Multioutput analysis of cargo handling firms: An application to a Spanish port

SERGIO JARA-DÍAZ[1,*], BEATRIZ TOVAR DE LA FÉ[2] & LOURDES TRUJILLO[2]
[1]*Universidad de Chile, Universidad de Ingeniera Civil, Fac. de Ciencias Fisicas Y Matematicas, Casilla 228-3, Santiago, Chile;* [2] *Universidad de Las Palmas de Gran Canaria, Spain*
*(*Author for correspondence, E-mail: jaradiaz@cec.uchile.cl)*

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

Abstract. Cargo handling in ports is a multioutput activity, as freight can arrive in many forms such as containers, bulk, rolling stock, or non-containerised general cargo. In this paper, the operation of cargo handling firms in a Spanish port is analysed through the estimation of a multioutput cost model that uses monthly data on three representative firms located at the Las Palmas port. This permits the calculation of product specific marginal costs, economies of scale (general and by firm) and economies of scope, which help identifying optimal pricing policies and the potential cost advantages of increasing production.

1. Introduction

Ports are a key component of the logistics chain and, therefore, their operation has a direct effect on relevant economic variables such as export competitiveness and final import prices, thus affecting economic development. This explains the governments' concern to set adequate competitive or regulatory conditions to enable the efficient operation of port activities, which are generally coordinated by entities known as Port Authorities. In most countries these are public entities that, in general terms, act as the regulatory body for all the companies operating at the port. Port regulation is not an easy task considering the diversity of activities developed at port facilities. Among those activities, cargo handling is of special relevance since the cost of this service generally represents about 80% of the costs incurred by a ship loading or unloading goods at a port (De Rus et al. 1994; Suykens 1996). In spite of the importance of this activity for the regulation of the sector, little is known in practice about the economics of this service. As stated by Turner et al. (2004), "Despite the significance of the seaport industry worldwide, relatively few empirical studies have been conducted" (p. 341). Among these, previous attempts at analysing port activities using a multioutput approach are definitely scarce.

Cargo handling in ports is a multioutput activity, as freight can arrive in many forms like containers, bulk, rolling stock, or non-containerised general cargo. Each type of movement involves the use of both common and specialised inputs. In this paper, the operation of cargo handling firms in ports is analysed for the first time by means of the estimation of a multioutput cost function, using detailed monthly data on three firms located at the Las Palmas port in Spain. Both size and traffic mix are first shown to be sufficiently diverse as to allow for a reliable estimation of a flexible (quadratic) cost function that permitted the calculation of product specific marginal costs, economies of scale (general and by firm) and economies of scope, which are some of the key concepts for the design of optimal policies regarding prices and production.

The paper is structured as follows: Section 2 presents the main cost concepts used by the multiproduct theory to describe an economic activity, which will be used for the empirical application of this paper. Section 3 presents cargo handling as a multioutput activity and synthesises previous works estimating production or cost functions in the port sector. Section 4 describes the data base and Section 5 contains the model, results and findings. Lastly, Section 6 includes the main conclusions.

2. Multiproduct cost concepts

The cost function $C(W,Y)$ represents the minimum expenditure necessary to generate the products contained in vector Y, at factor prices W. The latter has been eliminated in the expressions below in order to simplify the mathematical formulae, which follows Baumol et al. (1982). First, the local variation in costs after the increase of one product keeping all other products constant is the marginal cost of product i, calculated as

$$\frac{\partial C}{\partial y_i} = C_i \tag{1}$$

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

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

The degree of global economies of scale represents the maximum growth rate that the product vector can reach when productive factors increase by the same proportion. Therefore, the presence of increasing returns of scale ($S > 1$) implies that a proportional growth of all products induces a less than proportional growth of costs, i.e. a production expansion exhibits advantages from the point of view of costs. Note that if prices are set equal to marginal costs under increasing returns, the firm will have losses.

Another useful concept resembles the idea of marginal cost but in a discrete manner. This is the incremental cost of product i, IC_i defined as the cost of adding that product to the line of production. This corresponds to

$$\mathrm{IC}_i = C(y_1, y_2, \ldots, y_n) - C(y_1, y_2, \ldots, y_{i-1}, 0, y_{i+1} \ldots, y_n) \tag{3}$$

This concept can be extended to a subset of products R and it is very useful since it allows the definition of specific returns to scale associated with a given subset of products. The degree of economies of scale specific to subset R is defined as

$$S_R(Y) = \frac{\mathrm{IC}_R(Y)}{\sum\limits_{j \in R} y_j \frac{\partial C(Y)}{\partial y_j}} = \frac{\mathrm{IC}_R(Y)}{\sum\limits_{j \in R} y_j C_j(Y)} \tag{4}$$

The interpretation of $S_R(Y)$ is similar to that of S. Note that, in this case, $S_R > 1$ implies that the application of prices equal to marginal costs would not cover incremental costs.

Two products are said to exhibit cost complementarity when the marginal cost of one of them diminishes as the other product increases. Formally, this means that

$$C_{ij}(Y) = \frac{\partial^2 C(Y)}{\partial\, y_i y_j} \leq 0, \tag{5}$$

and represents some form of advantage in joint production, with the inequality holding strictly over a set of non-zero measure.

The concept of economies of scope is useful to analyse whether it is advisable or not to have the firm diversified or specialised. Thus, economies of scope measures 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 N into two subsets T and $N-T$ is carried out, the degree of economies of scope SC_T of subset of products T with relation to its complementary subset $N-T$ is defined as

$$\mathrm{SC}_T(Y) = \frac{1}{C(Y)}[C(Y_T) + C(Y_{N-T}) - C(Y)] \tag{6}$$

in such a way that the partition of the production set will increase, decrease or not alter total costs depending on whether $SC_T(Y)$ is larger than, smaller than or equal to zero, respectively. Thus, if $SC_T(Y) > 0$ economies of scope are said to exist and it is cheaper to produce vector Y jointly than to produce vectors Y_T and Y_{N-T} separately. In other words, it is not advisable to specialise but to diversify production. It is easy to see that SC 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:

$$S_N(Y) = \frac{\alpha_T S_T(Y) + (1 - \alpha_T) S_{N-T}(Y)}{1 - SC_T(Y)} \tag{7}$$

with

$$\alpha_T = \frac{\sum_{j \in T} y_j \frac{\partial C(Y)}{\partial y_j}}{\sum_{j \in N} y_j \frac{\partial C(Y)}{\partial y_j}} \tag{8}$$

This relation shows that, in the absence of economies of scope (SC = 0), S would be a weighted average of the specific economies of scale of each subset. The existence of economies of scope (SC > 0) favours the presence of overall economies of scale.

3. Cargo handling as a multioutput activity

Though there is no uniform pattern for port organisation, there is an increasing trend towards the *landlord* model in the world (Juhel 2001; Baird 2002). Under this model, the public sector provides port infrastructure in the strict sense (lighthouses, quays, loading and unloading areas, etc.) and private companies supply the superstructure required to provide port services (office buildings, machinery, etc.). These services, which are generally provided by private companies, include cargo handling, which encompasses all handling operations from placing cargo on the dock to loading it on the ship and vice versa. In the past decades, new cargo handling and vessel design technologies have been developed, improving the productivity of the vessel by dramatically reducing her stay time at the port. This technology can be labelled as cargo unitization, which implies packing several small cargo items into a standard unit which can be handled with specifically designed equipment. The main standard units used are pallets, containers, roll-on/roll-off trucks and trailers. Thus, regarding cargo handling inputs and costs, the unitization process implies that the type of package used to unitise the cargo is more important than the nature of the cargo itself.

General cargo handling operations vary depending on whether the cargo is in break-bulk or unitised form and, within the latter category, if it is containerised or roll-on/roll-off cargo, namely, cargo that is driven on and off the vessel. These different handling processes imply that costs vary in each case and, therefore, they should be treated as separate products to acknowledge the multioutput nature of the activity under consideration.

As advanced in the introduction, economic empirical studies of port activities are quite limited in number (Turner et al. 2004), and those that apply the cost function approach constitute an even smaller set (Tovar et al. 2002). Out of these, only Jara-Diaz et al. (1997, 2002) analysing infrastructure services and Martinez-Budria et al. (1998) on the management of the SEED (Stated-owned Stevedoring Management Company) can be cited as multioutput studies. It is worth mentioning as well the articles by Rekers et al. (1990) and Tongzon (1993) that estimated Cobb-Douglas production functions for container manipulation, finding opposite results regarding scale economies. Also, Kim and Sachish (1986) estimated a translogarithmic single output cost function for port infrastructure and services, finding increasing returns, similar to Martínez-Budría (1996) using a Cobb-Douglas cost function.[1]

It is important to highlight what a multioutput analysis permits in the study of cargo handling activities. Single output cost analysis can deal only with total volume moved. When output is described as a scalar hiding multiple outputs, the observed variation in total output (volume) might be reflecting disproportionate variations in each of the real outputs. This causes various important problems. Evidently, if product specific marginal costs are too different, a single figure will represent a biased estimate of the marginal cost of the bundle mix. Furthermore, the impossibility of estimating economies of scope will bias the estimate of scale economies, because potential advantages (or disadvantages) of joint production will not be captured as the presence of economies (or diseconomies) of scope, but as something related to scale. The results of Martínez-Budría (1996) and Jara-Díaz et al. (2002) are quite useful to illustrate this type of problem, as the same type of data were used in both papers that differ only in the approach. The latter authors found moderate returns to scale and economies of scope using the multioutput approach, that can be compared with the strongly increasing returns found by the former author. This is exactly the type of bias induced when a multioutput activity is looked at as a single output one.

For synthesis, the analysis of cargo handling activities in ports should be looked at as a multioutput activity, where outputs should be defined according to the type of unit being handled. From this, product specific marginal costs, economies of scale and economies of scope can be properly calculated.

4. Empirical study: Data

In order to estimate a cost function, we need data on expenditure, production and input prices for various firms during one period (cross section), for one firm along various periods (time series) or for various firms along various periods (panel or pool). We gathered data directly from three firms operating within the port area of Las Palmas located in Gran Canaria (Canary Islands). According to the total cargo volume, the Port Authority of Las Palmas is the fourth largest within the Spanish system (see Appendix A). Out of the three ports under this authority, the port of Las Palmas carries 86% of that total. The three terminals are private firms operated under concession and can be regarded as typical among medium size firms within the Spanish port system.

Although the terminals (T1, T2 and T3) deal mainly with containers, they also operate roll-on/roll-off cargo (ro–ro) as well as general break-bulk cargo. We obtained detailed monthly data from 1992 through 1997 for T1, from 1991 through 1999 for T2, and from 1992 through 1998 for T3. Out of the three products, general break-bulk cargo (“general cargo”) represents an average of 9.9% of the total tons moved monthly, containers represent 87.4% and ro–ro 2.7% . Table 1 shows the monthly values obtained for the

Table 1. Total expense (million pesetas of December, 1999) and monthly average production (thousands tons).

Variable	Sample	Terminals		
		T1	T2	T3
Total monthly expense				
Mean	94.8	73.6	81.9	129.4
Containers				
Mean	59.2	53.1	33.5	97.4
Max–min	310–15	74–32	62–15	310–49
General cargo				
Mean	5.6	0.6	9.9	4.4
Max–min	29–0	3–0	29–0	14–0
Ro–ro cargo				
Mean	2.1	1.0	0.8	4.7
Max–min	11–0	3–0	4–0	11–0
Production–aggregated				
Mean	66.8	54.7	44.1	106.5
Max–min	325–15	78–32	77–15	325–58

entire sample and for each of the three terminals, both in terms of the three defined products as well as the total expense incurred during service provision. It also includes a production-aggregated figure representing total tons. It is worth stressing that data were gathered directly from the firms files and that all the details were discussed with executives when necessary, particularly for the monthly assignment of expenses. Data are described in detail in Tovar (2002).

These averages show that monthly expenses do not vary monotonically with total production. This makes the different output composition a likely explanation for cost differentials, if factor prices were similar for the three companies. For example, the only explanation for the expense of T2 larger than those of T1 would be the difference in the traffic mix, particularly the larger volume of general cargo. This already suggests higher marginal costs for general cargo, which reinforces the need for a multioutput analysis. Note that maximum and minimum values show significant variability of products across observations (maximum values up to five times the average value), which is a very good property of the data base for the econometric study. The presence of nil minimum values are relevant as well because economies of scope calculations require products to reach those value levels. In order to have a first view of the cost output relation, it is interesting to observe data as if it were the case of a single product process. For that, a "pseudo-mean-cost" for the activity is presented in Figure 1 based on the aggregated production volume.

The curve looks as a traditional one using a single output approach, and graphically suggests the presence of economies of scale and, therefore,

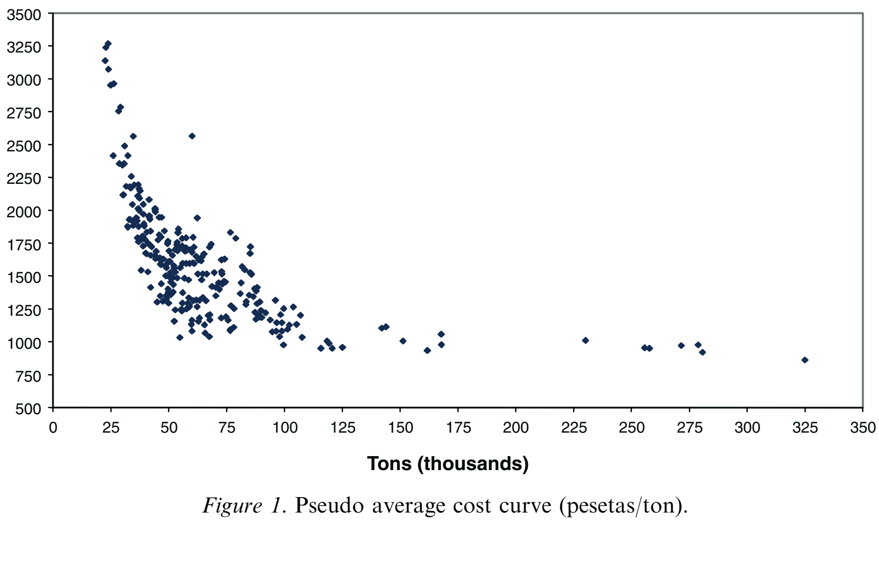

Figure 1. Pseudo average cost curve (pesetas/ton).

“marginal costs” that should fall below the average figures, i.e less than 750 pesetas/ton for all products. We will see later that this is not the case.

The productive factors have been grouped into four categories: personnel, total area, capital and intermediate inputs. The personnel working in port terminals may be classified in two categories: stevedores or port workers, who handle cargo, and non-port workers, who do not (administratives, executives, maintenance and control personnel, among others). In turn, port workers are divided into two categories: those who are on the payroll (ordinary employment) and those who are not (special employment). These latter can be recruited on a provisional basis by any company to work 6-h shifts, under the management of the *Sociedad Estatal de Estiba y Destiba (SEED)*. The information available is in number of men per month for non-port workers and in number of shifts per month for port workers. The price of each type of work is calculated as the ratio between the labour expense of each type and the number of workers in the case of non-port workers, or the number of worked hours in the case of port workers computed on a 6-h shift basis.

Regarding occupied space, each terminal can make use of an area that has been granted under concession, which may be increased by provisionally renting – upon prior request – additional area from the port authority, turning area into a variable factor. Total area is measured in monthly square meters. Its price is the ratio between expenses and total area.

Capital encompasses all the components of tangible assets of the company – i.e. buildings, machines, etc. The monthly cost results from the addition of the accounting depreciation for the period plus the return on the active capital of the period and the shares of stock of the SEED. This rate of return evidences the compensation earned by risk-free capital, which is made up of bank interest plus a risk premium. For the period under analysis the return for both concepts amounts to 8% per annum. The price of capital is the ratio between the capital cost and the active capital of the period (net fixed assets under exploitation).

Lastly, the rest of the productive factors used by the company that have not been included in any of the three preceding categories, such as office supplies, water, electricity, and the like, have been classified as intermediate consumption. The monthly expense results from the aggregation of the rest of the current expenses other than depreciation, personnel expenses and payment for area, after the pertinent corrections in a manner such that the resulting monthly expense truly reflects monthly consumption and not accountancy. The price of electricity has been used as an indicator of the price of intermediate consumption.

Labour costs account for an average of 53% of the monthly expense for the entire sample. Total area represents 13%, capital amounts to 8% and intermediate consumption reaches 26%. Within personnel, non-port workers account for 21% of personnel expense, while ordinary workers and special workers represent 36% and 43%, respectively. The figures per company reveal similar patterns.

Although using monthly data might suggest that some factors could not be adjusted easily, which would make a case for a short run cost function, this does not seem to be the case. Potential fixed factors are non-port personnel, total area and equipment.[2] However, the possibility for terminals to rent additional area and machinery and to recruit port personnel under special labour relationship indicates some adjustability in the short run. A first analysis using the correlation matrix showed that non-port personnel, equipment and total area do vary with production and, therefore, that there is no empirical evidence to believe that they play a fixed factor role. The terminals are somehow adapting these factors with production and a long-run model was regarded as appropriate. Even so, a short-run model including total area as the only possible fixed factor will be used for control.

5. Model and results

The most popular flexible functional forms are the translogarithmic and quadratic forms. One of the advantages of the quadratic function is its suitability for the analysis of economies of scope and incremental costs, which is the reason why it was chosen. For the long-run model, the econometric specification of the total cost function is

$$\begin{aligned}\mathrm{CT} = {} & A_0 + \sum_{i=1}^{m} \alpha_i (y_i - \overline{y_i}) + \sum_{i=1}^{n} \beta_i (p_i - \overline{p_i}) + \phi(T - \overline{T}) \\ & + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m} \delta_{ij}(y_i - \overline{y_i})(y_j - \overline{y_j}) + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij}(p_i - \overline{p_i})(p_j - \overline{p_j}) \\ & + \sum_{i=1}^{m}\sum_{j=1}^{n} \rho_{ij}(y_i - \overline{y_i})(p_j - \overline{p_j}) + \sum_{i=1}^{m} \lambda_i (y_i - \overline{y_i})(T - \overline{T}) \\ & + \sum_{i=1}^{n} \mu_i (p_i - \overline{p_i})(T - \overline{T}) + \pi(T - \overline{T})(T - \overline{T}) + \sum_{i=1}^{N} \vartheta_i D_i \end{aligned} \tag{9}$$

where y_i is amount of output i, p_i is input i price, m is the number of outputs, n is the number of inputs, T is the time index (trend), D_i is the firm specific dummy and N is the number of firms. Variables with a horizontal bar are sample means. Company *dummies* have been included to capture specific effects and T is included to capture possible technical change. Applying Shephard's lemma, the equation for the input i expense is

$$G_i = p_i \cdot x_i = p_i \cdot \left[\beta_i + 2\gamma_{ii}(p_i - \overline{p_i}) + \sum_{j \neq i}^{m} \gamma_{ij}(p_j - \overline{p_j}) + \sum_{j=1}^{n} \rho_{ij}(y_j - \overline{y_j}) + \mu_i(T - \overline{T}) \right] \quad (10)$$

where x_i is the demand for input i. The system formed by Equation (9) and the six expenditure Equation (10) was estimated using Zellner's seemingly unrelated equations procedure, which is a two-stage, consistent and asymptotically efficient estimation procedure. The directly estimated parameters are shown in Appendix B, from which we have selected the relevant variables for analysis and discussion.[3]

Table 2 contains all the parameters related with first order coefficients, including the results for both the long and short run cost models.

The similar results confirm that the long run model is indeed appropriate. Marginal cost estimates do vary across products and show the expected order: containers exhibit the lowest value, followed by ro–ro cargo and general cargo. If these results are compared against maximum tariffs currently applied at the port, grouped by type of cargo, these happen to be always above our marginal costs estimates, which reinforces the quality of the estimation. Note that the marginal costs for both general cargo and ro–ro are definitely larger than the maximum single figure that could be expected from the pseudo average cost curve in Figure 1. In what follows, the long run model estimates are used for calculations.

Table 2. Expense, marginal costs, demand for factors and trend (at the mean).

Parameter	Long-run model		Short-run model	
	Estimate	*t*-Statistic	Estimate	*t*-Statistic
Total cost at the mean	96680	140.02	97394	138.92
Marginal cost containers (ptas/ton)	745	28.48	684	20.72
Marginal cost general cargo (ptas/ton)	1974	14.19	2056	14.96
Marginal cost ro–ro cargo (ptas/ton)	1056	2.96	1139	3.051
Demand for ordinary workers	1.58	69.74	1.58	73.66
Demand for special workers	2.34	45.86	2.33	49.13
Demand for intermediate consumption	983	87.30	981	88.27
Demand for total area	61593	106.85		
Demand for capital	583266	40.61	589240	44.83
Demand for non-port workers	0.02	76.67	0.02	78.28
Trend	−67	−1.96	−64	−1.89

We calculated marginal costs by product for each firm at the corresponding means, and they happened to show very little variation regarding the mean estimate in Table 2. If container tons are converted into containers units, the marginal costs are 7596, 8435 and 8425 *pesetas*/unit for T1, T2 and T3 respectively (less than the maximum published tariff, 12145 *pesetas*/unit). Note that the trend coefficient shows that pure technical change diminishes costs (at a decreasing rate, though, as evidenced by the positive sign of the square-in-time variable).

Table 3 shows both global and product specific economies of scale calculated at the sample mean. These are all statistically significant. Note that although product specific economies of scale are very close to one for all three products, global economies of scale are above one, which, by virtue of Equation (7), suggests the presence of economies of scope, confirmed below.

The results by firm are displayed in Table 4, where global economies of scale for T3, the largest terminal, are shown to be smaller than the other two – which present similar values. This suggests that economies of scale are exhausted at the largest level of production, and that the two smaller terminals should increase production.

Based on the estimated parameters, all relevant orthogonal partitions of the product vector are analysed, i.e., the cost of serving all products with a single firm is compared to the same production with

- Three companies: each one specialising in one product (SC);
- Two companies: one specialising in containers and the other one offering the other two products (SC_C);
- Two companies: one specialising in general cargo and the other offering the other two products (SC_{MG})
- Two companies: one specialising in ro–ro cargo and the other one offering the other two products (SC_R)

Table 5 summarises the results obtained. All SC estimates are within the theoretically expected range (−1,1) and all of them are significant. The presence of different types of economies of scope reinforces the existence of global returns to scale in spite of constant product – specific ones. The

Table 3. Global and product-specific Economies of Scale at the sample mean.

Economies of scale	Estimate	*t*-Statistic
Global	1.64	33.18
Containers	1.01	254.80
General cargo	1.00	251.87
Ro–ro cargo	1.08	32.30

Table 4. Global economies of scale by terminal.

	Estimate	*t*-Statistic
Mean	1.64	33.18
T1	2.26	32.61
T2	2.13	24.63
T3	1.07	37.17

results show that, for the volumes moved, it would not be convenient from the point of view of costs to split each firm into two or three, each one moving a specific product type. Note that this should be interpreted in a very strict sense, i.e. if the three products are to be produced at the levels synthesized in Table 1 because of exogenous reasons, it would be better done (less costly) with one firm than with two or three firms.

Irrespective of the partition used, the savings obtained in these cases (SC_C, SC_{MG}, and SC_R) are very similar. The reason behind this is that the only terms that depend upon the selected partition are the second-order terms representing the cross-products within T and $N-T$, which happen to be relatively small when compared with the first-order terms (Jara-Diaz et al. 2002).

6. Conclusions

A long run multioutput cost function for cargo handling at ports has been estimated using data obtained from representative firms operating at the port of Las Palmas in Spain. This study provides the first empirical estimates of marginal costs, global and product-specific economies of scale, and economies of scope in cargo handling activities. It confirms the advantages of the multioutput approach over the single output analysis, revealing large differences in product-specific marginal costs per ton and avoiding the misinterpretation of scale economies due to scope advantages.

Results show that containerised cargo presents the smallest marginal costs for all firms, while non-containerised general cargo has the largest

Table 5. Economies of scope.

	Estimate	*t*-Statistic
SC	0.782	21.20
SC_C	0.387	20.95
SC_{MG}	0.393	21.37
SC_R	0.389	20.83

(2.65 times the cost of the container). The largest firm exhibits slightly increasing returns to scale while the smaller are still in the increasing returns zone, which suggests the convenience of increasing their scale of production. All firms exhibit economies of scope for every possible partition of the product set, which indicates the inconvenience to split each firm into two or three, each one moving a specific product type at the observed production volumes (which are quite small for ro–ro and general cargo relative to containers).

As the firms face increasing returns, marginal cost pricing would not be financially viable. In fact, observed average minimum prices for the different services are larger than the estimated marginal costs, but they are of comparable magnitudes, which suggests that those minimum prices are a reasonable target. Estimation of demand models would help knowing whether this observed minimum price levels could be potential second best (Ramsey) prices needed to cover costs in the presence of increasing returns.

Clear increasing returns to scale for the two smaller firms combined with economies of scope for all possible partitions of the product set do suggest that these two firms would do better operating as one, as this would result in cost savings, which would be physically feasible as the two terminals occupy neighbouring sites. Note that this might call for stricter local regulation as a result of diminishing competition in the port, although a duopoly would prevail. However, regional competition with other ports has some influence in this case, as the container traffic of Las Palmas that is transhipment shows an increasing trend.

Appendix A. Main Spanish port authorities: Number of ports, cargo handled, stevedoring firms and terminals (1999).

Port authority (Number of ports)	Total cargo handled in 1999 (thousands tons)					Terminals
	Break-bulk general cargo	Ro-ro cargo	Containers	Total	Steve-doring firms	Multi-pourpose/container
Bahía de Algeciras (4)	1186	2178	18737	22101	8	1/1
Valencia (3)	3053	1775	12360	17188	14	3/1
Barcelona (1)	983	4077	10264	15324	14	2/2
Las Palmas (3)	1892	2409	4906	9207	16	3/0
Bilbao (1)	3017	492	3807	7316	9	2/0
S.C. Tenerife (5)	341	2721	2421	5483	12	4/0
Baleares (5)	116	5101	737	5954	13	2/0
Vigo (1)	985	1015	657	2657	5	1/0
Alicante (1)	253	175	691	1119	5	2/0

Source: Port authorities.

Acknowledgements

This research was partially funded with Grants from Fondecyt, Chile, project 1010687, the Millennium Nucleus "Complex Engineering Systems" and Gobierno Autónomo de Canarias. Prof. Jara-Díaz would like to thank the hospitality at the Universidad de Las Palmas de Gran Canaria while working on this research.

Appendix B. Results of the estimation of the long term model.

Parameters	Estimate	*t*−Statistic
$\mathbf{A}_0$	96680.2	140.02
α_{cont}	744.568	28.4829
α_{gc}	1973.57	14.192
α_{roro}	1055.81	2.96036
$\beta_{\text{poe (price ordinary employment)}}$	1.57685	69.7386
$\beta_{\text{pse (price special employment)}}$	2.33895	45.8603
β_{pi}	982.53	87.2994
β_{parea}	61592.9	106.851
β_{pk}	583266	40.6078
$\beta_{\text{pnpw (price non-port worker)}}$	0.021919	76.6747
$\mathbf{\Phi}$	−67.0148	−1.96005
δ_{c2}	−0.068971	−1.38758
δ_{cgc}	0.408093	0.731457
δ_{croro}	4.57755	2.95849
ρ_{cpoe}	9.95E−03	14.0028
ρ_{cpse}	0.02	13.7777
ρ_{cpi}	5.818	11.3792
ρ_{cparea}	180.843	8.57526
ρ_{cpk}	7785.87	12.7272
ρ_{cpnpw}	2.62E−04	19.6209
λ_{ct}	0.120936	0.802607
δ_{g2}	−0.518286	−0.369375
δ_{groro}	1.15946	0.14253
ρ_{gpoe}	0.037099	8.06544
ρ_{gpse}	0.078918	7.53744
ρ_{gpi}	8.45203	3.37413
ρ_{gparea}	−109.421	−0.906247
ρ_{gpk}	18048.7	6.12378
ρ_{gpnpw}	4.48E−04	8.00074
λ_{gt}	−0.469081	−0.745456
δ_{r2}	−40.9608	−3.93965
ρ_{rpoe}	0.037754	3.32395
ρ_{rpse}	20.5144	3.07318
ρ_{rparea}	−583.417	−1.72881
ρ_{rpk}	−4811.55	−0.633114
ρ_{rpnpw}	7.67E−04	4.62008
λ_{rt}	−0.734985	−0.389156

Appendix B. Continued.

Parameters	Estimate	t–Statistic
γ_{poe2}	−7.20E−06	−5.27695
γ_{poepse}	−2.11E−05	−2.83304
γ_{poepi}	9.25E−03	3.33348
$\gamma_{poeparea}$	−0.307449	−1.8727
γ_{poepk}	6.33105	2.70774
$\gamma_{poepnpw}$	1.90E−07	2.93544
μ_{poet}	−0.015786	−14.0831
γ_{pse2}	−2.33E−05	−2.50139
γ_{psepi}	0.028954	3.75454
$\gamma_{pseparea}$	0.788301	1.65227
γ_{psepk}	−8.6808	−1.47648
$\gamma_{psepnpw}$	1.69E−07	1.09846
μ_{pset}	9.91E−03	3.69417
γ_{pi2}	−15.0668	−6.15439
$\gamma_{piparea}$	901.258	3.01249
γ_{pipk}	2696.68	1.04295
γ_{pipnpw}	4.67E−05	0.497954
μ_{pit}	1.24028	1.80033
γ_{parea2}	−10391.1	−0.804397
$\gamma_{pareapk}$	−209552	−1.32998
$\gamma_{pareapnpw}$	−0.045851	−5.74755
μ_{pareat}	196.049	4.92183
γ_{pk2}	−1.33E+06	−0.977757
γ_{pkpnpw}	0.231914	3.91454
μ_{pkt}	125.511	0.180318
γ_{pnpw2}	−5.59E−09	−3.97384
μ_{pnpwt}	−9.87E−05	−6.41019
Π	0.142629	1.30249
$\theta_{T.1}$	−2460.71	−11.1526
$\theta_{T.2}$	−2479.14	−7.86803

Dependent variable: Total expenditure

Mean of dependent variable = 94783.3	Std. error of regression = 10802.5
Std. dev. of dependent var. = 34819.9	R^2 = 0.903733
Sum of squared residuals = 0.308070E+11	Durbin–Watson statistic = 0.991747
Variance of residuals = 0.116693E+09	Corrected R^2 = 0.870825

Dependent variable: Ordinary worker expenditure

Mean of dependent variable = 17964.1	Std. error of regression = 3989.9
Std. dev. of dependent var. = 8563.97	R^2 = 0.84924
Sum of squared residuals = 0.420269E+10	Durbin–Watson statistic = 0.667191
Variance of residuals = 0.159193E+08	Corrected R^2 = 0.842659

Dependent variable: Special worker expenditure

Mean of dependent variable = 21447.9	Std. error of regression = 7773.31
Std. Dev. of dependent var. = 12515.1	R^2 = 0.613797
Sum of squared residuals = 0.159520E+11	Durbin–Watson statistic = 0.538230
Variance of residuals = 0.604243E+08	Corrected R^2 = 0.596938

Appendix B. Continued.

Dependent variable: Non-port worker expenditure	
Mean of dependent variable = 10410.9	Std. error of regression = 2223.66
Std. dev. of dependent var. = 4445.35	R^2 = 0.749944
Sum of squared residuals = 0.130539E+10	Durbin–Watson statistic = 0.773278
Variance of residuals = 0.494466E+07	Corrected R^2 = 0.739029
Dependent variable: Intermediate consumption expenditure	
Mean of dependent variable = 24534.2	Std. error of regression = 4597.01
Std. dev. of dependent var. = 8445.03	R^2 = 0.702706
Sum of squared residuals = 0.557898E+10	Durbin–Watson statistic = 1.26826
Variance of residuals = 0.211325E+08	Corrected R^2 = 0.689728
Dependent variable: Total area expenditure	
Mean of dependent variable = 7071.48	Std. error of regression = 1035.59
Std. dev. of dependent var. = 2897.86	R^2 = 0.871917
Sum of squared residuals = 0.283125E+09	Durbin–Watson statistic = 0.513589
Variance of residuals = 0.107244E+07	Corrected R^2 = 0.866326
Dependent variable: Capital expenditure	
Mean of dependent variable = 12985.4	Std. error of regression = 5212.91
Std. dev. of dependent var. = 7728.52	R^2 = 0.545660
Sum of squared residuals = 0.717404E+10	Durbin–Watson statistic = 0.391706
Variance of residuals = 0.271744E+08	Corrected R^2-squared = 0.525827

Notes

1. For a summary of literature about econometric estimation of production and cost functions in ports, see Tovar et al. (2002).
2. Unlike area and non-port personnel, which are measured in homogeneous units – sq. m and men/month, respectively – and therefore they do not present any problems for aggregation purposes, equipment as a variable comprises such different machinery as a postpanamax crane, a forklift truck, or a chassis. For aggregation purposes, two possible indicators were considered: power and purchase value. The former was considered inadequate because it weighs very different machines on an equal footing, such as a crane and a forklift truck because they have similar lifting power. Therefore, purchase price of equipment was chosen.
3. Only one term was omitted in the final cost function, i.e. the crossing between special workers price and ro-ro cargo, which was not significant with a counterintuitive sign.

References

Baumol W, Panzar J & Willig R (1982) *Contestable Markets and The Theory of Industry Structure*. Harcourt, Bruce and Jovandich, Inc., New York.

Baird A (2002) Privatization trends at the world's top-100 container ports. *Maritime Policy and Management* 29(3): 271–284.

De Rus G, Román, C. & Trujillo L (1994) *Actividad Económica y Estructura de Costes del Puerto de La Luz y de Las Palmas*. Puertos de Las Palmas. Ed. Cívitas. Madrid.

Jara Díaz S, Martínez-Budría E, Cortes C & Vargas A (1997) Marginal costs and scale economies in spanish ports. *25th European Transport Forum*. Proceedings Seminar L, PTRC, London, pp. 137–147.

Jara Díaz S, Martinez-Budría E, Cortes C & Basso L (2002) A multioutput cost function for the services of spanish ports' infrastructure. *Transportation* 29: 419–437.

Juhel M (2001) Globalisation, privatisation and restructuring of ports. *International Journal of Maritime Economics* 3: 139–174.

Kim M & Sachish A (1986) The structure of production, technical change and productivity in a port. *International Journal of Industrial Economics* 35: 209–223.

Martínez-Budría E (1996) Un estudio econométrico de los costes del sistema portuario español. *Revista Asturiana de Economía* 6: 135–149.

Martínez-Budría E, González-Marrero R & Díaz J (1998) Análisis económico de las Sociedades Estatales de Estiba y Desestiba en España. *Working paper* 97/98-1. Universidad de La Laguna. Tenerife.

Panzar J & Willig R (1977) Economies of scale in multioutput production. *Quaterly Journal of Economics* 91: 481–494.

Rekers RA, Connell D & Ross DI (1990) The development of a production function for a container terminal in the port of Melbourne. *Papers of the Australasian Transport Research Forum*, 15: 209–218.

Suykens F (1996) Influence of Port Tariffs on Maritime Transport. *VI International Congress of Maritime Traffic and Port Handling*. Vigo (Spain).

Turner H, Windle R & Dresner M (2004) North American containerport productivity: 1984–1997. *Transportation Research E* 40: 339–356.

Tongzon JL (1993) The Port of Melbourne Authority's pricing policy: its efficiency and distribution implications. *Maritime Policy and Management* 20: 197–203.

Tovar B (2002) *Análisis multiproductivo de los costes de manipulación de mercancías en terminales portuarias. El Puerto de La Luz y de Las Palmas*. (A multioutput cost analysis for cargo handling services in port terminals. La Luz y de Las Palmas' Port) Ph. D. Departamento de Análisis Económico Aplicado. Universidad de Las Palmas de Gran Canaria. España (Available from: http://www.eumed.net/tesis/btf/index.htm).

Tovar, Jara-Díaz & Trujillo (2002) Cost and Production Functions in port sector: a literature review. World Bank Working Paper, No: 3123. World Bank.

About the authors

Sergio R. Jara-Díaz is Professor of Transport Economics at Universidad de Chile. Holds both Ph.D. and M.Sc. from MIT. Research on transport demand (income effect, value of time, users' benefits), multioutput transport cost functions (scale and scope in transport industries), public transport (modelling, pricing) and time allocation.

Beatriz Tovar-de la Fé is Assistant Professor of microeconomics at the University of Las Palmas de Gran Canaria, doing research in the 'Economics of Infrastructures and Transport' group. She specializes in the study of production, efficiency and performance applied to the transport sector and network industries. She has recently published in Utilities Policy.

Lourdes Trujillo is Associate Professor of microeconomics at the Universidad de Las Palmas de Gran Canaria. She has consulted for the European Commission, the OECD and the World Bank. She advises governments in Latin America on transport and water sector reform. She has recently published in World Development, Transport Policy and Utilities Policy.