

**PRODUCTION AND COST FUNCTIONS AND THEIR APPLICATION TO THE PORT SECTOR
A LITERATURE SURVEY**

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Abstract

Seaports provide multiple services to ships, cargo, and passengers. These services can be performed by a combination of public and private initiatives. Usually, the role of public sector institutions is to regulate and supervise private firms. In performing that task public sector institutions need to know firms' cost structure deeply. This paper offers a review of the literature about ports' cost structure and of its implications for regulation. The paper argues that the operation of port terminals should be analysed by means of multiproduct theory. This approach allows the calculation of several cost indicators (economies of scale, scope, and so forth) which are key tools to help regulators.

Key words: multiproduct, economies of scale and scope, port and cargo handling.

JEL Classification system: L9

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1. Introduction

The estimation of key indicators in the firms' cost structure, such as marginal costs, economies of scale and scope, plays an essential role in the determination of the optimal industrial structure and therefore, represents a fundamental tool contributing to ease the regulators' job. This paper focuses on the contribution of the literature towards the study of production and cost functions in the port industry and provides a detailed and critical analysis of the relevant aspects of cost functions.

The analysis of firms' cost structure has always been an important task for economists since a thorough knowledge of costs can be useful for many policy purposes -although, the specific policy aim drives what to estimate and how to estimate it. In particular, knowledge of a port firm's cost structure also helps reach the best decisions in relation to the regulation of the sector. In most countries, the port industry is subject to some kind of control by the public sector since it is generally in charge of planning future investments –among other functions-. In this context, deep knowledge of port firms' cost structure results essential not only to decide where, when and how much to invest but also to suggest optimal tariff structures.

The main purpose of this paper is to review the economic literature on econometric estimation of production and cost functions in the port sector which assumes an efficient behavior of the firm. Before getting into the issue, section 2 deals with a brief revision of the alternative methodologies used for the analysis of the port sector. Section 3 describes the main theoretical aspects of multiproduct theory, focusing on the instruments provided by this theory for the determination of relevant cost concepts. Section 4 provides an analysis of the theoretical aspects related to the econometric estimation of production and cost functions. Section 5 presents a detailed review of economic literature dealing with the econometric estimation of production and cost functions in the port industry assuming an efficient scenario. Lastly, section 6 concludes.

2. Alternative methodologies

The first generation of papers analyzing ports' production and cost structure focused on planning and managing future investments. More specifically, the empirical estimation of port cost functions starts in the seventies with a study carried out by *Wanhill (1974)* aimed at designing a model which allowed determination of the optimal number of berth minimizing total cost for port use. These costs resulted from the addition of two different components: the cost of providing infrastructure (berth) and the cost of the ship's stay in the port. 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 *Wahnill (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.¹ At the same time, the manual shows the difficulty to measure the return on port terminal operations on the basis of the data generally available in the ports' yearbooks and yet this it is essential to make estimations of the production and cost function in order to analyze productivity growth, economies of scale and technical change.

The branch of the literature concerned with the optimal planning of ports or port terminals which started with the two papers mentioned above, continued with the papers by *Janson and Sheneerson (1982)*, *Sheneerson (1981, 1983)*, *Janson (1984)*, and *Fernández et al. (1999)*. 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. This explains why all these papers 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.

Two criticisms have been leveled against these models which add users and operators' costs. On the one hand, the vessel's time is introduced as a productive factor in the port cost function, even though –following *Hooper (1985)*– it is more convenient to consider it a product component representing service quality. On the other hand, when the productive process to be modeled includes more than two inputs or outputs, as in the case of ports, the selected functional form should not impose their separability a priori (*Burgess, 1974*), but it should be empirically contrasted. Furthermore, costs analysis should enable to carry out

¹ This cost has a fixed component that is independent of the volume of cargo handled (which includes, for example, the costs of capital of berths, sheds, etc.) and a variable cost which depends on the total tonnage handled (and includes the costs of labor, maintenance, fuel, etc.).

evaluations of ports' return and productivity by calculating different indicators, such as in the studies by *De Monie (1989)*, *Dowd and Lechines (1990)*, *Talley (1994)*, and *Conforti(1992)*. Additionally, it would allow comparisons of the productive efficiency among various firms and throughout the time for a single firm.

Following this line of study, a new branch of research which differs from the typical papers considering that firms are minimizing costs and, therefore, allows the analysis of situations in which this assumption is breached. Thus, it admits the possibility that firms may be inefficient. There are two different techniques to carry out this type of studies. The first is called *Data Envelopment Analysis (Roll and Hayuth, 1993; Martínez Budría et al.,1999, and Tongzon, 2001)* and the second is the econometric frontier and distance functions estimation (*Liu, 1995; Baños-Pino et al.; 1999; Notteboom et al., 2000; and Estache et al., 2002*).

The Data Envelopment Analysis (DEA) and the frontier function estimation represent two alternative methods to estimate production and cost frontiers and, therefore, to measure efficiency. Both techniques allow derivation of relative efficiency ratios within a group of analyzed units, so the efficiency of the units is compared through an *efficient envelopment*. However, while frontier function estimation uses econometric methods, the DEA is a non-parametric technique based on linear programming. These methods are applied to cross-section samples although, but if panel data are available, it can also be used to measure technical change and the change in efficiency.²

3. Production, costs and optimal industrial structure

Although most productive activities developed in the real world are multi-productive, until not too long ago, the development of production theory focused on single-productive processes. The well-developed theory which allowed empirical contrast of the relevant single-productive concepts was not applicable to multi-productive processes.

The application of the single-productive theory to multi-productive processes through the use of aggregates to measure the product caused some inconsistent results which led to the development of new theoretical concepts to deal with multi-productive processes and, for the first time, arrive at an endogenous determination of the industrial structure (*Baumol et al. 1982*). Unlike single-productive firms, whose cost-production structure can be described with

² For a summary of literature about port efficiency, see *González and Trujillo (2002)*.

relatively few interrelated concepts, multi-productive firms' cost analysis requires the description of several new concepts. This led to the development of a theory which –as could be expected- considered single-production as a particular case.

Empirical determination of all cost concepts for a certain industry can be achieved through the econometric estimation of the corresponding cost function $C(W, Y)$. The explanatory variables of such function, after all variable factors have been assumed, are product vector Y and price vector of productive factors W . The latter has been eliminated in the expressions below in order to simplify the mathematical formula.

Thus, the marginal cost of product i can be obtained as a derivative of the cost function with respect to such product.

$$\frac{\partial C}{\partial y_i} = Cm_i \quad (1)$$

On the other hand, the degree of global economies of scale is a technical property of the productive process which is defined in transformation or production functions. However, dual relations allow calculation of the degree of the economies of scale directly through cost function (*Panzar and Willig, 1977*) as follows:

$$S = \frac{C(Y)}{Y \nabla_y C(Y)} \quad (2)$$

The degree of global economies of scale represents the maximum growth rate that product vector can reach when productive factors vector increases. Therefore, the presence of increasing returns of scale ($S > 1$) implies that an increase of productive factors by a certain proportion λ enables an increase of the set of products by a proportion greater than λ , showing that a production expansion enjoys advantages from the point of view of costs.

Another way in which the firm's operations can change is through the variation of the production of a specific output, considering the other products' output constant. In order to study the cost of this variation, it is necessary to define the incremental cost of product i . The incremental cost of product i is represented by the cost of adding the i th product plus the vector of products produced by the firm and can be expressed as:

$$CI_i = C(y_1, y_2, \dots, y_n) - C(y_1, y_2, \dots, y_{i-1}, 0, y_{i+1}, \dots, y_n) \quad (3)$$

Although the average cost is not defined in multiproduct because Y is a vector³, the

³ In this case, it is possible to define a *ray average cost* C/λ related to the product proportional expansion from a

average incremental cost is defined and reads:

$$CIME_i = \frac{CI_i(Y)}{y_i} \quad (4)$$

Incremental cost and average incremental cost definitions are used to identify the specific returns to scale of a given product y_i :

$$S_i(Y) = \frac{CI_i(Y)}{y_i \frac{\partial C(Y)}{\partial y_i}} = \frac{CIME_i(Y)}{\frac{\partial C(Y)}{\partial y_i}} = \frac{CIME_i(Y)}{C_i(Y)} \quad (5)$$

where $C_i(Y)$ is the marginal cost of product i . Then, the degree of scale economies specific to a product y_i is the quotient between the product's average incremental cost and marginal cost. They will be increasing, constant or decreasing depending on whether $S_i(Y)$ is larger than, equal to, or smaller than one, respectively.

The incremental cost definition can be extended to a subset of products R which is very useful since it allows the identification of the specific return to scale for a given subset of products. Accordingly, the degree of economies of scale specific to subset R is defined as follows:

$$S_R(Y) = \frac{CI_R(Y)}{\sum_{j \in R} y_j \frac{\partial C(Y)}{\partial y_j}} = \frac{CI_R(Y)}{\sum_{j \in R} y_j C_j(Y)} \quad (6)$$

The economies of scale specific to the subset of products R will be increasing, constant or decreasing depending on whether $S_R(Y)$ is larger than, equal to, or smaller than one, respectively. Consequently, if $S_R > 1$, setting tariffs equal to the marginal cost would not cover incremental costs. Note that equation (2) represents a particular case of equation (6) when R equals M .

Cost complementarity between two different products can be analyzed following the expression (7). With values smaller than or equal to zero, it indicates a weak cost complementarity:

$$C_{ij}(Y') = \frac{\partial^2 C(Y')}{\partial y_i \partial y_j} \leq 0, \quad i \neq j, \quad \forall 0 \leq Y' \leq Y \quad (7)$$

However, the expansion of the output vector may mean the introduction of new products in the production line giving rise to a new concept related to production diversification. This last

bundle of products Y^0 .

possibility leads to a specific concept of multiproduct called economies of scope.

The economies of scope concept is useful to analyze whether it is advisable or not to have the firm diversified or specialized. Thus, economies of scope measure the relative cost increase that would result from the division of the production of Y into two different production lines T and $N-T$. Formally, if an orthogonal partition of product vector M into two subsets T and $N-T$ is carried out, the degree of economies of scope ED_T of subset of products T with relation to its complementary subset $N-T$ will follow this expression:

$$ED_T(Y) = \frac{1}{C(Y)} [C(Y_T) + C(Y_{N-T}) - C(Y)] \quad (8)$$

in such a way that the partition of the production will increase, decrease or not alter total costs depending on whether $ED_T(Y)$ is larger than, equal to, or smaller than zero, respectively. Accordingly, if $ED_T(Y) > 0$, there are economies of scope and, therefore, it is cheaper to produce the product vector Y jointly than product vectors Y_T and Y_{N-T} separately. In other words, it is not advisable to specialize the production. It is easy to see that ED should be in the interval $(-1, 1)$.

Lastly, there is a relation between the degrees of economies of scale and scope represented by the equation:

$$S_N(Y) = \frac{\alpha_T S_T(Y) + (1 - \alpha_T) S_{N-T}(Y)}{1 - ED_T(Y)} \quad (9)$$

where

$$\alpha_T = \frac{\sum_{j \in T} y_j \frac{\partial C(Y)}{\partial y_j}}{\sum_{j \in N} y_j \frac{\partial C(Y)}{\partial y_j}} \quad (10)$$

This relation shows that, in the absence of economies of scope ($ED=0$), S would be a weighted average of the specific economies of scale of each subset. However, the existence of economies of scope ($ED>0$) favors the presence of economies of scale.

4. Econometric estimations of production and cost functions

The first objective of the applied production analysis is the empirical measurement of economically relevant information enabling the thorough description of economic agents' behavior. For smooth technologies (i.e., twice continually differentiable), this includes

function value (for example, cost level), function gradient (for example, derived demands or marginal costs) and the Hessian (for example, the elasticity matrix of derived demands or the derivatives of marginal costs). Therefore, when choosing the functional form to be used for the empirical estimation, the aim should be to choose a specification with enough parameters to enable the analysis of all these effects without imposing a priori restrictions.

The functional form used in the first empirical papers on production function estimations in the port sector is the Cobb-Douglas function, which reads as follows:

$$Y = AL^\alpha K^\beta T^\gamma \quad (11)$$

$$Y > 0, K > 0, L > 0, T > 0, \alpha \geq 0, \beta \geq 0, \gamma \geq 0$$

where Y is the output, L is the labor factor, K is the capital factor, T is the technology level and A , α , β , and γ are the constant parameters to be estimated. α , β , and γ represent product elasticities with relation to labor, capital and technology, respectively, i.e., each one indicates the relative share of the corresponding factor in the total product.

The Cobb-Douglas functional form –although easy to estimate- presents important limitations. This functional form has been widely used in the literature to evaluate scale effects, since the latter could be easily contrasted parametrically through function exponents. This function belongs to the homogenous functions group⁴ and, therefore, it restrains the way in which scale effects⁵ and elasticities of substitution⁶ take place. There are other functional forms which do not present these limitations. Thus, the constant elasticity of substitution function (CES) is the natural extension of Cobb-Douglas function since it allows the elasticity of substitution to take values different from the unit. The following obvious step is to generate a function allowing the elasticity of substitution to change when the product or the proportion of productive factors used varies. The production function enabling these two generalizations is the translogarithmic function.

The estimation of a production function in the case of multiproduct is more complex, since the scale representation $Y=f(X)$ has to be changed for more general ways of representation $F(X,Y)=0$, which usually solves assuming separability to enable representations as $g(Y)=f(X)$. In these cases, it is very advantageous to use a cost function since it relates the

⁴ The function is homogenous of degree $\alpha + \beta + \gamma$. If $\alpha + \beta + \gamma > 1$, there are increasing returns to scale; if $\alpha + \beta + \gamma = 1$, this indicates the presence of constant returns; and if $\alpha + \beta + \gamma < 1$, then, there are decreasing returns to scale.

⁵ This is so because its scale elasticity is constant, i.e., it does not change before variations in the proportion of productive factors and/or production level.

⁶ The marginal rate of technical substitution equals the unit, for all production levels and for any combination of productive factors.

cost of obtaining a certain production (which can be a vector) with the price of the productive factors used. As known, duality theory enables the empirical study of production structure through cost function estimation.

Most empirical studies apply cost functions which are twice differentiable in relation to productive factors prices. Under these conditions, the cost function has an important property known as Shephard's lemma, which allows generation of demand functions per factors like the derivative of $C(W, Y)$ with respect to each factor's price.⁷ Those derived functions encompass subsets of cost function parameters. As many additional equations to the cost function can be obtained as there are productive factors in the production process, without the need to introduce any other additional parameter. The system's estimation through cost function and derived-per-factor demand functions generates more efficient parameter estimations than those obtained with only the cost function. This represents the most practical advantage of a cost function (*McFadden, 1978*).

On the other hand, the functional form selected to represent a cost function needs to meet certain regularity conditions to ensure that it is a true cost function, i.e., a function consistent with the idea of achieving a certain production volume at the minimum expense, on the basis of certain given factor prices. It is widely known (*see Varian 1978*) that the appropriate functional form representing a cost function must be non-negative, linearly homogenous, concave and non-decreasing in factor prices. Furthermore, a cost function must be non-decreasing in outputs when assuming free disposability.⁸

In addition to these generic conditions, a cost function must meet other requirements if it is to be used in the estimation of a multi-product process (*Baumol et al. 1982*). First, the function must provide reasonable cost figures for product vectors with some component at zero level, since not all the firms need to produce all industry products. The Cobb-Douglas function and the translog function, for example, violate this condition.⁹ Secondly, the function must not prejudge the presence or absence of any cost property playing an important role in the analysis of the industry. On the contrary, the functional form must be consistent with the satisfaction or violation of those properties, so the empirical results obtained arise from the data and not as a consequence of the selected functional form. This property is called

⁷
$$\frac{\delta C(W, Y)}{\delta w_i} = x_i \quad (\text{Shephard's lemma})$$

⁸ Linear homogeneity in factor prices results essential for the existence of a dual relation between transformation and cost functions (*Caves et al., 1980*).

⁹ In this case, the problem can be solved by applying Box-Cox transformations, although this highly complicates the interpretation of parameters.

substantive flexibility of the functional form. Once again, the Cobb-Douglas functional form represents an example of the violation of this condition since the form itself imposes the result that there is no weak complementarity of costs, regardless of the fact that reality may be different.¹⁰ This is the reason why the Cobb-Douglas function is not suitable for multi-productive cost function estimations. Thirdly, the function must not require the estimation of an excessive number of parameters and, lastly, it must not impose restrictions on the value of the first and second partial derivatives.

Therefore, based on the foregoing, it is clearly preferable to use functional forms which avoid restrictions imposed by the functional form itself -such as the so-called flexible functional forms- developed on the basis that they provide a good local approximation of a twice differentiable arbitrary function (*Diewert, 1974*). Moreover, this allows empirical contrast of additional restrictions, such as homogeneity, homotheticity, separability, constant returns to scale and constant elasticities of substitution, directly from the data instead of them being imposed a priori (*Dodgson, 1985*).

Caves, et al.(1980) indicate three problems that may turn the flexible functional forms used empirically less attractive, namely: the violation of regularity conditions in the production structure, the estimation of an excessive number of parameters and the impossibility to work with observations at zero production levels. On the basis of this perspective, the most frequently flexible functional forms used in the port sector are analyzed below: the quadratic function and the translogarithmic function.

The quadratic function, first proposed by *Lau (1974)*, is a Taylor expansion of second order and is consistent with the following equation:

$$C = \alpha_0 + \sum_i^m \alpha_i y_i + \sum_i^n \beta_i w_i + \frac{1}{2} \sum_i^m \sum_j^m \delta_{ij} y_i y_j + \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} w_i w_j + \sum_i^m \sum_j^n \rho_{ij} y_i w_j \quad (12)$$

where C is the total cost, Y is the output vector, W is the productive factors vector and, α_0 , α_i , β_i , δ_{ij} , γ_{ij} , and ρ_{ij} are parameters to be estimated.

The translog function is a quadratic form where variables have been expressed in logarithms:

$$\begin{aligned} \ln C = & \alpha_0 + \sum_i^m \alpha_i \ln y_i + \sum_i^n \beta_i \ln w_i + \frac{1}{2} \sum_i^m \sum_j^m \delta_{ij} \ln y_i \ln y_j + \\ & \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} \ln w_i \ln w_j + \sum_i^m \sum_j^n \rho_{ij} \ln y_i \ln w_j \end{aligned} \quad (13)$$

¹⁰ In fact, if there were cost complementarity, an estimation using Cobb-Douglas function would produce biased marginal cost estimates.

Both flexible functional forms present advantages and drawbacks. Then, the selection between them depends on the policy issue and context at stake. One of the advantages of the quadratic function is that it is well defined for zero values so it allows consideration of those cases in which some output vector element is nil, i.e., it enables the analysis of economies of scope and incremental costs (*Roller, 1990*). On the contrary, the translog function does not allow zero values and then, it is not suitable for the study of economies of scope unless a proper output transformation is applied, such as a Box-Cox transformation. Although this provides a solution, it complicates significantly the interpretation of parameters.

Another advantage of the quadratic function is that it allows the determination of marginal costs considered at the approximation point α_i , and Hessian values δ_{ij} , which result essential for the subadditivity analysis (*Jara Díaz, 1983*). On the other hand, there are two disadvantages generally mentioned about the quadratic function. The first is that it is not possible to ensure that linear homogeneity in prices is met. However, this condition can be imposed simply by normalizing cost function by one factor price (*Martinez-Budría et al., 2003*). The second is that the cost function is very strict as regards specification of fixed costs whose effect should be captured by a single parameter, α_0 . The problem with this is that, in fact, fixed costs may vary depending on which subset of total products group is being produced. In order to solve this issue and give the functional form the capacity to capture these differences in fixed costs that may arise among firms producing different groups of products, dummy variables, F_i , are introduced. The value of these variables is represented by the unit when there is some production of product i , or zero otherwise. This leads to the following flexible fixed costs quadratic function (*Mayo, 1984*):

$$C = \alpha_0 + \sum_i^m \alpha_i y_i + \sum_i^n \alpha_i F_i + \sum_i^n \beta_i w_i + \frac{1}{2} \sum_i^m \sum_j^m \delta_{ij} y_i y_j + \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} w_i w_j + \sum_i^m \sum_j^n \rho_{ij} y_i w_j \quad (14)$$

In contrast, the translog function's main advantage is that it allows the analysis of the underlying production structure, such as homogeneity, separability, economies of scale, etc. through relatively simple tests of an appropriate group of estimated parameters. Its first order coefficients at the approximation point are the cost-product elasticities calculated at this approximation point (usually the mean) in a manner such that their addition represents an estimation of the inverse of the degree of economies of scale (*Jara-Díaz, 1983*).

The number of parameters to be estimated is larger in the quadratic function than in the translog (*Caves et al., 1980*) and this is so because the restraints imposed on the translog function to ensure it fulfills the conditions of homogeneity of degree one in factor prices,

symmetry, etc., limit the number of free parameters to be estimated.¹¹ Even though ordinary least squares could be used to estimate any one of these two functions, if having additional information, it can be used to improve the estimate efficiency. Applying Shephard's lemma ensures that there is a group of factor demand equations that can be derived from the cost function. In this way, we can obtain as many additional equations to cost function as there are productive factors (n) involved in the estimation of costs, without introducing any additional parameter. The maximum likelihood method can be used to estimate the unknown parameter, specifying that $n+1$ equations bear normal additive errors. Although cost functions can be estimated alone, it is clearly more efficient to estimate parameters from the $n+1$ equations system.¹²

Lastly, it is worth mentioning that estimating these functions at the approximation point (generally the sample mean) represents usual practice in the empirical paper and there are basically two reasons for this. First, this results in an immediate estimation of the gradient at the approximation point and Hessian elements. Second, multicollinearity between linear, square and cross terms is avoided because independent variables variations are magnified. In fact, if expansion is carried out around zero values, multicollinearity problems arise, although estimates are the same (*Jara-Díaz, 1983*).

5. Production and cost functions in ports

The literature on port production and cost structure is about 25 years old. While it addresses many of the general issues raised in the theory survey above, of particular interest is the set of contributions focusing on economies of scale and, in some cases, economies of scope. Two different approaches can be distinguished within this group of papers. The first approach is represented by the studies using production functions, such as *Chang (1978)*, *Reker et al., (1990)* and *Tongzon (1993)*. The second approach encompasses the studies that estimate cost functions, whether single-productive as in *Kim and Sachis (1986)* and *Martínez Budría (1996)*, or multi-productive as in *Jara-Díaz et al. (1997)*, *Martínez Budría et al.*

¹¹ Non-normalized quadratic function has $m + n + 1$ parameters more than the translog function restricted to linear homogeneity in prices.

¹² From n equations of factors derived demand only $n - 1$ are linearly independent. Zellner (1962) iterative process consists of a two-phase estimation procedure with one equation less to obtain maximum likelihood estimations of the complete system. For further details, see *Christensen and Greene (1976)*

(1998), Jara-Díaz et al. (2002) and Tovar et al (2003)¹³. Tables 2.1 and 2.2 summarize the main features of these papers.

5.1. Data and functional specification

The study carried out by Chang in 1978 represents the first reference in the literature where a port production function was estimated. This author estimates a production function to analyze the productivity and convenience of expanding the capacity of the port of Mobile (Alabama-USA). Formally, he estimates a Cobb-Douglas production function represented by the following equation:

$$Q = A L^\alpha K^\beta e^{\gamma(T/L)} \quad (15)$$

where: Q = annual gross earning to the port in 1967 prices (wage payments to port workers not included), L = Men-Year; the average number of employees, per year (excluding port workers), K = Port net assets value at 1967 prices, $e^{(\gamma(T/L))}$ = Proxy for technological progress, (T/L) ¹⁴ = Tons per unit of labour, α , β and γ are parameters to be estimated. The empirical estimation is performed through ordinary least squares and uses annual time series data covering a 21-year period (1953-1973) considered in logarithms.

Also for the purpose of analyzing productivity and offering an alternative indicator of factor partial productivity measures, Reker et al. (1990) estimate a production function for three container terminals situated in the Port of Melbourne. This is the first study estimating a production function for port terminals and modeling cargo handling service. Reker et al. (1990), following De Neufville and Tsunokawa (1981), consider that it is better to estimate a production function than resorting to the usual approach of estimating a cost function. The main reason for this lies with the difficulty to obtain reliable data on productive factor prices.

To take advantage of the great number of individual performance measures which had been previously calculated, the authors consider them as productive factors (independent variables) of the production function. Although they acknowledge that the selected productive factors are not completely independent, they assume that the degree of

¹³ This work represents a summary of Tovar's thesis (2002), available at: <http://www.fcee.ulpgc.es/~btovar/tesis.pdf>.

¹⁴ T/L as proxy implies assuming that K/L does not change if r/w remains constant (*Harrod-neutral and Hicks neutral technological progress*).

dependency can be omitted. The estimation of the function is carried out through a multiple regression of productive factors in order to estimate the following the Cobb-Douglas function:

$$Q = A C^\alpha B^\beta L^\gamma \quad (16)$$

where: Q = number of TEUs¹⁵, C = Net crane operation time, B = Berth hours, L = labor, α , β and γ are parameters to be estimated.

The data used for the empirical estimation are monthly -covering from May of 1984 to February of 1990 (both inclusive)- and relate to three terminals located at the port of Melbourne. The information about the different terminals was taken as if it were coming from only one since this was thought to be the only way to gather enough reliable data to carry out the estimation. Moreover, the authors claim that the similarities among terminals, regarding their geographical location and the equipment used as well, allow this course of action, at the same time that data confidentiality is secured.

Tongzon (1993), as *Reker et al. (1990)*, estimates the production function of container handling, although, in this case, the author's objective is to examine whether the new tariff policy at the Port of Melbourne improved port efficiency and, at the same time, assess the contribution of the different factors involved in port efficiency. This study considers monthly data from May of 1984 to February of 1990 for container berths in the port of Melbourne and estimates the following production function:

$$Y = A X_1^\alpha X_2^\beta X_3^\gamma \quad (17)$$

where: Y = number of TEUs per berth hour, X_1 = number of cranes per berth hour, X_2 = labor per berth hour, X_3 = number of TEUs carried by land per berth hour, α , β and γ are parameters to be estimated.

As in *Reker et al. (1990)*, the model specification estimated by *Tongzon (1993)* results from various tests aimed at achieving the best adjustment of data on the basis of different criteria such as consistency with a-priori restrictions, coefficient significance and the absence of serial correlation.

The studies by *Chang (1978)*, *Reker et al. (1990)* and *Tongzon (1993)* all apply a Cobb-Douglas functional form which –although easy to estimate- presents the important limitations described above in section 2.3. Therefore, we emphasize the idea that it is clearly preferable to use the so-called flexible functional forms which avoid placing these kinds of restrictions.

¹⁵ *Twenty feet equivalent unity.*

A flexible functional form commonly used in empirical analyses is the translogarithmic function, which can be considered as an expansion of second order in logarithms of the variables in Taylor series. Indeed, this is the approach followed by *Kim and Sachis (1986)* in their study of the port of Ashdod. This paper represents the first reference in the literature of a port cost function estimation. In this paper, the authors focus on three objectives: first, the analysis of the port production structure placing special emphasis on the productive factors substitution pattern and the determination of the existence or absence of economies of scale. Secondly, they attempt to determine the nature and the impact of technological change, i.e., not only the technological change ratio is analyzed but also whether possible biases in this change could alter the productive factors shares. Lastly, they explore the interrelation between the port internal economies of scale and the external technological change, in the determination of factors total productivity. For this purpose, factors total productivity is decomposed into two parts: one related to the economies of scale and the other induced by technical change.

In order to estimate the technical change and the technology of port operations –taken as the services provided by infrastructure and cargo handling-, *Kim and Sachis (1986)* specify a long-run total cost function. The selected functional form is the following translogarithmic function:

$$\begin{aligned} \ln c = & \alpha_0 + \alpha_y \ln y + \sum_i \alpha_i \ln w_i + \frac{1}{2} \gamma_{yy} (\ln y)^2 + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln w_i \ln w_j \\ & + \sum_i \gamma_{iy} \ln w_i \ln y + \sum_i \theta_{it} \ln w_i \ln t + \theta_{yt} \ln y \ln t + \beta_t \ln t + \frac{1}{2} \beta_{tt} (\ln t)^2 \end{aligned} \quad (18)$$

where: C = Minimum total cost, Y = Tons of cargo, W_i = Prices for factor i , T = represents a technology index, specifically, the ratio of containerized cargo, $i, j = 1, \dots, n$; are indexes of n production factors, α_0 , α_y , α_i , γ_{yy} , γ_{ij} , γ_{iy} , θ_{it} , θ_{yt} , β_t , β_{tt} are parameters to be estimated. All variables are defined on the basis of the sample mean (expansion point).

The technology indicator used -the ratio of containerized cargo- shows zero values for the first years of the sample, since containerization was not introduced in the port of Ashdod until 1970. Consequently, the translog function degenerates into zero values for technology level. The problems created by this can be solved by using a Box-Cox transformation for the technology indicator variable, t , specified in (16) as:

$$t = \frac{(T^{*\theta} - 1)}{\theta} \quad (19)$$

This hybrid translog function approximates the ordinary translog function when θ approximates zero. The authors chose $\theta = 0.01$ so (17) is virtually identical to $\ln t$. For this estimation, the authors used time series data of 18 annual observations (1966-1983) of the Port of Ashdod (Israel). Applying the iterative technique modified by Zellner, a system of equations was estimated. These equations consisted of the translog total cost function, the factor cost share equation (Shephard's lemma) and the appropriate parametric restrictions so cost function meets the conditions of symmetry and homogeneity in factor prices.¹⁶.

Martínez Budría (1996) analyzed the provision of port infrastructure services managed by the Spanish Port Committees that evolved into the present port authorities and, at the same time, to analyze the differences between them. It assumes that the technology used by all port authorities is the same and that it can be analyzed through a model with an error structure including a fixed time effect and a specific individual effect. The fixed time effect is common to all firms although it varies along periods and it reflects the technical change during the observation period. On the other hand, the specific individual effect enables the analysis of the reasons for cost differences. He estimated the cost function estimation with a panel of data of 135 observations from 27 ports of general interest, covering a five-year period (1985-1989). The functional form specification selected by the author is consistent with the following Cobb-Douglas function:

$$CT_{it} = A \square Q_{it}^b \square w_{it}^{c_1} \square \Gamma_{it}^{c_2} \square m_{it}^{c_3} \square e^{\sum_i d_i D_i} \square e^{\sum_i d_i D_i} \square e^{\xi_{it}} \quad (20)$$

where: CT_{it} = Total costs of port i during period t, Q_{it} = Activity of port i during period t, w_{it} = Labor input price in port i during period t, m_{it} = Intermediate inputs price in port i during period t, r_{it} = Capital input price in port i during period t, d_i = Specific individual effect of firm i, D_i = Dummy variable for firm i, d_t = Time effect of year t, D_t = Dummy variable representing period t, ξ_{it} = Error term, and, A, c_1, c_2, c_3 , parameters to be estimated.

¹⁶ Linear homogeneity in factor prices is achieved by placing the following restriction:

$$\sum_i \alpha_i = 1, \sum_j \gamma_{ij} = \sum_i \gamma_{iy} = \sum_i \theta_{it} = 0$$

and symmetry is ensured with the following restriction:

$$\gamma_{ij} = \gamma_{ji}$$

Cobb-Douglas functions can be considered as a first order expansion in logarithms of Taylor series variables (*McFadden, 1978*). One of the interests of this function is that all the elasticities of derived demands even cost function parameters which, under Shephard's lemma, are also equal to cost shares. Therefore, first and second order effects are mixed in Cobb-Douglas function. This explains why, as observed above, it is advisable to use functional forms which avoid a-priori restrictions in the first and second order derivatives, i.e., flexible functional forms¹⁷.

A year later, in 1997, a multi-product version of this paper prepared by *Jara-Díaz et al. (1997)* is presented in the European Transport Forum. The aim of this new paper is to determine the specific marginal costs of each product, and the economies of scale and scope of Spanish port infrastructure services. The model estimated differs from the one used by *Martínez Budría (1996)* basically in three aspects. Firstly, *Jara-Díaz et al. (1997)* change the functional form specification and decide to apply a flexible functional form. Secondly, although *Martínez Budría (1996)* acknowledged the multi-productive nature of the activity, in his paper, he used a product-aggregated measure, while in *Jara-Díaz et al. (1997)*, product is defined as a five-component vector. Lastly, panel data estimation techniques used in both papers differ. Thus, in *Martínez Budría (1996)*, function estimation is performed through least squares with dummy variables (fixed effect model), while in *Jara-Díaz et al. (1997)*, a system of equations made up by cost function and factor-derived demand functions is estimated, using Zellner iterative technique.

The database used for cost function estimation is the same as the one used by *Martínez Budría*, and the functional form selected for long-run cost function was the following quadratic function:

$$\begin{aligned}
C = & \alpha_0 + \sum_i^m \alpha_i (y_i - \bar{y}_i) + \sum_i^n \beta_i (w_i - \bar{w}_i) + \sum_i^m \sum_{j \neq i}^m \alpha_{ij} (y_i - \bar{y}_i)(y_j - \bar{y}_j) + \\
& + \sum_i^n \sum_{j \neq i}^n \beta_{ij} (w_i - \bar{w}_i)(w_j - \bar{w}_j) + \sum_i^m \sum_j^n \delta_{ij} (y_i - \bar{y}_i)(w_j - \bar{w}_j) + \xi
\end{aligned} \tag{21}$$

where: C = Long-run total cost, y_i = Output vector, w_i = Inputs vector, \bar{y}_i = Mean value of outputs sample, \bar{w}_i = Mean value of inputs sample, ε = Error term, α_0 , α_i , β_i , α_{ij} , β_{ij} , δ_{ij} , are parameter to be estimated. This same model was reestimated by *Jara-Díaz et al. (2002)*,

¹⁷ Furthermore, the application of flexible functional forms does away with the need to meet separability and homogeneity restrictions, since they can be considered as contrastable assumptions.

the same model as in *Jara-Díaz et al. (1997)* is re-estimated, using a pool of data of 286 observations of 26 general-interest ports covering an eleven-year period (1985-1995).

Using a similar structure as in *Jara-Díaz et al., (1997)*, *Martínez Budría et al. (1998)* deepen the knowledge of the Spanish port system and analyze the results of the reform of loading/unloading operations in Spanish ports. They rely on a database prepared from port traffic data available in the Annual Reports of Spanish ports and a survey submitted to the 34 State-owned Loading and Unloading Companies of the Spanish port system. This survey was finally completed by 24 of these companies, thus providing authors with 119 observations used to build a panel data for the 1990-1996 period. This panel is biased since not all the companies had all the information for all the sample period.

The functional specification applied to carry out the estimation is represented by the following generalized translog function:

$$\begin{aligned} \ln c = & \alpha_0 + \sum_i^m \alpha_i \ln w_i + \sum_i^m \sum_{j \geq i}^m \alpha_{ij} \ln w_i \ln w_j + \sum_i^n \beta_i \ln y_i + \\ & \sum_i^n \sum_{j \geq i}^n \beta_{ij} \ln y_i \ln y_j + \sum_i^m \sum_j^n \delta_{ij} \ln w_i \ln y_j + \sum_i^n \sum_j^n \beta_{ij} \ln y_i \ln y_j + \\ & \theta_1 T + \theta_2 T^2 + \sum_i^m \theta_{1i} T \ln w_i + \sum_i^n \theta_{1i} T \ln y_i \end{aligned} \quad (22)$$

where: C = Total cost, w_i = Price of productive factor i , Y_i = Amount produced of product i , T = Time, α_0 , α_i , α_{ij} , β_i , β_{ij} , θ_1 , θ_2 , θ_{1i} , θ_{1i} , δ_{ij} , are parameter to be estimated. Equation (20) is estimated together with factor-derived demand equations (Shephard's lemma) and a group of restrictions placed on the parameters commonly used in translog functions to ensure homogeneity of degree one in factor prices of the cost function¹⁸. Estimation was performed following the iterative technique modified by Zellner. This same

Finally, *Tovar et al (2003)* represents the first paper estimating a long-run total cost function for cargo handling service in multi-purpose port terminals operating in the ports of *La Luz* and *Las Palmas* located in Gran Canary. The paper estimates marginal costs and economies of scale and scope, not only to deepen the knowledge about a key port activity but also to contribute to the sector regulation. The database consists of a panel of incomplete monthly data about the three terminals (1991 to 1999, 1992 to 1997 and 1992 to 1998 for each of them), prepared on the basis of the information arising from the terminals, Las Palmas Port

¹⁸The following restriction ensures that cost function is homogeneous of degree one in factor prices:

$$\sum_i \alpha_i = 1, \sum_i \sum_{j \neq i} \alpha_{ij} = \sum_i \sum_{j \neq i} \beta_{ij} = 0, \sum_i \theta_{1i}$$

Authority, SESTIBA -State-owned Loading and Unloading Company- and the Commercial Registry.

The econometric specification of the long-run total cost function is the following:

$$\begin{aligned}
 CT = & A_0 + \sum_{i=1}^m \alpha_i (y_i - \bar{y}_i) + \sum_{i=1}^n \beta_i (p_i - \bar{p}_i) + \phi(T - \bar{T}) + \frac{1}{2} \sum_{i=1}^m \sum_{j=1}^m \delta_{ij} (y_i - \bar{y}_i)(y_j - \bar{y}_j) \\
 & + \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \gamma_{ij} (p_i - \bar{p}_i)(p_j - \bar{p}_j) + \sum_{i=1}^m \sum_{j=1}^n \rho_{ij} (y_i - \bar{y}_i)(p_j - \bar{p}_j) + \sum_{i=1}^m \lambda_i (y_i - \bar{y}_i)(T - \bar{T}) \\
 & + \sum_{i=1}^n \mu_i (p_i - \bar{p}_i)(T - \bar{T}) + \pi(T - \bar{T})(T - \bar{T}) + \sum_{i=1}^N \vartheta_i D_i
 \end{aligned} \quad (23)$$

where: y_i = Amount of product i , p_i = Price of productive factor i , m = Number of product, n = Number of productive factors, T = Time trend, D_i = Firm dummy, N = Number of firms. All the variables marked with a horizontal bar reflect the value of the entire sample mean.

In fact, it is a quadratic function deviated from the sample mean where firm dummies have been included to capture specific effects as well as a time trend crossed with all the variables which reflects a possible technical change. Using the iterative technique modified by Zellner, the authors estimate a system of equations made up by total cost function (21) and the equations of expense in factors resulting from the application of Shephard's lemma, which allows determination of as many additional equations to cost function as variable productive factors are involved in cost estimation, without the need to introduce any additional parameter.

5.2. Product definition.

In almost all empirical applications, the authors have had to deal with the problem of defining the product. The reason is that, although most economic production activities are multi-productive, it was not until *Baumol et al., (1982)* in the 80's that there appeared a systematized theoretical body enabling the deep analysis of multi-productive activities nature with definition of new specific concepts related to multiproduct that could be contrasted empirically. In spite of the Baumol et al. contribution, the initial empirical analyses of multi-productive activities continued to rely on an aggregate to represent the product, or used attributes to capture the multi-productive nature that was being omitted. In some cases, real output vector dimension makes it impossible to estimate a flexible functional form and, thus, forces some kind of aggregation even though this results in loss of information. However, as shown by *Jara-Díaz (1982)*, this simplification implies not only loss of information but also

may cause misinterpretation of the coefficients estimated in the empirical analyses the policy makers and regulators need to be aware of.

Once these theoretical developments started to be taken into account, the analysis of the definition of the product used for empirical estimations of production and cost functions in the port industry reveals a great variety of approaches and commitments to address the importance of the issue. One of the factors driving the specific definition of the product used is what each author considers to be port activity. Before analyzing the product definition, it is thus important to point out that not all the authors consider the port from a comprehensive point of view.

Reker et al., (1990), Tongzon (1993) and *Tovar et al (2003)* focus their papers in cargo handling service in port terminals while *Jara-Díaz et al., (1997), Martínez Budría (1996)* and *Jara-Díaz et al. (2002)* exclusively analyze the provision of port infrastructure by port authorities. In another paper, *Martínez Budría (1998)* studies the activity performed by State-owned Loading and Unloading Companies (*Sociedades Estatales de Estiba y Desestiba*) (pool of port workers) operating in Spain. As regards *Kim and Sachis (1986)*, port activity is considered from an integral perspective encompassing not only the services provided by infrastructure but also the rest of port services. Lastly, in the case of *Chang (1978)*, there is no mention at all of what the author considers port services. Even though the exclusion of payments to port workers from gross benefit and the hours worked by them from labor factor seems to indicate that the author is modeling the services provided by infrastructure, this is not clearly and unambiguously established since, on the other hand, he also rejects the tons handled as a variable representing the product and chooses the gross benefit instead, on the grounds that official statistics generally include tons that passed through the port but were not necessarily handled by the port.

With this context in mind, the diversity of product definition can be summarized as follows. *Reker et al., (1990)*, and *Tongzon (1993)*, define product as the number of TEUs and the number of TEUS by berth hour, respectively. In the latter, the author justifies this product measure for it being consistent with the Port Authority's objective of maximizing berth use. *Kim and Sachis (1986)* and *Martínez Budría (1996)* use annual cargo tons by port as product measure. In both studies, the authors acknowledge the multi-productive nature of the activity under analysis, however they estimate a single-productive cost function. In the case of *Kim and Sachis, (1986)* because they have a limited number of observations, although they remark that it would be advisable to disaggregate by type of cargo to avoid the aggregation

bias. Furthermore, *Martínez Budría (1996)* chooses an aggregate of the activity because he assumes that the cost share of a ton of cargo is independent of the activity where it is handled. This is a restrictive assumption according to results obtained in further studies carried out by *Jara-Díaz et al. (1997)* and *Jara-Díaz et al. (2002)*.

Lastly, *Jara-Díaz et al. (1997)*, *Martínez Budría et al. (1998)* and *Jara-Díaz et al (2002)*, define a product vector. In both papers by Jara Díaz et al., port activity of infrastructure service provision is represented by a five-component vector: the tons of general non-containerized cargo handled (GNCC), of general containerized cargo (GCC), of liquid bulk (LB), of solid bulk (SB), and CANON which consists of an aggregated index of other activities using part of the infrastructure and which basically represents room granted under a concession or leased to private firms by port authorities.

Moreover, *Martínez Budría et al (1998)* model in their paper the activity of those State-owned Loading and Unloading Companies which, according to the authors, reflect cargo handling services so product vector has two components: tons of general cargo handled (GC) and of solid bulk (SB). Lastly, in the study by *Tovar et al (2003)*, a three-product vector is considered for the analysis of cargo handling service, namely: thousands of container, roll-on/roll-off and general cargo tons handled.

5.3. Independent variables.

Independent variables definition used in the different papers varies according to the activity under study¹⁹, or because of the type of function to be estimated, namely: production function or cost function. Then, productive factors are the independent variables in a production function, while in the case of a cost function, factor and product prices are considered.

In those papers where a production function is estimated, independent variables basically represent labor and capital and, in some cases, technological progress. There are at least two ways to define labor factor. On the one hand, labor can be defined as the total number of workers. On the other hand, it can be defined as the total number of worked hours. When working hours differ among the different workers, it seems more suitable to use the second measure; otherwise, any one can be used.

¹⁹ In some studies, only a part of the port activity is analyzed (services provided by infrastructure, or cargo handling services), whereas in some other works, port activity is analyzed in whole.

In all three analyzed papers estimating production functions, i.e. *Chang (1978)*, *Reker et al. (1990)*²⁰, and *Tongzon (1993)*, labor factor is defined as the number of workers. As regards the variables used to represent capital factor, diversity is still larger. Thus, in *Chang (1978)* capital is measured as the value of port net assets; in *Reker et al. (1990)*, they use berth hours, while in *Tongzon (1993)* the selected variable is the number of cranes per berth hour. Furthermore, these papers include other variables used to reflect different aspects such as technological change (*Chang, 1978*) or the effect on production of factors other than capital and labor, such as land connections, etc. (*Tongzon, 1993*).

When estimating cost functions, it is necessary to have information about the price of the productive factors involved in the process. *Kim and Sachis (1986)* take into account two productive factors: labor and capital. Labor is measured by the actual number of worked hours, which is determined through the application of the Divisia index²¹. In this way, they aggregate the hours worked by workers performing different tasks weighted by the importance that each task bears in total labor costs. Labor price arises from the ratio of total labor cost to the actual number of workers. As regards capital, this input involves three types of assets: equipment (cranes), other depreciated equipment (service equipment and facilities) and other non-depreciated assets and materials. Capital input price is calculated through the following *Christensen-Jorgenson (1969) User Cost*:

$$P_{k,t}^i = q_{k,t}^i (r_t^i + \delta_t^i) \quad (24)$$

²⁰ This work shows several weaknesses. Firstly, there is no definition of independent variables, so the reader finds it difficult to know exactly what each of them relates to. Thus, it calls the attention that crane operation time variable represents labor factor. Secondly, it looks very surprising that the authors chose to consider equation (2.37) as a model, at the same time that they acknowledge that the elimination of variable L enables a better adjustment of data (they turn from an $R^2 = 0.66$ to an $R^2 = 0.85$). In the third place, the independence of explanatory variables is assumed, although the authors themselves believe that they are not completely independent.

²¹ The Divisia index is defined as follows:

$$DI^t = \frac{1}{2} \sum (S_i^t + S_i^0) \ln(P_i^t / P_i^0)$$

where t indicates a specific year, i indicates a specific subcomponent of production factor, P_i^t is the price of factor i in year t, S_i^t is the cost share of factor i in year t and results from the following expression:

$$S_i^t = \frac{P_i^t X_i^t}{\sum_i P_i^t X_i^t}$$

where X_i^t represents the factor amount (value).

where q_k is the asset price, δ is the depreciation rate and r is the type of interest, each of them in relation to asset i in year t . Upon calculation of capital service use cost for each type of asset, they are aggregated through the application of a Divisia price index.

Martínez Budría (1996), *Jara Díaz et al. (1997)* and *Jara Díaz et al. (2002)* consider the quotient resulting from the division of personnel total costs by the number of workers to be an adequate variable approximating labor factor price. On the other hand, *Martínez Budría et al. (1998)* applies the quotient between personnel cost and the number of worked hours. Lastly, in *Tovar et al (2003)*, both approximations are used. A further distinction is made between port and non-port workers. The price for non-port workers is approximated by the quotient between total costs for this type of workers and the number of workers; while in the case of port workers, the number of worked hours is used as denominator.

For capital, there are slight differences across studies. In *Martínez Budría (1996)*, capital price is approximated by the ratio between the amortization of the period and the number of linear meters of berths with a depth over 4 meters²². In *Jara Díaz et al. (1997)* and *Jara Díaz et al. (2002)*, the authors apply a similar variable. Although, for the purpose of incorporating the concept of economic cost, in their study in 1997, the authors include a 5 per-cent rate of return on net fixed assets to the amortization of the period while in 2002, they incorporate a 6 per-cent rate of return. In *Tovar et al (2003)*, the approximation used is the ratio of the cost of capital to the active capital of the period. The cost of capital results from the addition of the accounting amortization for the period plus the return on the active capital of the period and the shares of stock of the State-owned Company. Lastly, in *Martínez Budría et al. (1998)*, capital input is not incorporated since, according to the authors, it is considered to be a residual category in this type of activity.

Finally, *Martínez Budría (1996)*, *Jara Díaz et al. (1997)*, *Martínez Budría et al (1998)* and *Jara Díaz et al (2002)* and *Tovar et al (2003)* use in their papers –in addition to labor and capital- an additional factor denominated intermediate input which consists of a variable capturing other activity-related cost allocations and whose price arises from the ratio between all cost allocations other than personnel costs and depreciations, and the total activity. In all the studies, the latter is represented by the total number of tons handled by the port, except in *Jara Díaz et al. (2002)* where it is represented by the annual revenues and in

²² Nevertheless, the author comments in his work that using the economic concept of cost instead of the accounting one does not improve estimation results.

Tovar et al (2003) where electricity price is used as the indicator since the prices of the rest of the components show no variations.

5.4. Estimation results: economies of scale and/or scope.

As explained above, the analyzed papers are heterogeneous in relation to the activity analyzed, the functional specification applied and the objectives pursued. This explains why the measures carried out by the different authors are also heterogeneous. There is a common denominator arising from all these measures -shown in *tables 2.1 and 2.2-*, i.e., the economies of scale, whose comparative analysis represents the main objective of this section. Moreover, this section comments as well on the results of the only two studies analyzed which estimate economies of scope due to the importance that this type of economies have to the present paper.

When comparing the empirical estimations of the economies of scale of the different papers referred to in this survey, it is important to bear in mind that the activity under analysis differs across the studies. All the papers focusing on the study of the services provided by infrastructure: *Chang (1978)*, *Martínez Budría (1996)*, *Jara Díaz et al (1997)* and *Jara Díaz et al.(2002)* conclude that there exist increasing returns to scale, although it is necessary to make further comments on this.

The first empirical estimation of the economies of scale existing in the provision of infrastructure port services was the study carried out by *Chang (1978)* for the port of Mobile. Even though *Chang (1978)* claims in his paper that, according to the results, the hypothesis of constant returns cannot be rejected, the author also affirms that the estimated points α and β^{23} suggest that returns are increasing in accordance with the production function estimated for the port of Mobile. Nevertheless, his conclusion is not definite if we consider the confidence intervals calculated by the same author.

As mentioned before, the other three papers, *Martínez Budría (1996)*, *Jara Díaz et al. (1997)* and *Jara Díaz et al. (2002)*, use similar databases: the same one in *Martínez Budría (1996)* and *Jara Díaz et al. (1997)* and another covering a greater time period in *Jara Díaz et al., (2002)*. Furthermore, in *Martínez Budría (1996)* a single-productive approach is considered, while in the other two studies, the authors consider a five-output vector.

²³ It represents the elasticity of gross benefit with respect to changes in labor and capital, respectively.

The result estimated by *Martínez Budría (1996)* for the economies of scale using a single-productive approach is 3.47, quite higher than the results arising from the application of a multi-product approach using similar data: 1.43 (1997) and 1.69 (2002) at the sample mean (the degree of economies of scale per port was also calculated in both studies). According to *Jara-Díaz et al.*, the reason for this difference lies with the presence of economies of scope, which cannot be revealed through the aggregate description of the product but have been contrasted in the last two studies.

Indeed, in *Jara Díaz et al., (1997)* and *Jara Díaz et al., (2002)*, the authors calculate the economies of scope at the sample mean for three subsets of output vector and their complements: in the first place, they studied if separating liquid bulks from the rest resulted in any benefit in costs and, in the second place, they analyzed the convenience of separating general cargo from liquid and solid bulks. Finally, they consider general cargo specialization. In both papers, all the cases analyzed showed that it was not advisable to specialize port infrastructure by type of product; although the savings obtained in the study of 1997 (about 36%) were slightly lower than in the study of 2002 (about 45%).

The literature that analyzes container terminals-berths using a production function (*Reker et al., 1990; Tongzon, 1993*), arrive at contradictory conclusions. On the one hand, *Reker et al. (1990)*, conclude that the main explanatory factor of production function is labor, represented by net crane hours variable and, although the authors do not mention so, estimations of α , β and γ , suggest the existence of decreasing returns. However -although the authors indicate that net crane operation time is the only significant parameter- they do not report any standard errors of parameters or coefficients t , and this prevents determination of confidence intervals in order to verify the hypothesis of decreasing returns. On the other hand, the parameters estimated by *Tongzon (1993)* suggest that production function is subject to increasing returns, although this contradicts an earlier conclusion drawn by the author in the sense that the returns suggested by his estimation are constant. Anyway, the absence of confidence intervals to contrast the hypothesis of constant returns prevents any conclusions.

The only paper that analyzes cargo handling activity in port terminals through cost function estimations is the study carried out by *Tovar et al (2003)*. The multi-productive approach developed in this paper allows estimations of marginal costs, scale economies – global and specific- and economies of scope. Estimation of the degree of economies of scale evaluated at the mean resulted in 1.64, thus indicating the existence of increasing returns of scale. The economies of scope were analyzed in order to evaluate if there was any benefits in

costs resulting from the specialization of the three terminals analyzed in one or some of the three products handled by them: containers, general cargo and Ro-Ro cargo. All relevant partitions of output vector were analyzed. In every case, the conclusion drawn is that it is not advisable to specialize. There are obvious savings as a result of joint production, either if compared to the extreme case of three firms specializing in one product each or when compared against any partition into two firms (one of them, a specialized firm).

Furthermore, *Kim and Sachis (1986)* analyze port activity from an integral point of view. Estimation of the first order coefficient for the output is positive, significant, and evidences that a production change by one per cent carries an increase in cost of only 0.765 per cent (which is equivalent to an $S=1.3$), thus, leading to the conclusion that port services production in the port of Ashdod is subject to increasing returns to scale at the approximation point. The authors explain that Ashdod is an artificial port located between two important breakwaters. This situation not only hinders its physical expansion but also supports the existence of increasing returns to scale.

Finally, *Martínez Budría et al. (1998)* only analyze management of port workers depending on the State-owned Loading and Unloading Companies [*Sociedades Estatales de Estiba y Destiba*]. Based on their analysis, the authors conclude that the degree of economies of scale evaluated at the mean results in 1.126, thus evidencing, the existence of increasing returns to scale.

6. Conclusions

This paper focuses on determining the contribution of literature towards the study of production and cost functions in the port industry and provides a detailed and critical analysis of the relevant aspects of cost functions. The estimation of key concepts in the firms' cost structure, such as marginal costs, economies of scale and scope, plays an essential role in the determination of the optimal industrial structure and therefore, represents a fundamental tool contributing to ease the regulators' job.

The first noticeable thing about this review is the limited literature on production and cost structure of port activities, particularly in connection with multi-productive cost functions of port terminals. Within the port area, a great diversity of activities are performed, going from infrastructure services, generally provided by port authorities, to cargo handling service, in most ports provided by private firms, and also covering other services such as mooring,

towage, etc. Each of these activities shows well-differentiated features and their own technology; then, they can be considered as different services (although related). From this perspective, it is difficult to speak about port activities in a broad sense. At this stage, it is clearly evident that some papers lack a precise definition of the service under analysis.

As regards port services, this paper emphasizes cargo handling since it represents more than 80% of the scale count of a ship performing loading and unloading operations. Therefore, studying this port activity is essential for port regulation and planning purposes. Surprisingly, only *Tovar et al (2003)* analyze this service from a cost of function point of view. The methodology used in that study takes into account the multi-productive nature of the activity as well as it contributes with relevant cost concepts which help regulators make proper decisions about port issues.

Even though a little limited, the literature analyzed shows that not only infrastructure but also cargo handling services present increasing returns to scale. The few multi-productive studies also suggest the presence of economies of scope between cargo types for both services.

Ultimately what this survey reveals is that applied research still has a long way to go in the sector. The proper approach is multi-productive and relevant results reinforcing the ones obtained in this paper can be obtained by applying the econometric tools available. Most probably, the lack of studies on the sector's cost behavior is due to the great difficulty of collecting information. This is unfortunate since the sector continues to have some important components of its business which have monopolistic features. Rents are thus being created and unless costs levels and structures are properly assessed, the levels and distribution of these rents are unlikely to be known. If governments are serious about their commitment to improve the competitiveness of their countries, they will have to ensure that port costs and hence rents are minimized and this can only be done if costs are measured and assessed properly. One of the regulator's tasks should be to help obtain relevant information from adequate sources for the performance of these types of studies. One way to do that is that the obligation to submit such information could be placed with regulated firms.

Table 2.1 Production function estimation for port sector

Author	Activity	Functional specification	Data	Variables (1)	Economies of Scale	Other Measurements
Chang (1978)	Infrastructure?	Cobb-Douglas	Time series Annual observations (21) (1953-1973)	$Q_1(L,K,e^{T/L})$	Constants	Average productivities Marginal Productivities
Reker et al. (1990)	Terminal-berth of Containers	Cobb-Douglas	Panel data Three terminal Monthly observations (70) (May 84-February-90)	$Q_2(C;B;L)$	Diminishing	Nothing
Tongzon (1993)	Terminal-berth of Containers	Cobb-Douglas	Panel data Three terminal Monthly observations (70) (May 84-February-90)	$Q_3(X_1, X_2, X_3)$	Increasing	Efficiency for wharf

- (1): Q_1 = Production = Annual gross earning to the port in 1967 prices (wage payments to port workers not included)
 Q_2 = Production = Number of TEUS
 Q_3 = Production = Number of TEUS per berth hour
 L = Men years (excluding port workers)
 K = Value of the clear assets of the port (prices of 1967)
 $E^{T/L}$ = Proxy for the technological progress, (T/L = Tons for unit of labour)
 C = Net crane operation time
 B = Berth hours
 L = Labor
 X_1 = Number of cranes per berth hour
 X_2 = Labour per berth hours
 X_3 = Number of TEUS carried per berth hour

Table 2.2 Cost functions estimation for port sector

Author	Activity	Functional specification	Data	Variables ⁽¹⁾	Scale economies evaluated in the approximation point	Other Measurements
MONOPRODUCTIVE COST FUNCTIONS						
Kin y Sachis (1986)	Infrastructure and services	Translogarithmic	Time series Annual observations (19) (1966-1983)	$CT_{LP}(Y, L, K, P_L, P_K)$	Increasing	Minimal efficient scale Factor demand price elasticity Cross elasticities
Martínez Budría (1996)	Infraestructure	Cobb-Douglas	Panel data 27 ports Annual observations (5) (1985-1989)	$CT_{it}(Q_{it}, W_{it}, m_{it}, r_{it}, d_i, d_t, D_i, D_t)$	Increasing	Cost factor elasticities Individual specific effects of each port Second stage analysis
MULTIPRODUCTIVE COST FUNCTIONS						
Jara Díaz et al. (1997)	Infraestructure	Quadratic	Panel data 27 ports Annual observations (1985-1989)	$CT_{ipit}(GL_{it}, GS_{it}, MGC_{it}, MGNC_{it}, CANON_{it}, w_{it}, r_{it}, m_{it})$	Increasing	Marginal costs for each product Economies of scope (ED > 0)
Martínez Budría et al. (1998)	Activity of the SEED (2)	Translogarithmic	Panel data 24 SEED Annual observations (1990-1996)	$CT_{it}(GS_{it}, MG_{it}, Pl_{it}, Pi_{it}, T)$	Increasing	Marginal costs for each product Costs product elasticities Total factor productivity for a subsample of 14 SEED
Jara Díaz et al. (2002)	Infraestructure	Quadratic	Panel data 26 ports Annual observations (1985-1995)	$CT_{ipit}(GL_{it}, GS_{it}, MGC_{it}, MGNC_{it}, CANON_{it}, w_{it}, r_{it}, m_{it})$	Increasing	Marginal costs for each product i Economies of scope (ED > 0)
Tovar et al (2003)	Cargo handling	Quadratic	Panel data 3 Port Terminals Monthly observations (1990-1999)	$CT_{ipit}(MGC_{it}, MG_{it}, ROD_{it}, Wnp_{it}, Wlc_{it}, Wle_{it}, m_{it}, r_{it}, D_i, T)$	Increasing	Marginal costs for each terminal Marginal costs for each product Economies of scope (ED > 0)

(1):
 CT_{LP} = Long term total annual cost
 Y = Tons of cargo
 L = Labor
 K = Capital.
 P_L = Labor price
 P_K = Capital price
 T_{it} = Total annual cost, both in port i year t
 Q_{it} = Tons of cargo, both in port i year t (thousands)
 Pl_{it} = Labor price
 Pi_{it} = Intermediate input price
 T = Temporal trend
 W_{it} = labor price, both in port i year t
 m_{it} = intermediate input, both in port i year t
 r_{it} = Amortization, both in port i year t
 d_i = Individual specific effect to port i
 d_t = Individual specific effect to year t
 D_i = Port-specific dummy variable

D_t = Firm-specific dummy variable
 CT_{ipit} = Long term total annual cost, both in port i year t
 GL_{it} = Tons of liquid bulks (thousands), both in port i year t
 GS_{it} = Tons of dry bulks (thousands), both in port i year t
 MGC_{it} = Tons of containerized general cargo (thousands), both in port i year t
 $MGNC_{it}$ = Tons of non-containerised general cargo (thousands), both in port i year t
 $CANON_{it}$ = Index added of other activities that use part of the infrastructure
 w_{it} = imput price, both in port i year t
 Wnp_{it} = Non port worker personal price, both in port i year t
 Wlc_{it} = Ordinary port worker price, both in port i year t
 Wle_{it} = Special port worker price; both in port i year t
 r_{it} = Capial price both in port i year t
 m_{it} = Intermediate input price
 MG_{it} = Tons of general cargo for port i in year t
 ROD_{it} = Tons of ro-ro cargo for port i in year t

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