et al.</i> , 2008)	Evaluate efficiency of Middle East and East African ports; aims to compare two stages of analysis, using cross- section method and panel data	Cross-section and panel data; 22 Middle East and East African ports; 2000-2005	Berth length; storage area; handling equipment; # ship calls	Throughput (tons)	Small ports are efficient while big ports are inefficient; for increasing port efficiency, ships arrival should increase the scale of production; inefficient ports with declining efficiency reduce their scale of operation to be efficient
(Barros & Managi, 2008)	Analyse efficiency drivers of sample of Japanese seaports by means of the two-stage procedure	Panel data; 39 Japanese port authorities; 2003- 2005	<pre># personnel; # cranes</pre>	# ships; tons of bulk; container TEU	There is dispersion of the efficient scores along the different Japanese seaports, which exhibit inherently differentiated levels of efficiency
(Herrera & Pang, 2008)	Gauge efficiency of container terminals across the world	Cross-section; 51 world ports;	Terminal area; # ship-to-shore gantries; # quay, yard and mobile gantries; # tractors and trailers	Container throughput	Margin for cost reduction is significant; most inefficient ports use inputs in excess of 20 to 40% of the level used in the most efficient ports; geographical location seems to be a determinant of efficiency; larger ports are more efficient than smaller ones
(Hung, Lu & Wang, 2010)	Contribute to empirical evidence on container port efficiency by studying sample Asia container ports	Cross-section data; 31 Asian container ports; 2003	Terminal area; # container gantry; # container berth; terminal length	Container throughput	Overall technical inefficiencies of Asian container ports are primarily due to pure technical inefficiencies rather than scale inefficiencies

Source: own composition
3.4 LIMITATIONS TO THE USE OF EFFICIENCY-BASED APPROACH METHODS

This sub-chapter focuses on understanding why the traditional productivity-based approach methods are not the most suitable ones when addressing the issue of port productivity; a number of factors limit the use and the conclusions that can be derived from using such models. In general, the practical reasons preventing the use of productivity-based approach methods are as follows:

- For a meaningful PIN and SFA analysis detailed financial information is needed. However, up to date detailed financial data is difficult to compile for a significant sample (number of ports);
- Different companies, ports and terminal operators define their cost base and their activities differently (e.g. sources aggregate data by port, by terminal, by concessionaire). These differences in the breakdown of the cost base does not allow for a comparable cost analysis;
- The DEA method ideally requires quantity data on inputs and outputs for a sample of companies, ideally over a number of years. However, port activity is highly dynamic with both infrastructure (e.g. berth length and area) and superstructure (e.g. gantry cranes) changing considerably over a short period of time. In practical terms this type of data is almost impossible to compile outside the industry context.

In this context, any analysis on container port productivity involving a large sample i.e. a large number of sample ports or terminals using these methods will be extremely difficult to undertake and any results obtained will, most likely, not be considered as robust or meaningful.

The academic literature on port productivity is more concerned with validating the theoretical approach using available, but often outdated data with limited geographical scope. Whilst this concept might be theoretically valid it has, in practice, little adherence amongst industry stakeholders.

While promising and instructive, these efforts have not translated into results that can be considered useful to port planners or terminal managers. The limitations to the use of efficiency-based approach methods have also been addressed by academic researchers; (González & Trujillo, 2008b) provide an extensive review of the port efficiency modelling literature. They found a wide range of approaches and results and a general lack of comparability due to differences in types of, port, production definitions, and input variables. These authors also identified the need for improved data collection.

From the literature review there are a number of issues that could be identified as limitations to the use of parametric and non-parametric methods. The major limitations to the use of these methods are identified below:

- In none of the studies mentioned above were the determinants (inputs/outputs) of port performance formally linked to or justified by a correspondingly valid empirical analysis. Variables were selected either subjectively or at best from previous literature, much of which was, in fact, based on subjective and arbitrary appraisal;
- Many researchers on port productivity have each applied parametric and non-parametric methods on different occasions, which implies that no consensus has been reached on a single and consistent approach in order to best analyse port performance;
- The apparent limitation on the consistent use of DEA or other analytic techniques is the variability and relevance of inputs. Authors have used inputs ranging from cargo uniformity and depreciation charges to berth length and the number of tugs, few of which are under the control of terminal developers or managers;
- Of the two widely used DEA models, the "CCR" (Charnes, Cooper, and Rhodes) version assumes consistent returns to scale, which does not correspond to the realities of container port development or operation. As terminals increase in scale, the binding constraint on their capacity and productivity will shift from resource to resource and they will change production functions as they progress from low-cost, low-density operations to high-cost, high-density operations. As an example, the authors found that the DEA-CCR, DEA-BCC models indicated that Los Angeles and Long Beach (terminal unspecified) were more efficient than Rotterdam, Hamburg, or some of the Hong Kong terminals. The FDH model found that most of the

ports and terminals examined had equally high efficiency and would therefore be of limited utility as an analytic tool. The DEA "BCC" variation returns to scale and may be more suitable.

- The efforts to model container terminal production frontiers using DEA or related techniques face some basic obstacles. At any given time, terminals present a suboptimal combination of production resources. Terminals do not have effective control over the land area available, and cannot adjust their area to match demand in the short run. Berth length and channel depth are likewise fixed in the short run, and often for the long run as well. Adding a new container crane is a multi-year, multi-million dollar investment decision. Even yard lift equipment such as RTGs or straddle carriers requires a substantial investment and lead time. In the short run, labour is almost the only variable input. In this context, the definition of the optimum production frontier is almost impossible to be obtained;
- The arguments above explain to some extent why some of the findings of the port frontier literature provide inconsistent results, for instance, when analysing the relationships between size and efficiency (Martinez-Budría, Diaz-Armas, Navarro-Ibañez, *et al.*, 1999) versus (Coto-Millan, Baños-Pino & Rodríguez-Álvarez, 2000), ownership structure and efficiency (Notteboom, Coeck & Van den Broeck, 2000) versus (Cullinane, Song & Gray, 2002) locational/ logistical status and efficiency (Liu, 1995) versus (Tongzon, 2001).

The DEA approach to efficiency analysis presents advantages over parametric approaches. This methodology accommodates multiple inputs and outputs, and provides information about the sources of their relative (factor specific) efficiency.

Under a DEA analysis, there is no necessity to pre-define relative weight relationships, which should free the analysis from subjective weighting and randomness. Similarly, DEA neither imposes a specification of a cost/production function nor requires an assumption about the technology. Moreover, firms, ports or terminals are benchmarked against an actual 'best' firm rather than against a statistical measure, an exogenous or average standard. The simplicity of inputs and the practicality of the output data make DEA particularly attractive for port-related efficiency studies, which explain the increasing number of academic publications on the subject. On the other hand, one could argue that the same features that make DEA a powerful tool also create major limitations. A summary of the major limitations is listed below:

- DEA does not allow for stochastic factors and measurement errors and there is no information on statistical significance or confidence intervals;
- Another major drawback of DEA is to the sensitivity of efficiency scores to the choice and weights of input-output variables. This is of major concern because a port or terminal can appear efficient simply because of its patterns of inputs and outputs. This issue also does not identify, which factors are more important for a study on port productivity as all considered factors in the analysis have an equal "weighting";
- Another important drawback is that in the port literature most DEA applications assume constant efficiency over time. On the long run this assumption is not valid. It does also not consider the incremental nature of port investment, and therefore favours ports that are not investing in new facilities or equipment at the time of the research or that are operating at capacity where any incremental productivity improvement is extremely difficult to achieve;
- Moreover, input (output) saving (increase) potentials identified under DEA are not always achievable in port operational settings, particularly if this involves small amounts of an indivisible input or output unit.

While DEA may be a promising theoretical approach, studies reviewed to date provide only limited practical insight. The studies confirm the existence of economies of scale in container terminal operations, but the existence of scale economies was never in doubt. The DEA studies may have been limited by their use of port-wide output data and characteristics, rather than terminal-specific information.

The choice of dependent variables may also limit the practical application of studies to date. The researchers used port leasing policy, berth occupancy, the availability of double-stack clearances, and other factors as dependent variables only to find them insignificant in the analysis. (Sharma & Yu, 2009) suggest combining DEA with data mining techniques to create a better diagnostic tool.

The efforts at modelling container port performance illustrate a classic dilemma: the data available to researchers often lacks explanatory power, and the data that is more directly related to efficiency is not published or confidential. Researchers are thus in the difficult position of trying to identify a production frontier using variables that are secondary or tertiary at best.

A study of the academic literature on the use of parametric and non-parametric methods in the measurement of container port productivity confirms the problems identified above in an debatable way by concluding that many of the variables used have no explanatory power, that better and more data is needed, and that the modelling effort overall is still at an early stage of development.

3.5 RATIONALE FOR KPI-BASED INDICATORS IN PORT PRODUCTIVITY MEASUREMENT

Based on the factors mentioned above it was decided that the most applicable methodology for analysing container port productivity are key performance indicator-based indicators. This rationale is due to several reasons:

- Data applicability: the data collected covers an identical type of infrastructure in all ports, namely container terminals. This is most common and easy to benchmark;
- Scope of analysis: in a KPI based approach, each indicator is similar across all ports that are part of the sample data. For example the indicator "berth length" or "throughput" have a similar interpretation across all sample ports;
- Data sources: in this document the KPI-based approach was designed in order to eliminate the bias relating to the origin of data (i.e. data sources).
 Data from most indicators come from the same data source and when different sources of data were used, these could be double-checked with other sources, e.g. quay length double-checked with Google Earth;
- Data measurement: in a KPI-based approach no specific methodology is needed for data collection.

Given the facts mentioned above a KPI-based approach is considered to be the most appropriate for the study of container port productivity.

The underlying idea is to address container port productivity from a point both academia and industry may find valuable. This can be achieved by using the productivity KPIs and applying multivariate data analysis, namely regression analysis, factor analysis and cluster analysis in order to assess what variables contribute most meaningfully to productivity and benchmarking a group of ports grouping them into relevant clusters.

3.6 PORT PRODUCTIVITY CONCEPTS

3.6.1 A DEFINITION OF CONTAINER PORT PRODUCTIVITY

For the purpose of this thesis, productivity is defined as the combined result of operational efficiency and resource utilization. Operational efficiency measures output per unit of input, and it is usually expressed as a ratio. Concerning resource utilization, it measures output against capacity and it is usually expressed as a percentage. As an illustration, TEU per terminal area is an efficiency measure whereas percentional used capacity per year is an utilisation measure.

Given the above mentioned definition, productivity of a given asset i.e. container port may be increased either by increasing operating efficiency or by increasing utilization, or both.

3.6.2 ESTIMATE PRODUCTIVITY

In this dissertation three key performance indicators of container port physical productivity are considered:

- Handling productivity: Containers (TEUs) / crane / year;
- Berth productivity: Containers (TEUs) / meter / year;
- **Terminal Area productivity:** Containers (TEUs) / m² / year.

There are several possible ways estimate container port productivity. All rely on a variety of assumptions, quantifiable relationships and a few rules of thumb. The general approach used in this study was selected primarily to suit the readily available port and terminal data elements, with the anticipation of regular data collection, analysis, and publication. More precise estimates are possible, but would require a much greater investment in data collection and analysis, and would change frequently as ports and terminals change their facilities.

As illustrated in Figure 3.1, container terminal capacity has five long-term constraints or dimensions.



FIGURE 3.1: THE FIVE DIMENSIONS OF CONTAINER TERMINAL CAPACITY

Source: (Smith, 2012)

Ports and marine terminal operators are continually reviewing and adjusting their capacity, and their operating practices within that capacity. Terminals attempt to balance the dimensions of capacity:

- berths long and deep enough for the biggest expected vessel;
- enough berths and cranes to avoid vessel delay;
- enough container yard area and density to avoid congestion;
- enough hours to turn the vessel.

To estimate the container terminal capacity, utilization, and productivity along the five dimensions in Figure 3.1 works well for dedicated container terminals that handle vessels with on-shore gantry cranes. The methodology does not work as well with multipurpose terminals that may also handle autos or break-bulk. In general, there is not any easy way to divide container yard space or other attributes among the uses. Terminals that also handle Ro-Ro or reefer vessels encounter the same issue. In such cases, the division of terminal space devoted to different cargo types is flexible, and capacity or productivity are not fixed or readily estimated.

Usually, container ports do not operate at or near their full capacity. A port operating at or near its full capacity is highly vulnerable to the least disruption and lacks the operating resilience to recover. Moreover, a port operating at capacity has no room for growth, and despite the current downturn in trade, growth will resume.

3.6.3 PERSPECTIVES ON PRODUCTIVITY

The choice of port productivity metrics should be dictated in large part by their intended use. There are a number of potential users of port performance metrics, including:

- terminal operators;
- labour unions;
- port authorities;
- customers (importers, exporters, third parties);
- shipping lines.

In this thesis the focus is on the terminal operator perspective.

Terminal operators use performance metrics to monitor terminal performance, plan capital expenditures, project revenue, etc. Their primary focus is on the productivity and efficiency of resources and imports under their control:

- labour hours;
- container cranes;
- yard equipment;
- terminal area.

The highest day-to-day priority of a terminal operator is to service the vessel quickly and efficiently. Pertinent productivity measures would include:

- crane lifts per hour;
- crane lifts per man hour;
- average cost of crane lifts;
- overall vessel discharge and loading rates;
- reliability of vessel turnaround times.

High-level measures such as TEU per gross acre are less useful, since they do not translate into management action items. Measures such as storage per container terminal area are more amenable to management initiative and influence.

The need for management action or capital investment is most likely to be signalled or triggered by complaints about growing congestion, escalating unit costs, or lengthening vessel turn time than by overall throughput or TEU per area. The most useful metrics would then be those that enabled management to identify the causes of declining performance and choose among possible responses. Rising vessel turn times might be due, for example, to a need for more cranes to handle larger vessels, inefficient crane operations, or yard delays that waste crane operator time.

Management would need to choose between acquiring more cranes, adding yard equipment, or seeking greater crane operator productivity.

The bottom line for terminal operations is cost. In the short run most terminal assets - land, berth space, cranes, yard equipment, and systems - are fixed, and stevedores' labour hours are the key variable. Man-hours per lift or an equivalent such as gang-hours per vessel is thus the key near-term operating metric.

This observation highlights a key feature of U.S. container terminals: the high cost of labour and low cost of land compared to their Asian or European counterparts. It is axiomatic that commercial operations will be managed to conserve the scarcest resource, and, in the case of U.S. container terminals, the scarcest resource is labour.

The (JWD Group, 2003) study for the Port of Houston made a crucial observation regarding the reaction of the privately operated APM (Maersk) terminal to growing trade volumes. Once average throughput at that terminal reached about 4,000 TEU/acre, the terminal operators aggressively sought more space. The terminal expanded, keeping TEU/acre at about 4,000 rather than investing in the capital and labour required to increase productivity. Increasing acreage is, ordinarily, a lower cost alternative compared to increasing throughput per acre.

It is reasonable to ask how much terminal operations rely on performance metrics versus the observations and experience of terminal managers. Does the decision to acquire additional reach stackers depend on a numerical benchmark or on the manager's conviction that the supply of reach stackers has become a bottleneck? Industry experience suggests that terminal expansion or capital investment needs are suggested or initiated through management observations, and perhaps vetted or justified by performance metrics.

3.7 SUMMARY

This chapter sets the scene for productivity measurement with a focus on container ports and presents an extensive literature review on container port and terminal productivity measurement. This provides a solid starting point for this study on productivity in the container port business and factors driving container port and terminal productivity. The different approaches in measuring container port productivity in academic literature and industry expertise are presented.

It is observed that there is a strong consensus on the desirability of measurement, the importance of productivity, and the potential for improvement. However, despite the extensive work dealing with port productivity, there is no uniform terminology and methodology to measure productivity. The academic coverage of productivity measurement in the port sector is not consistent. Independently of the techniques chosen, productivity measurement of a range of port or terminals is a challenge, given the dissimilarities between ports and even terminals within the same port.

It was argued that the productivity of a container port/terminal depends on the efficient use of land, labour and capital (Dowd & Leschine, 1990). It was established that the terminal quay length, the terminal surface and the number of quay cranes can be used as relevant variables directly affecting container terminal efficiency (Notteboom, Coeck & Van den Broeck, 2000).

Having this in consideration, a working definition of container port productivity is put forward. This thesis considers three container port physical productivity indicators, that the literature review on performance indicator based approach, showed to be the most consensual and universally applied, namely:

- Handling productivity: Containers (TEUs) / crane / year;
- Berth productivity: Containers (TEUs) / meter / year;
- **Terminal Area productivity:** Containers (TEUs) / m² / year.

These will be further detailed in the next chapter, concerning methodology for productivity measurement, as well as in chapter 5, that presents the empirical analysis undertaken.

4 METHODOLOGY FOR PRODUCTIVITY MEASUREMENT

4.1 INTRODUCTION

In this chapter are described the sampling strategy, methodology for the data collection and data treatment process. Furthermore, are introduced the different data analysis techniques used for the empirical data analysis.

The type of research undertaken in this dissertation is causal in nature, more specifically **to test hypotheses about cause-and-effect relationships through the use of multivariate data analysis**, as explained in chapter 1.3.2. The results obtained are based on databases whose input data comes from secondary sources i.e. data collected from industry databases, port operator information and international institutions. Subsequently, causal research is used to understand how changes in the independent variables (e.g., throughput, berth length, terminal area, etc.) affect the dependent of the variable (e.g., container port productivity).

4.2 CHOICE OF SAMPLE AND DATA COLLECTION

Having a strategy for data collection, treatment and presentation is a critical step for the success of the research and to the process of assembling the available data into a set of attributes i.e. variables⁶. The resulting database can then be used for empirical analysis aimed at understanding container port characteristics and the drivers of port productivity.

4.2.1 CHOICE OF SAMPLE

In this sub-chapter is explained the process of creating a sample of ports to be analysed. The first step consisted gaining access to a database with historical container port throughput. This information was obtained through a subscription of

⁶ A variable is an attribute whose value can change.

the database CI Online Liner Intelligence. This database contains the worldwide container port throughput time series between 1970 and 2008. Bearing in mind that the focus of this thesis is the Mediterranean region, ports in other regions have not been taken into consideration.

As explained in sub-chapter 1.1.4, the adopted definition of Mediterranean range includes the ports of Portugal, Morocco and Romania, which are arguably still under the influence of this sea from a competition dynamics point of view.

The initial selection resulted in a total of 111 container ports in the Mediterranean, which were ranked from largest to smallest. Then, each port and individual market shaped was determined calculating their throughput per port as a share of the Mediterranean total throughput.

The rationale behind this ranking was to select a smaller, but yet representative sample of ports that would handle a very significant share of the market. Taking into consideration the cumulative market share, the top-30 ports were selected for further analysis. These represent a very significant share - around 90% - of the region's total container throughput.

For comparison purposes, it should be noted that the average market share of the top-30 container ports is 3% (90% market share divided by 30 ports), whereas the average share of the remaining ports is only 0.12% (10% divided by 111 minus 30 ports) i.e. the larger ports handle on average 24 times more TEUs than the smaller ports.

The top 30 ports in the Mediterranean region handled above 40 million TEU in 2008 and all of these por had a throughput above 380 million TEU for that year. Moreover, virtually all transhipment traffic - 22 million TEU - has transited through the top-30 ports. The smaller ports outside the top-30 were regarded as less interesting as per the curve of decreasing returns implies that adding one more port beyond this point does not add much throughput to the total Mediterranean range sample.

At this point, six additional ports were included in the sample, resulting in a total of 36 ports. The inclusion of these extra ports in the sample is justified by their special interest. These ports are Las Palmas, Santa Cruz de Tenerife, Hayderpasa, Sines,

Cagliari and Thessaloniki. More precisely, the reasoning behind the addition of these ports to the sample was the following \square

The container ports of Las Palmas and Santa Cruz de Tenerife were added because, even though they are not situated in the Mediterranean Sea, they have a significant role in the competition dynamics of the Mediterranean region. Both of them are transhipment ports and handle freight that, for its most part, crosses the Mediterranean Sea. Moreover, Las Palmas and Tenerife have significant container throughputs with 1.31 and 0.40 million TEUs respectively, for 2008 – the year for the cross-section data.

he remaining four ports were added following a different logic: Hayderpasa, Sines, Cagliari and Thessaloniki were considered on the basis of their likely future role as large Mediterranean container ports, which will mean additional competition to already established ports. All of those four ports already have significant installed capacity levels comparable to other large container ports, or have plans to do so.

To illustrate:

- Sines had a throughput of just 0.23 million TEU in 2008, but a theoretical capacity of 0.80 million TEU. By 2011 the port had surpassed the 0.5 million TEU mark in 2011 with a theoretical terminal capacity above 1 million TEU.
- Cagliari offers a very favourable geographical location and has a vocation to be a hub port, with 90% its traffic being transhipment traffic and more than 1.1 million TEU of theoretical terminal capacity in 2008. For Cagliari, 2008 was an atypical year with very low throughput, just 0.31 million TEU, whilst in the previous four years throughput at the port has been around 0.6 million TEUs.
- Hayderpasa has significant investments planned, although these had not yet materialised into an increased capacity in 2008. Therefore, the port was operating close to its maximum theoretical capacity.
- Thessaloniki has historically been a large port, with traffic above 0.35 million TEUs in the years leading to 2008. It is also a regional hub for the black sea.

The total sample of 36 ports handled just over 42.6 million TEU in 2008. Moreover, all of these port \bigcirc ad a throughput above 400 million TEU for that year with the exception of five of the six ports mentioned above. This can be justified given the

rationale behind their addition to the sample, which was essentially their potential for future growth.

Figure 4.1 gives an overview of the sample Mediterranean container ports selected and Figure 4.2 illustrates the share of transhipment of those 36 container ports considered in the dissertation's database. The green circles provide a visual indication of the ports size, measured in container throughput and share of transhipment respectively for 2008, as indicated in the legend.



FIGURE 4.1: OVERVIEW OF MEDITERRANEAN CONTAINER PORTS IN SAMPLE

Source: own elaboration (based on data from CI Online Liner Intelligence)



FIGURE 4.2: TRANSHIPMENT TRAFFIC FOR MEDITERRANEAN CONTAINER PORTS IN SAMPLE

Source: own elaboration (based on data from CI Online Liner Intelligence and OSC)

4.2.2 AVAILABLE DATA AND SOURCES

4.2.2.1 DATA COLLECTION PROCESS

Having access to accurate and reliable data is of critical importance because it is the basis for robust research findings. Missing or incomplete data hinder the analysis and results. Consequently, the first step of the data collection process was to map all the available port data in the container port industry that influences productivity and group them according to the likelihood of obtaining these data.

As can be depicted in Table 4.1, data to support container port productivity variables can be collected from various sources. It should also be noted that data on port layout, facilities and equipment is more commonly available, while operational data tend to be scarce and financial and human resources data is often confidential and not publicly available.

Data elements placed on the "always" section are customarily available from port authorities, port operators, public directories or international institutions such as the Eurostat, UNCTAD or the World Bank.

Data elements that are often, although not consistently, available were placed on the "sometimes" section. These help complete the productivity picture and usually are not confidential although not all ports release this data.

Data categorised as "estimated" is helpful to an understanding of productivity but needs to be estimated or calculated. These data may have different values depending on the estimation method used and assumptions made.

Lastly, "confidential" data refers mainly to cost, labour and productivity related data that are typically not made available outside an organization. Also in this case, data values may vary depending upon the methodology used and assumptions made, which can vary from port to port.

TABLE 4.1: AVAILABLE PORT DATA, LIKELY PROBABILITY OF BEING OBTAINED AND DATAUSED IN THE EMPIRICAL ANALYSIS

Available Port Data	Source	Used in dissertation							
Always									
Throughput	Port Authority, Directories	Yes							
Depth Alongside	Port Authority, Directories	Yes							
Berth Length	Port, Directories	Yes							
Berths #	Port, Directories								
Cranes & Types	Port, Directories	Yes							
Terminal area	Port, Directories	Yes							
Sometimes									
Terminal Theoretical Capacity	Port, Directories	Yes							
Transhipment TEUs	Port, Directories	Yes							
Avg. Crane Moves/hour	Port, Terminals								
Container Yard Area	Port, Directories								
Rail Acres	Port, Directories								
Vessel Calls	Lloyd's but at significant cost								
TEU Slots	Port, Terminals								
	Estimated								
Vessel TEU	TEU Relationship								
Vessel Length	Length Relationship								
Avg. Dwell Time	Benchmarks, Assumptions								
Berth Capacity	Benchmarks, Assumptions								
Crane Capacity	Benchmarks, Assumptions								
Container Yard Capacity	Benchmarks, Assumptions								
Confidential									
Revenues Costs and other financial data									
Man-hour									
Vessel Turnaround Time									
Rates									
Working Crane Hours									

Source: own elaboration

In the context of data availability it is important to address why it was not used in this dissertation. It is mainly due to the lack of availability of financial data. In fact, reliable and comprehensive financial data is not made available neither by por nor terminal operators.

Also, differences between the various costing and accounting systems are likewise a major problem when attempting to compare ports from different countries. Even within a single country, port financing and institutional structures (private, landlord, tool, etc.) are often not comparable.

Moreover, several other aspects influence port financial performance including price and access regulation, market power, statutory freedom and access to private equity. For these reasons, physical productivity measures are considered as more reliable performance indicators than financial measures.

In Table 4.2 additional non-port related data that was used in the dissertation to support the database is shown. Finally, Table 4.3 indicates the derived data obtained from the available port data.

UNCTAD
World Bank Development Indicators
Based on measurement in Google earth

TABLE 4.2: ADDITIONAL RELATED DATA USED IN THE ANALYSIS

Source: own elaboration

TABLE 4.3: DERIVED DATA USED IN THE ANALYSIS

Data	Calculation
Terminal Used Capacity	Throughput / Terminal theoretical capacity x 100
Terminal Free Capacity	1 – (Throughput / Terminal theoretical capacity) x 100
Transhipment share	Transhipment throughput/ Throughput (total) x 100
Compound Annual Growth Rate	((Throughput _{year i} / Throughput _{year j})^(1/(i-j)))-1
Kale	Source: own elaboration

The next step in the research involved making decisions concerning sources, unit of analysis and period of analysis.

4.2.2.2 SOURCES

A concern that was identified early on was the occasional differences in methodology when measuring a given variable. One way to attempt to overcome this issue was by choosing one single database that allowed a compilation of variables in a coherent way.

The initial idea was to retrieve information on terminal and berth characteristics as well as container throughput and port capacity from the database CI Online Liner Intelligence. However, the CI Online Liner Intelligence data on terminal and berth characteristics was unsatisfactory since it was not available for all the 36 ports identified above, creating a missing data issue; moreover the data was often not up to date or correct, resulting in a trustworthiness issue.

Hence, to overcome the lack of data the cross-section database was completed by collecting data from other reputable sources, namely $po \mathcal{D}$ and terminal operat \mathcal{D} websites. This step involved a careful effort of making sure the data was consistent and reliable.

In Table 4.4, the last column indicates the sources for each variable taken into consideration. In brief, the sources were port authorities and terminal operators websites and annual reports; the CI Online Liner Intelligence database; UNCTAD and the World Bank; and reports from Ocean Shipping Consultants and Dynamar.

4.2.2.3 UNIT OF ANALYSIS

Another decision to take was the definition of the scope of the analysis, namely whether to use the container port or the container terminal as the unit of analysis. Ideally, the unit of choice would be the container terminal as it represents one homogenous functional system. However, the lack of terminal-specific annual throughput data and other layout and equipment information for a significant number of terminals belonging to the 36 ports in the sample prevented the use data for individual terminals.

There is a possible justification behind this lack of data for individual terminals: port authorities are often reluctant or unable to provide terminal-specific throughput, because the data are proprietary to the terminal operator, which is often private and has no obligation to make this data publicly available.

So, the decision was made to have the container port as the unit of analysis in this dissertation. Nonetheless, this simplification is not considered of critical importance as many of the container ports in the Mediterranean are operated by one single terminal operator, or when in presence of several operators, the terminal layout and equipment characteristics are very similar.

4.2.2.4 PERIOD OF ANALYSIS

Concerning the period of analysis, the year 2008 was selected as reference, because it was the last year for which a comprehensive set of data for traffic, infrastructure and other indicators was made available from public sources.

In addition, when the data collection process began (early 2011), 2008 was the most recent year for which container port throughput was available in the Containerisation International Yearbook and CI Online Liner Intelligence database. Generally, there is an average gap of two calendar years between initial report of the data and its confirmation and public availability.

Moreover, the pre-crisis period was considered in order to avoid abnormalities in the data series. In fact, 2008 is considered a "normal" year before the start of the economic crisis that affected Europe in particular. Although the global financial crisis started in the end of the third quarter of 2008 - Lehman Brothers filed for bankruptcy on September 15th - the effect of the crisis was masked by the relative good economic performance of the world economy during the first 3 quarters. By contrast 2009 and 2010 were atypical years with 2009 showing a general contraction of economic and port activity and 2010 being a year of partial recovery with above average container port growth.

Taking all these factors under consideration, and in order to have the possibility to undertake a solid analysis, two databases – a time-series and a cross-sectional -

The first set of data consists of a time series⁷ 1970-2008 for container throughput per port based on data retrieved from the CI Online Liner Intelligence database (www.ci-online.co.uk; last accessed in March 2011). The second set of data is a cross-section⁸ of 14 variables collected for the 36 sample ports for the year 2008. These 14 variables were put forward taking into consideration their potential contribution to explain productivity and the limitations to data collection.



FIGURE 4.3: DIAGRAM OF THE DATA COLLECTION PROCESS

Source: own composition

⁷ In time series data the values of one or more variables are observed over a period of time.

⁸ In cross-section data, values of one or more variables are collected for several sample units, or entities, at the same point in time.

Figure 4.3 schematically illustrates the sequence of steps involved i hoice of sample and the data collection process and the relationship between the data collection process to the methods used in the empirical analysis.

4.2.3 VARIABLES DESCRIPTION

In order to model container port productivity and choose the relevant variables, it is important to determine the core business of a container port in today's world. Despite the recent interest in the role of ports in the logistical supply chains, the core activity of container ports is centred on handling as much container throughput as possible with efficient use of infrastructures and superstructures such as container cranes, berth length, depth alongside, and terminal area.

As described in chapter 3, economic theory indicates that effective handling of container throughput depends largely on efficient use of port land, labour and capital (Dowd & Leschine, 1990). As a result, productivity of container handling is directly related to the land-sea interface where containers are loaded and unloaded. This productivity is strongly influenced by characteristics of berth, cranes and yard equipment, use of terminal area and storage area and stevedores' productivity.

From an engineering point of view, the layouts of container terminals as well as the conditions of infra and super structure are key factors \bigcirc assess the land-sea interface productivity. Software solutions such as NavisTM Terminal operating Solutions help terminal operators increase capacity and optimize operations to obtain lower operating costs. This type of software has the capabilit \bigcirc coordinate and automate the planning and management of container and equipment moves in complex business environments. Thus, to achieve the operational targets of container terminals it is important to consider berths, cranes, yard equipment and terminal areas (Le-Griffin & Murphy, 2006).

Taking into account the considerations made in previous sub-chapter 4.2.2, the selected variables influencing container port productivity are listed in Table 4.4, together with their description, units and the source of the collected data. These variables are then explained in further detail.

Abb.	VARIABLE	DEFINITION	UNITS	SOURCE
area	Terminal Area	Total area of the terminal including loading and unloading area as well as storage area.	hectare	Port Authority, Port Operator and checked for accuracy with Google Earth
berth	Berth Length	Total length of container terminals in a given port.	meter	Port Authority, Port Operator websites and checked for accuracy with Google Earth
cagr0408	CAGR 2004-2008	Compound annual growth rate calculate for the period 2004-2008.	%	Own elaboration based on Containerisation International Online data
cagr9808	CAGR 1998-2008	Compound annual growth rate calculate for the period 1998-2008.	%	Own elaboration based on Containerisation International Online data
сар	Terminal Capacity	Terminal theoretical or declared capacity, meaning the maximum cargo handling capability per year.	TEU	Ocean Shipping Consultants report, port authority and port operator websites
capfree	Terminal Free Capacity	Difference between terminal capacity and the registered throughput for a given year.	%	Own calculation based on throughput and capacity data
centrality	Centrality Index	Index which relates the shortest route between both entry points in the Mediterranean with the shortest routes between those entry points touching the port.	[0, 1]	Own elaboration based on measurements using Google Earth
cranes	Quay Cranes	Number of container quay cranes in a port.	#	Port Authority, Port Operator and checked for accuracy with Google Earth
depth	Depth Alongside	Maximum depth alongside container terminals in a port.	meter	Port Authority, Port Operator websites
gdp	GDP growth	2008 GDP growth (annual %).	%	The World Bank
Isci	Liner Shipping Connectivity Indicator	LSCI can be considered a proxy of the accessibility to global trade ie. a measure of connectivity to maritime shipping and as a measure of trade facilitation.	[0, 1]	Review of Maritime Transport 2010, UNCTAD
throu	Throughput	Port container throughput measures the loading and unloading of containers. Data refer to coastal shipping as well as international journeys. Transhipment traffic is counted as two lifts at the intermediate port (once to off-load and again as an outbound lift) and includes empty units.	TEU	Containerisation International Online (www.ci- online.co.uk, accessed Dec. 2010)
trans	Transhipment Port	Transhipment port is a port with high percentage of transhipment cargo, namely above 80% of the cargo is en route and is not destination cargo.	discrete	Own assessment based on data
trans_sh	Transhipment Incidence	Transhipment share of total container throughput.	%	Ocean Shipping Consultants report, port authority and port operator websites

TABLE 4.4: LIST OF SELECTED VARIABLES INFLUENCING CONTAINER PORT PRODUCTIVITY

Source: Own composition

4.2.3.1 CONTAINER PORT THROUGHPUT AND COMPOUND ANNUAL GROWTH RATE

Data on container port throughput in TEU was obtained from CI Online Liner Intelligence (<u>www.ci-online-co.uk</u>, last accessed March 2011) for the period from 1970 to 2008. This allowed ranking ports in the Mediterranean range according to their container throughput in 2008, as well as calculating the compound annual growth rates (CAGR) for the periods 2004-2008 and 1998-2008.

4.2.3.2 BERTH LENGTH, DEPTH ALONGSIDE, QUAY CRANES AND TERMINAL AREA

Container ports in the sample are characterized by their berth length, depth alongside, number of container ship-to-shore (STS) quay cranes i.e. the cranes used to load and unload containers from ships, as well as terminal area. This is done using the information available on the websites of port authorities and terminal port operators for the period in analysis.

4.2.3.3 THEORETICAL CAPACITY AND FREE CAPACITY

Another indicator used was the theoretical capacity⁹ in terms of container throughput. This measure is made available by most terminal operators per container terminal and indicates the maximum cargo handling capability per year - the combined product of a port's facilities and associated services. The information is usually presented in TEU per year, which already considers the typical port operations profile. This data was collected from the websites of port authorities and terminal port operators for the period in analysis.

The values for port free capacity for container cargo were calculated and refer to the difference between the port theoretical capacity and the registered throughput.

⁹ This is a theoretical or optimal capacity as indicated by the Port Authority or Terminal Operator.

4.2.3.4 TRANSHIPMENT SHARE AND TRANSHIPMENT PORT

Transhipment incidence, or transhipment share, is the share of the total container throughput - measured in TEUs - that is handled in transhipment operations i.e. unloaded and loaded back into container ships without leaving the port (on the landside).

In the context of this definition, transhipment traffic is counted twice i.e. once when a container is unloaded and again when the container is loaded back to the ship. Data concerning transhipment was collected from several reliable sources, namely (Ocean Shipping Consultants, 2006, 2010; Dynamar B.V., 2007).

The variable Transhipment Port is a binary variable that can assume values of 1 and 0, with 1 indicating the transhipment share for that particular port is above 50%, and hence it is considered a transhipment port; and 0 indicating that the absence of that attribute.

4.2.3.5 PORT CONNECTIVITY (LINER SHIPPING CONNECTIVITY INDEX)

The level of connectivity of a container port is proxyed by the Liner Shipping Connectivity Index (LSCI) for the country where the port is situated. The LSCI can be considered as a measure of connectivity to maritime shipping and as a measure of trade facilitation. This index consists of five components, namely (i) the number of ships that provide services; (ii) their container carrying capacity; (iii) the number of companies; (iv) the number of services provided; and (v) the size of the largest vessels that provide services from and to each country's seaports. The higher the index, the easier it is to access a high capacity and frequency global maritime freight transport system, and thus, effectively participate to international trade (UNCTAD, 2010).

The LSCI can also be a useful input when it comes to choice of ports. In many studies of port choice models, the frequency of shipping services and directness and flexibility of routes is one of the crucial determinants of port choice (Slack, 1985; Bird & Bland, 1988). On the other hand it is also argued that ports face a constant risk since the port client has rearranged its service networks or has engaged in new partnerships with other carriers (Tongzon & Heng, 2005). This effect – of port throughput and connectivity being affected by the strategy of individual shippers – has been identified for smaller

Mediterranean ports in the database, which have suffered considerable changes in throughput in very short periods of time.

4.2.3.6 CENTRALITY INDEX

For the purpose of this thesis the centrality index consists of an indicator which relates the shortest maritime route between both entry points in the Mediterranean with the shortest routes between those entry points touching the port. Having port X as an example, one would have a comparison between the "Gibraltar Strait – Suez Canal" route and "Gibraltar Strait – Port X – Suez Canal" route. In this context, the formula that is considered was "Gibraltar-to-Suez / Gibraltar-to-Port X-to-Suez" route. Therefore, all values are below 1. First the distances were measured using Google Earth tool and then the Centrality Index was calculated for each port. The rationale behind this index is to try to identify any type of correlation between geographical location and container port productivity.

4.2.3.7 GROSS DOMESTIC PRODUCT

Gross Domestic Product (GDP) is commonly used as measure for assessing the performance of the economy. Data on GDP growth rate at country level for 2008 was obtained from the publicly available World Development Indicators 2010 released by the World Bank¹⁰. GDP growth rate measures how fast the economy is growing in real terms using the local currency.

4.2.4 VARIABLES NOT SELECTED

It is important to mention that a few variables, although relevant, were not considered in this analysis, namely vessel calls and labour.

Information on vessel calls was initially collected but only was available for some countries (Spain, Portugal). It was not possible to use it for the whole sample, and thus it was dropped at a later stage. A similar situation occurred with container yard capacity

¹⁰ http://data.worldbank.org/data-catalog/world-development-indicators

data which was also not widely available, hence dropped at a later stage. It is however included in analysis container yard area.

As for labour, this is not considered in the analysis due to the fact that it was not possible to compile reliable sources of container port labour. These labour data are usually available at port authority level, consisting of various types of full-time, part time, administrative and operational jobs. Depending on the country or region it may or may not include the, often private, container terminal operators' labour force. Moreover, the information available on labour often referred to the port authority workers and was not disaggregated for container business, and so could mask the results.

Another set of variab that were not selected were the hourly performance of port equipment, in particular the (average) number of movements of STS cranes. This variable is sometimes considered as being one important productivity measure as it has a direct impact in time in port of container ships. This variable was not included in the database, since it was not possible to gather consistent and regular information.

4.3 METHODS USED FOR EMPIRICAL ANALYSIS

In this sub-chapter are introduced the methods used in this thesis to analyse the data. Given the goal and research questions of the present thesis (see sub-chapter 1.3.1 for further detail) the models selected to analyse the data are based on multiple regression analysis and grouping segmentation analysis. Experience

As a recap, the research questions, as put forward in chapter one, are the following:

- **Research question 1:** Is container port size correlated with container port productivity? Are bigger container ports more productive than smaller ones?
- **Research question 2:** Is geographical centrality i.e. the proximity to the Mediterranean navigational centreline correlated to container port productivity?
- **Research question 3:** Are ports with high transhipment shares more productive than non-transhipment ports?

4.3.1 REGRESSION ANALYSIS

Regression analysis is one of the most frequently used tools in research and it allows the analysis of relationships between independent and dependent variables. Regression analysis can provide insights that few other techniques are able to and the most significant benefits of using regression analysis are (Mooi & Sarstedt, 2011):

- indicate if independent variables have a significant relationship with a dependent variable;
- indicate the relative strength of different independent variables' effects on a dependent variable;
- 3. make predictions.

Regression analysis allows the analysis of relationships between independent and one dependent variable(s). The dependent variable is usually the outcome under analysis (e.g., container port productivity), while the independent variables are the instruments available to achieve those outcomes with (e.g., throughput, capacity, berth length, depth alongside and number of cranes).

In other words, the purpose is to ascertain the causal effect of independent or explanatory variables upon the dependent variables. More precisely, three indicators of physical port productivity are considered:

- *Handling Productivity* measured as TEU per ship-to-shore quay crane i.e. throughput per number of STS quay cranes (TEU/#).
- *Berth Productivity* measured as TEU per meter of container berth i.e. throughput per berth length (TEU/m);
- *Terminal Area Productivity* measured as TEU per hectare of terminal i.e. throughput per terminal area (TEU/ha);

In order to explore productivity in the container port business, data was collected on the underlying variables of interest (see table 4.4) and employed regression analysis to estimate the quantitative effect of the causal variables upon the dependent variable that they influence.

To answer the research questions, special attention will be given to the impact of the variables container throughput (THROU), theoretical capacity (CAP) and free capacity (CAP_FREE) as a proxy for size (question 1), variable centrality index (CENTRALITY) to address the issue of the relevant of centrality in productivity (question 2) and transhipment port (TS_PORT) and transhipment share (TS_SHARE) to check the impact of transhipment related variables on container port productivity (question 3).

Given there are multiple strongly related variables, it is advised to conduct first a correlation analysis and check if there is collinearity present. Simply put, collinearity is a data issue that arises if two or more independent variables are highly correlated. This step is particularly important since a data requirement of regression analysis is that no or little collinearity is present.

Once established the existence of multicollinearity amongst the variables, a factor analysis is conducted as a way to overcome this issue and proceed with the regression analysis. By using factor analysis is created a small number of factors that have most of the original variables information in them but nonetheless, which are mutually uncorrelated. These factors scores will then be used as input for the regression analysis and therefore the collinearity between the original variables will no longer be an issue an possible to proceed with the regression analysis.

Knowing about the effects of independent variables on dependent variables can be very useful for it can help direct efforts and investments if it is known what increases productivity. Also, knowing about the relative strength of effects is useful because it may help answer questions such as if size of a port matters to port productivity. Lastly, regression analysis allows the comparison between the effects of variables measured on different scales such as the effect of capacity measured in TEU, transhipment share measure in percentage or berth length measured in metres.

As a final note, both factor analysis and regression analysis fall within the scope of multivariate data analysis (MDA) which is the analysis of multiple variables in a single relationship or a set of relationships. MDA refers to all statistical techniques that simultaneously analyse multiple measurements on individuals or objects under research.

The purpose of multivariate analysis is to measure, explain, and predict the degree of relationship among variates¹¹ (weighted combinations of variables). Thus, the multivariate character lies in the multiple variates (multiple combinations of variables), and not only in the number of variables or observations (Hair, Black, Babin, *et al.*, 2010). For more information on decision tree on research methodology, see appendices I and II.

4.3.2 GROUPING ANALYSIS

This section complements the regressions analysis, by further exploring common characteristics of data subgroups. This grouping analysis conveys a structure and homogeneity to the existing set of the data and hence further analysis of the different subgroups and their common characteristics is made easier.

This analysis is done from two perspectives: static view for year 2008 based on crosssection data and evolution view using time-series 1970-2008. Thus, groups are created based on similarities of a number of common characteristics such as total throughput, throughput growth in absolute and percentage terms, historical period of highest growth, among others. In terms of the historical evolution are analysed a number of key performance parameters.

In this context, exploratory data analysis (EDA) will be used. EDA is an approach to analysing data sets to summarize their main characteristics in easy-to-understand form, often with visual graphs, without using a statistical model or having formulated a hypothesis. There are a number of tools that are useful for EDA and typical graphical techniques used in this dissertation are: box plot, histograms and scatter plot.

¹¹ The variate is a linear combination of variables with empirically determined weights. The variables are specified by the researcher, whereas the weights are determined by the multivariate technique to meet a specific objective (Hair, Black, Babin, *et al.*, 2010).

4.4 SUMMARY

In this chapter is described the methodology used in the empirical data analysis. The research is causal in nature and based on secondary data. A sample of top 36 Mediterranean container ports was selected and two data sets have been constructed: a time series for container throughput 1970-2008, and a cross-sectional of 14 variables collected for the year 2008. These data sets will be used for modelling and empirical analysis aimed at understanding container port characteristics, differences between ports and their productivity.

Concerning the different data analysis techniques used for the empirical data analysis, these are based on multiple regression analysis and further complemented by grouping analysis.

5 EMPIRICAL ANALYSIS

5.1 INTRODUCTION

In this chapter the empirical analysis is undertaken. Different yet complementary data analysis techniques are used in order to better understand the topic of container port productivity. Multiple regression analysis is done using a cross-section database with a sample of 36 Mediterranean container ports and 14 variables for the year 2008¹². This analysis is complemented by a grouping analysis where ports are grouped along different dimensions, using both the abovementioned cross-section database and a time-series database for container throughput for the same sample of ports¹³.

Figure 5.1 gives an overview of the 1970-2008¹⁴ container throughput time series for the sample of Mediterranean ports, and Table 5.1 displays the cross-sectional data collected for the 14 variables under analysis.



FIGURE 5.1: CONTAINER THROUGHPUT FOR MEDITERRANEAN PORTS IN SAMPLE 1970-2008 (M. TEUS)

Source: own composition (based on CI Online Liner Intelligence data)

¹² Using Eviews7 software package.

¹³ Using Microsoft Excel 2010.

¹⁴ The year 2008 was selected as reference, because it was the last year for which a comprehensive set of data for traffic, infrastructure and other indicators was made available from public sources at the time the data collection process began (early 2011). For a more detailed explanation on the period of analysis, see chapter 4, sub-chapter 4.2.2.4.

#	Country	Port Code	Port Name	Throughput (TEU)	Theoretical Capacity (TEU)	Free Capacity (%)	Tranship. Port (discrete)	Tranship. Share (%)	Berth Length (m)	Depth Alongside (m)	Quay Cranes (#)	Area (ha)	Liner Shipping Connectivity Index [0,1]	Centrality Index [0,1]	CAGR 2004-2008 (%)	CAGR 1998-2008 (%)	GDP annual growth (%)
1	Spain	VLC	Valencia	3,597,215	4,000,000	10.1	0	44.0	3,882	16.0	29	160	0.677	0.918	10.9	14.0	0.9
2	Italy	GIT	Gioia Tauro	3,467,772	4,200,000	17.4	1	95.0	3,395	18.0	25	160	0.559	0.964	1.2	5.0	-1.3
3	Spain	ALG	Algeciras	3,324,310	4,000,000	16.9	1	95.0	2,062	16.0	18	77	0.677	0.992	2.5	6.2	0.9
4	Egypt	PSD	Port Said	3,202,000	3,300,000	3.0	1	92.0	2,570	16.5	22	60	0.525	0.997	29.9	0.0	7.2
5	Spain	BCN	Barcelona	2,569,547	2,600,000	1.2	0	39.0	2,460	16.0	23	101	0.677	0.894	6.0	8.9	0.9
6	Malta	MXX	Marsaxlokk	2,330,000	2,400,000	2.9	1	93.0	2,140	17.0	23	65	0.299	0.990	9.8	8.1	5.4
7	Turkey	AMB	Ambarli	2,262,000	2,300,000	1.7	0	39.0	3,360	15.5	33	82	0.356	0.680	16.0	0.0	0.7
8	Italy	GOA	Genoa	1,766,605	2,250,000	21.5	0	12.4	1,956	15.0	15	129	0.559	0.760	1.6	3.4	-1.3
9	Israel	HFA	Haifa	1,395,900	1,500,000	6.9	0	37.0	1,360	14.0	8	50	0.198	0.879	6.0	5.3	4.3
10	Romania	CNZ	Constantza	1,380,935	1,500,000	7.9	1	70.0	1,378	14.5	15	52	0.264	0.621	29.9	30.3	9.4
11	Spain	LPA	Las Palmas	1,311,834	1,400,000	6.3	1	64.0	2,160	14.0	14	82	0.677	0.733	13.2	12.0	0.9
12	Italy	SPE	La Spezia	1,246,139	1,300,000	4.1	0	11.9	1,402	14.0	11	33	0.559	0.745	3.7	5.5	-1.3
13	Egypt	DAM	Damietta	1,236,502	1,300,000	4.9	1	78.0	1,050	14.5	8	61	0.525	0.997	-0.4	14.8	7.2
14	Lebanon	BEI	Beirut	945,105	1,145,000	17.5	0	43.0	1,934	15.5	11	37	0.289	0.844	19.4	12.5	9.3
15	Morocco	PTM	Tangier	920,708	3,000,000	69.3	1	99.0	1,635	18.0	16	80	0.298	0.995	102.2	50.8	5.6
16	Morocco	CAS	Casablanca	917,875	1,000,000	8.2	0	7.0	880	12.0	9	61	0.298	0.911	13.3	14.1	5.6
17	Turkey	IZM	Izmir	895,000	1,000,000	10.5	0	2.0	1,050	13.0	7	28	0.356	0.827	2.2	8.5	0.7
18	Turkey	MER	Mersin	854,500	2,500,000	65.8	0	6.0	1,470	14.0	12	110	0.356	0.803	9.9	13.5	0.7
19	France	MRS	Marseilles	847,651	3,200,000	73.5	0	10.0	2,085	15.0	14	69	0.662	0.819	-1.5	2.6	-0.1
20	Israel	ASH	Ashdod	827,900	1,000,000	17.2	0	1.0	1,700	15.5	15	78	0.198	0.894	17.6	8.6	4.3
21	Italy	TAR	Taranto	786,655	2,000,000	60.7	1	86.0	2,050	15.5	10	102	0.559	0.832	0.6	0.0	-1.3
22	Italy	LIV	Leghorn	778,864	800,000	2.6	0	9.3	1,600	13.0	11	41	0.559	0.795	4.1	3.1	-1.3
23	Syria	LTK	Latakia	570,000	800,000	28.8	0	1.0	1,870	14.5	18	15	0.127	0.782	9.3	0.0	4.5
24	Portugal	LIS	Lisbon	556,062	600,000	7.3	0	19.4	1,260	14.5	8	24	0.350	0.853	1.6	4.6	0
25	Algeria	ALZ	Algiers	530,521	800,000	33.7	0	3.0	1,088	10.5	10	17	0.078	0.996	29.6	0.0	2.4
26	Italv	NAP	Naples	481,521	500,000	3.7	0	5.0	, 1,645	13.2	6	20	0.559	0.905	6.7	4.2	-1.3
27	Portugal	LEI	Leixoes	450,026	600,000	25.0	0	4.1	900	12.0	5	22	0.350	0.798	5.2	6.5	0
28	Greece	PIR	Piraeus	431,056	1,800,000	76.1	1	59.0	2,100	16.0	14	80	0.271	0.874	-22.5	-7.4	-0.2
29	Spain	MAL	Malaga	428,623	480,000	10.7	1	96.0	723	16.0	5	34	0.677	0.988	36.1	57.9	0.9
30	Egypt	EDK	El Dekheila	402,800	500,000	19.4	0	5.0	1,520	14.0	9	50	0.525	0.982	5.1	0.0	7.2
31	Spain	SCT	Tenerife	397,536	450,000	11.7	0	2.0	1,575	16.0	7	29	0.677	0.727	65.6	4.8	0.9
32	Egypt	ALY	Alexandria	385,000	1,000,000	61.5	0	5.0	2,837	14.0	8	30	0.525	0.984	6.7	-2.5	7.2
33	Turkey	HAY	Haydarpasa	360,000	400,000	10.0	0	1.0	945	10	4	10	0.356	0.704	2.6	1.1	0.7
34	Italy	CAG	Cagliari	307,527	1,100,000	76.7	1	90.0	1,520	16.0	8	40	0.559	0.931	-12.3	0.0	-1.3
35	Bortugal		Sines	238,940	450,000	40.9 70 0	0	1.0	596 730	12.0	4 2	19 21	0.271	0.738	- 6.6	2.8	-0.2
20	i ultuyai	SING	Silles	255,110	000,000	70.9	T	00.0	100	10.0	5	21	0.330	0.000	04.7	0.0	0

TABLE 5.1: CROSS-SECTIONAL DATABASE

Source: Own composition
5.2 MULTIPLE REGRESSION ANALYSIS

Even though it is interesting to know which port comes out on top, from an economic point of view and in order to address the research questions, it is more useful to know what variables have higher influence on the physical productivity indicators under analysis. The idea is to understand if container port productivity in the Mediterranean is driven by size, proximity to the shortest navigation route or by share of transhipment. The regression model is used for this purpose, to explain how a number of independent variables relate to the physical productivity indicators for container ports. In this subchapter are performed 3 single equation regressions, the regression models are specified and estimated, and interpretation of the regression models is done.

5.2.1 THE REGRESSION MODEL

Regression analysis is essentially a way of fitting a "best" line through a series of observations. By "best" line is understood that it is fitted in such a way that it results in the lowest sum of squared differences between observations and the line itself. The true line would be the line that holds in the population. Regression models are generally described as in equation [5.1]. Using matrix notation, the standard regression may be written as:

$$Y = \alpha X + \varepsilon \quad [5.1]$$

Where *Y* is a *N*-dimensional vector containing observations on the dependent variable and *X* is a $N \times k$ matrix of independent variables, α is a *k*-vector of coefficients and ε is a *N* vector of disturbances.

The initial multiple regression model should consider, for each of the three container port productivity measures established (namely, throughput per crane, throughput per berth and throughput per terminal are), the 14 selected independent variables (namely, container throughput, theoretical capacity, free capacity, transhipment port and share, berth length, depth alongside, quay cranes, container terminal area, liner shipping connectivity index, centrality index, compound annual growth rate for the periods 1998-

2008 and 2004-2008, and GDP growth rate). The regression function notation is as follows in equation [5.2]:

$$Y_i = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + (\dots) + \alpha_{14} X_{14}$$
 [5.2]

Where,

 Y_i , physical container port productivity measured as throughput/cranes (Y_1), throughput/berth (Y_2) and throughput/area (Y_3)

 α_0 , constant

 α_n , coefficients n=1:7

 X_1 , terminal area (AREA)

 X_2 , berth length (BERTH)

 X_3 , compound annual growth rate for period 2004-2008 (CAGR0408)

 X_4 , compound annual growth rate for period 1998-2008 (CAGR9808)

 X_5 , theoretical capacity (CAP)

 X_6 , free capacity (CAP_FREE)

*X*₇, centrality index (CENTRALITY)

 X_8 , quay cranes (CRANES)

*X*₉, depth alongside (DEPTH)

 X_{10} , gross domestic product growth rate (GDP)

X₁₁, liner shipping connectivity index (LSCI)

X₁₂, container throughput (THROU)

X₁₃, transhipment port (TS_PORT)

and X₁₄, transhipment share (TS_SH)

5.2.2 DATA REQUIREMENTS

At this poir s necessary to check if the data underlying the analysis meets the requirements for multiple regression analysis. Given that the variables under analysis are related to each other and to the concept of productivity in container ports, there is the potential risk of multicollinearity¹⁵. This would raise the problem that the regression

¹⁵ Collinearity is an expression of the relationship between two (collinearity) or more (multicollinearity) independent variables. Two independent variables are said to exhibit complete collinearity if their correlation coefficient is 1, and complete lack of collinearity if their correlation coefficient is 0. Multicollinearity occurs when any single independent variable is highly correlated with a set of other independent variables. An extreme case of collinearity/multicollinearity is singularity, in which an independent variable is perfectly predicted (i.e.

coefficients, although determinate, possess large standard errors, meaning the coefficients cannot be estimated with great precision or accuracy. To check for multicollinearity, a covariance analysis is done.

The purpose of a covariance analysis is to assess measures of association between the selected variables. The first step is a visual examination of the correlations, identifying those that are highly correlated. Table 5.2 shows the correlation matrix for the 14 selected variables regarding physical port productivity. Correlation values above 20% are highlighted in yellow, values above 50% are highlighted in orange and values above 70% are highlighted in red.

As can be seen, all variables are highly correlated, with the exception of compound annual growth rates calculated for both periods 1998-2008 and 2004-2008 (CAGR9808 and CAGR0408), free capacity (CAP_FREE), centrality index (CENTRALITY) and gross domestic product (GDP), which present non-significant correlation with the other variables.

The three physical productivity indicators that constitute the dependent variables, involve four base variables namely, terminal area (AREA), berth length (BERTH), number of quay cranes (CRANES) and container throughput (THROU). As can be seen, these four variables are highly positively correlated with values around 0.70 and above.

In addition, the correlation of the variable terminal area (AREA) with variables berth length (BERTH), theoretical capacity (CAP), number of cranes (CRANES), depth alongside (DEPTH) and container throughput (THROU) is above 0.5, which is very high.

Also, the correlation between area (AREA) and other variables is below 0.2 only in relation with the abovementioned exceptions i.e. compound annual growth rates calculated for both periods 1998-2008 and 2004-2008 (CAGR9808 and CAGR0408), free capacity (CAP_FREE), centrality index (CENTRALITY) and gross domestic product (GDP).

correlation of 1.0) by another independent variable (or more than one) (Hair, Black, Babin, et al., 2010).

TABLE 5.2: UNWEIGHTED ORDINARY (PEARSON) CORRELATION MATRIX

Covariance Analysis: Ordinary Sample: 1 36 Included observations: 36

Correlation	AREA	BERTH	CAGR0408	CAGR9808	САР	CAP_FREE	CENTRALITY	CRANES	DEPTH	GDP	LSCI	THROU	TS_PORT	TS_SH
AREA	1.00													
BERTH	0.69	1.00												
CAGR0408	-0.11	-0.13	1.00											
CAGR9808	0.09	-0.20	0.55	1.00										
CAP	0.80	0.71	0.00	0.07	1.00									
CAP_FREE	0.02	-0.08	0.07	-0.10	0.07	1.00								
CENTRALITY	0.13	0.12	0.10	0.15	0.26	0.12	1.00							
CRANES	0.69	0.84	-0.02	-0.02	0.77	-0.24	0.06	1.00						
DEPTH	0.53	0.52	0.32	0.25	0.60	0.17	0.33	0.53	1.00					
GDP	-0.15	0.00	0.28	0.25	-0.05	-0.17	0.25	0.08	0.07	1.00				
LSCI	0.35	0.35	-0.09	0.07	0.32	-0.12	0.10	0.12	0.31	-0.35	1.00			
THROU	0.70	0.71	-0.07	0.01	0.85	-0.41	0.21	0.82	0.47	0.04	0.33	1.00		
TS_PORT	0.22	0.06	0.20	0.31	0.33	0.21	0.33	0.13	0.57	0.09	0.18	0.24	1.00	
TS_SH	0.37	0.26	0.21	0.39	0.52	0.08	0.41	0.34	0.70	0.13	0.25	0.46	0.92	1.00

Where:

AREA, Terminal Area

BERTH, Berth Length

CAGR0408, Compound Annual Growth Rate 2004-2008

CAGR9808, Compound Annual Growth Rate 1998-2008

CAP, Theoretical Capacity

CAP_FREE, Free Capacity

CENTRALITY, Centrality Index

CRANES, Quay Cranes DEPTH, Depth Alongshore GDP, Gross Domestic Product LSCI, Liner Shipping Connectivity Index THROU, Container Throughput TS_PORT, Transhipment Port TS_SH, Transhipment Share In case the independent variables are highly correlated it raises the multicollinearity issue as previously mentioned, making it difficult to estimate the parameters of the regression with good precision i.e. with small standard errors. Looking at all the variables, it can be seen that several of these pair-wise correlations are quite high, suggesting that there may be a severe collinearity problem. As a consequence, performing a regression analysis with using these explanatory variables, would present a serious risk of multicollinearity.

In order to deal with this issue, there are a few potential choices. One course of action to address high correlation is to drop some of the measured variables in the regression analysis. However, this would lead to less explained variance. Another option is to create composite scores by summing measured variables, which would also explain less variance. Yet another option, and the one embraced in this thesis, is to create factor scores, which explain more variance.

So, the best option in these circumstances is to see how the variables match together. To this purpose, a factor analysis is performed which allow \bigcirc create factors, uncorrelated linear combinations of weighted observed variables, and explain a maximum amount of variance in the data.

Often, factor analysis is used to look for latent variables¹⁶. Although latent variables are not directly measured; they influence responses on measured variables and include unreliability due to measurement error. The observed (measured) variables could be linear combinations of the underlying factors. A factor analysis describes the factor structure of the data.

Hence, in this thesis a factor analysis is used to correct correlation and explain the contribution of variables. A new artificial variable, which is a linear combination of highly correlated variables, is used. The weights are the results of the factor analysis and these weights indicate how all those variables contribute to explain productivity.

¹⁶ Unobserved or latent variable, meaning the basic variable underlying a phenomenon.

5.2.3 FACTOR ANALYSIS

In light of what was mentioned earlier, a factor analysis is performed at this point with the intention to determine the number of factors and respective factor scores. These factors will then be used in sub-chapter 5.2.4 estimation of the regression model, as variables for the regression models.

Factor analysis procedures are based on the initial computation of a complete table of inter-correlations among the variables i.e. correlation matrix. The correlation matrix is then transformed through estimation of a factor model to obtain a factor matrix containing factor loadings for each variable on each derived factor. The loadings of each variable on the factors are then interpreted to identify the underlying structure of the variables, in this case influencing container port physical productivity indicators under analysis.

Since, as previously shown, the variables CAP_FREE, GDP, CAGR0408, CAGR9808 and CENTRALITY present low correlation, these variables are not taken into consideration in the present factor analysis.

For all the remaining 9 variables that present a high degree of correlation, a factor analysis is performed. In effect, a Maximum Likelihood (ML) factor model is then estimated for those 9 variables, namely: area (AREA), berth length (BERTH), theoretical capacity (CAP), number of cranes (CRANES), depth alongside (DEPTH), liner shipping connectivity index (LSCI), container throughput (THROU), transhipment port (TS_PORT) and transhipment share (TS_SH).

The model is estimated using Squared Multiple Correlation (SMC) initial communalities and Velicer's¹⁷ Minimum Average Partial (MAP) criterion to select the number of factors.

In addition, a rotation is performed using the orthogonal Varimax method, as well as an estimation of the factor scores to be used in the regression. Lastly, the retained factors are identified and named.

¹⁷(Velicer, 1976) minimum average partial method (MAP). Simulation evidence suggests that MAP (along with parallel analysis) is more accurate than more commonly used methods such as Kaiser-Guttman (Zwick & Velicer, 1986).

5.2.3.1 Specification of the number of factors

The first objective is to specify the number of factors. To do so, the factor model was estimated and the initial estimates were obtained. Table 5.3 summarizes the eigenvalues, showing the values, the forward difference in the eigenvalues, the proportion of total variance explained, the cumulative value and the cumulative proportion.

Eigenvalues	: (Sum = 9	Θ , Average = 1)			
				Cumulative	Cumulative
Number	Value	Difference	Proportion	Value	Proportion
1	5.09	3.35	0.57	5.09	0.57
2	1.74	0.87	0.19	6.83	0.76
3	0.87	0.42	0.10	7.70	0.86
4	0.45	0.09	0.05	8.15	0.91
5	0.36	0.14	0.04	8.52	0.95
6	0.23	0.10	0.03	8.74	0.97
7	0.13	0.04	0.01	8.87	0.99
8	0.09	0.05	0.01	8.96	1.00
9	0.04		0.00	9.00	1.00

TABLE 5.3: RESULTS FOR THE EXTRATION OF COMPONENT FACTORS

Of particular interest is to check the proportion column, which shows that the first principal component accounts for 57% of the total variance, while the second accounts for 19%. Together these 2 factors account for 76% of the total variance, which is to say they explain as much of the variance as nearly seven variables do.

Figure 5.2 presents an intuitive way of viewing the information concerning the specification of the number of fact []. It displays the scree plot of ordered eigenvalues and the cumulative proportion of variance explained. The scree plot shows the sharp decline between the first and second eigenvalues. The horizontal red line marks the mean value of the eigenvalues that is always 1 for eigenvalue analysis conducted on correlation matrices.





The scree test indicates that two factors may be appropriate when considering the changes in eigenvalues, namely when identifying the "elbow" in the eigenvalues. The two factors retained represent over 76% of the variance of the 9 variables, deemed sufficient in terms of total variance explained (Hair, Black, Babin, *et al.*, 2010). Combining all these criteria together leads to the decision to retain two factors for further analysis.

5.2.3.2 ESTIMATION OF THE FACTOR MODEL

In this sub-chapter, a factor specification is estimated using maximum likelihood method. The number of factors is selected using Velicer's minimum average partial (MAP) method, and the starting values for the communalities are taken from the squared multiple correlations (SMCs). The results of the estimated model are displayed in Table 5.4.

The estimation used all 36 observations in the work file, and converged after 7 iterations. Velicer's MAP method has retained two factors, labelled "F1" and "F2". Examination of the unrotated loadings indicates that AREA, BERTH, CAP, CRANES and THROU load on the first factor, while TS_PORT, TS_SH and DEPTH load on the second factor.

TABLE 5.4: UNROTATED FACTOR LOADINGS MATRIX

Factor Method: Maximum Likelihood Covariance Analysis: Ordinary Correlation Sample: 1 36 Included observations: 36 Number of factors: Minimum average partial Prior communalities: Squared multiple correlation Convergence achieved after 7 iterations

	Unrotated	Loadings	Communality	Uniqueness
	F1	F2	communancy	oniqueness
AREA	0.72	0.37	0.65	0.35
BERTH	0.83	0.26	0.76	0.24
CAP	0.74	0.52	0.82	0.18
CRANES	0.84	0.34	0.83	0.17
DEPTH	0.33	0.70	0.60	0.40
LSCI	0.23	0.25	0.12	0.88
THROU	0.77	0.46	0.80	0.20
TS_PORT	-0.21	0.92	0.88	0.12
TS_SH	0.00	1.00	1.00	0.00

The last two columns show communality and uniqueness estimates which assign the diagonals of the correlation matrix into common (explained) and individual (unexplained) components¹⁸. It is observed that, for example, the percentage of the correlation accounted for by the two common factors is 82% for CAP, 83% for CRANES variables, 80% for TS_PORT and 100% for TS_SH. Only LSCI presents a low communality value of 12%, all the other variables present values above 60%.

Table 5.5 provides summary information on the total variance and proportion of common variance accounted for by each of the factors. Note that the first factor F1 accounts for 51% of the common variance and the second factor F2 accounts for the remaining 49%.

Factor	Variance	Cumulative	Difference	Proportion	Cumulative
F1	3.26	3.26	0.08	0.51	0.51
F2	3.19	6.45		0.49	1.00
Total	6.45	9.71		1.00	

TABLE 5.5: TOTAL VARIANCE AND PROPORTION OF COMMON VARIANCE

¹⁸ The communalities are obtained by computing the row norms of the loadings matrix, while the uniquenesses are obtained directly from the ML estimation algorithm.

5.2.3.3 FACTOR ROTATION

The estimated loadings and factors are not unique; it is possible to obtain others that fit the observed covariance structure identically. This observation lies behind the notion of factor rotation, where the transformation matrices are applied to the original factors and loadings. The purpose is to obtain a simpler factor structure.

So, factor rotation is performed on the two estimated factors using Orthogonal Varimax Rotation Method. The results are shown in Table 5.6 below.

TABLE 5.6: ORTHOGONAL VARIMAX ROTATION OF COMPONENTS ANALYSIS FACTOR MATRIX

Rotation Method: Orthogonal Varimax Factor: Untitled Initial loadings: Unrotated Convergence achieved after 3 iterations

Rotated loadings		
	F1	F2
AREA	0.79	0.18
BERTH	0.87	0.04
CAP	0.85	0.32
CRANES	0.90	0.12
DEPTH	0.49	0.60
LSCI	0.29	0.19
THROU	0.86	0.26
TS_PORT	0.02	0.94
TS_SH	0.25	0.97

Rotated loadings: L * inv(T)'

The results are similar to those of the un-rotated matrix in Table 5.4, with the exception of variable LSCI that didn't seem to load in any factor in particular and now is more defined and clearly loads on factor 1.

Examination of the rotated loadings indicates that AREA, BERTH, CAP, CRANES, LSCI and THROU load on the first factor. It seems reasonable to label the first factor as an indicator of terminal or quay operation since these variables are all to some degree involved in the operation of unloading and loading of containers.

It can be seen that the variables TS_PORT, TS_SH and DEPTH load on the second factor. Given the nature of these variables, it may be concluded that this factor is related to

transhipment. Transhipment involves the utilisation of large ships that require greater depth alongside the berth, and often use a hub-and-spoke network system that privileges transhipment hubs and dedicated terminals. From this point onwards, factor 1 is referred to as OPERATIONAL and factor 2 as TRANSHIPMENT.

5.2.3.4 ESTIMATION FACTOR SCORES

The coefficients scores were estimated using the exact coefficients method. These will be used in the regression estimation undertaken in sub-chapter 5.2.4.

The factors used to explain the covariance structure of the observed data are unobserved, but may be estimated from the loadings and observable data. These factor score estimates may be used in subsequent diagnostic analysis, or as substitutes for the higher-dimensional observed data.

Table 5.7 presents the rotated scores estimations for factors Operational and Transhipment for the sample of 36 Mediterranean container ports under analysis.

oha	Operational	Transhipment
ODS	Factor	Factor
Alexandria	-0.13	-0.91
Algeciras	1.13	1.31
Algiers	-0.71	-0.82
Ambarli	1.84	-0.46
Ashdod	0.13	-1.09
Barcelona	1.43	-0.35
Beirut	-0.18	0.17
Cagliari	-0.91	1.69
Casablanca	-0.48	-0.77
Constantza	-0.28	0.96
Damietta	-0.70	1.30
El Dekheila	-0.49	-0.82
Genoa	0.85	-0.96
Gioia Tauro	2.16	1.05
Haifa	-0.25	0.02
Haydarpasa	-1.12	-0.77
Izmir	-0.57	-0.89
La Spezia	-0.14	-0.72
Las Palmas	0.00	0.72
Latakia	-0.05	-1.05
Leghorn	-0.30	-0.75
Leixoes	-0.95	-0.73
Lisbon	-0.68	-0.37
Malaga	-1.38	1.98
Marsaxlokk	0.72	1.36
Marseilles	0.65	-0.97
Mersin	0.34	-1.01
Naples	-0.68	-0.78
Piraeus	-0.12	0.61
Port Said	1.20	1.21
Sines	-1.37	0.96
Tangier	0.14	1.68
Taranto	-0.17	1.39
Tenerife	-0.56	-0.89
Thessaloniki	-1.16	-0.76
Valencia	2.79	-0.56

TABLE 5.7: ROTATED FACTOR SCORES ESTIMATIONS

5.2.4 ESTIMATION OF THE REGRESSION MODEL

At this point, having overcome the multicollinearity issue, the regression model is specified and estimated. Since seven independent variables are included, this is a multiple regression model and the productivity regression function is as follows in equation 5.3:

$$Y_i = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_6 X_6 + \alpha_7 X_7$$
 [5.3]

Where,

 Y_i , physical container port productivity measured as throughput/cranes (Y_1), throughput/berth (Y_2) and throughput/area (Y_3)

 α_0 , constant

- α_n , coefficients n=1:7
- X_1 , factor Operational (F1)
- *X*₂, factor Transhipment (F2)
- X_3 , free capacity (CAP_FREE)
- *X*₄, gross domestic product (GDP)

 X_5 , compound annual growth rate for period 1998-2008 (CAGR9808)

 X_6 , compound annual growth rate for period 2004-2008 (CAGR0408)

and X_7 , centrality index (CENTRALITY).

Table 5.8 shows the correlation matrix between the independent variables, using the factor variables TRANSHIPMENT and OPERATIONAL and gives an idea how the different variables are related to each other.

TABLE 5.8: CORRELATION MATRIX WITH FACTOR VARIABLES

Covariance Analysis: Ordinary Sample: 1 36 Included observations: 36

Correlation	OPERATIONAL	TRANSHIPMENT	CAP_FREE	GDP	CAGR0408	CAGR9808	CENTRALITY
OPERATIONAL	1.00						
TRANSHIPMENT	0.02	1.00					
CAP_FREE	-0.20	0.14	1.00				
GDP	-0.03	0.14	-0.17	1.00			
CAGR0408	-0.10	0.24	0.07	0.28	1.00		
CAGR9808	-0.09	0.43	-0.10	0.25	0.55	1.00	
CENTRALITY	0.11	0.40	0.12	0.25	0.10	0.15	1.00

This is a very different scenario then the one in Table 5.2, which showed the correlation matrix for all the selected explanatory variables. The correlation between variables has decreased significantly overall, with most values below 0.3 (highlighted in green). By using the factors in the regression the risk of multicollinearity has been significantly reduced.

Now, the regression model is run for the dependent variable physical container port productivity, using the three previously mentioned indicators:

- Y₁, handling productivity (throughput per number of STS quay cranes);
- *Y*₂, berth productivity (throughput per berth length);
- Y_3 , terminal area productivity (throughput per terminal area).

As a final note, all 36 observations are used with valid data for all of the relevant variables. There are no missing observations in the sample.

5.2.4.1HANDLING PRODUCTIVITY

The regression model for Y_1 (throughput/cranes) is estimated using the method of the ordinary least squares (LS). The model specification is given by:

 $THROU_CRANES = C(1) + C(2)*OPERATIONAL + C(3)*TRANSHIPMENT + C(4)*CAP_FREE + C(5)*GDP + C(6)*CAGR9808 + C(7)*CAGR0408 + C(8)*CENTRALITY$

The regression equation with the estimated values of the coefficients is as follows:

THROU_CRANES = 74013.70 + 8713.33*OPERATIONAL + 12598.49*TRANSHIPMENT -819.58*CAP_FREE - 814.82*GDP - 39.72*CAGR9808 - 192.21*CAGR0408 + 46398.13*CENTRALITY

Table 5.9 presents the regression results for the dependent variable Y_1 (throughput/cranes).

TABLE 5.9: ESTIMATION OUTPUT OF Y_1 (THROUGHPUT PER CRANE, 2008)

Dependent Variable: THROU_CRANES Method: Least Squares Sample: 1 36 Included observations: 36

Variable	Coefficient	Std. Error	t-Statistic	Prob.
С	74013.70	48123.84	1.54	0.14
OPERATIONAL	8713.33	5540.14	1.57	0.13
TRANSHIPMENT	12598.49	6268.91	2.01	0.05
CAP_FREE	-819.58	221.88	-3.69	0.00
GDP	-814.82	1739.30	-0.47	0.64
CAGR9808	-39.72	529.88	-0.07	0.94
CAGR0408	-192.21	278.42	-0.69	0.50
CENTRALITY	46398.13	56460.19	0.82	0.42
R-squared	0.49	Mean depend	lent var	88519.55
Adjusted R-squared	0.36	S.D. depende	ent var	38623.70
S.E. of regression	30921.52	Akaike info c	riterion	23.71
Sum squared resid	2680000000.00	Schwarz crite	erion	24.06
Log likelihood	-418.77	Hannan-Quinn criter.		23.83
F-statistic	3.80	Durbin-Watso	on stat	1.28
Prob(F-statistic)	0.01			

It can be observed that the overall model fit, as indicated by R-squared (0.49), adjusted R-squared (0.36) and significance of the F-statistic (p-value of 0.01) is good. Both R-squared and adjusted R-squared present values above 30% which is good for cross-sectional model regressions¹⁹²⁰. With an F-value of 0.01, well below 0.05, the current model is significant. This means that the regression equation describes the data well.

Given that the model is significant, the analysis continues by interpreting individual variables. In order to analyse the effects of the independent variables separate the coefficient, its sign and the correspondent t-value are checked.

¹⁹ R-squared lies between 0 and 1, where a higher R2 indicates a better model fit. When interpreting the R-squared, higher values indicate that more of the variation in dependent variable is explained by variation in independent variables (Hill, Griffiths & Lim, 2011).

²⁰ It is noteworthy to mention that in cross-sectional data involving several observations, as is the case, it is common to obtain low R-squared because of the diversity of the cross-sectional units. Therefore, it is no surprising to find relatively low values for R-squared in cross-sectional regressions. What is relevant is that the model is correctly specified, that the regressors have the correct (that is theoretically expected) signs, and that the regression coefficients are statistically significant (Wooldridge, 2008). In addition, it is not straightforward what values are appropriate for R-squared, as this varies according to research areas. As an indication, in longitudinal studies R-squared values of 0.90 and higher are common. In cross-sectional designs, values of around 0.30 are common while for exploratory analysis, using cross-sectional data, values of 0.10 are typical (Mooi & Sarstedt, 2011).

Looking at the p-values, it can be seen that GDP, CAGR9808, CAGR0408 and CENTRALITY are not statistically significant in explaining THROU_CRANES.

The variable OPERATIONAL is almost significant at 0.10 and the coefficient has the expected positive sign. Moreover, as the t-value is larger than one, it is fair to say it still has some impact. It may be concluded that throughput per crane increases as variables related to container port operations increase.

The variable OPERATIONAL (Factor 1 composed of terminal area, berth length, capacity, number of cranes and throughput) is related to operational size. From these results may be concluded that port size does matter to physical productivity, measured as throughput per crane.

Two variables have significant impact on THROU_CRANE at 0.05 level that are TRANSHIPMENT and CAP_FREE. Looking at the sign in the coefficients column is found that TRANSHIPMENT is positively related to productivity and is expected that as this variable increases so does productivity. It is possible to infer that throughput per crane is higher when there is more transhipment. This is possible due to higher crane performance in larger ports with higher transhipment share as the STS cranes at those ports are generally new and more efficient in order to cater for larger and wider container ships.

CAP_FREE is negatively related to THROU_CRANE. The reasoning could be that the closer to full capacity a terminal is operating the more productive it is (in the sense of output per unit of input). An efficient container port terminal operating at, or close to, its maximum capacity typically implies that that all the ports' subsystems are also operating close to its maximum operational capacity. This includes the terminal STS cranes.

The t-values also show the importance of a variable in the model. In this case, CAP_FREE is the most important, followed by TRANSHIPMENT and OPERATIONAL. A more detailed analysis of the results is done in sub-chapter 5.2.5 – interpretations of results.

In order to check for heteroskedasticity, a common problem with cross-sectional data, the Breusch-Pagan-Godfrey test is done. The results of the test on the Y1 (throughput per crane) regression are presented in Table 5.10.

This output contains both the set of test statistics, and the results of the auxiliary regression on which they are based. The F-statistic and Chi-square statistics reported in the top panel do not reject the null hypothesis of constant error variance and conclude there is no evidence of heteroskedasticity.

TABLE 5.10: HETEROSKEDASTICITY TEST FOR Y_1 (THROUGHPUT PER CRANE)

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.44	Prob. F(7,28)	0.87
Obs*R-squared	3.57	Prob. Chi-Square(7)	0.83
Scaled explained SS	1.92	Prob. Chi-Square(7)	0.96

Test Equation: Dependent Variable: RESID^2 Method: Least Squares Sample: 1 36 Included observations: 36

Variable	Coefficient	Std. Error	t-Statistic	Prob.
С	1.66E+08	1.66E+09	0.10	0.92
OPERATIONAL	-95920777	1.91E+08	-0.50	0.62
TRANSHIPMENT	1.65E+08	2.16E+08	0.76	0.45
CAP_FREE	-7404733	7657877	-0.97	0.34
GDP	6284309	60028775	0.10	0.92
CAGR9808	-13722543	18287937	-0.75	0.46
CAGR0408	- 5658345	9609253	-0.59	0.56
CENTRALITY	1.09E+09	1.95E+09	0.56	0.58
R-squared	0.10	Mean depend	ent var	7.44E+08
Adjusted R-squared	-0.13	S.D. depende	ent var	1.01E+09
S.E. of regression	1.07E+09	Akaike info cr	riterion	44.61
Sum squared resid	3.19E+19	Schwarz crite	erion	44.96
Log likelihood	- 794.94	Hannan-Quinn criter.		44.73
F-statistic	0.44	Durbin-Watso	on stat	2.05
Prob(F-statistic)	0.87			

Figure 5.3 displays a graph of the actual and fitted values for the dependent variable Y_1 (throughput/cranes), along with the residuals. The actual value is always the sum of the fitted value and the residual.



FIGURE 5.3: ACTUAL, FITTED AND RESIDUALS GRAPH FOR Y_1 (THROUGHPUT PER CRANE)

Overall, it seems that this is a useful model that appears to satisfy the key assumptions of regression analysis. Looking closer at the residuals plot in Figure 5.3 the exceptions are Algeciras, Ambarli, Haifa, Damietta, Izmir, Latakia, and El Dekheila. These are marked with a red circle. The discussion on these exceptions is carried out in sub-chapter 5.2.5.

5.2.4.2 BERTH PRODUCTIVITY

At this point is estimated the regression model for Y_2 (throughput/berth), using the method of the least squares (LS) as in the previous model. The model specification is given by:

 $THROU_BERTH = C(1) + C(2)*OPERATIONAL + C(3)*TRANSHIPMENT + C(4)*CAP_FREE + C(5)*GDP + C(6)*CAGR9808 + C(7)*CAGR0408 + C(8)*CENTRALITY$

The regression equation with the estimated values of the coefficients is as follows:

THROU_BERTH = 589.22 + 145.84*OPERATIONAL + 109.52*TRANSHIPMENT - 6.50*CAP_FREE + 8.97*GDP + 2.97*CAGR9808 - 2.20*CAGR0408 + 241.45*CENTRALITY

In Table 5.11 is presented the regression results for the dependent variable Y_2 (throughput/berth).

TABLE 5.11: ESTIMATION OUTPUT OF Y₂ (THROUGHOUT PER BERTH, 2008)

Dependent Variable: THROU_BERTH Method: Least Squares Sample: 1 36 Included observations: 36

Variable	Coefficient	Std. Error	t-Statistic	Prob.
С	589.22	390.27	1.51	0.14
OPERATIONAL	145.84	44.93	3.25	0.00
TRANSHIPMENT	109.52	50.84	2.15	0.04
CAP_FREE	-6.49	1.80	-3.61	0.00
GDP	8.97	14.11	0.64	0.53
CAGR9808	2.97	4.30	0.69	0.49
CAGR0408	-2.20	2.26	-0.97	0.34
CENTRALITY	241.45	457.88	0.53	0.60
R-squared	0.61	Mean depend	lent var	647.00
Adjusted R-squared	0.51	S.D. depende	ent var	357.90
S.E. of regression	250.77	Akaike info c	riterion	14.08
Sum squared resid	1760750.00	Schwarz criterion		14.43
Log likelihood	-245.44	Hannan-Quinn criter.		14.20
F-statistic	6.18	Durbin-Watso	on stat	1.46
Prob(F-statistic)	0.00			

The overall model fit is good, as indicated by R-squared (0.61), adjusted R-squared (0.51) and significance of the F-statistic (p-value of 0) indicating that the current model is significant. Observing the last column of the output table, it can be seen that the variables OPERATIONAL, TRANSHIPMENT and CAP_FREE are statistically significant. It is interesting to note that these are the same three variables that appeared as significant as in the previous model concerning handling productivity.

Looking at the signs of the coefficients, these seem to make economic sense: as OPERATIONAL and TRANSHIPMENT increases, so does the physical productivity indicator throughput per berth. CAP_FREE has once again a negative impact on Y_2 . These results are consistent with the ones for handling productivity, where the significant variables are also OPERATIONAL, TRANSHIPMENT and CAP_FREE.

Here to hay be concluded that port size does matters to physical productivity, measured as throughput per berth length. Moreover, berth productivity is higher when there is more transhipment. This is possible due to a more intense use of the berth since transhipment vessels tend to be larger and demand to stay as little time as possible in port. And again, terminal free capacity is negatively related to berth productivity, the reason being that the closer to full capacity a terminal is operating the more productive it is in the sense of output per unit of input. This would apply to throughput per berth length. Further analysis is done in sub-chapter 5.2.5 – interpretations of results.

As previously, the Breusch-Pagan-Godfrey test is run to check for heteroskedasticity. Table 5.12 presents the results for physical productivity indicator throughput per berth.

TABLE 5.12: HETEROSKEDASTICITY TEST FOR Y_2 (THROUGHPUT PER BERTH)

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.48	Prob. F(7,28)	0.84
Obs*R-squared	3.87	Prob. Chi-Square(7)	0.80
Scaled explained SS	1.52	Prob. Chi-Square(7)	0.98

Test Equation: Dependent Variable: RESID^2 Method: Least Squares Sample: 1 36 Included observations: 36

Variable	Coefficient	Std. Error	t-Statistic	Prob.
С	-48039.08	93011.00	-0.52	0.61
OPERATIONAL	-971.02	10707.66	-0.09	0.93
TRANSHIPMENT	483.38	12116.19	0.04	0.97
CAP_FREE	-387.41	428.84	-0.90	0.37
GDP	-516.80	3361.61	-0.15	0.88
CAGR9808	331.51	1024.12	0.32	0.75
CAGR0408	-480.97	538.12	-0.89	0.38
CENTRALITY	129550.30	109123.00	1.19	0.25
R-squared	0.11	Mean depend	ent var	48909.73
Adjusted R-squared	-0.12	S.D. depende	nt var	56578.66
S.E. of regression	59763.34	Akaike info cr	iterion	25.03
Sum squared resid	1E+11	Schwarz crite	Schwarz criterion	
Log likelihood	-442.49	Hannan-Quinn criter.		25.15
F-statistic	0.48	Durbin-Watso	2.28	
Prob(F-statistic)	0.84			

The F-statistic and Chi-square statistics reported in the top panel, on the right-hand side do not reject the null hypothesis of constant error variance. It is possible to conclude there is no evidence of heteroskedasticity.

In Figure 5.4 are presented the actual and fitted values for the dependent variable Y_2 (throughput/berth), along with the residuals.



FIGURE 5.4: ACTUAL, FITTED AND RESIDUALS GRAPH FOR Y_2 (THROUGHPUT PER BERTH)

Overall, this is a useful model that seems to satisfy the key assumptions of regression analysis. Looking closer at the residuals plot in Figure 5.4 the exceptions (marked with a red circle) are Algeciras, Casablanca, Naples and El Dekheila. The discussion on these exceptions is carried out in chapter 5.2.5.

5.2.4.3 TERMINAL AREA PRODUCTIVITY

Here, is estimated the regression model for Y_3 (throughput/area) and, similarly to the previous regressions, using the method of the least squares (LS). The model specification is given by:

 $THROU_AREA = C(1) + C(2)*OPERATIONAL + C(3)*TRANSHIPMENT + C(4)*CAP_FREE + C(5)*GDP + C(6)*CAGR9808 + C(7)*CAGR0408 + C(8)*CENTRALITY$

The regression equation with the estimated values of the coefficients is as follows:

THROU_AREA = 29347.83 + 1471.01*OPERATIONAL + 2406.32*TRANSHIPMENT -275.47*CAP_FREE + 447.13*GDP - 329.15*CAGR9808 + 67.11*CAGR0408 -105.88*CENTRALITY

Table 5.13 shows the regression results for the dependent variable Y_3 (throughput/area).

TABLE 5.13: ESTIMATION OUTPUT OF Y₃ (THROUGHPUT PER AREA, 2008)

Dependent Variable: THROU_AREA Method: Least Squares Sample: 1 36 Included observations: 36

Variable	Coefficient	Std. Error	t-Statistic	Prob.
С	29347.82	14695.46	2.00	0.06
OPERATIONAL	1471.01	1691.78	0.87	0.39
TRANSHIPMENT	2406.32	1914.32	1.26	0.22
CAP_FREE	-275.47	67.76	-4.07	0.00
GDP	447.13	531.12	0.84	0.41
CAGR9808	-329.14	161.81	-2.03	0.06
CAGR0408	67.11	85.02	0.79	0.44
CENTRALITY	-105.88	17241.10	-0.01	1.00
R-squared	0.46	Mean depend	lent var	21425.71
Adjusted R-squared	0.33	S.D. depende	ent var	11546.35
S.E. of regression	9442.43	Akaike info c	Akaike info criterion	
Sum squared resid	250000000.00	Schwarz criterion		21.69
Log likelihood	-376.07	Hannan-Quin	n criter.	21.46
F-statistic	3.48	Durbin-Watso	on stat	2.09
Prob(F-statistic)	0.01			

The overall model fit is good, as indicated by R-squared (0.46), adjusted R-squared (0.33) and significance of the F-statistic (p-value of 0.01) indicating that the current model is significant. Concerning the individual variables, CAP_FREE and CAGR9808 are statistically significant and both present a negative sign for the coefficient. However, looking at the t-statistics the value for CAGR9808 is well below 1.50, so it is needed to consider this variable with some reservation.

Concerning the sign of the coefficient CAP-FREE variable, this is negatively related to container port productivity (as well as in the previous two models). Again, the reasoning is that productivity increases as terminal free capacity decreases (volume is needed to increase productivity). The closer to full capacity a terminal is working the more productive it is (in the sense of output per unit of input).

As for the variables OPERATIONAL and TRANSHIPMENT, these are not statistically significant. This is not in line with the conclusions from the previous two models. A possible explanation is that concerning terminal area productivity, there are other more relevant variables not considered in the model influencing its behaviour. For instance, the dwell time of containers or the storage cost per day.

There are several cases where terminal areas are used as container storage areas. In these cases, the

As for heteroskedasticity, the results of the Breusch-Pagan-Godfrey test for Y3, throughput per area are presented in Table 5.14 below:

TABLE 5.14: HETEROSKEDASTICITY TEST FOR Y_3 (THROUGHPUT PER AREA)

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	1.11	Prob. F(7,28)	0.39
Obs*R-squared	7.81	Prob. Chi-Square(7)	0.35
Scaled explained SS	3.56	Prob. Chi-Square(7)	0.83

Test Equation: Dependent Variable: RESID^2 Method: Least Squares Sample: 1 36 Included observations: 36

Variable	Coefficient	Std. Error t-Statistic		Prob.
С	26298456.00	133000000.00	0.20	0.84
OPERATIONAL	-5875669.00	15293916.00	-0.38	0.70
TRANSHIPMENT	-5267200.00	17305741.00	-0.30	0.76
CAP_FREE	-995976.70	612520.20	-1.63	0.12
GDP	3325745.00	4801440.00	0.69	0.49
CAGR9808	-2877993.00	1462772.00	-1.97	0.06
CAGR0408	873885.30	768602.20	1.14	0.27
CENTRALITY	84755708.00	156000000.00	0.54	0.59
R-squared	0.22	Mean dependent var		69346205
Adjusted R-squared	0.02	S.D. depende	ent var	86284785
S.E. of regression	85360937	Akaike info cr	39.56	
Sum squared resid	2.04E+17	Schwarz criterion		39.91
Log likelihood	-704.00	Hannan-Quinn criter.		39.68
F-statistic	1.11	Durbin-Watso	1.89	
Prob(F-statistic)	0.39			

Figure 5.5 shows the actual and fitted values for the dependent variable Y_3 (throughput/area), and the residuals from the regression in graphical form.



FIGURE 5.5: ACTUAL, FITTED AND RESIDUALS GRAPH FOR Y_3 (THROUGHPUT PER AREA)

Overall, it seems that this is a useful model that seems to satisfy the key assumptions of regression analysis. It can be observed that a few ports are not well fitted, namely Algeciras, Port Said, La Spezia, Ashdod, Latakia, El Dekheila, and Haydarpasa. These exceptions are marked with a red circle. The discussion on these exceptions is carried out in sub-chapter 5.2.5.

5.2.5 INTERPRETATION OF RESULTS

Table 5.15 provides information on the model fit i.e. how well the independent variables relate to the dependent variable. The R-squared provided for the three models seems highly satisfactory and is above the value of 0.30 that is common for cross-sectional analysis. As it was to be expected, the R-squared and the adjusted R-squared are similar, and also presents values above 0.30.

 \overrightarrow{P} is also taken into consideration the significance of the F-statistic test. The summary of the results from the three models in Table 5.15 indicates that all three regression models are significant both at a 5% and 1% significance level.

Model	R-squared	Adjusted R- squared	S.E. of regression	F-statistic	Prob F-statistic
(1) THROU_CRANES	0.49	0.36	30921.52	3.80	0.01
(2) THROU_BERTH	0.61	0.51	250.77	6.18	0.00
(3) THROU_AREA	0.46	0.33	9442.43	3.48	0.01

TABLE 5.15: SUMMARY OF THE RESULTS FROM THE MODELS

Next, after assessing the overall fit of the regression models, further attention is given to the individual parameters. As previously stated, the main purpose of regression analysis is to investigate the relationship between dependent variable productivity and several explanatory variables. Table 5.16 presents the estimation results per measure of physical productivity for container ports, making it easier to compare values.

	тні	THROU_CRANES		THROU_BERTH		т	HROU_AREA		
Variable	Coefficient	t-Statistic	Prob.	Coefficient	t-Statistic	Prob.	Coefficient	t-Statistic	Prob.
С	74013.70	1.54	0.14	589.22	1.51	0.14	29347.82	2.00	0.06
OPERATIONAL	8713.33	1.57	0.13	145.84	3.25	0.00	145.84	3.25	0.39
TRANSHIPMENT	12598.49	2.01	0.05	109.52	2.15	0.04	109.52	2.15	0.22
CAP_FREE	-819.58	-3.69	0.00	-6.49	-3.61	0.00	-6.49	-3.61	0.00
GDP	-814.82	-0.47	0.64	8.97	0.64	0.53	8.97	0.64	0.41
CAGR9808	-39.72	-0.07	0.94	2.97	0.69	0.49	2.97	0.69	0.06
CAGR0408	-192.21	-0.69	0.50	-2.20	-0.97	0.34	-2.20	-0.97	0.44
CENTRALITY	46398.13	0.82	0.42	241.45	0.53	0.60	241.45	0.53	1.00

TABLE 5.16: SUMMARY OF ESTIMATION RESULTS PER MEASURE OF PHYSICAL PORT PRODUCTIVIY

Legend: yellow: p-value <= 0.10 green: p-value between 0.10 and 0.50 For ease of interpretation, the p-values were categorised as follows: p-values smaller than 0.10 indicating very significant variables (highlighted in green); p-values between 0.10 and 0.50 indicating not neglectable variables (highlighted in yellow); and p-values above 0.50 indicating variables that can be neglected.

From the t-statistics and their significance levels can be seen that among the explanatory variables entered in the regression analysis, terminal free capacity, transhipment and operational have the major impact on the physical productivity indicators under analysis (y1, throughput per crane; y2, throughput per berth length; y3, throughput per terminal area). These variables - CAP_FREE, TRANSHIPMENT and OPERATIONAL - are consistently the top three more important with t-statistics always above 1.50 and significant or not neglectable significant levels.

The remaining four variables – GDP, CAGR9808, CAGR0408, CENTRALITY - are also consistent in the sense their t-statistics are always below 1, indicating they are not so important in explaining the physical productivity indicators under analysis. Their significance levels are mainly not significant with values close to 0.50 or above. The only exception being CAGR9808 in the model with y3 (throughput per terminal area), which is significant at 0.10. However, the t-statistic is well below 1.50.

A first observation is that the variables that influence productivity vary according to the three measures of physical port productivity (throughput per crane, berth or terminal area. The only variable that is very significant to explain all three variables of port productivity is the CAP_FREE i.e. the free available port capacity, with a negative coefficient for three measures.

The impact of GDP, CAGR9808 (negative on throughput per area), CAGR0408 and CENTRALITY are not significant in all three models.

In order to answer **research question 1**, special attention is given to factor OPERATIONAL which incorporates elements related to port capacity and throughput, and CAP_FREE.

Scale increases (larger ports) has led to a higher productivity as a result of scale advantages i.e. the larger ports being more productive than smaller ones assuming that ports are operating clos \bigcirc at full capacity.

In fact, it is more likely for larger ports to operate close full capacity as their throughput is less affected by fluctuations in demand and larger ports in the Mediterranean have agreements with the largest shipping companies that guarantee a significant part of their traffic. Additionally, an increase in infrastructure capacity at a large port represents a smaller share of the port's total capacity than the same increase in capacity at a smaller port.

This assumption is not valid if ports are not using the full capacity. So it is possible that a smaller port with a high degree of capacity utilisation scores better on the productivity indicators that a larger port with low capacity utilisation.

It should be noted that this analysis is influenced by the definition used for container port productivity, which deals with the por hysical attributes and does not cover any labo related issues. The more free capacity, the less the port is using its infrastructure superstructure and hence the smaller the physical productivity indicator considered.

The variable Centrality Index (CENTRALITY) was introduced to address **research question 2**, giving information on the issue of the relevance of centrality for productivity. In theory, a positive sign for the coefficient of this variable Centrality, which does happen, since it is expected a positive relationsh between productivity and centrality. However, it is not statistically significant as can be seen.

The fact of a port being more central will have an impact in the shipping line's choice. Between two ports of equal size and equal infrastructure, it could be expected that the one which is more central would be chosen and hence generate more throughput. This would mean that throughput per crane, per berth, per area would be higher in that port.

However the impact of centrality is not considered to be important, as mentioned. This could be due to a number of reasons: i) centrality is not important for the shipper, i.e. it is possible that it is relevant from the point of view of the shipping line, but not necessarily so from the point of view of port productivity; ii) central ports have a size or free capacity which makes them less productive; iii) the used indicator for centrality is not a good one.

Also, in the question of centrality it is also difficult to distinguish the cause (new ports being built more centrally to serve shipping line) from the effect (those new ports have

higher productivity). In fact, the newest (greenfield²¹) ports in the Mediterranean that are part of this sample were all built with high centrality. This is the case of Port Said, Tangier, Sines and less recently Marsaxxlok, Algeciras and Gioia Tauro.

In order to address **research question 3**, particular attention is given to the variable TRANSHIPMENT, that is composed of variables transhipment (TS_PORT), transhipment share (TS_SHARE) and depth alongside (DEPTH). This variable is significant in two models, indicating that it has a positive impact on handling and berth productivity. Only in terminal area productivity is not significant. This is likely an indication that transhipment ports are prone to be more productive than others. The size and type of ships accommodated by a terminal affect the productivity of the terminal operations. Transhipment ports handle a larger number of larger vessels and this could explain their higher productivity. Transhipment ports use their berths and cranes more intensely than other ports; however, the storage area is less densely used than other ports.

Considering the variable, GDP, the reason why the impact of GDP is not significant may be due to the fact that ports in the same country have all same GDP in the database, so there is not much variation. Oftentimes GDP of foreland and hinterland are important and the GDP of the country is not always a good approximation. So, GDP is relevant for throughput, but clearly not for productivity.

The variables CAGR9808 and CAGR0408 refer to compound annual growth rates (CAGR) of the throughput for ports in the sample, for the periods 1998-2008 and 2004-2008 respectively. The issue seems to be there is no clear defined tendency and therefore no statistical significance. For example, there are ports with high physical productivity and low CAGR, such as Algeciras and Gioia Tauro working close to full capacity and no recent significant increase in throughput. Other ports also with high productivity have a high CAGR, namely Port Said and Tangier Med. Moreover there are a number of ports who did not exist in 1998 and have only recently become statistically relevant in the 2004 to 2008 period with very high CAGR but no corresponding operational productivity.

²¹ Greenfield investment is the investment in a structure in an area where no previous facilities exist.

	Residual Plot				
obs	THROU_CRANES	THROU_BERTH	THROU_AREA		
Valencia	1 9 1		ا ۾ ا		
Gioia Tauro		101	101		
Algeciras			I		
Port Said	I AT	1 9-1	الهسيل ا		
Barcelona		1 9 1	1 Q		
Marsaxlokk	<u>9</u>		_>		
Ambarli		✓ 1	1 / 1		
Genoa		1 7 4			
Haifa		اه ا			
Constantza					
Las Palmas			et l		
La Spezia		1 4			
Damietta		I de la constante de la consta	10		
Beirut		< '			
Tangier					
Casablanca			10		
Izmir		1 19	· >>>		
Mersin	I 91	1 8	' ~ '		
Marseilles			ا هم		
Ashdod		19 1	et 1		
Taranto	' X '	1 🔶 1	100 1		
Leghorn	19	1 🤞 1	1 à		
Latakia	ୁ କ(104 1			
Lisbon	be I	10 1			
Algiers	I 🏹 I		· >>>		
Naples		«< ·			
Leixoes		· >• ·			
Piraeus	4	1,800	· ≪ _ !		
Malaga) () () () () () () () () () (9 1			
El Dekheila		di i	en 1		
Tenerife	1 Q 1	1 1	A		
Alexandria		10 1			
Haydarpasa		י (א' י			
Cagliari		10 1	1 afres		
Thessaloniki		1 91			
Sines	` ∙₀	। ò।	1 🗸 1		

FIGURE 5.6: VALUE OF RESIDUAL PLOTS FOR THE THREE MODELS

Figure 5.6 displays the residual plots from the three regressions in graphical form. Looking at the residual plots it is easy to spot the exceptions. They are identified in Table 5.17.

Regression Y ₁ Handling productivity	Regression <i>Y</i> ₂ Berth productivity	Regression Y_3 Terminal Area productivity
Algeciras	Algeciras	Algeciras
Ambarli	Casablanca	Port Said
Haifa	Naples	La Spezia
Damietta	El-Dekheila	Ashdod
Izmir		Latakia
Latakia		El-Dekheila
El-Dekheila		Hayderpasa

TABLE 5.17: EXCEPTIONS OF RESIDUAL PLOTS VALUES

Source: own composition

There are two ports that are exceptions in all three residual plots: Algeciras, which is underestimated, and El-Dekheila, which is overestimated. The potential reasoning behind the underestimation of Algeciras and overestimation of El-Dekheila is as follow

Port of Algeciras

The port of Algeciras is an outlier in all productivity measurements. It is by far the most productive container port in the Mediterranean by berth and crane (handling) productivity and the second most productive by terminal area productivity. The port of Algeciras is also the second largest Mediterranean port by transhipment throughput. It is managed by APM Terminals and is dedicated to serve Maer the world's largest shipping company; APM Terminals, has the same ownership as Maersk and hence both companies are vertically integrated.

The reason for Algeciras above-average productivity is becourse it is heavily congested. This means that there are very few idle times in port operations hence increasing the productivity of the infrastructure.

The level of congestion has become so critical that a "reliever" port has recently been built just across the Strait of Gibraltar, Tangier-Med, is growing at a considerable rate and absorbing the demand that otherwise, would have been directed to Algeciras. This means there is practically no free capacity. The issue then may be that once there is no more free capacity this variable will stop and will not take into account the queues building up. This leads to an underestimation of the productivity.

Port of El Dekhelia

The port of El Dekhelia is also an outlier in all productivity measurements. Contrary to Algeciras it is one of the least productive ports in the Mediterranean. There are a number of possible explanations to this fact. El Dekhelia is the neighbour port of Alexandria and is managed by the same company.

A closer analysis of the port shows that there is a significant terminal area dedicated to container handling, but has currently a mixed-use i.e. there is handling of cargo which is not containerised and therefore not accounted as container traffic thus explaining lower berth and terminal area productivity in terms of containers.

Additionally, the ports' STS cranes are old and do not have a comparable performance to more modern cranes hence decreasing crane productivity.

In order to have a more in depth interpretations of th \square



5.3 GROUPING ANALYSIS

The objective of the grouping analysis is to identify groups of objects - in these case container ports - that are very similar with regards to some of their characteristics: throughput, transhipment share and geographical locations and assign them into groups. After having decided on the grouping variables the grouping procedure needs to be decided to form the different groups of objects. In this specific case the grouping was undertaken by interval of values.

In practical terms and in order to be able to define the type of analysis a number of techniques are used to build meaningful groups. The development of a group analysis usually involves three sequential steps:

- measurement of some form of similarity or association among the entities to determine how many groups really exist in the sample;
- the actual grouping process whereby entities are partitioned into mutually exclusive groups;

In the context of the present thesis the objective of this chapter is to identify ports that have similar levels of productivity and aggregate them through their common characteristics.

As mentioned above data was collected on berth length, gantry cranes (#), terminal area (hectare), container throughput (TEUS), quay depth, transhipment share (%), and theoretical capacity (TEUS).

In this dissertation and in order to address the research questions through a group-based approach three types of grouping were considered based on the variables considered as the most important physical productivity indicators.

	Crane productivity (TEU/ #STS crane)	Berth productivity (TEU/ m berth)	Terminal area (TEU/ sqm terminal)
Throughput-based grouping 4 groups	Figure 5.9	Figure 5.10	Figure 5.11
Centrality Index-based grouping 4 groups	Figure 5.12	Figure 5.13	Figure 5.14
Transshipment share- based grouping 3 groups	Figure 5.17	Figure 5.18	Figure 5.19
	Source: owr	n composition	

TABLE 5.18: GROUPS VS. PHYSICAL PORT PRODUCTIVITY INDICATORS - INDICATION OF FIGURES

5.3.1 THROUGHPUT-BASED APPROACH

In order to address the research question 1: does size matter? Are larger container ports more productive than smaller ones? Four different groups have been considered according to their throughput from the 36 port sample. These are indicated in Table 5.19 that gives an overview of the port grouping based on container throughput.

	Group 1	Group 2	Group 3	Group 4
Group characteristics	More than 2 million TEU	Between 1 and 2 million TEU	Between 0.5 and 1 million TEU	Less than 0.5 million TEU
# elements in Group	7	6	12	11

TABLE 5.19: PORT GROUPING BASED ON CONTAINER THROUGHPUT

Source: own composition

The rational for this grouping is relatively straightforward: ports have been grouped according to their throughput and whether it surpasses certain throughput thresholds. The number of groups and the threshold levels has been arbitrarily defined. As there is a continuum of data and there are no "natural" group categories. The idea is to classify ports according to descending throughput, respectively: large container ports, medium, small and very small ports.






Validation of Research Question 1: Is size an important factor in port productivity?

In order to validate this research question, the four "port throughput" groups were plotted against the three indicat \widehat{p} of physical productivity that were considered (see Figures 5.9 to 5.11).

The result is interesting and validates the initial grouping. Looking at Figure 5.9 it can be observed that container throughput is an important factor in crane productivity. Operationally, the rationale for increased handling productivity with increased port throughput can be explained as follows: larger ports are served by larger ships, which in turn demand higher performance STS cranes to ensure a faster turnaround. This explanation is also coherent with the results of the berth productivity analysis which has been undertaken in Figure 5.10.



FIGURE 5.9: THROUGHPUT VS. HANDLING PRODUCTIVITY



Note: Average crane productivity (y-axis) is 92,984 TEU per STS crane. Values are shown above or below average.

The outlier in group 1 is the port of Ambarli in Turkey, which has significantly lower crane productivity than the average (both within the group as in absolute terms). This fact may be explained by a number of reasons: i) operational issues: the port quays are not exclusively dedicated to container handling and the quay cranes are not exclusively dedicated to container loading and unloading and must therefore be able to load/ unload other type of bulk cargo; ii) terminal layout: the port piers are long and narrow thereby preventing and optimal container flow and storage on the landside and iii) technological issues: the STS cranes are old and have only a reduced reach being able to handle smaller vessels.

In group 2, the port of Haifa is the outlier with berth and crane productivity well above the average. This may be explainable with the fact that the container terminal in the port is a dedicated, recent facility equipped with new high-performance STS cranes. Apparently, from information of the Port Authority website, the port is being operated close to its maximum capacity which leads to an increased handling productivity.

In group 4 - very small ports group - there is no port that is able to demonstrate an above-average crane productivity and the same is true for the small port group, with the exception of two ports which are Casablanca and Izmir.







Note: Average berth productivity (y-axis) is 677 TEU/m. x-axis represents port throughput. Values are shown above or below average.

Looking at Figure 5.10 it can be observed that container throughput is an important factor in berth productivity. In fact there are no elements of group 4 – ports with a throughput below 0.5 million TEU i.e. very small container ports - with an above-average berth productivity. In the following group all but two ports have below average berth productivity. Above the one million TEU threshold – medium and large container ports – only one port has a berth productivity well below average, whereas for the largest ports these have on average much higher productivity than the rest of the sample. This leads to the conclusion that the larger container ports are also the most productive. This conclusion is aligned with the one obtained in the regression analysis. Volume is necessary for higher levels of productivity.

In terms of terminal area productivity the situation is relatively different from the two previous analyses (see Figure 5.11). The graph shows that there are elements from groups 2, 3 and 4 both above and below average. Nonetheless there is a clear trend that shows that, on average, terminal area productivity increases with port size.



FIGURE 5.11: THROUGHPUT VS. TERMINAL AREA PRODUCTIVITY



The outliers with the highest performance values within each group: Hayderpasa (very small ports with a throughput below 0.5 million TEU), Lisbon (small port with a throughput between 0.5 and 1 million TEU) and La Spezia (medium-sized port with a throughput between 1 and 2 million TEU) are all ports which are located within an urban area thus making the expansion of their port infrastructure is extremely difficult and costly.

It may be concluded that due to their difficulty to expand, the ports identified above have succeeded in implementing effective operations with the relatively limited area available, for example by achieving a reduced container transit time through the terminal area.

Contrary to berthing procedures and crane operations the terminal container area can be managed in a number of different ways depending on container arrangement, so height, number of gantry cranes of container lifters, and level of automation for instance. The issue of pricing also plays an important role; for example the high costs for container storage at port terminals are an incentive for reduced container stays in port. Given the larger number of parameters influencing the terminal container area productivity a larger dispersion of productivity values was expected and this dispersion is validated by the Figure 5.11 above.

Moreover, the terminal area can be used for other activities than dedicated container handling: it can be used for container storage – be it short, medium or long-term-logistics activities, administrative activities (e.g. border and safety), transport (rail or road terminal) which take up terminal area space and do not contribute to terminal productivity.

5.3.2 CENTRALITY INDEX-BASED APPROACH

To address research question 2 (does centrality play a role in port productivity) four groups were considered according to their Centrality Index. Similarly to the methodology applied in the throughput-based approach the rationale behind this grouping is also related to threshold criteria as can be seen in Table 5.20 below:

TABLE 5.20: PORT GROUPING BASED ON CENTRALITY INDEX (CI)

	Group 1	Group 2	Group 3	Group 4
Group characteristics	CI larger than 0.95	CI between 0.90 and 0.95	CI between 0.85 and 0.90	CI below 0.85
# elements in Group	10	6	4	16

Source: own composition

Validation of Research Question 2: Is Centrality an important factor in port productivity?

In order to validate the abovementioned research question, the group "centrality index" was plotted against the three types of productivity that were considered. In Figures 5.12 to 5.14, the three productivity indicators are plotted against the four sub-groups and the analysis is then undertaken.

FIGURE 5.12: CENTRALITY INDEX VS. HANDLING PRODUCTIVITY



Source: Own composition

Note: Average crane productivity (y-axis) is 92,984 TEU per STS crane. Values are shown above or below average



FIGURE 5.13: CENTRALITY INDEX VS. BERTH PRODUCTIVITY

Source: Own composition

Note: Average berth productivity (y-axis) is 677 TEU/m. Values are shown above or below average







Note: Average terminal area productivity (y-axis) is 20,032 TEU per hectare. Values are shown above or below average

The analysis of the data above shows that it is difficult to determine a meaningful correlation between the centrality index and any of the three productivity indicators considered. This conclusion is aligned with the results from the regression analysis.

In fact "centrality" being an exogenous parameter i.e. not strictly related to port physical or operational characteristics, congregates very different types of ports in each group. For example, the group with the highest centrality i.e. grouping those ports that are located closest to the shortest navigational route between Gibraltar and Port Said, joins large high-performing hub ports like Algeciras, together with small "historical" ports like Algiers as well as container ports which are under accelerated development such as Tanger-Med. In this context, it is expected that centrality does not have a strong correlation with port productivity.

In effect, all of the considered sub-groups have a significant spread. It can hence be concluded that centrality by itself is not a significant factor for the three physical port productivity indicators considered in this dissertation.

5.3.3 TRANSHIPMENT SHARE BASED APPROACH

To address Research Question 3: whether transhipment ports are more productive, three groups were considered according to their transhipment share. This grouping is illustrated in Table 5.21 below:

	Group 1	Group 2	Group 3
Group characteristics	More than 75% transhipment	Between 20% and 75% transhipment	Less than 20% transhipment
# elements in Group	9	9	18
	3		10

TABLE 5	5.21: GRO	DUPING	BASED	ON	TRANSHIPME	NT SH	ARE

Source: own composition

The number of groups and the threshold levels has been defined in order to have a group where transhipment is the major driver of the port activity and another one where it is not; the nine ports in between constitute one quarter of the sample and build a different group. Hence, three large groups could be defined: ports that have a strong majority of transhipment traffic, ports that do not have a significant share of transhipment traffic and ports that are "in the middle" i.e. where there is a balance between transhipment and origin and destination traffic. The grouping is graphically illustrated in Figures 5.15 and 5.16.



FIGURE 5.15: TOP 36 CONTAINER PORTS IN THE MEDITERRANEAN BY TRANSHIPMENT SHARE (DESCENDING ORDER)

Source: own composition



Source: own composition

Validation of Research Question 3: Is transhipment an important factor in port productivity?

In order to validate the research question 3, the group "transhipment share" was plotted against the three types of productivity indicators that are considered in this dissertation. Similarly to the previous analysis, firstly the three physical productivity indicators are plotted against the three sub-groups and the analysis is then undertaken (see Figures 5.17, 5.18 and 5.19).









Note: Average crane productivity (y-axis) is 92,984 TEU per STS crane. Values are shown above or below average.



FIGURE 5.18: TRANSHIPMENT SHARE VS. BERTH PRODUCTIVITY

Source: Own composition

Note: Average berth productivity (y-axis) is 677 TEU/m. Values are shown above or below average.









Note: Average terminal area productivity (y-axis) is 20,032 TEU per hectare. Values are shown above or below average.

In this grouping it is noticeable that transhipment share is an important factor in handling and berth productivity (see Figure 5.18). In fact, in both cases there are four ports in group 3 (ports with marginal transhipment share) with an above-average berth and handling productivity.

There are a number of factors that explain the strong variations within each of the groups. In group 1 - high transhipment share – there are elements who display low productivity indicators across the board.

One possible explanation refers the ports of Cagliari and Taranto, which had significantly higher throughputs in previous years and in 2008 were operating well below capacity. This means that infrastructure (berth and terminal area) and superstructure (cranes) were not being used to their full potential, hence their reduced productivity levels. The same situation is applicable for Las Palmas who also has a considerable share of transhipment.

Another possible explanation for the low physical productivity for container ports with high transhipment shares is related to the gap between available port capacity (berth, crane, terminal area) i.e. the supply side and the demand for port services (throughput) i.e. the demand side. For example, the ports Tangiers and Malaga were going through very significant infrastructure expansion projects just before 2008, meaning that in 2008 these ports were operating well below the maximum port capacity despite presenting very high historical traffic growth. In these ports there is a considerable gap between available capacity (supply side) and container traffic (demand side). This reasoning is also applicable to ports in group 2 with low productivity. For instance, the lowest point in this group refers to Port of Sines, which also went through significant infrastructure expansion just before 2008 an urrently operating well below capacity.

Another visualisation of this grouping is depicted in Figure 5.20, where the three groups are plotted in a "transhipment throughput vs. transhipment" graph.



FIGURE 5.20: TRANSHIPMENT THROUGHPUT VS. TOTAL THROUGHPUT (GROUPING)

Source: Own composition Note: Transhipment throughput (y-axis) total throughput (x-axis).

Figure 5.21 shows clearly that 4 of the top-6 container ports in the Mediterranean: Gioia Tauro, Algeciras, Port Said and Marsaxxlokk are dedicated transhipment ports. Figure 5.21 shows the location of these ports in the context of the global trade routes, namely the East-West and the North-South trade routes. This Figure also shows that that there is isproportionate amount of small container ports which do have negligible transhipment traffic and are typical origin and destination ports.



FIGURE 5.21: LOCATION OF THE FOUR LARGEST MEDITERRANEAN TRANSHIPMENT PORTS AND THE GLOBAL TRADE ROUTES

Source: Own composition

5.3.4 GROWTH-SHARE MATRIX APPROACH

The growth-share matrix²² is constructed by plotting the market growth rate as a percentage on the vertical axis and the relative market share on the horizontal axis (see Figure 5.22).

Relative market share rather than absolute market share is used because it gives a better representation of the relative market strength of competitors. By using this grouping method and parameterizing data in relation to its average values, that is the intersection of x- and y- axis as the average values of both set of values, four groups are automatically created.

In the case of container ports in the Mediterranean a growth share matrix can be built using the average growth rate of the set of ports (see above) versus their market share. The set of data chosen was the period between 2003 and 2008 for assessing the port growth and year 2008 for determining the market share. Other time periods could be chosen, but 2003 was the first year for which consistent data for all ports had been released.

²² The BCG matrix is a chart that had been created by Bruce Henderson for the Boston Consulting Group in 1970 to help corporations with analysing their business units or product lines. Nonetheless, the principles of analysis remain valid.

FIGURE 5.22: GROUPING OF PORTS ACCORDING TO COMPOUND ANNUAL GROWTH RATE AND MARKET SHARE (2003-2008)





Note: i) average market compound annual growth rate (x-axis) 8.71%. Average port share (y-axis) 2.78%; ii) three ports belonging to group 3 have not been shown for ease of visualization. Their high compound annual growth rates would distort the graph.

As detailed in the note, the Mediterranean container market has grown at an average annual growth rate (weighted) of 8.71%. By 2008 the total Mediterranean container market reached 42.6 million TEU up from 28 million TEU in 2003. The average market share of the 36 ports was 2.78% (100/ 36). The absolute market share varied from Valencia with 3.60 million TEUs and an 8.4% share of the Mediterranean market and Sines with 0.23 million TEU and 2.5% share.

As expected, there are four quadrants in the growth-share matrix. Quadrant 1, with above average growth and market share has 6 elements; quadrant 2, with above average market share, but below average growth has 7 elements; quadrant 3 with below average market share, but above average growth has 8 elements, and; quadrant 4, the below average market share and below average growth has the remaining 15 elements.

One factor that should be noted is the range of x-axis – the compound annual growth rate - that varies between plus and minus 40% indicating the vitality of the

Mediterranean container market. The grouping of ports according to the abovementioned criteria is as follows:

Name of Port	Growth relative to growth average	Share relative to average share	# group
Constantza	0.38	0.46%	1
Ambarli	0.16	2.53%	1
Marsaxlokk	0.04	2.69%	1
Barcelona	0.01	3.26%	1
Port Said	0.21	4.74%	1
Valencia	0.14	5.67%	1
Damietta	-0.03	0.13%	2
La Spezia	-0.04	0.15%	2
Las Palmas	-0.01	0.30%	2
Haifa	-0.02	0.50%	2
Genoa	-0.07	1.37%	2
Algeciras	-0.03	5.03%	2
Gioia Tauro	-0.07	5.37%	2
Sines	4.58	-2.23%	3
Malaga	1.97	-1.77%	3
Lattakia	0.06	-1.44%	3
Ashdod	0.01	-0.83%	3
Mersin	0.04	-0.77%	3
Tangier	0.98	-0.62%	3
Casablanca	0.07	-0.62%	3
Beirut	0.17	-0.56%	3
Thessaloniki	-0.11	-2.22%	4
Cagliari	-0.12	-2.18%	4
Haydarpasa	-0.01	-1.93%	4
Alexandria	-0.14	-1.87%	4
Tenerife	-0.1	-1.84%	4
El Dekheila	-0.04	-1.83%	4
Piraeus	-0.32	-1.77%	4
Leixoes	-0.01	-1.72%	4
Naples	-0.07	-1.65%	4
Algiers	0.00	-1.53%	4
Lisbon	-0.09	-1.47%	4
Livorno	-0.03	-0.95%	4
Taranto	-0.05	-0.93%	4
Marseilles	-0.08	-0.79%	4
Izmir	-0.04	-0.68%	4

TABLE 5.22: GROUPING CRITERIA ACCORDING TO THE GROWTH-SHARE MATRIX APPROACH

Source: Own composition

Having already grouped ports into four different groups, the next step is to understand if those groups have correspondence with port productivity indicators. In the Figures 5.23, 5.24 and 5.26 the port groups are plotted against combinations of each of two of the three productivity indicators berth, crane and terminal area productivity.



FIGURE 5.23: BERTH PRODUCTIVITY VS. HANDLING PRODUCTIVITY

This Figure shows that there is a positive correlation between handling and berth productivity. This correlation is valid both for the whole set of ports as well as within each group.

The outlier in Figure 5.23 which has both the highest berth and handling productivity is the port of Algeciras. Algeciras is the third largest Mediterranean port by throughput and is growing below the region's average. The most likely reason being the port's heavy congestion and traffic of large vessels which drives higher berth and handling productivity.

Plotting together the two productivity factors that are more closely related, berth and handling productivity, against the four groups it becomes apparent that there is a clear differentiation by port size being the larger ports more productive than smaller ones. By analysing the output a number of interesting conclusions can be reache

Source: Own composition Note: x-axis TEU per berth length (m); y-axis TEU per STS crane

- Large ports are far more productive than smaller ports both in terms of berth productivity as well as crane productivity. Berth productivity in larger ports paperoximately double the in smaller ports and almost three times more than in smaller slower growing ones. The relationship is approximately similar in terms of handling productivity with larger slower growing ports having two times the productivity of smaller ports and 30% more than group1 ports;
- Large ports with slower growth rates achieve higher average berth and handling productivity than fast growing ones: the most plausible explanation is that large, slow growing ports have managed to adjust better infrastructure capacity and demand thereby optimising the utilization of the infrastructure subsystems (berth, cranes). In short, slow growing ports have reached a certain level of congestion who force them to make better use of their infrastructure and specially of their equipment;
- Smaller ports with higher growth have higher productivity than smaller ports with lower growth. Although the difference is not significant in terms of handling productivity, it is becomes noticeable in terms of berth productivity. This effect is probably due to the larger average ship size that serve faster growing ports.



FIGURE 5.24: BERTH PRODUCTIVITY VS. TERMINAL AREA PRODUCTIVITY

Source: Own composition Note: x-axis TEU per berth length (m); y-axis TEU per terminal area (hectare). Figure 5.24 shows that there is a positive correlation between terminal area and berth productivity; nonetheless this is a weaker correlation to handling productivity. This correlation is valid both for the whole set of ports as well as within each group.

The outliers in Figure 5.24 with both ports having the two highest berth and terminal area productivities are the ports of Algeciras and Port Said. Their layout can be depicted in Figures 5.25.



FIGURE 5.25: PORTS OF ALGECIRAS (LEFT) AND PORT SAID (RIGHT)

Source: Google Earth

Algeciras is the third largest Mediterranean port by throughput whereas Port said is the fourth largest. Both ports have a compact layout with most landside space being taken for container storage. This compact arrangement drives terminal area productivity. It should be noted that both ports are managed by APM Terminals and have a transhipment share above 90% of the total throughput.

Plotting together berth and terminal area productivity (Figure 5.24) against the four groups it becomes apparent that as for the previous output there is a clear separation by port size being the larger ports more productive than smaller ones. The relationship in terms of terminal area productivity is approximately the same for the other KPI's having larger ports, on average, twice the terminal area productivity of the smaller ports.

Plotting handling productivity vs. terminal area productivity shows the biggest dispersion of ports within each group, as can be depicted in Figure 5.26.

60,000 Ferminal area productivity (TEU per ha) 50,000 40,000 30,000 Average values (unweighted) 20,000 TEU per TEU per Group crane (STS) hectare 10,000 107,203 31,904 139,601 25,884 70,868 16.575 66,197 17 656 50,000 100,000 150,000 200,000





▲1 ◆2 ■3 ▲4

Handling productivity (TEU per STS crane)

Note: x-axis TEU per STS crane; y-axis TEU per terminal area (hectare).

As for the previous groupings the outliers in Figure 5.26 are the ports of Algeciras and Port Said with Algeciras having the highest handling productivity and Po \bigcirc id the highest terminal area productivity.

The result is interesting and validates the initial grouping. Ports in groups 1 and 2 show high average terminal productivities as well as high handling productivity. These results are aligned with the conclusion that larger ports are also the most productive. Inversely, ports in groups 3 and 4 shows have and terminal area productivities. This is due to two reasons:

- For ports in group 4 (below average throughput and share); these ports tend to receive smaller ships with smaller loads per scale. They are therefore equipped with less efficient cranes which are not as productive as those from larger ports and hence the smaller crane productivity. It is interesting to notice that some ports in group 4 have above-average terminal productivity. This can be explained because many are capacity constrained and thus have to make the most use of their small terminal area.
- For ports in group 3, these are built as modern container ports from the onset, but the fact that they are growing at a fast pace implies that they are oversized against their current traffic (as they were equipped and built to accommodate

much higher traffic levels). This explains both their low handling as well as their low terminal area productivity. Cranes in fact are idle a significant part of their time.

5.4 GROUPING BY TIME SERIES

In this chapter an historical analysis of container port throughput will be undertaken based on the CI Online database. As for the previous chapters groups are created based on similarities of a number of common characteristics such as total throughput, throughput growth in absolute and percentage terms, historical period of highest growth, among others.

A historical or time series analysis is a collection of observations of well-defined data items obtained through repeated measurements over time. A time series can generally be decomposed into three cyclic components: i) the trend component i.e. the long term direction of the series; ii) the seasonal component i.e. the systematic, calendar related movements of the series and iii) the irregular component i.e. the unsystematic, short term fluctuations of the series.

The trend component is defined as the 'long term' movement in a time series without calenda calenda calenda irregular effects, and is a reflection of the underlying level. It is the result of influences such as population growth, price inflation and general economic changes i.e. the drivers or fundamental indicators.

The seasonal component in a time series is defined as a recurrent type of events that influences the time series. Most of the times these events have an yearly pattern such as summer or Christmas holidays, but there are also shorter seasonal cycles, for example weekly, monthly, or quarterly cycles and longer ones like the 11-year sunspot cycle. When data is collected on a yearly basis it is generally assumed that the seasonal component is not significant.

The irregular component, also defined as the residual, is what remains after the seasonal and trend components of a time series have been estimated and removed. It results from short term fluctuations in the series which are neither systematic nor predictable. In a highly irregular series, these fluctuations can dominate movements, which will mask the trend and seasonality. In the case of time series of port container throughputs used in this dissertation there are no seasonal fluctuations.

This chapter aims to analyse a number of key factors in terms of historical throughput. This analysis is based both on historical traffic data and recent 2008 data has been considered when relevant. The historical throughput series allows the following information:

- Throughput: Container throughput in TEU (1970 to 2008 data) and indirectly variations in port throughput;
- Start of port operations: year when the port started with container operations or when container operations started to have some significance.

5.4.1 RATIONAL FOR TIME SERIES GROUPING

The rational for grouping in a historical throughput analysis is relatively straightforward: ports have been grouped according to their current throughput and whether it surpasses throughput thresholds and according to the age of the port. The number of groups and the threshold levels has been arbitrarily defined. As there is a continuum of data and there are no "natural" group categories.

Four different groups have been considered according to their size (throughput) from the 36 port sample. Table 5.23 gives an overview of group characteristics and Figure 5.27 illustrates port grouping considered.

	Group 1	Group 2	Group 3	Group 4
Group characteristics	More than 1.0 million TEU added between 1999 and 2008	Less than 1.0 million TEU added between 1999 and 2008 AND added throughput between 1999 and 2008 more than 80% of current throughput	Less than 1.0 million TEU added between 1999 and 2008 AND added throughput between 1999 and 2008 between 50 and 80% of current throughput	Less than 1.0 million TEU added between 1999 and 2008 AND added throughput between 1999 and 2008 less than 50% of current throughput
# elements in group	8	6	8	14
	Valencia	Taranto	Beirut	Genoa
	Gioia Tauro	Dekhelia	Mersin	Haifa
	Algeciras	Sines	Casablanca	La Spezia
Ports	Port Said	Malaga	Lathakia	Marseilles
	Barcelona	Tangiers	Algiers	Ashdod
	Masaxxlok	Cagliari	Damietta	Livorno
	Ambarli		Las Palmas	Lisbon
	Constanza		Izmir	Naples
				Leixoes
				Piraeus
				Santa Cruz de Tenerife
				Alexandria
				Haydarpasa
				Thessaloniki

TABLE 5.23: PORT GROUPING BASED ON ADDED THROUGHPUT (1999 - 2008)

Source: own composition



FIGURE 5.27: GROUPING BASED ON ADDED THROUGHPUT (1999 - 2008)

Source: own composition

Note: x-axis added throughput between 1999 and 2008 (negative values not depicted); y-axis percentage of added throughput (98-08) vs. 2008 throughput.

5.4.2 EVOLUTION OF CONTAINER THROUGHPUT

The evolution of the container port throughput in the Mediterranean is illustrated in Figure 5.28. In 2008 container port throughput in the Mediterranean – for the top-36 ports – has reached 42.6 million TEU. Most of this throughput was added in the last decade of the period between 1999 and 2008. In this period throughput increased provided by 23.9 million TEUs, from 18.7 million TEU in 1999 to 42.6 in 2008.







Breaking down ports into the four groups – see Figures 5.29 to 5.31 - it can be observed that in the last decade of the period, ports in group 1 i.e. the ones who have added more throughput in the Mediterranean market have surpassed ports in group 4 who have been traditionally the market leaders. In fact, the start of the differentiation of ports in the different groups started to take place around 1995 when average throughput of ports in group 1 had a very significant growth.

By 2008 the eight ports in group 1 i.e. the ones with more significant added growth, had more than 50% of container market in the Mediterranean, whereas the share of the ports in group 4 decreased significantly over the period. Group 2 has significantly increased its market share from a very low base in year 2000. The market share of group 3 ports has been relatively constant for a significant period growing in line with the market.

FIGURE 5.29: BREAKDOWN OF EVOLUTION OF CONTAINER PORT THROUGHPUT IN THE MEDITERRANEAN REGION



Source: own composition

FIGURE 5.30: MARKET SHARE EVOLUTION BY GROUPS OF CONTAINER PORT THROUGHPUT IN THE MEDITERRANEAN REGION







FIGURE 5.31: EVOLUTION OF AVERAGE PORT THROUGHPUT (TEUS)

Source: own composition

5.4.3 PRODUCTIVITY INDICATORS

In order to answer the research questions with the historical throughput grouping, the three physical productivity indicators – throughput per crane, per berth, and per terminal area - are plotted against the four groups described above (see Figures 5.32 to 5.35).

The results obtained are similar across the three productivity indicators. Group 1 i.e. the larger ports and the ones who have added more capacity in the previous decade, have shown much higher average productivity across all three productivity indicators. Group 3 i.e. the ports who have added between 50 and 80% of throughput in the 1998 to 2008 period, have consistently ranked second across the three productivity indicators followed by groups in groups 4 and 2.

The results of this grouping are coherent with previous results. Group 1 groups 52% of all throughput and 71.9% of all transhipment throughput and therefore it was expected that it would present the highest productivity of the groups. Moreover, group 1 ports also have the highest average throughput with 2.77 million TEU in 2008, three times the average throughput of group 3 ports, approximately four times the average throughput of group 2 ports. The ranking of the average throughput is also the ranking of all the productivity indicators.

Group 3 groups ports where growth in the last decade represents between 50 and 80% of the current throughput i.e. a two to five fold increase in throughput in the last 10 years. Group 3 ports have a threefold increase in average throughput from 330,000 TEU to 910,000 TEU in 2008.

The ports in Group 4 refer those which have grown below the market average in the last decade. Average throughput for ports in this group grew from 550,000 to 730,000 TEU in the decade before 2008.

It should be noted however that the indicators below present a significant level of dispersion, in particular groups 1, 2 and 3 as they have a smaller number of ports in their groups.



FIGURE 5.32: MAXIMUM, MINIMUM AND AVERAGE BERTH PRODUCTIVITY

Source: own composition

FIGURE 5.33: MAXIMUM, MINIMUM AND AVERAGE HANDLING PRODUCTIVITY



Source: own composition





Source: own composition

A subsequent step in the analysis is to compare the grouping with used capacity in the container ports. As for previous results the highest average terminal used capacity is for group 1 followed by groups 3, 4 and 2.

The explanation of this fact is in line with arguments presented previously. Larger ports with higher transhipment shares present higher productivity indicators and more optimised usage of terminal areas. The next most productive ports are those smaller ports who managed to seize the exceptional growth that occurred in this period.

These ports also show a good usage of terminal capacity. Ports in group 4 are older, historic ports which have constraints on development and operate with a capacity cap. In this context, although small and constrained ports have lower productivity indicators their terminal area usage is considerable. Ports in group 2 are young ports that did not operate in 1999 and have a since managed to grow significantly. This growth however presents a significant gap between the port throughput and the available.



FIGURE 5.35: MAXIMUM, MINIMUM AND AVERAGE TERMINAL CAPACITY USAGE

The Mediterranean Sea provides a good example where intermediate hubs have contributed to the repositioning of the region within global trade flows. In the Mediterranean, extensive hub-feeder container systems and short sea shipping networks emerged since the mid-1990s to cope with the increasing volumes and to connect to other European port regions.

Mediterranean container terminals are typically owned, in whole or in part, by carriers which are efficiently using these facilities. Marsaxlok Malta, Gioia Tauro, Cagliari and Taranto in Italy and Algeciras in Spain act as turntables in a growing transhipment business in the region. These sites were selected to serve continents, not regions, for transhipping at the crossing points of trade lanes, and for potential productivity and cost control. They are typically located far away from the immediate hinterland that historically guided port selection.

However, the transhipment business remains competitive. The transhipment hubs in North Africa offer very low deviations from the optimum navigation route, such as Tangier-Med or Port Said.

Additionally, maritime shipping companies can opt for an additional deviation if it implies additional cargo from hinterland transportation that can be added to discretionary transhipment cargo. Thus, transhipment cargo handled at ports such as Valencia and Barcelona has grown in spite of higher deviations. Valencia has even been selected to be MSC's Mediterranean hub.

5.5 SUMMARY

In this chapter a regression analysis and data analysis were undertaken where ports are grouped along different dimensions.

The regression analysis identified that port throughput and the share of transhipment are drivers of container port productivity. This means that port with higher throughput and higher share of transhipment traffic tend to have higher port productivity. On the other hand port centrality - the variable that indicates how much ports are located close to the shortest navigational such as between the entry and exit points in the Mediterranean – does affect port productivity in the Mediterranean container ports.

After the regression analysis a data analysis was undertaken. The data analysis consisted in grouping ports considering three different approaches: throughput-based, centralitybased and transhipment-share based grouping. Each of the approaches: throughput, centrality and transhipment was plotted against each of the three infrastructure productivity indicators defined previously: handling, berth and terminal area productivity.

The results from the data analysis are coherent with the results obtained in the regression especially in terms of berth productivity.

Finally, an historical data analysis was undertaken which allows an historical perspective of container port throughput and its evolution. The historical data analysis aims to explain through the evolution of container port some characteristics that container ports currently have. Historically, four types of container ports can be identified. Large transhipment ports, large legacy ports, small legacy ports and small but fast growing transhipment ports. All of these four groups have a number of different characteristics which make them unique.

6 CONCLUSIONS AND POLICY IMPLICATIONS

The present conclusions and policy implications chapter aims to summarise the key points of the thesis, to put forward the conclusions namely addressing the research questions, discuss potential policy implications of the research that was undertaken and identify topics for future research.

The justification for this thesis arises from the fact that traditional port productivity measurement techniques have not been considered to be satisfactory for widespread use amongst the different stakeholders of the container port industry. This fact happens for two major reasons: firstly, productivity measurement techniques such as the Data Envelopment Analysis, Price Index Number or Stochastic Frontier Analysis used in academic research, are too time consuming to be used in a straightforward way. Secondly, these techniques do not have a generalised acceptance by the port stakeholders – port operators, shipping lines and others – and therefore lack practical usefulness in terms of pricing, operational efficiency, legal and regulatory framework, among other possible uses.

There are two major questions that were addressed in this thesis. The first one was agreeing on a definition of what container port productivity means and to define a reduced number of key performance indicators. The analysis of the industry best practices and a review of academic literature on port productivity have established that handling, berth and terminal area productivity measured in TEU per crane; TEU per mete Perth and TEU per hectare, are key indicators of physical productivity of container ports.

The second question is to understand whether physical port productivity in the Mediterranean is driven by three different characteristics: port throughput, proximity to the shortest navigation route and by share of transhipment.

The methodological approach consisted on a multiple regression analysis considering fourteen explanatory variables. This empirical analysis is complemented by two other types of analysis, a grouping by key performance indicators and a grouping by time-series. To this end two datasets are used, a time-series dataset for 36 container ports in the Mediterranean range over a thirty-eight-year period, and a cross-sectional dataset for the same 36 container ports in the Mediterranean range.

In the context of the container port industry, the Mediterranean has become a key region as a transhipment node for the world's largest container flows. This PhD thesis considers the Mediterranean as a whole including recent container port developments in North Africa and the Middle East.

The reasons for the focus in the Mediterranean are manifold:

- 1. Firstly, the Mediterranean has a strategic geographical location along the circumequatorial route and along the North-South Atlantic route that makes it one of the most favourable regions for transhipment operations in the world. It is located along one of the major shipping trade routes: from Southeast Asia to Northern Europe and to America's West coast. The opening of the "new" Panama Canal will further improve the profile of the Mediterranean in the container port industry by allowing circum-equatorial routes with all but the largest container ships.
- 2. Secondly, there is a significant increase in local origin and destination traffic as well as significant differentiation of container ports in terms of age, layout, and level of congestion, which allows for a comprehensive research on port productivity.
- 3. Thirdly, the market structure of container ports in the region is changing, similarly to what has happened in other regions of the world. In order to accommodate the increasing volumes and to connect to other ports, an extensive hub-feeder networks and short sea shipping networks emerged the Mediterranean since the mid-1990s. Before the emergence of large hub ports in the Mediterranean, Mediterranean ports were regularly bypassed by vessels operating on liner services between the Far East and Northern Europe.
- 4. In fourth place, although globalization has strengthened the role of the Mediterranean in international maritime transport and a number of new large container ports have been built in recent years, this range of ports is not a common object of study when compared to other container port ranges in the world, namely Asia, America or Northern Europe.

6.1 CONCLUSIONS ON RESEARCH QUESTIONS

This sub-chapter recalls the three research questions of this dissertation and describes the policy implications arising from the answer to those questions.

Firstly, the overall conclusions of this dissertation should be remembered. The conclusions on physical port productivity have three major elements: the first is the identification of the need for a common indicators defining of container port productivity, the second is the answer to the three research questions – the relationship between container port productivity and container port size, transhipment share and distance to the shortest route - and third are the conclusions derived from the time series analysis. All of these three elements have different and wide reaching policy implications.

The following subchapter addresses the research questions that were put forward in chapter 1.

<u>Research question 1</u>: The first research question is whether port throughput is an important driver of productivity, namely the three selected indicators of physical port productivity (throughput per crane, throughput per berth length and throughput per terminal area). It has been established that, in fact, the size of a container port, or port terminal, has a direct and positive correlation with port physical productivity. The conclusions on research question number one are as follows:

- 1. The conclusion that physical port productivity is influenced by throughput in the sense that, bigger ports usually handle larger vessels, which translates into more containers being handled by port call. This is possible due to higher crane performance in larger ports with higher transhipment share as the STS cranes at those ports are generally new and more efficient in order to cater for larger and wider container ships. This also leads to a higher productivity per berth length.
- 2. In this context one of underlying trends would be for container traffic to increasingly concentrate on larger infrastructures. As ships become bigger and make fewer stops at larger hubs, they load/ unload a higher number of containers per stop. This concentration trend is verified through the analysis of the time-based series where the market share and average size of the large Mediterranean hub ports has increased significantly. It should also be remembered that large container

ships do need few but larger container terminals to operate. In order to maintain the competitive advantage offered by these ships in terms of economies of operations, a container port needs to be productive.

3. In light of these conclusions there is not a strong business case in investing in smaller port infrastructures as these would not have the same growth potential as larger transhipment or gateway ports, both for public as well as for private investors. In this context, a phased or incremental development of container ports is no longer desirable as these smaller ports will need a long period of time to reach an acceptable productivity level.

In fact, the few Greenfield container port developments projects in the Mediterranean have already started from their inception with large or very large capacities e.g. Malaga, Port Said, Sines, Tangier Med or Taranto. These greenfield ports have furthermore been managed and financed either by integrated shipping and port operations companies – Maersk Group - like Tangier Med or Port Said, which guarantees very high levels of demand from the start of operations or by international container port management companies – PSA and Hutchinson Ports - as in Sines, Malaga or Taranto who offer privileged conditions to its large portfolio of clients and is also able to quickly build-up demand in its facilities.

<u>Research question 2</u>: Another of the conclusions of the thesis is that centrality i.e. the proximity of the port to the shortest navigational route between both ends of the Mediterranean is not a factor driving productivity.

- This means that ports located farther away from the Mediterranean centreline such as Constate Barcelona or Ambarli are as productive (according to the physical productivity indicators selected) as those who are located closer such as Algiers, Damietta, Marsaxxlok or Gioia Tauro.
- 2. In short, the conclusion above shows that the geographic location of a port is not linked to physical port productivity. The fact that Greenfield container ports in the Mediterranean are located close to the centreline probably more linked to operational reasons that to productivity ones.
<u>Research question 3</u>: Yet another important conclusion of the thesis is that container port productivity is driven by the share of transhipment. Together with the conclusion that size also drives productivity, this could mean in practice that new port developments would need to have three major characteristics to become successfu

- 1. Dependent with very large capacities. In fact one of the key conclusions of this thesis is larger volumes, in particular transhipment, allow for increased physical productivity i.e. productivity increases with higher throughput regardless of the size of the port. This is likely an indication that transhipment ports are prone to be more productive than others. Transhipment ports handle a larger number of larger vessels and this could explain their higher productivity. Transhipment ports use their berths and cranes more intensely than other ports, which leads to higher productivity.
- 2. Description of the transhipment as it has been demonstrated that larger ports concentrate most of the transhipment traffic in the Mediterranean. From the point of view of vessel operators only the travel time of a vessel is economically productive and therefore any scale should be as short as possible. The efficiency of cargo transhipment enabled by performing STS-cranes and containerization reduces the handling times of vessels in ports from days or even weeks down to hours thus increasing productivity. Reductions in vessel handling times increase the proportion of travel time allowing for more trips per year and the generation of revenue for shippers and indirectly for higher port productivity for port operators.
- 3. able to grow very quickly in order to be able to become economically efficient. As mentioned above these are the characteristics of recent Greenfield container ports in the Mediterranean such as Malaga, Port Said, Sines, Tangier Med or Taranto.

6.2 CONCLUSIONS ON PORT PRODUCTIVITY

The outcome of this dissertation - derived from the review of academic literature and review of industry literature and publications - is that currently there are no agreed container port productivity indicators that are commonly benchmarked across the industry and that are openly published by ports or port authorities nor compiled and benchmarked by institutions related to the maritime industry at worldwide level.

The concept of productivity in container ports may be considered as a key operational, economic and financial indicator and is often used as an argument to justify investments, promote the port and attract customers. However, the concept is not a straightforward one. Port productivity means different things for different people.

The outcome of measuring productivity has the ability to affect the interests of all the ports' stakeholders: stevedores, shipping lines, port authorities, shippers and governments. As the interests of all the stakeholders are not always aligned, there is often reason for some of the stakeholders to take advantage of the difficulties to measure productivity to put forward their own individual interests or agendas.

In fact, it is generally acknowledged among economists that productivity is very difficult to measure given that quantifying an intangible quality is not a straightforward task. This seems to be particularly true in the case of the shipping container industry. The data are hard to collect; productivity measurements in circulation are not standardized and there are so many variables, even within a single terminal, that often similar productivity studies may produce differing conclusions.

It is widely recognised that having access to commonly accepted productivity indicators that can be benchmarked across different transport infrastructure allows users to make more informed decisions. "By improving transparency in port performance, port operators and users can make more informed decisions on port investment or port choice thereby leading to lower transport costs and greater trade efficiency" (UNCTAD, 2012a).

Implicitly, improving transparency in port performance should considerably reduce the asymmetry of information between port operators and port users.

Possible policy implications derived from the implementation of a set of port productivity indicators by the container port industry across the different stakeholders are analysed below.

It is to be expected that, similarly to other industries, the existence of commonly accepted productivity indicators will have a considerable impact on a number of the industry stakeholders: industry regulators, infrastructure operators, infrastructure owners, infrastructure users, labour, and investors, among others. There are examples of complex transport infrastructure industries where sets of productivity indicators are implemented worldwide and accepted by all major operators and stakeholders; in the road infrastructure, railroad infrastructure and airport industries ther we but universal key performance indicators in the industry that are accepted by all operators, be it public or private and by the infrastructure's major customers, railway operators, logistics integrators, airlines, among others.

For the time being there is no such set of indicators against which the difference port container terminal operators can assess their performance against. In particular there are no common methodologies for collecting or reporting data, which makes inter port, or operator comparisons very difficult.

The policy implication of the widespread implementation of key performance indicators are as follows:

- 1. For <u>regulators</u>, container ports contain elements of both natural monopolies and dominant position and therefore regulation is of fundamental importance. The uncertainty regarding productivity indicators and unit costs prevents the setting of modern regulations such as the "Consumer Price Index X" price cap concept that is intended to create appropriate incentives for productive efficiency and pass on part of those incentives to the final client i.e. the user of services through lower fees. The introduction of such type of regulation only becomes possible when key productivity indicators and operational unit costs become known.
- 2. For <u>infrastructure owners</u>, understood here as port authorities exploring their container terminal under a landlord regime i.e. through concessions, ensuring and enforcing high levels of productivity of their tenants is key to maintaining the overall competitiveness of the infrastructure they own.

A detailed and up to date knowledge of port performance is particularly important for two main reasons. Firstly, during the concession period in order to maintain high level of competitiveness during regular operations and secondly, during the tendering processes, in order to able to determine and demand high levels of service for new concessions, or renewal of concessions.

As many container ports operate under a landlord model where terminal infrastructure and operations are concessioned to specialised container port companies, having up to date information on the productivity of their concessionaires/ tenants is critical. It allows the port owners not only to react faster and more efficiently to any variation in the, often perceived, competitiveness of the port as well as impose penalties or fines in case previously agreed competitiveness levels and/or levels of service are not met by the concessionaires. In short, for port owners, productivity indicators can be a tool to monitor, incentivise and punish concessionaires.

During the tendering process for the award of terminal operations having a defined set of productivity indicators becomes very relevant to define the level of service to be offered by prospective concessionaires. In this context, having a target level of productivity can become a critical factor in the award of the concession together with other more conventional factors such as price or port fees, among others.

For <u>port infrastructure users</u> – the most important of them being the shipping lines

 understanding the productivity levels offered by each container port is key to
 making an informed decision on port choice. The decision-making process shipping
 lines on port choice is a complex one and depends on several variables of which
 productivity could be one of them (Grosso & Monteiro, 2011).

The knowledge and comparability of indicators is a critical factor to be considered. For infrastructure users the existence of productivity indicators that can be benchmarked across different infrastructure i.e. container port terminals, decreases the risk of having to make decisions based on asymmetric or incomplete information.

Asymmetric information can be defined as the poor availability of good quality information about the characteristics of a particular good or service (e.g. quality, benefits, costs and risks) that prevents firms and individuals from making fully

informed business decisions and can lead to significant research, intermediation and risk assumption costs. For example, banks may be reluctant to offer loans to a container port operator because of significant uncertainties about the likely success of their new investment and may in some cases, require further information about its commercial viability to help inform their decision. In the end a loan can be made available, but with more difficult conditions e.g. lower value, higher interest rate, shorter payment period, need for collateral, in order to reflect the perceived risk of the industrial operation.

The underlying risks associated with the lack of information means that the biggest clients of container port i.e. the largest shipping lines – Maersk, MSC, CMA-CGM - have vertically integrated the port operations into their business either through separated business units such as APM Terminals, through minority shareholding such as CMA-CGM at Marsaxlokk or through preferential service contracts as MSC in Valencia.

This operational risk is eliminated in case of a vertical integration of the container port operation and the shipping operation. Vertical integration occurs when a firm merges or takes over another firm above or below its own industry category. This has occurred in the container port industry with APM Terminals, which is part of the holding that also manages Maersk the largest shipping line in the world. By owning the 'operating company' i.e. the shipping line and the 'infrastructure operator' i.e. the container port operator APM/ Maersk is able to obtain container traffic at lower costs and guarantee its own stable supply of container traffic without having to worry about fluctuations in container freight rates and of lowering demand.

The vertical integration of container ports and shipping companies has resulted in a profound change in market structure due to the dominance of one shipping line at a specific transhipment port, like Maersk at Algeciras and Port Said, CMA at Fos and Marsaxlokk or MSC at Valencia and Sines. The appearance of large container ships has reduced the number of possible ports of call and the concentration of large vessels in a reduced number of large ports has further reinforced this trend.

Companies with worldwide presence also bring uniform management and operational methodologies and operating efficiencies are expected to be benchmarked and converging towards similar key performance indicators. Med ports and terminals managed by these companies have focused on attracting transhipment traffic with no or minor hinterland connectivity and correspondingly little local origin/ destination traffic. For the time being this small number of ports has managed to attract a significant share of container growth in the Med.

A strategic analysis of the industry in the Mediterranean over the last two decades has shown that ports have lost market power and do not have de facto control over shippers' decisions. Port services are fairly similar and switching costs are low between a relatively large number of Mediterranean (hub) ports.

Despite this loss of market power by port operators a number of shippers have decided to have preferred and/or dedicated relationships with one terminal operator, who generally has a long-term contract for a container terminal. This concept reduces risks, both for shipper and operator.

On the other hand the integrated companies would be able to sell a larger number of services within the group and eliminating some intermediaries, thus earning a higher profit for themselves and potentially being able to pass on some of the profits to their clients by lowering container charges and or port fees.

More transparent and disseminated information also helps to reduce the market power that container port operators hitherto have. With significant market power firms have the ability to raise the price (or reduce the quality) of a good or service without losing its customer base because of a lack of actual or potential competition. For example, the presence of significant economies of scale may act as barriers to entry for new firms in capital intensive and labour intensive sectors as is the container port industry.

4. <u>Labour</u>. In theory, increasing levels of infrastructure asset productivity, such as berth and terminal area productivity do not have a direct relationship with labour costs as these costs are considered to be a fixed cost component and usually are not related to the overall performance of the infrastructure.

The increasing containerisation levels and the increased use of more performing container handling equipment and IT applications have turned port operations into a more capital intensive industry and have reduced the intensity of the labour component. However, crane or handling productivity is related to some extent to labour productivity as STS cranes and other port equipment are still labour intensive activities. Moreover, recent initiatives to liberalise port-related work through the socalled "port reform packages" in the European Union have put in question the rigidity of labour regulations and bylaws in the port sector. In this context, there is increased scope for relating port performance with labour performance and indirectly with labour costs.

In the medium to long term indexing port productivity to labour productivity and ultimately labour income i.e. salary and benefits in a liberalised market could become an aspiration of port operators. Moreover, the setting of the level of productivity in port operations could become important in terms of defining workforce levels i.e. the definition of a minimum number of works of and the respective labour costs.

On the other hand, the workforce of container ports has increasingly become more differentiated due to its specialisation in operating complex handling equipment. The aspiration to share the benefits of increased port productivity could be materialised in case transparent port productivity indicators become standard.

5. For <u>investors</u> the assessment of asset productivity is a key factor for the valuation of the asset. For other utilities and transport infrastructures the measurement of its productivity, when compared with its competitors and identifying the improvement potential is fundamental to understand the underlying value and quality of the asset.

Higher asset productivity has a positive impact on reducing the unit costs, meaning that more productive ports have potential for a lower cost base.

Higher port productivity has a direct correlation with maximised revenue levels and minimised operational expenditures. From an investor perspective the ports that are able to offer higher productivity to clients will consequently be in a position to charge more for an efficient service. Moreover, these ports will have and increased "lock in" power to retain clients who will be reluctant to change their operations to less productive infrastructures.

Moreover, ports that are able to achieve higher productivities are also able to reduce their capital investments as expansion capex can be delayed because of higher port productivity. Additionally, infrastructure expansion and investment cycles can be minimised as the additional throughput achieved by the expansion of a highly productive port will be higher than an equivalent expansion at a less productive port.

One of the biggest concerns of investors in port infrastructure is paying the price premiums experienced in some of the latest sales of port businesses and the need to recover these investments. Addressing this issue requires a very careful due diligence phase identifying and quantifying all the possible upsides and risks associated with the asset. Investors in port infrastructure generally concerned with the following issues:

- need to address the port congestion problem;
- need to increase port productivity and maximize the use of port infrastructure;
- new forms of ownership and financing port investment necessitating reliable port asset valuation;
- need for more effective port infrastructure, superstructure and equipment condition monitoring and maintenance.

In this context, productivity-related issues are expected to become an even more important factor in the decision making process of investors. For investors the situation described above will have profound implications on their investment policies as investors will prefer investing in larger more productive ports rather than in smaller infrastructures.

For investors in infrastructure assets the underlying fundamental is that Med ports can be developed to become similar in terms of operational efficiency to other major ports. The largest and most productive facilities are now managed by companies with worldwide presence such as APM ports, PSA or DP World.

There are nevertheless a few cases of recent greenfield container terminals in the Mediterranean who have managed to rapidly achieve a very significant throughput apparently contradicting the trend described above, as Port Said or Tangiers. These greenfield ports are however owned or managed by large shipping companies who on one hand can guarantee a significant throughput from the first years and on the other hand these ports also serve as reliever ports of other congested ports situated nearby.

For public and private investors there would not be much sense in investing in smaller port infrastructures as these would not have the same growth potential as larger transhipment or gateway ports.

Despite the current uncertainty on key productivity indicators Mediterranean container ports and terminals are nowadays interesting enough to attract investment from major port operators. At a strategic level Med ports have attractive characteristics such as strong traffic, low demand risk, assets with long life, stable legal and regulatory framework (at European Union level at least), etc. Operationally, there is enough critical mass, in terms of throughput and financial return and profitability for such investments;

In short, productivity could be an important factor on the choice of a container port for shippers if it would be linked to lower service and/ or unit prices, for example. Increased operational productivity does generally lead to reduced unit costs and reduced unit times of operation.

Productivity might have a strong influence on the value of the port as a transport infrastructure asset due to several factors: potential for increased unit revenue, reduced unit operating cost and reduced need for capital expenditure either by delaying it or even eliminating the need for further expenditure. This second reason is closely linked to the value of the container port as an infrastructure asset and this has implication across all the stakeholders.

One of the conclusions of this dissertation is that port size influences productivity; consequently one of the industry trends would be for traffic to concentrate on larger infrastructures. As traffic concentrates in larger infrastructures it becomes much harder for new container ports and new hubs to break successfully into the market. In fact, with the more productive terminals being the larger ones and where the larger ships tend to operate this means that in order to invest in a port then small or medium-sized ports would be less economically viable than larger ports.

6.3 SUGGESTIONS FOR FUTURE RESEARCH

This latest sub-chapter puts forward suggestions for future research and identifies questions that could not be addressed in this thesis.

One issue that could not be addressed because of the lack of access to financial data from container port companies is the relationship between operational efficiency and economic and financial efficiency. This relationship would be of great interest to analyse. However this step is difficult to make as both port operators and concessionaires do not disclose their accounts. Even port management companies, where it would be expected to find more useful and accurate date, do not present a breakdown per port nor geographic area.

The focus of the research applied to the context of this thesis would be to understand if the economies of scale, which are valid and responsible for an increase in average ship size, are also valid for larger ports and/ or if there are increasing or decreasing returns to scale. Optimally it would be possible able to calculate the optimum size of port terminal.

Another interesting research topic would be to understand the effect of the increase in available capacity of large transhipment ports in the Mediterranean and the respective impact on port fees.

On a theoretical basis the massive increase in port capacity, which is by and large decoupled, for short and medium-term, from the increase in demand (container traffic) would imply a decrease in port fees to attract more traffic. It has been proven that transhipment ports compete for container traffic almost exclusively on two factors: geographic location and price. In the Mediterranean region price is therefore the only differentiator. In case of overcapacity, and in order to maintain its traffic and gain market share from competing ports, it would be expect that ports would constantly lower their fees. Not doing so would imply that in the longer term their traffic would be lost to other ports.

Based on the above, shipping companies would then be moving freely between those container terminals and ports who would offer them the lowest fee. This strategy is partly used by MSC who has dispersed operations across a large number of ports in the Med.

There are of course imperfections to this theory: terminals owned by shipping companies have a captive market such as the APM ports of Algeciras and Gioia Tauro and other ports operators have long-term agreements with their main based shipping company, such as Fos (Marseille) and CMA-CGM.

Operationally, the transhipment concept does not allow for a quick change in ports as a significant amount of traffic must be moved from one port to another.

The approach taken in this dissertation is sufficiently general to be used as a framework for further research, possibly on a different set of ports. The results of this thesis are of high relevance to the port authorities and container terminal operators that are constantly dealing with how to tackle their port's productivity issues.

Lastly, it should be acknowledged this is a limited study of port productivity. However, it can be stated that looking at these three physical productivity measures gives a good initial overview of container productivity in the Mediterranean ports. Furthermore, this methodology can be utilised in other ports.

ENGLISH SUMMARY

This thesis 'Productivity in the Container Port Business – Case Study of the Mediterranean Range' addresses the issue of container port productivity in the Mediterranean. The Mediterranean has become a key region as a transhipment node for the world's largest container flows. This PhD thesis considers the Mediterranean as a whole including recent container port developments in North Africa and the Middle East. The Mediterranean Sea has historically and geographically grouped together countries and respective ports around its shores. The Mediterranean basin is the area around the Mediterranean Sea, and reaches three continents: Europe (south), Asia (near east) and Africa (north).

The reasons for the focus in the Mediterranean are manifold. Firstly, the Mediterranean has a strategic geographical location that makes it one of the most favourable areas for transhipment operations in the world. It is located along one of the major shipping trade routes: from Southeast Asia to Northern Europe and to America's West coast. The opening of the "new" Panama Canal will further improve the Mediterranean profile in the container port industry.

Secondly, there is a significant increase in local origin and destination traffic. Currently, around the Mediterranean there are significant and growing origin and destination markets in Southern Europe, North Africa and Middle East.

Thirdly, the market structure in the region is changing. In order to cope with the increasing volumes and to connect to other European ports, an extensive hub-feeder container systems and short sea shipping networks emerged the Mediterranean since the mid-1990s. Earlier, Mediterranean ports were typically bypassed by vessels operating on liner services between the Far East and Europe.

In fourth place, although globalization has strengthened the role of the Mediterranean in international maritime transport of goods, this range of ports is still less studied than other ranges.

The rationale for this thesis arises from the fact that traditional port productivity measurement techniques are not considered to be satisfactory to the container port industry for two major reasons. Firstly, they are either too time consuming and complex

to be used in a straightforward way such as the Data Envelopment Analysis, Price Index Number or Stochastic Frontier Analysis and secondly these techniques do not have a generalised acceptance by the port stakeholders – port operators, shipping lines and others – and therefore lack practical usefulness in terms of pricing, operational efficiency, legal and regulatory framework, among other possible uses.

The container shipping industry could lay claim to being the world's first truly global industry. Likewise it could claim to be the industry which, more than any other, makes it possible for a truly global economy to work. It connects countries, markets, businesses and people, allowing them to buy and sell goods on a scale not previously thought possible.

The goal of this dissertation is threefold:

- to identify the drivers of productivity in the container port industry;
- to understand what are the different concepts in measuring container port productivity in academic literature and industry expertise;
- to identify the main variables influencing port productivity in the Mediterranean specifically what influences container port productivity.

The research questions that arise from the goal definition above are:

- 1. What is container port productivity and how is it measured?
- 2. What are the variables influencing container port productivity?
- 3. This leads to three questions that are going to be verified in the modelling and empirical work of the thesis, namely:
 - **Research question 1:** Is container port size correlated with container port productivity? Are bigger container ports more productive than smaller ones?
 - **Research question 2:** Is geographical centrality i.e. the proximity to the Mediterranean navigational centreline correlated to container port productivity?
 - **Research question 3:** Are ports with high transhipment shares more productive than non-transhipment ports?

The methodological approach consisted on a multiple regression analysis considering fourteen explanatory variables. This empirical analysis is complemented by two other types of analysis, a grouping by key performance indicators and a grouping by timeseries. To this end two datasets are used, a time-series dataset for 36 container ports in the Mediterranean range over a thirty-eight-year period, and a cross-sectional dataset for the same 36 container ports in the Mediterranean range.

Different yet complementary data analysis techniques are used in order to better understand the topic of container port productivity. Multiple regression analysis is done using a cross-section database with a sample of 36 Mediterranean container ports and 14 variables for the year 2008. This analysis is complemented by a grouping analysis where ports are grouped along different dimensions, using both the abovementioned crosssection database and a time-series database for container throughput for the same sample of ports.

Regression analysis is one of the most frequently used tools in research. In its simplest form, regression analysis allows researchers to analyse relationships between one independent and one dependent variable. The dependent variable represents usually the intended outcome (e.g., productivity), while the independent variables are the instruments available in order to achieve those outcomes with (e.g., cranes).

Regression analysis can provide insights that few other data analysis techniques can. The key benefits of using regression analysis are:

- Indicate if independent variables has a significant relationship with a dependent variable;
- Indicate the relative strength of different independent variables' effects on a dependent variable;
- Make predictions.

In this sub-chapter container port productivity is analysed taking into consideration, as mentioned previously, three different variables:

- Handling Productivity measured as TEU per ship-to-shore quay crane i.e. throughput per number of STS quay cranes (TEU/#);
- *Berth Productivity* measured as TEU per meter of container berth i.e. throughput per berth length (TEU/m);
- *Terminal Area Productivity* measured as TEU per hectare of terminal i.e. throughput per terminal area (TEU/ha).

This thesis has proven that the research questions can be answered and that size and the share of transhipment are drivers of productivity, whereas the proximity of shortest shipping route in the Mediterranean (centrality) does not drive productivity. The two types of analysis were coherent on the robustness of the outcome.

One of the other results of the thesis is that the existence of a common definition for container port productivity and the identification of a common set indicators for container port productivity will lead to the possibility of more robust comparison amongst ports and to more informed decision from the different clients, service providers, terminal operators, infrastructure owners, regulators and policy makers.

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REFERENCES

- Abrahamsson, B.J. & Vardi, M. (1973) *Economic considerations with regard to port congestion surcharges*. Haifa, Israel Shipping Research Institute.
- Abulafia, D. (2011) *The Great Sea: A Human History of the Mediterranean*. New York, Oxford University Press, USA.
- Aigner, D., Lovell, C.A.K. & Schmidt, P. (1977) Formulation and estimation of stochastc frontier production function models. *Journal of Econometrics*. 6:21–37.
- Al-Eraqi, A., Mustafa, A., Khader, A. & Barros, C.P. (2008) Efficiency Of Middle Eastern And East African Seaports: Application Of DEA Using Window Analysis. *European Journal of Scientific Research*. 23 (4), 597–612.
- Ashar, A. (1997) Port Productivity Revisited. *Port Development International*. (November), 1–3.
- Ashar, A. (1985) Producticity And Capacity Of Container Terminals. *WWS World Wide Shipping*. (November).
- Baird, A.J. (2002) Privatisation Trends At The World's Top-100 Container Ports. *Journal of Maritime Policy & Management*. 29 (3), 271–284.
- Banker, R.D., Charnes, A. & Cooper, W.W. (1984) Some models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*. 30:1078–1092.
- Barros, C. & Managi, S. (2008) *Productivity Drivers In Japanese Seaports*. Lisbon, WP 15/2008, School of Economics and Management, Technical University of Lisbon.
- Barros, C.P. (2006) A Benchmark Analysis Of Italian Seaports Using Data Envelopment Analysis. *Maritime Economics & Logistics*. 8 (4), 347–365.
- Barros, C.P. (2005) Decomposing Growth In Portuguese Seaports: A Frontier Cost Approach. *Maritime Economics & Logistics*. 7 (4), 297–315.

- Barros, C.P. (2003) Incentive Regulation And Efficiency of Portuguese Port Authorities. *Maritime Economics & Logistics*. 5 (1), 55–69.
- Barros, C.P. & Athanassiou, M. (2004) Efficiency In European Seaports With DEA: Evidence From Greece And Portugal. *Maritime Economics & Logistics*. 6 (2), 122– 140.
- Baños-Pino, J., Coto-Millan, P. & Rodriguez, A. (1999) Allocative efficiency and overcapitalization: an application. *International Journal of Transport Economics*. 26:181– 199.
- Bendall, H. & Stent, A. (1987) On measuring cargo handling productivity. *Maritime Policy* and Management. 14:337–343.
- Bennathan, E. & Walters, A.A. (1979) *Port pricing and investment policy for developing countries*. New York, Oxford University Press, USA.
- Beškovnik, B. (2008) Measuring And Increasing The Productivity Model On Maritime Container Terminals. *Pomorstvo–Journal of Maritime Studies*. 2:171–183.
- Bichou, K. & Gray, R. (2004) A Logistics And Supply Chain Management Approach To Port Performance Measurement. *Maritime Policy & Management*. 31 (1), 47–67.
- Bird, J. & Bland, G. (1988) Freight forwarders speak: the Perception of Route Competition via Seaports in the European Communities Research Project. Part 1. *Maritime Policy & Management*. 15 (1), 35–55.
- Blonigen, B. & Wilson, W. (2006) New Measures Of Port Efficiency Using International Trade Data. Cambridge, MA, No. 12052, NBER Working Paper, National Bureau of Economic Research.
- Bobrovitch, D. (1982) Decentralised Planning and Competition in a National Multi-Port System. *Journal of Transport Economics and Policy*. 16 (1), 31–42.
- Bonilla, M., Medal, A., Casasús, T. & Sala, R. (2002) The Traffic in Spanish Ports: an Efficiency Analysis. *International Journal of Economics Transport*. 29 (2), 215–230.

Bown, A.H.J. (1953) Port economics. London, Dock and Harbour Authority.

Bown, A.H.J. (1967) Port Economics. 2nd edition. W.A. Flere (ed.). London, Foxlow.

BRS (2012) Cellular Fleet at 1st July 2012. July. AXMarine Corporate.

- BTE (1984) Container Terminal Productivity In Port Jackson From 1977 To 1981. Bureau of Transport Economics, Australian Government.
- Bureau of Industry Economics (1993) International Performance Indicators: Waterfront. BIE Research Report. 47.
- Bureau of Industry Economics (1995) Waterfront 1995: International Benchmarking. *BIE Report*. 95 (16).
- Casaca, A.C.P. (2005) Simulation And The Lean Port Environment. *Maritime Economics* & *Logistics*. 7 (3), 262–280.
- Charnes, A., Cooper, W.W. & Rhodes, E. (1978) Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research*. 2 (6), 429–444.
- Chen, C., Hsu, W. & Huang, S. (2003) Simulation And Optimization Of Container Yard Operations: A Survey. In: *Proceedings of International Conference on Port and Maritime R and D and Technology*. 2003 pp. 23–29.
- Chen, T. (1999) Yard Operations In The Container Terminal A Study In The "Unproductive Moves". *Maritime Policy & Management*. 26 (1), 27–28.
- Choi, Y. (2005) Analysis Of Combined Productivity Of Equipments In Container Terminal.
- Chung, K.C. (1993) Port Performance Indicators. *Infrastructure Notes, Transportation, Water and Urban Development Department, The World Bank*. No 6 (December 1993), 1–5.
- Clark, X., Dollar, D. & Micco, A. (2002) Maritime Transport Costs And Port Efficiency. *Policy Research Working Paper, The World Bank*. 2781 (February).
- Clark, X., Dollar, D. & Micco, A. (2004) Port Efficiency, Maritime Transport Costs And Bilateral Trade. *Working Paper 10353, National Bureau of Economic Research* (*NBER*). (March), 1–48.
- Coelli, T., Estache, A., Perelman, S. & Trujillo, L. (2003) *A Primer On Efficiency Measurement For Utilities And Transport Regulators*. Washington, D.C., The World Bank.

- Committee on Productivity of Marine Terminals (1986) *Improving Productivity In US Marine Container Terminals*. U.S. Maritime Administration.
- Connor, J.T. & Boyd, A. (1966) *The economic impact of United States ocean port*. Washington, D.C., USGPO - United States Government Printing Office.
- Coto-Millan, P., Baños-Pino, J. & Rodríguez-Álvarez, A. (2000) Economic Efficiency In Spanish Ports: Some Empirical Evidence. *Maritime Policy & Management*. 27 (2), 169–174.
- Coulter, D.Y. (2002) Globalization of Maritime Commerce: The Rise of Hub Ports. In: Sam J. Tangredi (ed.). *Globalization and Maritime Power*. Washington, D.C., Institute for National Studies, National Defense University. pp. 133–142.
- Cullinane, K. & Song, D. (2003) A Stochastic Frontier Model Of The Productive Efficiency Of Korean Container Terminals. *Applied Economics*. 35:251–267.
- Cullinane, K., Song, D.-W. & Gray, R. (2002) A Stochastic Frontier Model Of The Efficiency Of Major Container Terminals In Asia: Assessing The Influence Of Administrative And Ownership Structures. *Transportation Research Part A: Policy and Practice*. 36 (8), 743–762.
- Cullinane, K., Song, D.-W., Ji, P. & Wang, T.-F. (2004) An Application Of DEA Windows Analysis To Container Port Production Efficiency. *Review of Network Economics*. 3 (2), 102–124.
- Cullinane, K., Song, D.-W. & Wang, T.-F. (2005) The Application of Mathematical Programming Approaches To Estimating Container Port. *Journal of Productivity Analysis*. (24), 73–92.
- Cullinane, K. & Wang, T.-F. (2006) The Efficiency Of European Container Ports: A Cross-Sectional Data Envelopment Analysis. *International Journal of Logistics*. 9 (1), 19– 31.
- Cunningham, B. (1926) *Port economics: an elementary study of port affairs*. London, Pitman.
- Dalenberg, D., Daley, J. & Murphy, P. (1992) Port Selection Criteria: An Application of a Transportation Re- search Framework. *The Logistics and Transportation Review*. 28 (3), 237–255.

- Daley, J. & Murphy, P. (1994) A Comparative Analysis of Port Selection Factors. *Transportation Journal*. 34:15–21.
- Davidson, N. (2010) Global Overview Of The Container Port And Terminal Sector: What Is The "New Normal"? In: *Presentation at TOC Europe 2010*. 2010 Valencia.
- De, P. (2006) Total Factor Productivity Growth: Indian Ports In The Era Of Globalisation. *Maritime Economics & Logistics*. 8 (4), 366–386.
- De, P. & Ghosh, B. (2002) Productivity, Efficiency And Technological Change In Indian Ports. *International Journal of Maritime Economics*. 4 (4), 348–368.
- Deutsche Bank Research (2011) Container shipping: Successful turnaround. International Topics - Current Issues. (March), 1–8.
- Dewulf, B., Van de Voorde, E. & Yzewyn, D. (1992) *Investment requirements in port infrastructures in the Community's lagging regions between 1994 and 2000.*
- Dowd, T. & Leschine, T. (1990) Container Terminal Productivity: A Perspective. *Maritime Policy and Management*. 17 (2), 107–112.
- Dragovic, B., Park, N. & Radmilovic, Z. (2006) Ship-Berth Link Performance Evaluation: Simulation And Analytical Approaches. *Maritime Policy & Management*. 33 (3), 281–299.
- Ducruet, C., Lee, S. & Song, J. (2011) Network Position And Throughput Performance of Seaports. In: Theo Notteboom (ed.). *Current Issues in Shipping, Ports and Logistics*.
 Brussels, Academic & Scientific Publishers (ASP). pp. 189–201.
- Dynamar B.V. (2007) *Transhipment & Feedering Trades , Operators , Ships*. Dirk Visser (ed.). Alkmaar, The Netherlands, September, Dynamar B.V.
- D'Este, G. & Meyrick, S. (1992) Carrier Selection in ro/ro Ferry Trade: Part 1; Decision Factors and Attitudes. *Maritime Policy and Management*. 19 (2), 115–126.
- Estache, A., Gonzalez, M. & Trujillo, L. (2001) Technical efficiency gains from port reform: The potential for yardstick competition in Mexico. In: *Policy Research Working Paper 2637*. 2001 Washington, D.C., The World Bank.

- Estache, A., Perelman, S. & Trujillo, L. (2005) Infrastructure Performance And Reform In Developing And Transition Economies: Evidence From A Survey Of Productivity Measures. World Bank Policy Research Working Paper 3514. (February).
- Ethridge, D. (2004) *Research Methodology in Applied Economics: organizing, planning and conducting economic research*. 2nd edition. Oxford, UK, Blackwell Publishing.
- European Commission (2011) *EU transport in figures Statistical Pocketbook 2011*. Luxembourg, European Union.
- Farrell, M.J. (1957) The measurement of production efficiency. *Journal of the Royal Statistical Society A*. 120:253–281.
- Fernández, J.E., De Cea, J. & Fernández, J.M. (1999) Port Privatization in Developing Countries: the Case of Container Terminals. *International Journal of Transport Economic.* XXVI (2), 293–314.
- FHWA (2004) *Freight Transportation Improvements And The Economy*. Washington, DC, U.S. Department of Transportation, Federal Highway Administration.
- Fourgeaud, P. (2000) Measuring port performance. The World Bank.
- Frankel, E.G. (1991) Port performance and productivity measurement. *Ports and Harbours*. pp.11–13.
- Freemont, A. (2007) Global maritime networks: The case of Maersk. *Journal of Transport Geography*. 15 (6), 431–442.
- Frost, J. (2008) Study on Potential Hub-and-Spoke Container Transhipment Operations in Eastern Canada for Marine Movements of Freight (Short Sea Shipping): Final Discussion Report. Transportation Development Centre.
- Fulginiti, L.E. & Perrin, R.K. (2005) Productivity And Welfare. *Journal of Productivity Analysis*. 24 (2), 133–155.
- Gan, G., Ma, C. & Wu, J. (2007) *Data Clustering: Theory, Algorithms, and Applications*. SIAM, Society for Industrial and Applied Mathematics.

- González, M. & Trujillo, L. (2008a) Efficiency Measurement In The Port Industry: A Survey Of The Empirical Evidence. London, Discussion Paper Series, Department of Economics No 07/08, School of Social Sciences, City University.
- González, M.M. & Trujillo, L. (2008b) Reforms And Infrastructure Efficiency In Spain's Container Ports. *Transportation Research Part A: Policy and Practice*. 42 (1), 243–257.
- Goodchild, a. V. & Daganzo, C.F. (2007) Crane Double Cycling In Container Ports: Planning Methods And Evaluation. *Transportation Research Part B: Methodological*. 41 (8), 875–891.
- Goodchild, A. & Daganzo, C. (2005) *Crane double cycling in container ports: affect on ship dwell time*.
- Goodman, A.C. (1984) Port Planning and Financing for Bulk Cargo Ships. Theory and a North American Example. *Journal of Transport Economics and Policy*. 18 (3), 237–252.
- Goss, R. (1993) The consumers' view of port efficiency. In: G. Blauwens, G. De Brabander, & Eddy Van de Voorde (eds.). *De dynamiek van een haven*. De Nederlandsche Boekhandel. pp. 197–209.
- Goss, R. (1967) Towards an Economic Appraisal of Port Investment. *Journal of Transport Economics and Policy*. 1 (3), 249–272.
- Goss, R.O. (1990) Economic policies and seaports: The diversity of port policies. *Maritime Policy & Management*. 17 (3), 221–234.
- Goussiatiner, A. (2007) In pursuit of productivity. Container Management. (August).
- Goussiatiner, A. (2009) Making things better. Container Management. (February).
- Grosso, M. & Monteiro, F. (2011) Criteria for Container Port Choice: Focus on the Mediterranean. *International Journal of Euro-Mediterranean Studies*. 4 (I), 139–160.
- Grosso, M. & Monteiro, F. (2008) Relevant strategic criteria when choosing a container port: the case of the port of Genoa. In: *Proceedings of the European Transport Conference 2008*. 2008 Leeuwenhorst, The Netherlands, 06-08/10/2008, ETC 2008.

- Hair, J., Black, W., Babin, B. & Anderson, R. (2010) *Multivariate data analysis. A global perspective*. 7th edition. Upper Saddle River, NJ, Pearson Prentice Hall.
- Hamilton, C. (1999) Measuring Container Port Productivity The Australian Experience. *The Australia Institute*. (17), 1–16.
- Han, C.-H. (2002) An empirical study on the determinants of port performance and efficiency. In: *Proceedings of the Second International Port Forum and Conference for the 20th Anniversary of Korean Association of Shipping Studies*. 2002 Gwangyang, Korean Association of Shipping Studies.
- Hanam Canada Corporation (2007) *Container Capacity Expansion Plans at Pacific Coast Ports*. Victoria, BC, Policy Research Branch, Strategic Policy Directorate, Policy Group, Transport Canada.
- Hanam Canada Corporation (2008) Pacific Coast Container Terminal Competitiveness Study. Victoria, BC, Policy Integration and Research Branch, Strategic Policy Directorate, Policy Group, Transport Canada.
- Haralambides, H.E. (2004) Determinants of price and price stability in liner shipping. In: *Workshop on The Industrial Organization of Shipping and Ports, National University of Singapore*. 2004 Singapore, March 5-6th.
- Heaver, T.D. (1995) The Implications of Increased Competition among Ports for Port Policy and Management. *Maritime Policy and Management*. 22 (2), 125–133.
- Herrera, S. & Pang, G. (2008) Efficiency of infrastructure: the case of container ports. *Revista Economia*. 9 (January-April), 165–194.
- Hill, R.C., Griffiths, W.E. & Lim, G.C. (2011) *Principles of Econometrics*. 4th edition. John Wiley & Sons, Inc.
- Hofseth, K., Heisey, S., Males, R. & Rogers, C. (2006) Development of Commodity-driven Vessel Movements for Economic Analysis of Port Improvements. Alexandria, Virginia, Institute for Water Resources, U.S. Army Corps of Engineers.
- HPH Trust (2012) *Overview of the container port industry*. Singapore, Hutchison Port Holdings Trust.

- Hung, S.-W., Lu, W.-M. & Wang, T.-P. (2010) Benchmarking the operating efficiency of Asia container ports. *European Journal of Operational Research*. 203 (3), 706–713.
- Huybrechts, M., Meersman, H., Van de Voorde, E., Van Hooydonk, E., *et al.* (2002) *Port Competitiveness*. Antwerp, De Boeck, Ltd.
- Imai, A., Nishimura, E., Hattori, M. & Papadimitriou, S. (2007) Berth allocation at indented berths for mega-containerships. *European Journal of Operational Research*. 179 (2), 579–593.
- Isbell, J. (2005) Satisfying the Needs of the Port's Clients. In: *Marine Terminal Management Training Program*. 2005 Long Beach.
- ISL (2012) SSMR May/June 2012. Shipping Statistics and Market Review. 56 (5/6).
- Jara-Díaz, S., Cortés, C.E., Vargas, A.D. & Martínez-Budría, E. (1997) Marginal Costs and Scale Economies in Spanish Ports. In: *25th European Transport Forum, Proceedings Seminar, PTRC, London*. 1997 pp. 137–147.
- Jeon, Y. & Park, Y. (2005) Status and Visions of Automated Container Terminals. In: *Proceedings of The Fifteenth International Offshore and Polar Engineering Conference*. 2005 Seoul, Korea, The International Society of Offshore and Polar Engineers.
- JWD Group (2003) *U.S. Container Terminal Throughput Density*. Houston, Port of Houston Authority (PHA).
- Kim, M. & Sachish, A. (1986) The structure of production, technical change and productivity in a port. *The Journal of Industrial Economics*. 35 (2), 209–223.
- Langen, P. de (2007) Port competition and selection in contestable hinterlands; the case of Austria. *European Journal of Transport and Infrastructure Research*. 7 (1), 1–14.
- De Langen, P.W. (2003) The Performance Of Seaport Clusters: A Framework To Analyze Cluster Performance And An Application To The Seaport Clusters In Durban, Rotterdam And The Lower Mississipi. Erasmus University Rotterdam.
- Lawrence, D. & Richards, A. (2004) Distributing the gains from waterfront productivity improvements. *Economic Record*. 80:43–52.

- Le-Griffin, H. & Murphy, M. (2006) Container terminal productivity: Experiences at the ports of Los Angeles and Long Beach. In: *Presentation at Container Terminal Productivity Conference, February 1st.* 2006 pp. 1–21.
- Lirn, T.C., Thanopoulou, H. a, Beynon, M.J. & Beresford, a K.C. (2004) An Application of AHP on Transhipment Port Selection: A Global Perspective. *Maritime Economics & Logistics*. 6 (1), 70–91.
- Liu, Z. (1995) The comparative performance of public and private enterprises. *Journal of Transport Economics and Policy*. 29 (3), 263–274.
- Lloyd's Marine Intelligence Unit (2008) *Study of Maritime Traffic Flows in the Mediterranean Sea*. Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC).
- Macário, R. & Viegas, J. (2009) Bottlenecks of efficiency and the development of port business. In: Hilde Meersman, Eddy Van de Voorde, & Thierry Vanelslander (eds.).Future challenges for the port and shipping sector. London, Informa Law. p. 174.
- Malchow, B. & Kanafani, A. (2001) A Disaggregate Analysis of Factors Influencing Port Selection. *Maritime Policy andManagement*. 28 (3), 265–277.
- Malchow, B. & Kanafani, A. (2004) A Disaggregate Analysis of Port Selection. *Transportation Research E.* 40 (4), 317–337.
- Malchow, M. (2001) An analysis of port selection. University of California, Berkeley.
- Marconsult (1994) *Major container terminals structure and performances*. Naples, Italy, Marconsult.
- Marlow, P.B. & Paixão Casaca, A.C. (2003) Measuring lean ports performance. *International Journal of Transport Management*. 1 (4), 189–202.
- Martinez-Budría, E., Diaz-Armas, R., Navarro-Ibañez, M. & Ravelo-Mesa, T. (1999) A Study of the Efficiency of Spanish Port Authorities Using Data Envelopment Analysis. *International Journal of Transport Economics*. 26 (2), 237–253.
- Martínez-Budría, E. (1996) Un estudio econométrico de los costes del sistema portuario español. *Revista Asturiana de Economía*. 5:135–149.

- McCarthy, E. (2006) Current and Future Role of Technology in Marine Terminals. *Marine Terminal Management Training Program*.
- Meersman, H., Monteiro, F., Onghena, E., Pauwels, T., et al. (2006) Social marginal cost calculation for ports. In: Grace: Generalisation of Research on Accounts and Cost Estimation. Leeds, University of Leeds. pp. 1–56.
- Meersman, H., Monteiro, F., Pauwels, T., Van de Voorde, E., et al. (2006) Marginal cost case studies for air and water transport. In: Grace: Generalisation of Research on Accounts and Cost Estimation. Leeds, University of Leeds. pp. 1–56.
- Meersman, H., Monteiro, F., Pauwels, T., Van de Voorde, E., *et al.* (2007) Marginal cost pricing in sea ports: how to model and assess differences between ports? In: *Proceedings of the European Transport Conference 2007*. 2007 Leeuwenhorst, The Nederlands, 17-19 October, European Transport Conference 2007. pp. 1–28.
- Meersman, H., Steenssens, C. & Van de Voorde, E. (1997) *Container throughput, port capacity and investment*. Antwerpen, Studiecentrum voor Economisch en Sociaal Onderzoek.
- Meersman, H., Van de Voorde, E. & Vanelslander, T. (2011) Competition concerns in ports and port services. In: *Proceedings of the OECD Round Table on Competition concerns in Ports and Port Services*. 2011 Paris.
- Meersman, H., Van de Voorde, E. & Vanelslander, T. (2008) *Future Challenges for the Port and Shipping Sector*. London, Informa.
- Meersman, H., Van de Voorde, E. & Vanelslander, T. (2010a) It's all about economics! *Maritime Policy and Management*. 37 (3), 175–177.
- Meersman, H., Van de Voorde, E. & Vanelslander, T. (2010b) Port competition revisited. *Review of business and economics*. 55 (2), 210–232.
- Meersman, H., Van de Voorde, E. & Vanelslander, T. (2002) Port Pricing Issues: Considerations on Economic Principles, Competition and Wishful Thinking. In: IMPRINT-EUROPE Implementing Reform in Transport Effective Use of Research on Pricing in Europe A European Commission funded Thematic Network (2001-2004).

- Meeusen, W. & Van den Broeck, J. (1977) Efficiency estimation from Cobb-Douglas production functions with composed error. *International economic review*. 18 (2), 435–444.
- Ministry of Transport (2011) *Container productivity at New Zealand ports*. Ministry of Transport.
- De Monie, G. (1987) *Measuring And Evaluating Port Performance And Productivity*. Geneva, UNCTAD Monographs on Port Management, No 6.
- Monteiro, F. (2010) A Importância dos Portos na Economia. *Revista de Marinha*. pp.26–28.
- Monteiro, F. (2005) *Competition in the Mediterranean Container Market Potential Strategies for Ports, Liner Companies and Other Players*. University of Antwerp.
- Monteiro, F. (2003) *The Concession Process In The Portuguese Port Sector*. Technical University of Lisbon, Technical Superior Institute.
- Monteiro, F. (2007) The importance of measuring port performance in intermodal supply chains. In: *Proceedings of 1st Scientific Conference: Competitiveness and complementarity of transport modes perspectives for the development of intermodal transport*. 2007 Chios, Greece, May 10-12.
- Mooi, E. & Sarstedt, M. (2011) A Concise Guide To Market Research: The Process, Data, And Methods Using IBM SPSS Statistics. Berlin, Springer.
- Musso, A. (1999) The role of mediterranean seaports as main links of the new cargo routes. In: *Seminar: Reinassence de la Méditerranée et les conséquences sur le transports*. Las Salinas, Anfeh, Libano, November.
- Musso, A., Piccioni, C. & Van de Voorde, E. (2012) Improving the competitiveness of Italian ports. In: Christiano Marinacci & et al (eds.). *Porti & navigazione: sostenibilità e sicurezza nel trasporto marittimo*. Roma, Edizioni ingegneria. pp. 241–254.
- Notteboom, T. (2004) Container Shipping And Ports: An Overview. *Review of Network Economics*. 3 (2), 4–24.

- Notteboom, T., Coeck, C. & Van den Broeck, J. (2000) Measuring and explaining the relative efficiency of container terminals by means of bayesian stochastic frontier models. *International Journal of Maritime Economics*. II (2), 83–106.
- Notteboom, T. & Konings, R. (2004) Network dynamics in container transport by barge. *Belgeo*. 5 (4), 461–477.
- Notteboom, T. & Rodrigue, J.-P. (2008) Containerisation, Box Logistics and Global Supply Chains: The Integration of Ports and Liner Shipping Networks. *Maritime Economics and Logistics*. 10 (1), 152–174.
- Ocean Shipping Consultants (2010) *Container Terminal Management a post crisis perspective*. Chertsey, United Kingdom, Ocean Shipping Consultants Ltd.
- Ocean Shipping Consultants (2006) *The European and Mediterranean containerport markets to 2015.* Chertsey, United Kingdom, Ocean Shipping Consultants Ltd.
- Olivier, D. (2009) Developing Utilization Indicators for Canadian Ports. In: 2009 Port Productivity Conference. 2009 Long Beach.
- Oram, R.B. & Baker, C.C.R. (1971) The efficient port. Oxford, UK, Pergamon.
- Paelinck, H. (2010) *Reeds Dictionary of Shipping and Marine Finance (Reeds Directory)*. Reeds.
- Park, R.-K. & De, P. (2004) An Alternative Approach to Efficiency Measurement of Seaports. *Maritime Economics & Logistics*. 6 (1), 53–69.
- Peston, M.H. & Rees, R. (1971) *Port Costs and the Demand for Port Facilities*. London, National Ports Council.
- Poitras, G., Tongzon, J. & Li, H. (1996) *Measuring Port Efficiency: An Application of Data Envelopment Analysis*. Department of Economics and Statistics. National University of Singapore.
- Port Authority of New York and New Jersey (1977) *Planning and Development Department Economic impact of the US merchant marine and shipbuilding industries : an input-output analysis*. Springfield, Va., National Technical Information Service.

- Port Authority of Portland (1971) *Economic impact of the port of Portland*. Oregon, Port Authority of Portland.
- Port Strategy (2011) Port Strategy insight for senior port executives. September, 17th.
- Porter, M.E. (2008) *On Competition, updated and expanded edition*. Boston, Harvard Business School Press.
- Productivity Commission (2003) *International benchmarking of container stevedoring*. Melbourne, Commission Research Paper.
- Productivity Commission (1998) International Benchmarking of the Australian Waterfront. *Research Report, AusInfo, Canberra, April*.
- Ranstrom, J. (2005) Increasing Throughput Using Automation. *Marine Terminal Management Training Program*.
- Reker, R.A., Connell, D. & Ross, D.I. (1990) The Development of a Production Function for a Container Terminal in the Port of Melbourne. In: *Papers of the Australian Transport Research Forum*. pp. 209–218.
- Rios, L.R. & Maçada, A.C.G. (2006) Analysing the Relative Efficiency of Container Terminals of Mercosur using DEA. *Maritime Economics & Logistics*. 8 (4), 331–346.
- Rodrigue, J. & Notteboom, T. (2008) The Geography of Containerization : Half a Century of Revolution , Adaptation and Diffusion. *GeoJournal*. 74:1–5.
- Rodrigue, J.-P. (2012) *The Containerization of Commodities: Integrating Inland Ports with Gateways and Corridors in Western Canada*. Calgary, Alberta, Canada, The Van Horne Institute.
- Rodrigue, J.-P., Comtois, C. & Slack, B. (2009) *The geography of transport systems*. 2nd edition. New York, Routledge.
- Roll, Y. & Hayuth, Y. (1993) Port performance comparison applying data envelopment analysis (DEA). *Maritime Policy & Management*. 153–161.
- RREEF (2009) *Global Ports: Trends And Opportunities*. San Francisco, April, RREEF Research.

- Ryan, R.H. & Adams, C.W. (1973) *Corpus Christi: economic impact of the port Austin*. University of Texas.
- Sachish, A. (1996) Productivity Functions as a Managerial Tool in Israeli Ports. *Maritime Policy and Management*. 23 (4), 341–369.
- Saundry, R. & Turnbull, P. (1999) Contractual (In)Security, Labour Regulation and Competitive Performance in the Port Transport Industry: A Contextualized Comparison of Britain and Spain. *British Journal of Industrial Relations*. 32 (June), 271–294.
- Schmidmeir, G. (2006) Leveraging Technology to Boost Port Productivity. Navis.
- Sharma, M.J. & Yu, S.J. (2009) Performance based stratification and clustering for benchmarking of container terminals. *Expert Systems with Applications*. 36 (3), 5016–5022.
- Shneerson, D. (1981) Investment in Port Systems. A Case of the Nigerian Ports. *Journal* of *Transport Economics and Policy*. XV:201–216.
- Shneerson, D. (1983) Short Term Planning for a Ports System. *Maritime Policy and Management*. 10 (4), 217–250.
- Slack, B. (1985) Containerisation and Inter-Port Competition. *Maritime Policy and Management*. 12 (4), 293–304.
- Smith, D. (2012) Container Port Capacity and Utilization Metrics. In: *Diagnosing the Marine Transportation System, June 27th*. 2012 The Tioha Group, Inc.
- Song, D.-W. & Han, C.-H. (2004) An econometric approach to performance determinants of Asian container terminals. *International Journal of Transport Economics*. 31 (1), 39.
- Song, D.-W. & Yeo, K.-T. (2004) A Competitive Analysis of Chinese Container Ports Using the Analytic Hierarchy Process. *Maritime Economics & Logistics*. 6 (1), 34–52.
- Song, D.W., Cullinane, K. & Roe, M. (2001) *The Productive Efficiency of Container Terminals. An Application to Korea and the UK.* England, Ashgate Publishing Company.

Stopford, M. (2009) Maritime Economics. 3rd edition. London, Routledge.

- Suykens, F. (1983) A few observations on productivity in seaports. *Maritime Policy* & *Management*. 17–40.
- SY & CG LLC. (2001a) Intermodal Productivity and Goods Movement, Phase I Gantry Crane Performance. Port Authority of New York and New Jersey.
- SY & CG LLC. (2001b) Intermodal Productivity and Goods Movement, Phase II Land Access to Port and Terminal Gate Operations. Port Authority of New York and New Jersey.
- SY & CG LLC. (2001c) Intermodal Productivity and Goods Movement, Phase III Logistics Operations of Marine Container Terminal. Port Authority of New York and New Jersey.
- Sánchez, R.J., Hoffmann, J., Micco, A., Pizzolitto, G. V, *et al.* (2003) Port Efficiency and International Trade: Port Efficiency as a Determinant of Maritime Transport Costs. *Maritime Economics & Logistics*. 5 (2), 199–218.
- Tabernacle, J.B. (1995) A study of the changes in performance of quayside container cranes. *Maritime Policy & Management*. 22:115–124.
- Talley, W.K. (1988) Optimum throughput and performance evaluation of marine terminals. *Maritime Policy and Management*. 15 (4), 327–331.
- Talley, W.K. (1994) Performance indicators and port performance evaluation. *Logistics and Transportation Review*. 339–360.
- Talley, W.K. (2009) Port economics. New York, Routledge.
- Tarkenton, L. (2005) Trends in Marine Terminal Operations Management. *Marine Terminal Management Training Program*.
- Taro, N. (2006) Trends in North American Terminal Operations. *Marine Terminal Management Training Program*.
- The Cornell Group (2007) *Container Terminal Parameters: A White Paper*. Maine, Maine Department of Transportation.
- The Tioga Group (2010) Improving Marine Container Terminal Productivity: Development of Productivity Measures, Proposed Sources of Data, and Initial Collection of Data from Proposed Sources. Cargo Handling Cooperative Program, MARAD.
- Tongzon, J. (2001) Efficiency measurement of selected Australian and other international ports using data envelopment analysis. *Transportation Research Part A: Policy and Practice*. 35:107–122.
- Tongzon, J. & Heng, W. (2005) Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). *Transportation Research Part A: Policy and Practice*. 39 (5), 405–424.
- Tovar, B., Jara-Díaz, S. & Trujillo, L. (2007) Econometric estimation of scale and scope economies within the Port Sector: a review. *Maritime Policy & Management*. 34 (3), 203–223.
- Transportation Canada (2012) Transportation in Canada 2011. *Transport Canada Annual Report 2012 - Government of Canada*.
- Trujillo, L. & Nombela, G. (1999) Privatization and Regulation of the Seaport Industry. *The World Bank Policy Research Working Papers Series*.
- Trujillo, L. & Tovar, B. (2007) The European port industry: an analysis of its economic efficiency. Discussion Paper Series, No. 07/05, Department of Economics, School of Social Sciences.
- Tsionas, E.G. & Loizides, J. (2001) A note on joint estimation of scale economies and productivity growth parameters. *International Journal of Production Economics*. 70:37–43.
- Turner, H., Windle, R. & Dresner, M. (2004) North American containerport productivity:
 1984–1997. Transportation Research Part E: Logistics and Transportation Review.
 40 (4), 339–356.
- U.S. Department of Transportation (2007) *Transportation for Tomorrow: Report of the National Surface Transportation Policy and Revenue Study Commission*. National Surface Transportation Policy and Revenue Study Commission.
- UNCTAD (1977) *Benefits from port improvements*. Geneva, United Nations Conference on Trade and Development.

- UNCTAD (1987) Manual on a Uniform System of Port Statistics and Performance Indicators. Geneva, United Nations Conference on Trade and Development.
- UNCTAD (1976) *Port Performance Indicators*. New York, United Nations Conference on Trade and Development.
- UNCTAD (2012a) *PPRN conceptual note*. Geneva, United Nations Conference on Trade and Development.
- UNCTAD (2010) *Review of Maritime Transport 2010*. Geneva, United Nations Conference on Trade and Development.
- UNCTAD (2011) *Review of Maritime Transport 2011*. Geneva, United Nations Conference on Trade and Development.
- UNCTAD (2012b) *Review of Maritime Transport 2012*. Geneva, United Nations Conference on Trade and Development.
- UNCTAD (1999) Technical note: the fourth generation port. UNCTAD Ports Newsletter. 19:9–12.
- Valentine, V.F. & Gray, R. (2001) The measurement of port efficiency using Data Envelopment Analysis. In: *Proceedings of the 9th World Conference on Transport Research*. 2001 Seoul, July 22–27th.
- Valleri, M. & Van de Voorde, E. (1996) Port Productivity: what do we know about it? In: Marisa Valleri (ed.). L'industria portuale: per un sviluppo sostenibile dei porti. Bari, Cacucci. pp. 125–141.
- VanderMey, A. (2012) The Future Of Global Shipping. Fortune. (May 21st).
- Vanelslander, T. (2005) *The economics behind co-operation and competition in sea-port container handling*. Antwerp, University of Antwerp.
- Veldman, S.J. & Bückmann, E.H. (2003) A Model on Container Port Competition: An Application for the West European Container Hub-Ports. *Maritime Economics & Logistics*. 5:3–22.
- Velicer, W.F. (1976) Determining the number of components from the matrix of partial correlations. *Psychometrika*. 41,321–327.

- Volk, B. (2002) *Growth factors in container shipping*. In: 2002 Launceston, April 15th. pp. 1–11.
- Van de Voorde, E. (2011) Seaports. In: Kenneth Button, Henry Vega, & Peter Nijkamp (eds.). *A dictionary of transport analysis*. Cheltenham, Elgar. pp. 353–356.
- Wang, T., Song, D. & Cullinane, K. (2003) Container port production efficiency: a comparative study of DEA and FDH approaches. *Journal of the Eastern Asian Society for Transportation Studies*. 5: (October), 698–713.
- Ward, T. (1998) New Ideas for Increasing Wharf Productivity. *Ports '98, American Society of Civil Engineers*. 1:69–78.
- Wooldridge, J. (2008) *Econometric Analysis of Cross Section and Panel Data*. 2nd edition. MIT Press Limited.
- World Bank (2003) Port Reform Toolkit. Washington, D.C., The World Bank.
- Yip, T.L., Sun, X. & Liu, J.J. (2009) Group Competition of Global Ports. *International* Association of Maritime Economists Conference IAME 2009. pp.1–12.
- Zallio, F. (2011) *Maritime Transport and Regional Cooperation in the Mediterranean Basin.* Policy Brief, GMF The German Marshall Fund of the United States.
- Zwick, W.R. & Velicer, W.F. (1986) Comparison of five rules for determining the number of components to retain. *Psychological Bulletin*. 99 (3), 432–442.

APPENDICES

I. EVOLUTION OF CONTAINER SHIPS



Source: (Rodrigue, Comtois & Slack, 2009) Note: length × width × depth below water in metres

II. DECISION TREE ON RESEARCH METHODOLOGY



Source: (Hair, Black, Babin, et al., 2010)

III. PROCESS IN MULTIVARIATE METHODS FOR DATA ANALYSIS



IV. LIST OF PORTS IN SAMPLE - BY PORT

Port	Country	Trade Region	Port Code		
Alexandria	Egypt	East Med/Black Sea	ALY		
Algeciras	Spain	West Mediterranean	ALG		
Algiers	Algeria	North Africa	ALZ		
Ambarli	Turkey	East Med/Black Sea	AMB		
Ashdod	Israel	East Med/Black Sea	ASH		
Barcelona	Spain	West Mediterranean	BCN		
Beirut	Lebanon	East Med/Black Sea	BEI		
Cagliari	Italy	West Mediterranean	CAG		
Casablanca	Morocco	North Africa	CAS		
Constantza	Romania	East Med/Black Sea	CNZ		
Damietta	Egypt	East Med/Black Sea	DAM		
El Dekheila	Egypt	East Med/Black Sea	EDK		
Genoa	Italy	West Mediterranean	GOA		
Gioia Tauro	Italy	West Mediterranean	GIT		
Haifa	Israel	East Med/Black Sea	HFA		
Haydarpasa	Turkey	East Med/Black Sea	HAY		
Izmir	Turkey	East Med/Black Sea	IZM		
La Spezia	Italy	West Mediterranean	SPE		
Las Palmas	Spain	West Africa	LPA		
Lattakia	Syria	East Med/Black Sea	LTK		
Leghorn	Italy	West Mediterranean	LIV		
Leixões	Portugal	Iberian Peninsular	LEI		
Lisbon	Portugal	Iberian Peninsular	LIS		
Malaga	Spain	West Mediterranean	MAL		
Marsaxlokk	Malta	West Mediterranean	MXX		
Marseilles	France	West Mediterranean	MRS		
Mersin	Turkey	East Med/Black Sea	MER		
Naples	Italy	West Mediterranean	NAP		
Piraeus	Greece	East Med/Black Sea	PIR		
Port Said	Egypt	East Med/Black Sea	PSD		
Sines	Portugal	Iberian Peninsular	SNS		
Tangier	Morocco	North Africa	PTM		
Taranto	Italy	East Med/Black Sea	TAR		
Tenerife	Spain	West Africa	SCT		
Thessaloniki	Greece	East Med/Black Sea	THE		
Valencia	Spain	West Mediterranean	VLC		

V. LIST OF PORTS IN SAMPLE - BY COUNTRY

Port	Country	Trade Region	Port Code		
Algiers	Algeria	North Africa	ALZ		
Alexandria	Egypt	East Med/Black Sea	ALY		
Damietta	Egypt	East Med/Black Sea	DAM		
El Dekheila	Egypt	East Med/Black Sea	EDK		
Port Said	Egypt	East Med/Black Sea	PSD		
Marseilles	France	West Mediterranean	MRS		
Piraeus	Greece	East Med/Black Sea	PIR		
Thessaloniki	Greece	East Med/Black Sea	THE		
Ashdod	Israel	East Med/Black Sea	ASH		
Haifa	Israel	East Med/Black Sea	HFA		
Cagliari	Italy	West Mediterranean	CAG		
Genoa	Italy	West Mediterranean	GOA		
Gioia Tauro	Italy	West Mediterranean	GIT		
La Spezia	Italy	West Mediterranean	SPE		
Leghorn	Italy	West Mediterranean	LIV		
Naples	Italy	West Mediterranean	NAP		
Taranto	Italy	East Med/Black Sea	TAR		
Beirut	Lebanon	East Med/Black Sea	BEI		
Marsaxlokk	Malta	West Mediterranean	MXX		
Casablanca	Morocco	North Africa	CAS		
Tangier	Morocco	North Africa	PTM		
Leixões	Portugal	Iberian Peninsular	LEI		
Lisbon	Portugal	Iberian Peninsular	LIS		
Sines	Portugal	Iberian Peninsular	SNS		
Constantza	Romania	East Med/Black Sea	CNZ		
Algeciras	Spain	West Mediterranean	ALG		
Barcelona	Spain	West Mediterranean	BCN		
Las Palmas	Spain	West Africa	LPA		
Malaga	Spain	West Mediterranean	MAL		
Tenerife	Spain	West Africa	SCT		
Valencia	Spain	West Mediterranean	VLC		
Lattakia	Syria	East Med/Black Sea	LTK		
Ambarli	Turkey	East Med/Black Sea	AMB		
Haydarpasa	Turkey	East Med/Black Sea	HAY		
Izmir	Turkey	East Med/Black Sea	IZM		
Mersin	Turkey	East Med/Black Sea	MER		

VI. LIST OF PORTS IN SAMPLE - BY TRADE REGION

Port Name	Country	Trade Region	Port Code		
Alexandria	Egypt	East Med/Black Sea	ALY		
Ambarli	Turkey	East Med/Black Sea	AMB		
Ashdod	Israel	East Med/Black Sea	ASH		
Beirut	Lebanon	East Med/Black Sea	BEI		
Constantza	Romania	East Med/Black Sea	CNZ		
Damietta	Egypt	East Med/Black Sea	DAM		
El Dekheila	Egypt	East Med/Black Sea	EDK		
Haifa	Israel	East Med/Black Sea	HFA		
Haydarpasa	Turkey	East Med/Black Sea	HAY		
Izmir	Turkey	East Med/Black Sea	IZM		
Lattakia	Syria	East Med/Black Sea	LTK		
Mersin	Turkey	East Med/Black Sea	MER		
Piraeus	Greece	East Med/Black Sea	PIR		
Port Said	Egypt	East Med/Black Sea	PSD		
Taranto	Italy	East Med/Black Sea	TAR		
Thessaloniki	Greece	East Med/Black Sea	THE		
Leixões	Portugal	Iberian Peninsular	LEI		
Lisbon	Portugal	Iberian Peninsular	LIS		
Sines	Portugal	Iberian Peninsular	SNS		
Algiers	Algeria	North Africa	ALZ		
Casablanca	Morocco	North Africa	CAS		
Tangier	Morocco	North Africa	PTM		
Las Palmas	Spain	West Africa	LPA		
Tenerife	Spain	West Africa	SCT		
Algeciras	Spain	West Mediterranean	ALG		
Barcelona	Spain	West Mediterranean	BCN		
Cagliari	Italy	West Mediterranean	CAG		
Genoa	Italy	West Mediterranean	GOA		
Gioia Tauro	Italy	West Mediterranean	GIT		
La Spezia	Italy	West Mediterranean	SPE		
Leghorn	Italy	West Mediterranean	LIV		
Malaga	Spain	West Mediterranean	MAL		
Marsaxlokk	Malta	West Mediterranean	MXX		
Marseilles	France	West Mediterranean	MRS		
Naples	Italy	West Mediterranean	NAP		
Valencia	Spain	West Mediterranean	VLC		

VII. LIST OF PORTS IN SAMPLE - BY PORT CODE

Port Name	Country	Trade Region	Port Code		
Algeciras	Spain	West Mediterranean	ALG		
Alexandria	Egypt	East Med/Black Sea	ALY		
Algiers	Algeria	North Africa	ALZ		
Ambarli	Turkey	East Med/Black Sea	AMB		
Ashdod	Israel	East Med/Black Sea	ASH		
Barcelona	Spain	West Mediterranean	BCN		
Beirut	Lebanon	East Med/Black Sea	BEI		
Cagliari	Italy	West Mediterranean	CAG		
Casablanca	Morocco	North Africa	CAS		
Constantza	Romania	East Med/Black Sea	CNZ		
Damietta	Egypt	East Med/Black Sea	DAM		
El Dekheila	Egypt	East Med/Black Sea	EDK		
Gioia Tauro	Italy	West Mediterranean	GIT		
Genoa	Italy	West Mediterranean	GOA		
Haydarpasa	Turkey	East Med/Black Sea	HAY		
Haifa	Israel	East Med/Black Sea	HFA		
Izmir	Turkey	East Med/Black Sea	IZM		
Leixões	Portugal	Iberian Peninsular	LEI		
Lisbon	Portugal	Iberian Peninsular	LIS		
Leghorn	Italy	West Mediterranean	LIV		
Las Palmas	Spain	West Africa	LPA		
Lattakia	Syria	East Med/Black Sea	LTK		
Malaga	Spain	West Mediterranean	MAL		
Mersin	Turkey	East Med/Black Sea	MER		
Marseilles	France	West Mediterranean	MRS		
Marsaxlokk	Malta	West Mediterranean	MXX		
Naples	Italy	West Mediterranean	NAP		
Piraeus	Greece	East Med/Black Sea	PIR		
Port Said	Egypt	East Med/Black Sea	PSD		
Tangier	Morocco	North Africa	PTM		
Tenerife	Spain	West Africa	SCT		
Sines	Portugal	Iberian Peninsular	SNS		
La Spezia	Italy	West Mediterranean	SPE		
Taranto	Italy	East Med/Black Sea	TAR		
Thessaloniki	Greece	East Med/Black Sea	THE		
Valencia	Spain	West Mediterranean	VLC		

	AREA	BERTH	CAGR0408	CAGR9808	САР	CAP_FREE	CENTRALITY	CRANES	DEPTH	GDP	LSCI	THROU	TS_PORT	TS_SH
Mean	59.05	1,746.89	13.60	8.30	1,610,417.00	25.34	0.86	12.72	14.66	2.17	0.35	1,182,966.00	0.36	37.99
Median	51.00	1,617.50	6.37	4.91	1,222,500.00	14.28	0.88	11.00	14.75	0.90	0.41	851,075.50	-	25.21
Maximum	160.00	3,882.00	102.15	57.85	4,200,000.00	76.68	1.00	33.00	18.00	9.40	0.58	3,597,215.00	1.00	99.00
Minimum	10.00	596.00	- 22.50	- 7.43	400,000.00	1.17	0.62	3.00	10.00	- 1.30	0.11	233,118.00	-	1.00
Std. Dev.	38.84	773.17	23.24	13.17	1,117,459.00	25.80	0.11	7.27	1.86	3.32	0.16	986,430.60	0.49	36.83
Skewness	1.01	0.89	2.07	2.52	0.92	0.99	- 0.33	1.00	- 0.56	0.80	- 0.25	1.28	0.58	0.47
Kurtosis	3.50	3.57	7.93	9.42	2.75	2.38	2.14	3.45	3.13	2.30	1.52	3.46	1.33	1.58
Jarque-Bera	6.44	5.24	62.23	100.07	5.22	6.46	1.76	6.33	1.91	4.54	3.66	10.20	6.17	4.37
Probability	0.04	0.07	-	-	0.07	0.04	0.41	0.04	0.39	0.10	0.16	0.01	0.05	0.11
Sum	2,125.97	62,888.00	489.71	298.84	57,975,000.00	912.37	31.03	458.00	527.70	78.20	12.65	42,586,784.00	13.00	1,367.74
Sum Sq. Dev.	52,807.32	20,922,508.00	18,902.98	6,071.81	43,700,000,000,000.00	23,297.27	0.39	1,851.22	120.79	385.95	0.86	34,100,000,000,000.00	8.31	47,483.53

VIII.DESCRIPTIVE STATISTICS