CHAPTER – II

LITERATURE SURVEY

The globalisation of the world economy has led to an increasingly important role for transportation. In particular, container transportation plays a key role in the process, largely because of the numerous technical and economic advantages it possesses over traditional methods of transportation. Standing at the crucial interface of sea and inland transportation, the significance of the container port and its production capabilities cannot be ignored.

Compared with traditional port operations, containerisation has greatly improved port production performance because of two reasons. To reap economies of scale and of scope, liner shipping companies and container ports are respectively willing to deploy dedicated container ships and efficient container handling systems. In so doing, port productivity has been greatly enhanced. On the other hand, many container ports no longer enjoy the freedom yielded by a monopoly over the handling of cargoes from within their hinterland; they are not only concerned, therefore, with whether they can merely physically handle cargo, but also whether they can compete for that cargo. Under such a competitive environment, port performance measurement is not only a powerful management tool for port operators, but also constitutes a most important input for informing regional and national port planning and operations. The object of this chapter is to survey previous studies of port efficiency and productivity, with a brief overview of works in other areas of the sector also.

There is a wealth of existing studies that analyse ports from different aspects: economic perspective studies such as charging structure of the facilities at the ports, etc.; economic impact studies like employment creation, etc.; port productivity and its determinant factors; investments and planning; port privatisation; port selection criteria; promoting competition; impact of inventory costs; impact of ship size etc. Cost estimates and economy of scale studies have provided a deeper knowledge of ports and the factors that determine their costs. There is a growing interest in the study of the role played by transport costs in models of international trade and a number of authors have recently investigated the determinants of transport costs from an empirical point of view. We will briefly overview these works before proceeding to works on port efficiency. This chapter is divided into two main sections, with the first section briefly reviewing studies apart those dealing with port efficiency and productivity and the second section dealing with studies in port efficiency and productivity, with emphasis on the studies using the method of technological frontier estimates.

1. OVERVIEW OF STUDIES OTHER THAN THOSE ON EFFICIENCY AND PRODUCTIVITY

Studies that analyse ports **from an economic perspective** date back to the 1960s with researchers like Goss (1967)[1], Heggie (1974)[2], etc. centering their studies on aspects like capacity and investment policies, charging structure of the port facilities, etc. The economic impact studies by Waters (1977)[3], Chang (1978)[4], etc., which valued port services in terms of quantity of employment created or cost reductions, arose out of the role of port infrastructure in economic activities.

Assessing the potential demand for container ports and associated multi-modal transportation facilities is a major issue in **port planning and development** (Benacchio et al, 2000; Hoffmann, 1998)[5], multi-modal facility development (US DOT, 1998)[6], and business decision-making in the international container transportation industry. Estimates of demand are key to evaluating not only the financial feasibility of a proposed port but also the economic benefits and costs and their distribution to the host state and to the nation as a whole (Bobrovitch, 1982; Bomba *et al*, 2001)[7]. The first generation of papers analyzing ports' production and cost structure which focused on planning and managing future investments started in the seventies with a study carried out by Wanhill (1974)[8] aimed at designing a model which allowed determination of the optimal number of berth minimizing total cost for port use or more specifically, the empirical estimation of port cost functions. According to Wanhill (1974), future investments and planning should be made taking into account the fact that port services cannot be stored and, that, therefore, there is a trade-off between port capacity cost and the cost of ships' stay in the port (service time plus waiting time) that is determinant and should be considered when planning.

The manual on port planning prepared by the UNCTAD Secretary in 1978 for developing countries follows the same line of work as Wanhill (1974) study. It relies on Monte-Carlo simulation techniques to calculate the costs of different types of terminals according to terminal features and ships' stay in the port. It points out that port planners should bear in mind that a planning policy exclusively aimed at reducing operators' port costs to the least (i.e., without considering ship's waiting time) will generally results in a sub-optimal service level. This, in turn, might result in the imposition of charges for port congestion which will not be economically acceptable. The branch of the literature concerned with the optimal planning of ports or port terminals continued with the papers by Jansson and Shneerson (1982)[9], Shneerson (1981, 1983)[10], Jansson (1984)[11], and Fernández et al. (1999)[12]. All these papers consider that the optimal use of a berth results from minimizing the addition of operators' port costs and the cost of ships' stay in the port. They adopt a queuing model as the basic form of port service production function, at the same time that they assume ships' arrival is at random and follows a Poisson distribution function while service time follows an exponential distribution. Fernandez et al. (1999) also covers the effects of privatization.

Among the **studies** that deal with **promoting competition among ports** Heaver (1995)[13] and the Australian Productivity Commission (1998)[14] used comparable indicators to try to see how inter-port competition could be promoted analytically.

The **inventory costs** resulting from the shipping process along the shipping route and ports usually are the main considerations of shippers. Inventory cost is commonly regarded as a major factor affecting shipping service decision in logistics literature. These studies usually determined the optimal shipping frequency by minimizing total shipping and inventory costs (e.g. Hall, 1987). Jansson and Shneerson (1987)[15] also proposed an economic model to analyze shipping service decision by minimizing total shipping and inventory costs.

Previous **studies on ship size** or ultra large ships were focused largely on economies of ship size. These studies indicate that economies of ship size occur at sea, while diseconomies of ship size are suffered in port, and that the choice of optimal ship size involves a balancing of the cost per ton at sea and the cost per ton in port (e.g., Jansson and Shneerson, 1987). Recently, Cullinane and Khanna (1999, 2000[16]) indicate that the diseconomies of ship size in port are not apparent and the optimal ship size tends to be large as a result of improving port productivity. Moreover, McLellan (1997)[17] provided detailed discussions about the effects of larger ships on ports. Lim (1998)[18] discussed that ships being large would impact all shipping industry. And Robinson (1998)[19] forecasted the shipping service position of ultra large ships based on the trend of shipping development. Garrod et al. (1985)[20] and Jansson and Shneerson (1985)[21] showed the importance of shippers' inventory costs when minimizing carriers' costs. Jansson et al. (1978)[22], Talley (1990)[23], and Lim (1998) found similar properties for general cargo and container ships.

The recent literature has shown a growing interest in studying **the role of trade costs** in models of international trade. Krugman's (1991)[24] seminal work in economic geography models emphasizes the crucial importance of trade costs. Recent studies have confirmed the significant impact of trade costs, not only for international trade levels but also for the structure of economic activities, (e.g., Radelet and Sachs, 1998)[25], whose study shows that shipping costs reduce the rate of growth of both manufactured exports and GDP per capita. These authors claim...."doubling the shipping cost (e.g. from an 8% to 16% CIF band) is associated with slower annual growth of slightly more than-half of one percentage point...". Deardorff (2001)[26] models local comparative advantage in a partial equilibrium framework and Venables and Limao (1999)[27] show how relative location affects specialisation patterns in a general equilibrium framework. A better understanding of trade costs might provide insights into a broad range of topics related to international specialisation (Hummels, Ishii and Yi, 2001)[28], factor content in trade (Donald and Weistein, 1998)[29], substitution between trade and foreign investment (Markusen and Venables, 1996)[30] and regional integration. Henderson, Shalizi and Venables (2001)[31] also emphasised the important role played by transport costs and their influence on trade and income. Hoffman and Kumar (2002)[32] analyse the mutual relationship between trade and its maritime transport cost and its relevance for globalization. Hummels (1999)[33] presents evidence of the importance of transport costs in the determination of trade patterns.

Amongst the **studies on transport costs** Limao and Venables' (2001)[34] should be highlighted. This work analyses the dependency of transport costs on geographical and infrastructural variables. The authors prove that distance and being landlocked affect positively transport costs. Although the geographical location of countries cannot be modified, the effect of distance can be lessened by improving the infrastructure of the origin, transit and destination countries (Limao and Venables, 2001; Martínez-Zarzoso, Pérez-García, San Juan-Lucas and Suárez, 2004)[35].

Clark, Dollar and Micco (2004)[36] focus on the determinants of maritime transport costs. Geographical factors, transport insurance, whether the cargo requires special transport conditions (i.e. refrigerated transport), trade imbalance, economies of scale, the development of containerised transport, number of maritime lines, port efficiency and anti-competition legal and practical restrictions, all determine maritime transport costs. Sánchez, Hoffmann, Micco, Pizzolitto, Sgut, and Wilmsmeier (2003)[37] demonstrate that port infrastructure in terms of efficiency affect transport costs. They base their analysis on quantitative port performance measures (turnaround time etc.). Wilmsmeier (2003)[38] proves the effect of institutional factors, analyzing the effect of the port operator model on transport costs for the case of South America. These studies analyse the explanatory variables of port efficiency and prove that the latter does not only depend on infrastructure, but on a series of variables related to administrative and political issues. Although a certain degree of regulation increases port efficiency and reduces maritime transport costs, over a threshold of high regulation levels, this effect works on the opposite direction, hence decreasing port efficiency and raising maritime transport costs.

Wilmsmeier and Pérez (2005)[39] analyse the effect of liner shipping network conditions on transport costs from different regions to South America. They show the reducing effect of maritime services supply on transport cost and how the structure of the deployed fleet for directly connected regions contributes to the level of transport costs. From a sectorial perspective, Martínez-Zarzoso, García-Menéndez and Suárez-Burguet (2003)[40] study the explanatory factors of both maritime and road transport costs for the Spanish exports of ceramic tiles. In this paper, transport costs are found to increase with longer distances and poor infrastructure. The cost of exporting a commodity depends on the selected port of departure at the country of origin, transport costs increasing when the cargo is not loaded at the most efficient port. Estimations of gravity equations carried out prove that distance is not an appropriate proxy of transport costs for the ceramic tiles sector. Anderson and van Wincoop (2004)[41] emphasise the need to obtain better transport costs measures and to use these measures in order to expand gravity models and treat the endogeneity of the transport costs variable in this kind of equations.

There have been few **studies** done **on the factors determining port choice**. In the context of container port competition, the trend points towards shipping lines as the key players in determining port choice with increasing attention given to by them to provide logistical services on a global basis in an integrated approach (Slack, 1985)[42]. Slack concluded that "the choice of port depended more on the price and quality of service offered by land and ocean carriers than on the attributes of ports themselves." Likewise, Branch (1986)[43] gave a general list of factors accounting for shippers' choice of port. Other studies attempting to identify and explain the various factors in port choice include Willingale (1984)[44] and Murphy, Daley and Dalenberg (1991; 1992)[45]. Robinson (2002)[46] suggested that shippers play the key role in determining port choice. He suggested that ports are "elements embedded in value-driven chain systems ..." and that it is important for the port and its service providers to offer sustainable value to its users vis-à-vis other competing value-driven chain systems. In evaluating the importance of port charges in the U.S., Malchow and Kanafani (2001)[47] have also found that port charges relative to other factors are not significant in port selection. Oceanic and hinterland distances, especially relevant in the East Asian context, also played a significant role according to them. On port competitiveness, Haezendonck and Notteboom (2001)[48] provided a comprehensive appraisal by showing that hinterland accessibility, productivity, quality; cargo generating effect, reputation and reliability are factors that proved critical in strengthening a port's competitiveness. As a whole, the factors that influence a port's competitiveness and its choice can be summarized in the extensive framework proposed by Rugman and Verbeke (1993)[49]. These factors were grouped into six categories that include factor conditions (production, labour, infrastructure, etc.); demand conditions; related and supporting industries; firm structure and rivalry; chance; and government intervention. There are numerous studies on freight transport choice by shippers, but they have centered on modal choice and carrier selection, rather than addressing the more specific question of choice between competing ports, e.g., Bardi (1973)[50], Gilmour (1976)[51], McGinnis (1979)[52], Ogden and Rattray (1982)[53], Brooks (1984; 1985)[54], Wilson et al. (1986)[55], and D'Este and Meyrick (1992)[56].

Intensified competition at the supply side creates pressures on cost management and on margins. The evolutions in supply chains and logistics models urge container ports and shipping lines to re-think their function in the logistics process. Recent literature has addressed **the impact of changes in logistics** on the functional role of ports and shipping in value chains. Robinson (2002) places the role of seaports within a new paradigm of ports as elements in value-driven chain systems. Notteboom and Winkelmans (2001)[57] and Heaver et al (2000) primarily discussed the changing role of port authorities in the new logistic-restructured environment, while Martin and Thomas (2001)[58] addressed structural changes in the container terminal community. Slack et al (2002)[59] demonstrates how the organisational restructuring of the container shipping industry is taking place against the backdrop of logistics.

The public sector has redefined its role in the port and shipping industries through **privatisation and corporatisation** schemes. During the last two decades in many countries the ownership of one of the most important trade entry points into any country, the seaport, has changed from being solely in the hands of national or local governments into, either wholly or partially, private hands. It is this change, which is called privatisation, which has attracted much interest from both academics and those working within the industry. Contemporary government intervention in an efficiency-oriented industry typically focuses on the issue of market liberalisation and the creation of a level playing field for fair competition, the monopoly issue and the public goods issue (Goss, 1990[60]; Baird, 2000[61]; De Monie, 1995[62]; Notteboom and Winkelmans, 2001 and Everett, 1996[63]). With the reassessment of the role of the government much attention is now paid to governance issues in ports and shipping (Brooks, 2001[64] and Wang, 2003)[65].

2. REVIEW OF STUDIES ON EFFICIENCY AND PRODUCTIVITY OF PORTS

The estimation of key indicators representing the technical production properties of firms within an industry, such as economies of scale and scope, plays an essential role in the determination of the optimal industrial organization, i.e. that which induces the best assignment of resources. As known, technical properties can be analyzed directly through the study of the relations between inputs and outputs by means of production or transformation functions. They can be analyzed as well from the estimation of cost functions, taking advantage of the dual properties of these functions regarding technology. The estimation of production and cost functions represents a fundamental tool for the proper regulation of any industry, contributing with precise results to the regulatory process. Measures of port efficiency or performance indicators use a diverse range of techniques for assessment and analysis, but although many analytical tools and instruments exist, a problem arises when one tries to apply them to a range of ports and terminals. Ports are very dissimilar and even within a single port the current or potential activities can be broad in scope and nature, so that the choice of an appropriate tool of analysis is difficult. Organizational dissimilarity constitutes a serious limitation to enquiry, not only concerning what to measure but also how to measure.

The activities of port production are complex and include pilotage, towage, berthing, cargo and container handling, warehousing, and logistics. Therefore, the improvement for ports' operating efficiency could include: improvement in efficiency through private sector management skills, enhancement of service quality through improved commercial responsiveness, reduction in the fiscal burden of loss making public enterprises, a reduction in the financial demands on central and local government through access to private sector capital, and additional revenue streams (McDonagh, 1999)[66]. Dowd and Leschine (1990)[67] propose that, from the standpoint of container terminal productivity, each port's player has his own self-interest and his own definition of productivity. As most port operations have been privatized, private operators aim to maximize output (container throughput) and operating efficiencies (Heaver *et al.*, 2000)[68].

The efficiency literature on ports' performance is relatively modest in comparison to the efficiency literature available on other infrastructure activities (Estache, Gonzalez, and Trujillo, 2002). However, it is not totally devoid of attempts to measure port efficiency. One common methodology is through the use of surveys. A recent indicator of port efficiency has been constructed from annual firm-level surveys for the years 1995 through 2000 and reported in the Global Competitiveness Report published by the World Economic Forum. These surveys ask firms to rank countries' port efficiency from 1 to 7, where 1 indicates that the firm strongly disagrees with the statement "Port facilities and inland waterways are extensive and efficient", whereas 7 indicates the firm strongly agrees with the statement. Drawbacks of survey data are, first, they rely on impressions of survey participants where observations of port efficiencies *per se* may be confounded with other factors connected with the country of the port's location. Second, existing surveys of port efficiencies have only been administered at a point in time or for a limited timeframe. Thus, there is almost no information on how port efficiencies evolve over time from these studies.

Traditionally, the performance of ports has been variously evaluated by calculating cargo-handling productivity at berth (Bendall and Stent, 1987; Tabernacle, 1995; Ashar, 1997)[69], by measuring a single factor productivity (De Monie, 1987)[70] or by comparing actual with optimum throughput over a specific time period (Talley, 1998)[71] (Cullinane, et. al, 2004)[72]. UNCTAD[73] 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. Various references, particularly UNCTAD monographs, provide a range of port indicators by ratio type[74] and category of operation.

There are many ways of measuring port efficiency or productivity, although reducible to three broad categories: physical indicators, factor productivity indicators, and economic and financial indicators[75]. Physical indicators generally refer to time measures and are mainly concerned with the ship (e.g. ship turnaround time, ship waiting time, berth occupancy rate, working time at berth). Sometimes, co-ordination with land modes of transport is measured, e.g. cargo dwell time or the time elapsed between cargo being unloaded from a ship until it leaves the port. Factor productivity indicators also tend to focus on the maritime side of the port, for example, to measure both labour and capital required to load or unload goods from a ship. Similarly, economic and financial indicators are usually related to the sea access; for example, operating surplus or total income and expenditure related to gross registered tonnes (GRT) or net registered tonnes (NRT), or charge per twenty foot equivalent unit (TEU). Port impacts on the economy are sometimes measured to assess the economic and social impacts of a seaport on its respective hinterland or foreland. The results may be provided in port statistics, e.g. the port of Rotterdam or by research institutes such as ISEMAR[76] in France. The heterogeneity of port activities (which include not only complex activities such as loading and unloading the cargo but also simpler activities such as mooring of ships) makes it difficult to consider the port industry as a whole, at least regarding the estimation of cost and production functions.

Though the literature on ports' performance is relatively modest, it is evolving however and can be classified into three main groups. The first covers partial indicators of productivity in the port system. The second group consists of studies with an engineering approach employing simulations and queueing theory. The third group of studies, which is the most recent, employs the formal approach of deriving the efficiency indexes of the ports with the help of technological frontier estimates.

2.1 Studies Using Partial Productivity Indicators

The first attempts to assess the port efficiency and productivity effects from reforms and technological changes relied on partial indicators of productivity. The academic literature adopting this approach to focus on specific ports spans over a 25 years period starting in the early 1980s, when Suykens (1983)[77] focused on maximization of throughput with the existing facilities and maximization of net profits (among others) to measure efficiency. The productivity of a container terminal is influenced by a range of factors, only some of which can be controlled by terminal operators (Dowd et al, 1990). In the studies by De Monie (1987), Dowd and Lechines (1990), Talley (1994), etc. costs analysis carry out evaluations of ports' return and productivity by calculating different indicators and also allow comparisons of the productive efficiency among various firms and throughout the time for a single firm. These studies have used the assessment of productivity based upon output per worker (De Monie 1987), output per wharf (Frankel 1991)[78]. Using these indicators for inter-port comparisons was suggested by Talley (1994)[79] and Tongzon (1995)[80]. Talley and Tongzon use them to compare different ports in an academic paper but many organizations have also used them in practice as instruments for the promotion of competition among ports. Talley (1994) showed how a port could maximize efficiency with Lagrangean modeling, since the shadow cost represents the cost needed to handle an additional container. Minimizing the shadow price for a given volume would be equivalent to maximizing a port's operational efficiency. Tongzon (1995) argued that a port's throughput efficiency affects its overall throughput since it influences the port's attractiveness to shippers. With a Cobb-Douglas function, he showed that throughput efficiency is affected by container mix (20-ft. versus 40-ft.), work practices, crane efficiency, vessel size, and cargo exchange. He argued also that port charges are important, but less so than service factors. Heaver (1995)[81] or the Australian Productivity Commission (1998) also used comparable indicators to try to see how inter-port competition could be promoted analytically. While all these studies generate useful insights on the performance of ports and the factors driving their costs, their main drawback was their partial view and the failure to recognize the need to have an analytically consistent approach to efficiency measurement. The main drawback of partial indicators is that they do not analyze the joint contribution of all inputs to production nor give an acceptable treatment to multi-output processes. This problem becomes particularly relevant in the port sector since port products are very diverse and many different inputs are involved in their production.

2.2 Studies Using an Engineering Approach

The engineering approach analyses productivity taking into account some potential result that the firm has not hitherto exploited and which, if used, could lead to an increase in the firm's productivity.

De Neufville et al. (1981)[82] analysed six eastern U.S. ports. By focusing on quay length and the number of cranes, the authors confirmed that scale economies exist at container ports. At these ports, they found that productivity increased with port size and argued that investing at major ports would be advantageous to investing elsewhere. Sachis (1996)[83] looked at the different techniques for measuring productivity, adopting an engineering method to take account of the technological investments when looking at the efficiency of Israeli ports and concluded that capital investment and the level of activity are the main factors affecting the productivity of these ports.

2.3 Studies Using the Formal Methods

To overcome the drawbacks faced by the earlier approaches, in recent years formal methods have been used for the measurement of efficiency in relation to productive activities and a significant progress has been made in it. The new technique is aimed at estimating the non-inferior sets, also called the frontiers. Frontiers are essentially envelopes which can approximated from various methodologies from the observed data on outputs or costs and the corresponding data on input quantities or input prices observed at the business unit level - either a port authority, a terminal, or any unit of interest to the analysis. The analysis reveals those units which operate at efficient levels of production or costs and of those who do not and hence do not fulfill the assumption of maximization of production or minimization of costs. The measure of efficiency is linked to the estimation of a frontier, since in order to estimate the efficiency of a production unit, it is necessary to have a standard with which to make the evaluation. For example, in order to claim that a port can cater for 20 per cent more ships, with the means at its disposal, it is necessary to know the reference used to measure the 100 per cent level. For example, in order to claim that a port can cater for 20 per cent more ships, with the means at its disposal, it is necessary to know the reference used to measure the 100 per cent level. Both theoretical and empirical measures of efficiency are based on ratios of observed output levels to the maximum that could have been obtained, given the inputs utilized. This maximum constitutes the efficient frontier which will be the benchmark for measuring the relative efficiency of the observations. The concept can be easily illustrated for a given amount of inputs or production factors. If one or more of the observed output components could be increased holding the other constant, then this point is inferior or inefficient. Analogously, an observed input combination is said to be inferior or inefficient in the production of a given output if one or more inputs could be diminished. Inefficiency translates into observed costs that are not minimum, which makes the association between expenses and production incorrect. The first author who suggested the use of the borders of production for the efficiency analysis was Farell. According to this author, the correct form to measure the efficiency was by means of the comparison of each observation (commonly companies) with the best observed practice. Much empirical research falls under this category and seeks to compare actual output to optimum output. A recent work by De Borger, Kerstens and Costa (2002)[84] claims that frontier models have found their way into the transport sector, and studies on the productivity and efficiency of almost all transport modes are appearing. There are multiple techniques to estimate this frontier, surveyed recently by Murillo-Zamorano (2004)[85], and the methods have been recently applied to examine port efficiency.

Two main approaches have been developed to estimate the frontier and measure efficiency. Both aim at estimating frontier functions but they differ in the way the frontier is estimated. The first technique is econometric modelling. Stochastic frontier modelling is the most common approach among these models. It relies on stochastic parametric regression-based methods. This technique starts with Aigner, et al. (1977)[86] and Meeusen and van de Broeck (1977)[87]. The main intuition in this approach is that the deviations from the frontier—i.e. best practice—is not totally under the control of the business unit analyzed because of policy, political, macroeconomic, and institutional or other reasons. The second uses non stochastic and non parametric mathematical programming methods. Within these optimization methods, the most popular was introduced by Charnes, et al. and is known as *Data Envelopment Analysis* (DEA). One of the main advantages of the approach is that it can yield results with a relatively modest set of data on the various business units to be analyzed. The former is stochastic in nature and can therefore, distinguish the noise effects from the inefficiency effects while the latter approach is not stochastic and deals with noise and inefficiency together, both termed inefficiency. The econometric approach is parametric and confuses the effects of a bad functional specification as inefficiency. The linear programming approach is non-parametric and therefore, less sensitive to this type of error. Thus the main advantages of the linear programming method are not imposing any functional form *a priori* on the data and handling multi-output processes easily. DEA is suited to measure efficiencies of deterministic industry for multiple inputs/outputs information. SFA is suited to measure efficiencies of stochastic industry for input/output information. It needs to assume a production function of the usual regression form and a distribution type of error item which is equal to the sum of two components, the first part is symmetric and captures statistical noise such as weather, luck, machine breakdown and other events beyond the control of firms, and the second part represents technical inefficiency of firms. SFA has been applied to measure performance of profit organizations.

The models preferences are evenly distributed between stochastic frontiers and DEA. A relatively modest volume of work following a diversity of approaches to measure efficiency clearly reveals a lack of consensus on the ideal approach. We review here studies using both the SFA as well as DEA methods, even though this thesis uses only DEA to measure efficiency.

2.3.1 Stochastic Frontiers

Econometric models consider random noise and can thus separate the measurement errors of efficiency estimates. They allow hypothesis to be contrasted. There can be two frontier versions: cost frontiers and production frontiers.

2.3.1.1 Stochastic Cost Frontiers

In cost frontier versions, frontiers that take into account more than one output can be estimated. Three studies quantify economic efficiency using a stochastic cost frontier, in which technological change is well specified as a trend or as temporal effects.

Banos-Pino, et. al. (1999)[88] specify a translog functional form for a sample of 27 Spanish ports and try to discover if the port authorities face difficulties in adjusting capital in the short run. The authors combine the cost frontier with the input oriented distance function, to measure the capacity of the capital stock and define labor as the average annual number of workers in the port. Banos et al. distinguish between the price of variable capital, defined as the ratio of investments realized in one year over investments over the previous year and the price of capital quasi -fixed approximated by the ratio between the use of capacity and the length of docks with a depth over 4 meters. The authors also incorporate other production factors which include "other expenditures" representing intermediate inputs, like the energy consumption and non recurrent labor inputs. The price of intermediate inputs is the ratio of consumption, external services and service costs over other port expenditures. The price of energy is obtained by allocating the energy inputs cost to ports according to the volume handled. They assume a single output technology and measure output through the volume of merchandise handled. The authors conclude that there is an overcapitalization of the sector, which decreases as port activity increases and that the Spanish ports are not minimizing costs.

Coto-Millan, et. al. (2000)[89] also opt for the flexible translog functional form to analyse the economic efficiency of the Spanish port authority in their ports, and in a second stage, attempt to discover if the type of organization and port size can explain the differences observed in the economic efficiency indexes.. Panel data for the period 1985-1989 were collected and analysed using the Cobb-Douglas and translog versions of the model. The authors rely on a dummy to distinguish between autonomous and other ports and on dock length to model the relevance of the size of ports. Labor prices are approximated by the ratio of total labor cost to the number of workers and the price of capital is obtained by dividing the amortization of the period by the length of docks. The authors also, like Banos-Pino (1999), assume a single output technology and measure output through the volume of merchandise handled. They add three components of port activity: cargo moved, boarded and unboarded passengers and vehicles with passengers. The environmental variables[90] have been incorporated by the authors in the form of a binary variable, which attempts to capture the influence of the type of organization (autonomous ports and the other ports), and the size of the port, reflected in the length of the dock with a draught exceeding four meters. These variables have been used to measure the intensity with which the above mentioned factors affect efficiency, through a second regression of efficiency indexes obtained in the first stage on the factors that influence efficiency[91]. The first stage of their analytical works reveals a ranking in which the smallest ports were the most efficient and the largest the least efficient and that autonomy did not necessarily help. When testing in a second stage the relevance of size for the level of efficiency, they conclude that sized does in fact not matter but that autonomy hurts efficiency levels.

The above two studies also incorporate intermediate inputs which include consumption expenses, energy, external work and other current expenses (not corresponding to operations or personnel). They estimate the price of these intermediate inputs based on the quotient between the cost of said inputs and the port activity, measured as the total merchandise handled.

Diaz (2003)[92] introduces a quadratic function to estimate and decompose productivity. He estimates the efficiency of 21 Spanish ports using panel data for the years 1990-1998 and attempts to value the impact of the organizational reforms of the stevedoring sector (handling of merchandise) in Spain between 1990 and 1998. The author quantifies the labour input from the hours worked. To incorporate capital input, he analyses the stevedoring sector,.with capital measure based on the crane usage time. The author distinguishes between three types of cargo requiring different methods of handling: containerized cargo, general cargo and solid bulk (which do not require special installations for its offloading). The price of labour is calculated by him as the ratio of the total labour cost to the number of hours worked, while that of capital is calculated by dividing the aggregate spending for the use of cranes with the usage time of those cranes. Analysing the Spanish stevedoring sector, Diaz finds productivity gains are essentially due to technological improvements, and to a lesser extent, are also due to economies of scale. In this sector, allocative efficiency is higher than technical efficiency.

2.3.1.2 Stochastic Production Frontiers

The functional form chosen in most of the studies is Cobb-Douglas, with translog form used in a couple of studies. None of the studies other than that of Liu incorporates technological change in the model specified in the study. The estimation method used most often is the method of maximum likelihood though L. Notteboom et. al. have the distinction of being the only study that has used the Bayesian technique of Monte Carlo estimation to the port sector.

Liu (1995)[93] sets out to test the hypothesis that public sector ports are inherently less efficient than those in the private sector. He focuses on production to calculate technical efficiency and compares the influence of public and private ownership in Britain. A set of panel data relating to the outputs and inputs of 28 commercially important U.K. ports over the period from 1983 to 1990 was collected for analysis. Liu assumes that the total wage payments as an approximation of the labor input and defines capital as the net value of fixed capital, including land, buildings, docks, berths, roads, storage and equipment. The author does focus on technical efficiency but does not compute port specific efficiency measures. He computes simply an average which he uses as a variable to explain in a second stage. Liu relies on 3 variables. Ownership is a dummy differentiating between private, trust and municipal ports. The size of ports enters as a dummy distinguishing between large, and, "medium and small" ports. Localization on the shore vs. elsewhere also enters as a dummy. Finally, the intensity of capital is measured as the ratio between the net value of fixed capital and the total wage bill. Liu assume a single output technology and measure output through the volume of merchandise handled. He measures the output through the revenue generated-excluding revenue from the sale of goods. This approach assumes that the ports are quite competitive and that tariffs reflect costs and hence that revenue reflects output. His comparison of the various ports leads him to suggest that in the UK for the 1983-1990 period, there is no significant advantage to private or public ownership when the policy environment is competitive. He also shows that size matters and being larger helps, that location matters but not a lot and that capital intensity has no significant impact. The results failed to identify ownership as a significant factor in production and the evidence implied no clear-cut efficiency advantage for any particular form of ownership.

Notteboom, Coeck and van den Broeck (2000)[94] apply a Bayesian approach based on Monte-Carlo approximation to the estimation of a stochastic frontier model aimed at assessing the productive efficiency of a sample of 36 European container terminals located in the Hamburg-Le Havre range and in the Western Mediterranean. The data analysed relates to the single year of 1994. The robustness and validity of the estimated model was tested by comparing the results with those of four benchmark terminals in Asia (Singapore, Kaohsiung and Hong Kong's MTL and HIT terminals).

Estache et. al. (2002)[95] apply SFA with Cobb-Douglas and Translog production function for the half-normal and truncated-normal distributions to estimate production efficiencies of 11 Mexico container ports with two inputs (including labor and capital) and one output (volume of merchandise handled) from 1996 to 1999. The authors explicitly state that they are studying the activities carried out by port authorities. The objective of the study is to show the utility of efficiency measures in promoting a yardstick competition system. The authors consider only the surface of the port tendered to by the port authorities as a measure of capital input. The authors conclude that the Mexican port reform of the early 1990s produced positive effects in practically all the port authorities. Therefore, they suggest that reforms that promote autonomy in port management can produce significant improvements in the sector. They also highlight the need to improve the data collection and publication systems, so as to be useful tools in the evaluation of port efficiency.

Cullinane, Song, and Gray (2002)[96] analyse the administrative and ownership structures of major container ports in Asia. The relative efficiency of these ports was then assessed using the SFA method with Cobb-Douglas production function for the half-normal, exponential, and truncated-normal distributions to estimate production efficiencies of 15 Asian container ports/terminals with unbalanced-panel data between 1989 and 1998. The authors clearly indicate that they analyse the container port terminals. The authors do not incorporate the labour input[97]. The authors incorporate three variables to measure the capital used by the container terminals: docks, surface area and cranes. Since the study analyses the activity of cargo terminals and container offloading, the output is measured in terms of containers moved. The authors claim that the level of deregulation has a positive influence on port efficiency, i.e., after analysing the property structure of the main container terminals in Asia, they find evidence that the transfer of property from the public to the private sector improves the economic efficiency of terminals, justifying the programs undertaken in the Asian ports to capture private investments.

Cullinane and Song (2003)[98] assessed the success achieved by Korea's port privatisation policies in increasing the productive efficiency of its container terminals using the SFA method with Cobb-Douglas production function. The stochastic frontier model was justified as the chosen methodology for estimating productive efficiency levels and is applied to cross-sectional data under a variety of distributional assumptions. A panel data model was also estimated. The authors define capital input as the net value of fixed capital and distinguish between buildings and land and mobile and cargo handling equipment. They employ a monetary approach to measure labour input by considering the total value of salary payments, distinguishing among the remunerations of directors and executives and employees to capture the differences in work qualifications. The authors measure the output based on the income that the container traffic generates for the port firms. The study shows that the greater the degree of private property, the greater the degree of efficiency, with only one exception. They also observe an increase in the efficiency of the terminals in South Korea after the introduction of competition in the sector.

Gonzalez (2004)[99] estimates a multi-output distance function and is the first study to do so in the port area. She also explicitly states that the activity studied is that carried out by the port authorities. To incorporate the effects of the environmental variables in a manner different from the previous studies, Gonzalez developed an alternative wherein the said variables are included into the specification of the technology and a measure of the "net" efficiency of the effect of these factors is obtained. This way, it is admitted that these environmental variables do affect the activity analysed, but are beyond the control of those responsible for the same. Her work does not seek to explain the causes that determine efficiency, but rather to incorporate two characteristics facing the Spanish port authorities unequally. The first is that there are inland ports, with captive traffic and with low competition levels, and continental ports where the alternatives for importing or exporting merchandise are numerous (rail, road, other ports), implying that the latter face a greater competition than inland ones. The second is the existence of refineries in places next to some ports, which implies that the quantity of liquid bulk (a very fast offloading product requiring limited infrastructure) and therefore total traffic is considerably greater in these ports. In addition to the above, Gonzalez also studies if the port reform process of the 1990s improved the efficiency of the 9 main Spanish ports in the 1990-2002 period. He uses panel data. For capital input, he uses the exact approach as that of Martin (2002). The author considers four outputs: containers, liquid bulk, remaining cargo and passengers. The study finds that the most efficient port authorities include both large and small ones and the same occurs with the least efficient. Gonzalez also shows that most Spanish port authorities analysed operate with increasing returns to scale. The results obtained by the authors also confirm that the Spanish port reform produced improvements in the productivity of the port authorities via technical progress.

Tongzon and Heng (2005)[100], in a bid to examine whether port privatisation leads to an improvement in the competitive position of ports, measure the efficiency of 25 international container ports (terminals) using cross-section data. They specify a Cobb-Douglas functional form and identify the relationship between the efficiency measured and the property structure of the terminals. Tongzon and Heng also do not incorporate labour input. To measure capital input, they incorporate three variables, viz. docks, terminal surface and cranes. The output is measured in terms of the total container traffic. The authors find a positive relationship between technical efficiency and privatization as well as between technical efficiency and port terminal size. They also find that the best property structure for container terminals is mixed organisation (public/private) and totally private, thus favouring private investments in port operations.

Rodríguez-Álvarez et. al. (2007)[101] estimate a system of compound equations for a distance function and the input spending equations, once again specifying a Translog function. They study the merchandise handling sector and evaluate both the technical and allocative efficiency of the three main container terminal of the port of Las Palmas (Spain). The passing of time is modeled through temporal effects. The authors regard the range of tangible assets of the firm as capital, taken as the sum of the accounting amortization and the return on the live capital of the period; as a quasi-fixed input they use the total surface of the port. The authors distinguish output between containers, rolling loads and general merchandise.

2.3.2 Data Envelopment Analysis

An alternative methodology to measure port efficiencies, used by a number of studies, is data envelopment analysis (DEA). Frontier models have assessed port efficiency both within a single country and across different countries. In particular, non-parametric frontier methods have been developed with applications across a wide range of sectors including transit services. Recent models propose or use data envelopment analysis (DEA) to evaluate port efficiency. The operating efficiency of a container port is a mixture of multiple inputs and multiple outputs, which is in compliance with the characteristics of DEA. This procedure uses data on inputs, outputs and production function theory to derive an estimate of the most efficient production frontier across a group of ports. Port efficiency measures are then based on deviations from this frontier. Data Envelopment Analysis (DEA) is one of the most important approaches to measuring efficiency. It is an operations research-based method for measuring the performance efficiency of decision units that are characterized by multiple inputs and outputs. DEA converts multiple inputs and outputs of a decision unit into a single measure of performance, generally referred to as relative efficiency. Since its introduction by Charnes *et al.* (1978)[102], there have been many applications of DEA. Some applications have involved efficiency evaluation of organizations with characteristics similar to ports, such as hospitals (Banker *et al.*, 1986)[103], schools (Ray, 1991)[104], courts (Lewin *et al.*, 1982)[105], and air force maintenance units (Charnes *et al.*, 1985)[106]. DEA has also been applied in the transportation sector to airlines (Banker and Johnston, 1994; Charnes *et al.*, 1996)[107], and railways (Oum and Yu, 1994)[108]. Yeh (1996)[109] was one of the first researchers to combine DEA with financial ratio analysis. She utilized DEA to evaluate bank performance. Emel *et al.* (2003)[110] applied DEA to 82 industrial firms comprising the credit portfolio of one of Turkey's largest commercial banks. He used financial ratios to measure overall performance in a single financial efficiency score—"the credibility score". Donthu and Yoo (1998)[111] assessed retail productivity by DEA. So DEA approach can be used to solve the weight assignment problem and its relative efficiency to measure firm performance.

The DEA with mathematical programming techniques has been applied to the measurement of port efficiency for hypothetical port data by Roll and Hayuth (1993). Theirs is probably the first attempt in this respect. However, this work 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. Since then there have numerous papers that have extended and applied alternative models of the DEA methodology, including BCC, Additive, FDH (Free Disposal Hull), *etc.* Marlow and Paixão (2002)[112] advocate that DEA should be used for port performance measurement. Its suitability has also been examined by Wang, Song and Cullinane (2002)[113]. There have also been several applications of DEA to the sea port industry: e.g. Tongzon (2001); Valentine and Gray (2001), Martinez-Budria et al (1999), etc.

Roll and Hayuth (1993)[114] show how DEA can be useful in assessing the relative effectiveness of various ways of organizing port services when limited data is available They also show the utility of the efficiency indexes for proposing efficiency improvement methods and for controlling the activity of the operators. They evaluated the efficiency of 20 virtual ports through DEA-CCR model with 3 inputs and 4 outputs. Roll and Hayuth define labor as the average annual number of workers in the port. They consider that capital is the annual average of all capital invested in ports and installations. The authors, to pinpoint the degree of specialisation of the port, also included the diversity of load, i.e., uniformity of cargo or merchandise, as an input. Roll and Hayuth adopt a measure of physical quantities of merchandises. They define the multi-output nature of a port through: total cargo considered (to reflect the effort needed to move one tonne of each kind of cargo), level of service (ratio of handling time and the total time a ship remains in port), customer satisfaction (measured through a survey) and the number of ships.

Martínez, Diaz, Navarro, and Ravelo (1999)[115] apply BCC model to assess global efficiencies of 26 Spain ports using 5 observations for each port from 1993 to 1997 and to examine efficiency evolution of individual port. They classified these 26 ports into three groups; namely, 'high complexity', 'medium complexity' and 'low complexity' ports using criteria that considers the port size and the composition of the output vector. The efficiency of those ports is evaluated through DEA-BCC model with 3 inputs and 1 output. To measure the labour input, the authors employ a monetary approach since they consider that the total value of salary payments is a good measure of work. Also, they measure capital input through depreciation expenses. They represent the multi-output activities of port authorities through the total merchandise handled, considering the activity of provision of infrastructure, and of income from installation rental, that measures the capacity of said authorities to attract economic activity. The authors conclude that the ports of 'high complexity' are associated with high efficiency, as well as have the greatest improvements in efficiency. The low complexity ports are placed second, with the efficiency greatly decreased and the medium ports are the lowest in efficiency. They find that the inefficiencies observed in Spanish ports are due to excess capacities.

Tongzon (2001)[116] uses both DEA-CCR and DEA-additive models with 6 inputs and 2 outputs to make an international comparison of technical efficiencies in 4 Australian and 12 other international container ports in 1996. The author represents land input through the area of terminals and defines labor as the average annual number of workers in the port. Tongzon includes separately the number of cranes, container berths, tugs and terminal areas as capital input. In addition, he adds a quality variable approximated by the delay time. The study confirms that the type as well as the size of port is not a determinant factor in the degree of port efficiency. Although, plagued by a lack of data availability and the small sample size (only 16 observations), more efficient ports than inefficient ports are identified. Realising this serious drawback, the author suggests that further work should be done in collecting more observations to enlarge the sample analysed.

Valentine and Gray (2001)[117] also applies DEA-CCR model with 2 inputs and 2 outputs to evaluate relative efficiencies of 31 global container ports out of the world's top 100 container ports for year 1998, and adopts cluster analysis to determine whether there is a particular type of ownership and organizational structure that leads to higher efficiency rating.

Itoh (2002)[118] analysed the container operation of eight ports in Japan by means of a DEA 'window' application. Their efficiency was measured between 1990 and 1999. A single output was employed, the amount of TEUs handled per year. Inputs were categorized as port infrastructure, superstructure and labour. The first models were run with container terminal area (m2), the number of container berths and the number of gantry cranes as inputs. However, he recognized that the initially used inputs were not related to labour. Additional models were run using an estimated value for container operations labour based on the total port labour and the value relation between the share of container cargo and conventional cargo handled at each port. While analysing results Itoh contextualizes them to single exceptional events such as the Maersk terminal relocation, the earthquake in Kobe and the late 1990s Asian monetary crisis. The scale efficiency is also analysed comparing the results of CCR and BCC models. Efficiency measurements using the labour input were found to be consistently higher hence verifying the fact that when one indicator is added to the DEA model, its discriminatory power decreases.

Martin (2002)[119] evaluates the effects that the reforms of the Spanish port system have had on productivity, separating technical progress from efficiency improvements. The object of analysis is the activity of a port but the unit of analysis is the port authority. The author uses the model proposed by Banker and Morey (1986) and calculates a Malmquist index for determining improvements, if any, in productivity and carries out a decomposition isolating the technical progress of the efficiency improvement. To measure labour input, the author incorporates the workers of the port authority (unit analysis) such as the stevedores, which in turn, provide their services to two different agents: stevedoring firms (carry out loading and offloading) and State stevedoring corporations (supply workers to the stevedoring firms). For capital input, he uses the same approach as Coto-Millan et. al. (2000) and also incorporates the surface area of the port. He finds that most Spanish ports have increasing returns to scale. The author shows that, after the port reforms of the 1990s, Spanish port authorities made significant progress in productivity, essentially based on technical progress, and improvements in technical efficiency, which occurs in a particularly relevant manner after 1997.

Bonilla et. al. (2002)[120] also applies the DEA-CCR method to 26 Spanish ports to analyse the relative efficiency of Spanish port authorities, with the help of panel data for the 1995-1998 period. The authors' work is a novel application, since the application of bootstrap techniques allows statistical inference to be made in the non-parametric estimates, obtaining confidence intervals in the efficiency results. Thus, this study successfully overcomes the criticism levelled at the DEA results that the DEA estimates are deterministic, that is, they lack a statistical base. The authors, without any specifications, just present the available equipment as an intermediate input. This study finds that the most efficient port authorities include both large and small ones and the same occurs with the least efficient.

A study of major world container ports was undertaken by **Park Ro Kyung (2002)**[121]. The purpose of the paper was to investigate the productive efficiency and competitive strength of world container ports using the DEA, Super-efficiency, and FDH methods with the raw data from previous research by Jun et al (1993). The main empirical results of this paper were as follows: Firstly, the ports of Singapore, Hongkong, Kilrung, Busan, Tokyo, and Longbeach were found to be efficient in the CCR model. The ports of Felixstowe, Bangkok, Singapore, Hongkong, Kilung, Busan, Tokyo, and Longbeach were found to be efficient in the BCC model. Secondly, the super-efficiency rankings under CRS and input-oriented model were as follows: Longbeach, Keelung, Singapore, Busan, Tokyo, and Honkong. It was difficult to differentiate the rankings under the VRS and input-oriented model, due to major difficulties posed by the ports of Singapore, Hongkong, and Longbeach. Thirdly, the FDH method showed that the inefficient ports were Bremerhaven, Antwerp, Le Havre, Kobe, Seattle, New York. The policy implications of this study were as follows: Firstly, when port authorities want to measure the international competitive strength of container ports and enhance their productive efficiency, they should consider the traditional method as well as introducing the Super-efficiency and FDH methods. Secondly, according to the analysis results of the super-efficiency and FDH methods, port authorities should recommend benchmarks ports and dominated ports as reference ports in order to enhance the productive efficiency of their container ports that have an efficiency rating of less than 1. Efficient ports whose efficiency ratings are over 1 in the input-oriented Super-efficiency model should also consider the usage of input and output elements used by more efficient ports.

Serrano and Castellano (2003)[122] considered the seaport as a multi product industry by defining two output variables for the different types of cargos, containerized freight and non containerized freight. The first was measured in units and the second in tons. Nine major Spanish container ports were analysed. Inputs were the length of berths in meters, the land area in square meters including warehouses, buildings, roads, and even gardens. A proxy variable for the number of cranes was defined as the average GT of container vessels. The rationale was that ports serving larger vessels need to have larger and more specialized cranes. Two models were computed. One considered vessel size as an input while the other did not. Balanced panel data encompassed the period of 1992 to 2000. Average efficiencies were 70 per cent for the model with the extra input and 65 per cent for the other one. From the empirical analysis Serrano and Castellano concluded that Spanish ports had excessive investment in infrastructure or that, because of the lumpiness in port investment, there was at the time excess capacity. Moreover an inverse relationship between efficiency and port size was emphasized.

Barros (2003a)[123] uses the CCR method to compare the efficiency achieved by some Portugese ports to indirectly infer the role of incentives introduced by the Portugese authorities. The author defines capital input as the net value of fixed capital but does not specify which assets are incorporated. This paper distinguishes the greatest number of outputs is: number of ships, movement of freight, gross tonnage, market share, break-bulk cargo, containerised cargo, roll-on/roll-off traffic, dry bulk, liquid bulk, and net income. Barros's is the only non-parametric study that incorporated the price of inputs. The price of labour is obtained by the usual method of dividing the total labour cost by the number of employees and that of capital is calculated by dividing the spending on equipment and buildings by the book value of the physical assets. The author concludes that the reforms made by the Portugese port authorities have placed those ports beyond the efficiency frontier. The port of Aveiro is an exception to the above result, and Barros proposes that the maritime authority establish inspection mechanisms that provide more explicit incentives for improving efficiency.

Barros (2003b)[124] implemented a DEA Malmquist index to ten Portuguese seaports in the 1999-2000 period. The multipurpose nature of national seaports was depicted with output measures of various types of cargo (movement of freight, break bulk cargo, containerised freight, solid bulk and liquid bulk). The number of ships was also considered as an output. The number of employees and the book value of assets were the adopted inputs.

Estache et. al. (2004)[125] identifies the sources of the productivity gains, decomposing the change in TFP into its main components by means of a Malmquist index, built from distance functions calculated by DEA. They do not distinguish between different types of port output but employ total quantity of merchandise as output. The authors conclude that reforms are an incentive to the operator to increase efficiency and productivity and introduce technological progress.

Turner et. al. (2004)[126] measured productivity trends on the top 26 continental U.S. and Canadian container ports using a DEA approach. The influence of the industry structure, Port Authority and carriers conduct were analysed with a Tobit regression. The specific analysed period, 1984 to 1997, lies between two major regulatory acts, the Shipping Act of 1984 and the Shipping Reform Act of 1998. DEA model inputs were restricted to physical measures of container port infrastructure. Disregarding long shore labour was justified on the basis that labour productivity differences were minimal due to standardized gang sizes and related work rules across North America's ports. Therefore model's inputs were defined as container terminal land (ha), container berth length (m) and number of quayside gentry cranes. Total throughput in TEU was the only output adopted. The DEA model results were only explicit in terms of aggregate results for the West, East and Gulf coasts. All of them developed a positive trend during the studied period but the West and Gulf coasts had clearly superior productivity averages than East coast's container port infrastructure. Finally this paper emphasized that "size matters" and stated the relationship between a greater number of railroads and increased container port productivity.

Cullinane et. al. (2004)[127] applied a DEA-window analysis to 25 of the world's top 30 container ports, according to the ranking in 2001. This study was intended to analyse container terminals separately though, due to data constraints, it was then decided to analyse container ports as a whole instead. This is a common problem due to data scarcity and lack of detail. They stated that the definition of efficiency variables should be based on ports objectives. For instance, if the objective of a port is to maximise its profits, then labour should be deemed as an input. On the other hand if the objective of a port is to increase employment, then labour may be accounted as an output variable. Bearing this in mind, inputs were defined as the total quay length, terminal area and number of quay gantry cranes. It was argued that there was a close relationship between the number of employees and the number of gantry cranes in container terminals. This relationship should be regarded with caution, since the fast pace of technology frequently introduces new machineries that require no drivers and there is a different use of labour in ports with different sizes and facilities. Container throughput was adopted as the only output on the basis that it was the most appropriate and analytically tractable indicator of the effectiveness of a container port. Cullinane et al. indicate two reasons why they chose an output oriented model, a theoretic one and a pragmatic one. Firstly an output oriented model was chosen on the basis that container ports must frequently review their capacity in order to stay competitive. Secondly, under a more pragmatic view, an output oriented model facilitates the results discussion when there is only one output. Both CCR and BCC models were applied, within a three year window analysis period. Results showed that production scale was not the main source of inefficiency for most container ports. In addition some world renowned ports such as Rotterdam, Hamburg and Antwerp were found to be inefficient comparing to smaller container ports that showed largely superior efficiency scores. However an in depth contextualization analysis of these results shown that larger container ports had invested heavily in capacity enlargement and new equipments. This caused a short term over capacity. They hypothesize that competition and competitiveness might explain these empirical inefficiency results, in opposition to the traditional economic theories.

Park and De (2004)[128] went beyond the traditional DEA approach and proposed a four stage procedure were productivity, profitability, marketability and overall efficiency were separately measured. Analysed variables encompassed berthing capacity, cargo handling capacity, cargo throughput, number of ship calls, revenue and customer satisfaction. Each of these variables was either considered as an input or an output, depending on the stage. Both CCR and BCC models where used to compute the four stage approach for 11 Korean ports. Inferences about increasing or decreasing returns to scale were taken. Results were somewhat mixed with some ports presenting increasing returns to scale in some phases and decreasing returns to scale in others. A factor specific efficiency analysis computed the single input/output potential decrease/increase when all other inputs and outputs were kept at current levels. This analysis was performed for the productivity, profitability and marketability stages. It was found that marketability improvements should be prioritized by Korean Port Authorities and that six of the eleven ports had significant input congestion.

Barros and Athanassiou (2004)[129] apply DEA to the estimation of the relative efficiency of a sample of Portuguese and Greek seaports. The broad purpose of this exercise was to facilitate benchmarking so that areas for improvement to management practices and strategies could be identified and, within the context of European ports policy, improvements implemented within the seaport sectors of these respective countries. The results of the analysis point to the inefficiencies of particular ports and appropriate benchmarks by which ports could improve performance. Scale efficiency was recommended as the paramount objective for the ports under study and privatisation was advocated as the most appropriate method for achieving economic efficiency. They distinguish the following outputs: number of ships, movement of merchandise, cargo handled and containers. The authors define the capital input in the same way as Barros (2003).

Cullinane et. al. (2005a)[130] analysed the relationship between the property structure of the ports and efficiency for the top 30 international ports using panel data for the years from 1992 to 1999. The authors find no evidence for upholding a relationship between privatization and efficiency.

Realising that DEA cross-sectional data approaches might be inferior to those utilizing panel data and given the characteristics of the container port industry and the random effects associated with each single measured value of production and the level of measured efficiency associated with it, Cullinane et al (2004) and Cullinane, Ji and Wang (2005) apply alternative DEA panel data approaches to derive the efficiency of container ports. In so doing, the development of the efficiency of each container port in the sample can be tracked over time and, in consequence, the efficiency results are ostensibly more convincing.

In order to examine the pros and cons of applying alternative non-parametric approaches (including DEA) to the container port industry, **Cullinane, Song and Wang (2005b)**[131] applied both DEA-CCR and DEA-BCC methods, as also another non-parametric method the Free Disposal Hull (FDH) Model to 57 of the world's leading container ports. On comparing the results, the authors found that the available mathematical programming methodologies lead to different conclusions and that the definition of input and output variables is crucial elements in meaningful applications of DEA and FDH. They conclude that the methodology to be applied is the relevant issue. They propose that a combination of DEA and FDH is the most appropriate for taking company and port authority decisions. Also, on the question of whether DEA-CCR or DEA-BCC should be applied, they state that, given the evidence on economies of scale in container terminals, DEA-BCC would be better choice if the objective is only to identify technical efficiency.

Cullinane et. al. (2006)[132] apply DEA (CCR as well as BCC) and SFA both to the same sample as the above and compare DEA and stochastic production frontiers. The study shows that, with the exception of Singapore, the ports with the greatest levels of private participation are the most efficient. It also concludes that the mean efficiency levels of terminals in hub ports is greater than in feeder ports, though with higher levels of dispersion within each group. The study also finds that 60% of the ports studied have decreasing returns. The authors suggest that the large ports have made major investments which have allowed them to grow, but after certain limit, they cannot grow any further - thus operating at the capacity levels for which they were designed. On the other hand, the smaller ports do not have physical restrictions for expansion of the same dimensions as that of large ports and so frequently have new ports or terminals installed, which are just starting to evolve. As a result, these ports operate below their capacity and can thus, benefit from increasing returns to scale.

An extensive analysis of European container terminals efficiency was accomplished by **Wang and Cullinane (2006)**[133]. They were able to compile data at the terminal level. This had been several times tried before, but always unsuccessfully, because data usually comes aggregated at the port level. In this paper 104 European terminals across twenty nine countries were analysed with CCR and BCC models. Considered inputs were the total quay length, terminal area and aggregated annual expenditure with terminal equipment. As usual in previous studies, a reliable source of labour data was not available. Following the established practice of precedent studies which focused in containerized cargo efficiency, container throughput was the only output considered. This study had an exceptional number of DMU relatively to former DEA approaches. Thus average efficiency results were naturally expected to be lower, as they did, since a larger sample allows for a higher discriminatory power among efficient DMUs. Anyhow, even with this in mind, average efficiencies of European container terminals were found to be quite low as the average efficiency score amounted only to 0.43 with the CCR model. A preliminary result analysis suggested larger terminals to be more likely to have higher performance levels than smaller ones. This was reinforced with a similar conclusion after a Tobit regression analysis. A comparison between container terminals grouped by their location in Europe revealed that the British Isles and Western European terminals had higher efficiency scores while Eastern European and Scandinavian terminals performed least efficiently.

Realising that DEA cross-sectional data approaches might be inferior to those utilizing panel data and given the characteristics of the container port industry and the random effects associated with each single measured value of production and the level of measured efficiency associated with it, Cullinane et al (2004) and Cullinane, Ji and Wang (2005) apply alternative DEA panel data approaches to derive the efficiency of container ports. In so doing, the development of the efficiency of each container port in the sample can be tracked over time and, in consequence, the efficiency results are ostensibly more convincing.

A MERCOSUR container terminal analysis was carried out by **Rios and Macada (2006)**[134] for the period between 2002 and 2004. A model validation procedure relied on close contact with a group of port executives. They were asked two times for suggestions during the implementation of the analysis. Firstly in the initial stage of model implementation and secondly after an initial model had been set up and preliminary results had been obtained. The latter led to the consideration of an extra output in the final model. A BCC model was used with five inputs, the number of cranes, the number of berths, the terminal area, the number of employees and the number of yard equipment. Initially the only considered output was the container throughput in TEU. Following the port executives suggestion a second output, the number of movements per hour per ship, was included in the final model. Of 23 analysed terminals 14 were 100% efficient during the 3 year period. However the number of efficient terminals decreased from 17 in 2002 to 14 in 2004. Five of the six large terminals were found to be efficient during the whole period.

A benchmark analysis of Italian seaports was accomplished by **Barros (2006)**[135]. Twenty four Italian Port Authorities were analysed over the years of 2002 and 2003. Seven outputs were considered: liquid bulk, dry bulk (including ro-ro cargo), number of ships, number of passengers, number of containers with TEU, number of containers with no TEU and total sales. Measured inputs included the number of employees, value of capital invested and size of operating costs. Using output orientation both CCR and BCC efficiency scores were computed using average values for the period. Only eight of the 24 Port Authorities were found to be inefficient with the BCC model while the CCR model results showed sixteen inefficient units. Most of the Port Authorities had decreasing returns to scale. Given the relatively high number of efficient units DEA-Cross Efficiency and DEA-Super Efficiency models were used. Trapavi Port Authority achieved the highest efficiency score with both of these models.

Garcia-Alonso and Martin-Bofarull (2007)[136] analyse the extent to which investment expenditure has led to improvements in efficiency and how far this improved efficiency increases the port's ability to attract traffic. They use DEA and study inter-port traffic redistribution from the land side. Thus, they analyse (i) changes in the levels of efficiency in each port and (ii) changes in the impact of the ports' respective competition policies on patterns of port selection in the Spanish provinces. The analysis focuses on the Ports of Bilbao and Valencia, ports which have invested heavily. They also evaluate, using the Goodman and Kruskal lambda coefficient, the extent to which the strategies used in each port have succeeded in attracting a greater volume of traffic and analyse how these strategies affected port selection in each region in the period studied. They have used a multi product production function. Inputs considered are staff and stevedores, materials consumed (measured in thousand euros at constant prices), quay length and stocking areas as variable The outputs are solid bulk and general cargo. They use the efficiency index for the Spanish port system to study the changes in efficiency that has taken place in the two ports. For this they consider a sample of 21 Port Authorities on the Spanish mainland for the period 1992–2002. The results of this investment, however, have been quite different. On comparing the volumes of expenditure on infrastructure in each port with the changes in the levels of traffic, it was found that the volume of investment expenditure that is intended to improve port installations is no guarantee that a port will successfully compete for traffic with other ports, that is, expenditure on the infrastructure of a port installation is not necessarily reflected in a gain in efficiency. This study also confirms that the gains in efficiency do not produce a clear redistribution of national maritime traffic in favour of the ports that achieve them.

The papers can also be classified according to the samples. Papers are based on samples coming from a single country, or they can include ports of different countries. Within the single-country sample, the most recent are Park and De (2004) study of Korean ports, Cullinane and Song (2003) analysis of Korean ports, Gonzalez and Trujillo (2005) study of Spanish ports, and Estache, Gonzalez and Trujillo (2001) study of Mexican ports. These papers have relatively few ports and a long time series. The paper on Mexico has the largest number of ports (13) while the paper on Spanish ports covers the longest time span (1990-2002). These papers have an output variable and use some proxies for capital, labour and other intermediate products as inputs.

Alternatively, the sample can cover ports from around the world. Among this group of papers we have Cullinane, Song, Ji and Wang, including the largest 30 container ports. Valentine (2001) study of 15 African ports, Valentine and Gray (2001) that study 31 container ports across the world, and Notteboom, et.al (2000) that included 36 European container terminals and 4 Asian terminals. All of these studies use DEA techniques, except Notteboom, et. al. They all use as inputs the number of cranes, the terminal area, and the container berth length. None of these papers uses labour input, except Notteboom et. al. They report no statistical significance for this input which is attributable to its multicollinearity with cranes. In turn, most of the papers cover developed nations, with the exception of Estache et.al. and Valentine (2001). referenced above.

3. SURVEY OF PORT STUDIES UNDERTAKEN IN INDIA

Although there are some studies, which have tried to understand the relationship between port performance and port traffic in India, there has been no concerted scientific effort to estimate the productivity of Indian ports, when ports alone handle over 80 per cent of the country's merchandise trade.

Ghsoh and De (2000)[137] studied the relationship between port performance, labour endowment and port throughput for the 12 major ports of India over the period 1985 to 1996. They constructed the Port Performance Index (PPI) with the help of Principal Component Analysis (PCA) using 8 variables: ship turnaround time, pre-berthing waiting time, percentage of idle time at berth to time at working berth, output per ship berth day, berth throughput rate, berth occupancy rate, operating surplus per tonne of cargo handled and rate of return on turnover. Then, using the OLS method, they estimated a quasi-production function using the constructed PPI as an independent variable along with labour and capital. Their findings showed that port traffic is highly contingent upon port performance. It was found that to attain higher traffic, ports needed to improve their operational performance factors like ship turnaround time and pre-berthing waiting time and also asset performance indicators like berth occupancy rate as these indicators were the ones that were related to port congestion. Labour employment was also found to have a positive and significant association with traffic.

De and Ghosh (2002)[138] have undertaken a study concerned with the performance of Indian ports (only major ports)in terms of labour productivity (LP) in relation to capital coefficients. They studied the effect of technological advancement - reflected by rising capital intensities - on the productivity of labour in Indian ports for a 20-year period between 1981-1982 and 2000-2001. Thus, this study examined: (i) the impact of advanced technology, which was proxied by rising K/L ratios, in the Indian port sector on the efficiency of factor use; and (ii) the factors influencing labour productivity across major ports. The generic labour and capital are the two inputs whereas port traffic is the output. The results they found can be summarised as follows: First, increasing use of overhead capital produced significant improvement in productivity. Second, there was an upward shift of the productivity locus, implying thereby that the major ports of India had witnessed some kind of technological metamorphosis between 1980-1981 and 2000-2001. Third, the most important factors that influence labour productivity in an aggregate sense were found to be the capital/labour ratio, and rate of return on turnover. It was also found that ship turnaround time and port's skilled human resources did not play any significant role in determining labour productivity.

De and Ghosh (2003)[139] undertake to analyse empirical causality between port performance and port traffic in the context of India. The authors have attempted to measure the performance of Indian ports by developing the Port Performance Index (PPI) with the help of Principal Component Analysis (PCA). The indicators they have taken into consideration are the operational performance indicators, viz., ship turnaround time, pre-berthing waiting time, percentage of idle time at berth to time at working berth, output per ship berth day, berth throughput rate, berth occupancy rate and financial performance (operating surplus per tonne of cargo handled and rate of return on turnover) for the 12 major ports of India for the period 1985-1999. They have applied unit root tests, cointegration tests and Granger causality test to determine the causal relationship. Their findings show that traffic does not lead to performance for any of the ports but, in fact, for most of the ports performance causes traffic in India.

Prabir De (2006)[140] studies the 12 major ports of India for the period 1980–1981 to 2002–2003 with the objective to assess total factor productivity (TFP) growth of the Indian port sector, particularly, (i) labour productivity in terms of value added per unit of labour and (ii) total factor productivity in terms of unexplained residual from the contributions of labour and capital. This is in order to check the extent of the impact of new technology on the productivity of the factors of production in the Indian port sector. He makes use of the production function approach to measure TFP, more explicitly, the Cobb-Douglas production function. The input variables are labour and capital whereas the output is port traffic. The stock of capital is measured using Perpetual Inventory Accumulation (PIA) method. The results he found are very interesting. Indian ports of the east coast have recorded higher output growth rates during the post-liberalisation period (1991–1992 to 2002–2003) than before (1980–1981 to 1990–1991). In west coast ports, with the exception of Cochin and Mormugao, growth rates decelerated in the post-liberalisation period. In the case of labour productivity, in the post liberalisation period Mumbai, New Mangalore, Tuticorin, and Chennai showed a fall in labour productivities whereas all others show a rise. Average annual growth rates of labour productivity for most of India's major ports significantly outweighed those of traffic. For the capital-labour ratio, with the exception of Haldia, Indian ports witnessed a rise in capital-labour ratio in the post-liberalisation period, indicating thereby that Indian ports have witnessed infusion of more capital, as well as fall in employment in the post-liberalisation period. In other words, Indian ports are becoming more capital intensive In case of TFP changes, with the exception of Kolkata, rest of the Indian ports exhibited statistically significant positive TFP changes over the period from 1980–1981 to 2002–2003. None of the Indian ports recorded statistically significant TFP change during the post-liberalisation period, except New Mangalore, which incurred statistically significant negative TFP change in the post-liberalisation period. This was indicative of the fact that the economic climate in the post-1991 period has not made any substantial impact on the performance of Indian ports.

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