ECONOMIES OF SCALE AND SCOPE IN SERVICE FIRMS WITH DEMAND UNCERTAINTY: AN APPLICATION TO A SPANISH PORT

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Economies of scale and scope in service firms with demand uncertainty: An application to a Spanish port

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Abstract

Although shipping companies assert that the majority of their lines work to a schedule with fixed days of arrival and departure which are programmed on a weekly basis, the demand which container terminals face is characterized by a degree of uncertainty. Up to now, the analysis of cargo handling port activities has given little attention to the relationship between demand variability and firm costs. We analyse how demand uncertainty affects input choices and therefore costs of production. Our results show that demand uncertainty affects port terminal marginal cost and has the effect of increasing the estimates of economies of scale and scope. We conclude that not taking demand uncertainty into account may yield misleading estimates of terminal costs and lead to the wrong conclusions for optimal policy design.

Keywords: Demand uncertainty, port terminals, scale economies, scope economies, cost function.

JEL Classification: L91, D24.

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1. Introduction

Port terminals face uncertainty with regard to the arrival of ships for a variety of reasons including adverse weather conditions, breakdowns, and delays at previous ports due to congestion. The scale of this uncertainty was illustrated by a study of port container terminals that monitored the arrival of over 5,000 ships on 23 trading routes between April and September 2006 and which found that over 40% of the ships arrived one or more days later than planned (Drewry Shipping Consultants, 2006). If terminals are unable to meet demand, ships may suffer unacceptable delays in offloading cargo which in turn may lead to shipping companies replacing the terminal with a less congested one.[1] This potential loss of clients provides terminals with incentives to contract sufficient factors of production to have a standby capacity which ensures that the probability of delay is minimized to some acceptable target level.

The upshot of this is that terminal production costs will be affected by the desire to cover uncertain demand. While the relation between demand uncertainty and production costs in service firms has been dealt with on a theoretical level by Duncan (1990) and has been widely explored in fields such as health economics (e.g., Gaynor and Anderson, 1995; Baker et al., 2004; Lovell et al., 2009), it has received scant attention in the transport economics literature.[2] At a theoretical level, Talley (2006) provides a framework for incorporating service quality targets such as port berth reliability, defined as the average percentage of time the port's berth is open to the berthing of ships. In the empirical literature, Rodríguez-Álvarez et al. (2010) estimate a multi-output cost function which incorporates demand variability. These authors show that demand uncertainty affects port terminal costs and that not taking this into account will lead to cost efficiency being underestimated.

The correct estimation of port container terminal costs is of crucial importance for policymakers, especially regulators. The estimation of multi-output cost functions provides useful information on key concepts such as marginal costs per company or product, which help define tariff caps. It also permits the estimation of global and product-specific economies of scale, which can aid in the development of an optimal tariff structure, as well as economies of scope, which can help in determining whether

[1] This is especially true when alternative ports or other means of transport are available to firms moving goods because shipping companies will have a stronger bargaining position than terminal operators (Wang and Cullinane, 2006). See also Notteboom (2006) on the costs associated with delays for the shipping firm and its clients.

[2] This in spite of the fact that Duncan (1990) explicitly recognised that the issue had applications in several fields, including transport.

companies should be specialized (Tovar et al., 2003). However, given that terminals' desire to meet demand uncertainty will influence their costs, it is likely that key concepts such as marginal costs, economies of scale and economies of scope may be poorly estimated when demand uncertainty is not accounted for.

The relationship between demand variability, production costs and economies of scale and scope is the focus of the present paper. In particular, we use a panel data set for three Spanish port terminals to estimate a multiproduct cost system, comprising a cost function and factor demand equations, which incorporates demand uncertainty to check the effects on various measures of economies of scale and scope. Using a cost system which does not take demand uncertainty into account as a benchmark, we find that when the effect of demand uncertainty is included, estimated global scale economies and economies of scope are higher. Our results show that when analyzing port terminal economies of scale and scope we should be careful to test for the effects of demand uncertainty on costs. Failure to do so may lead to biased estimates of these economies and give rise to misleading policy recommendations in terms of pricing and optimal market structure.

The paper proceeds as follows. Section 2 outlines the theoretical background, where we discuss the incorporation of demand uncertainty into costs and the various concepts of economies of scale and scope we use. The data are described in Section 3. In Section 4 we present the empirical specification of the cost system. Our results are presented and discussed in Section 5 and Section 6 concludes.

2. Theoretical Background

The starting point for our theoretical framework is the stylized analysis of cost functions in the presence of stochastic demand provided by Duncan (1990) in a context where "… *what the firm incurs cost to produce is the option, the capacity, or the readiness to provide service at a certain level and only incidentally the observed output*." In this setting, the terminal produces a provision-of-service probability, β, implying that it is prepared to accept all clients up to capacity and that capacity exceeds demand with probability β.

To derive his cost function, Duncan (1990) begins with a firm who faces a production function $y = f(x)$. Demand for the firm, d, is a random variable with conditional distribution function $G(\cdot|d_{-1})$, where d_{-1} represents all relevant information that can be used to predict the probability that demand will be exceeded.

The probability that demand falls below service capacity is:

$$Pr[d \leq y|d_{-1}] = Pr[d \leq f(x)|d_{-1}] = G(f(x)|d_{-1}) = \beta$$

Now, if $G(\cdot|d_{-1})$ is invertible, instead of $y = f(x)$ we can write $G^{-1}(\beta|d_{-1}) = f(x)$. This production relation describes the production behaviour of the firm who produces so that capacity exceeds demand with probability β. Cost analysis is performed simply by replacing output in the conventional cost function by target service capacity, $G^{-1}(\beta|d_{-1})$. Denoting target service capacity by $G^{-1}(\beta|d_{-1}) = y^*$, the cost function becomes:

$$C = C(y^*, w) \tag{1}$$

where w represents input prices.

Two issues arise here. First, the specification of the cost function (1) implicitly assumes that none of the inputs can be adjusted after demand is realized, so there is no role for actual observed output in the determination of firm costs. Second, the provision-of-service probability is not observed by the empirical researcher.

Gaynor and Anderson (1995) resolved these issues by proposing an empirically implementable version of the Duncan (1990) model. Gaynor and Anderson (1995) begin by dividing inputs into three broad categories: fixed, quasi-fixed and variable. Fixed inputs (k) include factors which are immobile over long periods of time. Quasi-fixed inputs (x_q), on the other hand, are those which cannot easily be adjusted in response to unexpected changes in demand, and would include some types of labour and any supplies and utilities which may be complementary to that labour. Finally, variable inputs (x_v) are those which can be perfectly adjusted (purchased in spot markets) once demand is realized, and would include utilities, supplies and some types of labour.[3]

[3] See Tovar de la Fé et al. (2004) for a detailed description of the factors which are required in the production of cargo handling services (basic infrastructure, superstructure, machines, mobile equipment and labour)

In our later empirical exercise we will be estimating a long-run cost function, so in what follows we shall ignore fixed inputs. With this, the production function can be rewritten as:

$$y = f(x_v, x_q) \tag{2}$$

The firm chooses variable and quasi-fixed inputs *before* demand is realized with the constraint that demand is met with probability β, so its cost minimization problem can be written as:

$$\min_{x_v, x_q} w_v \cdot x_v + w_q \cdot x_q \tag{3}$$

$$\text{s.t. } G(f(x_v, x_q)|d_{-1}) = \beta \tag{4}$$

where w_v and w_q are the input prices. Assuming again that G is one-to-one, the constraint can be written as $G^{-1}(\beta|d_{-1}) = f(x_v, x_q)$. Denoting target service capacity by $G^{-1}(\beta|d_{-1}) = y*$, as before, this gives rise to the following input demand functions:

$$x_v = x_v(y^*, w_v, w_q) \tag{5}$$

$$x_q = x_q(y^*, w_v, w_q) \tag{6}$$

where x_v and x_q are chosen, *ex ante*, as a function of the target service capacity.

Then, demand is realized. Gaynor and Anderson (1995) assume that the firm can adjust its variable inputs once demand is realized. The firm's cost minimization problem thus becomes:

$$\min_{x_v} w_v \cdot \{x_v(y^*, w_v, w_q) + \Delta x_v\} \tag{7}$$

$$\text{s.t. } y = f\left(x_v(y^*, w_v, w_q) + \Delta x_v, x_q(y^*, w_v, w_q)\right) \tag{8}$$

where Δx_v represents the adjustment to variable inputs. The restriction in (8) implies that variable inputs depend not only on realized output but also on the target service capacity. They depend on the target service capacity indirectly because they are functions of the quasi-fixed inputs, which in turn have been chosen to meet target

service capacity, y^*. The fact that the variable inputs can be adjusted once demand is realized implies that they are also a function of realized output. [4]

Given this, *ex post* costs can be expressed as:

$$C = C(y, y^*, w_v, w_Q) \tag{9}$$

which can be seen to be a function of realized output, the target service capacity (which embodies the provision of service probability) and input prices.

Finally, target service capacity, y^*, is not directly observable. However, the greater the demand variability, the greater the target service capacity must be in order to satisfy a given provision of service probability. Target service capacity will thus be a function of the standard deviation of demand, σ_y (Gaynor and Anderson, 1995; Baker et al., 2004), so that $y^* = y^*(\sigma_y)$. Substituting this for y^* in (9), the cost function can be written as:

$$C = C(y, \sigma_y, w_v, w_Q) \tag{10}$$

where costs are expressed as a function of input prices, realized output, and demand variability which proxies target service capacity and which can be estimated. In our empirical application we will estimate the cost function jointly with the factor demand equations. Applying Shephard's Lemma, the factor demands, x_j^*, are:

$$x_j^* = \frac{\partial C}{\partial w_j} = x_j^*(y, \sigma_y, w_v, w_Q) \tag{11}$$

In the context of the economic theory of ports, note that these factor demand equations bear considerable similarity with what Talley (2006) denominates 'resource functions'. For a given set of 'port operating options', which are the means by which the port can vary the quality of its service (e.g., loading/unloading rates and berth reliability), the resource function is defined as the relationship between the minimum amount of a given resource (input) employed by a port and the levels of its port operating options and cargo received. As port terminals choose inputs with the aim of meeting uncertain demand and thereby providing a better service and higher reliability, the factor demand equations (11) are consistent with the Talley resource function.

[4] Baker et al. (2004), on the other hand, derive a similar cost function assuming that inputs can be adjusted upward but not downward. The crucial issue is that at least some adjustment can be made, making inputs a function of realized demand (output).

In our empirical application we will estimate the cost function jointly with the set of factor demand equations in order to calculate marginal costs, economies of scale and economies of scope and determine how demand uncertainty affects these measures. Economies of scale in this context will occur when a proportional increase in outputs leads to a lower proportional growth in costs. With the existence of standby capacity, the marginal costs of increasing outputs can be expected to be low (or in the extreme, zero), giving rise to economies of scale.

In general, economies of scope may arise from either cost complementarities that may be generated between different output categories or the spreading of common costs over an expanded product mix. Scope economies from spreading common costs arise when excess capacity of indivisible physical resources - and its associated costs - can be reduced by producing two outputs jointly rather than separately. This "shared-inputs" source of economies of scope allows multi-product firms to enjoy lower relative cost levels (Bailey and Friedlaender, 1982).[5]

In line with this, economies of scope will arise in the case of port terminals due to the presence of common (non-operational) costs related to non-port personnel and general expenses, as well as complementarities in production through the use of common inputs. Among these common inputs are surface space, labour managed by the firm, shore cranes used for containers and some forms of general cargo, port security services, etc.[6] In a context such as ours where ports terminals contract common inputs not only as a function of actual output and input prices but also to respond to demand uncertainty (as shown by the demand equations, (11)), the presence of this additional service capacity in order to meet the provision of service probability will be expected to increase the potential for economies of scope.

We finish this section by discussing the measures of economies of scale and scope that we use. The degree of global economies of scale, *S*, is the maximum proportional increase in output made possible from a proportional increase in all factors. Given multiple outputs and a cost function $C(Y)$ where $Y = y_1, \ldots, y_M$ is a vector of outputs and the vector of factor prices has been suppressed to simplify notation, global economies of scale can be calculated following Panzar and Willig (1977) as:

[5] Indeed, Hicks (1935) stated that most firms produced several products "… largely because there are economies to be got from producing them together, and these economies consist largely in the fact that different products require much the same overhead."

[6] See Jara Díaz et al. (2006) for a detailed discussion of common and specialized inputs in port operations.

$$S = \frac{C(Y)}{\sum_{i=1}^{m} y_i \left[\frac{\partial C(Y)}{\partial y_i}\right]} \tag{12}$$

where $S > (<)(=) 1$ denotes increasing (decreasing) (constant) returns to scale.

For product specific economies of scale, we begin with the incremental cost of product i (IC_i). This is defined as the change in total cost caused by the introduction of product i, or alternatively the total cost of producing the complete output vector Y minus total cost if product i were discontinued:

$$IC_i = C(Y) - C(Y_{-i}) \tag{13}$$

where $Y_{-i} \equiv (y_1, \ldots, y_{i-1}, y_{i+1}, \ldots, y_M)$. Product specific scale economies for product *i* (S_i) are then defined as:

$$S = \frac{IC_i}{y_i \left[\frac{\partial C(Y)}{\partial y_i}\right]} \tag{14}$$

This can be generalized to a subset of the firms products, where the scale economies specific to the subset of products $R \subset M$ is:

$$S = \frac{IC_R}{\sum_{i \in R} y_i \left[\frac{\partial C(Y)}{\partial y_i}\right]} \tag{15}$$

Economies of scope, on the other hand, captures the idea that cost savings may be possible from producing several outputs in one firm as opposed to each output being produced in a separate firm. The degree of economies of scope measures the percentage increase in cost that results from dividing the production of Y into two different production lines. For an orthogonal partition of the product vector M into subsets T and $M - T$, the degree of economies of scope (SC_T) is given by:

$$SC_T = \frac{C(Y_T) + C(Y_{M-T}) - C(Y)}{C(Y)} \tag{16}$$

where $SC_T \subset (\ 1,1)$. When $SC_T > 0$, economies of scope exist as it is cheaper to produce Y jointly than to produce the production lines Y_T and Y_{M-T} separately.

Finally, the relation between economies of scope and scale can be expressed as:

$$S = \frac{\alpha_T S_T + (1 - \alpha_T) S_{M-T}}{1 - SC_T} \tag{17}$$

where

$$\alpha_T = \frac{\sum_{j \in T} y_j \left[\frac{\partial C(Y)}{\partial y_j}\right]}{\sum_{j \in M} y_j \left[\frac{\partial C(Y)}{\partial y_j}\right]}$$

If there are no economies of scope ($SC_T = 0$), economies of scale are simply a weighted average of the specific economies of scale of each subset of production. The presence of economies of scope $SC_T > 0$ can be seen to magnify economies of scale.

Before we turn to the empirical specification of the cost function we describe the data that we use.

3. Data

The data we use have been gathered directly from the three port terminals operating in the Las Palmas Port Authority zone in Gran Canaria (the Canary Islands), Spain. The Las Palmas Port Authority is the fourth largest in Spain in terms of total cargo volume and three container port terminals operate under this Authority. These three terminals we study are private enterprises operating under concession and would qualify as typical medium-sized firms within the Spanish Port System.

We have monthly data covering the period 1991-1999. The data run from 1992 to 1997 for Terminal 1, from 1991 to 1999 for Terminal 2 and from 1992 to 1998 for Terminal 3, yielding a final unbalanced panel data set of 264 observations. As we are estimating a long-run cost function, we need information on costs, outputs and input prices.[7]

Our measure of costs is monthly total operating expenditure. Regarding outputs, the terminals mainly deal with containers, although they also operate roll-on/roll-off cargo and general break-bulk cargo. All of these are measured in total tons.

The inputs used are labour, total area, capital and intermediate inputs. There are two broad categories of labour, non-port personnel and port personnel. Non-port personnel (*LNP*) includes, among others, administrative staff, executives and maintenance staff, whereas port personnel refers to stevedores or port workers, who handle cargo. The Port personnel are in turn divided into two categories: those on the payroll (*L1*) and

[7] See Tovar et al. (2007) for a survey of production and cost function estimation in the port sector.

those who are not (*L2*). Those not on the payroll can be hired by the terminals on a provisional basis to work 6-hour shifts. The information available on labour is the number on staff per month for non-port personnel and the number of hours worked for port workers. The price of non-port personnel (w_{LNP}) is calculated as the average labour expenditure per worker, while the price of port workers (w_{L1} and w_{L2}) is total labour expenditure per hour worked.

With regard to area (*LAND*), the terminals under analysis 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. The addition of both types of areas is called total area and the area used is measured in monthly square meters. The price of the total area (w_{LAND}) is the quotient of the area-related expense divided by the total area square meters.

Capital (*CAP*), which consists of the monthly cost of the tangible assets of the company such as buildings and machinery. This cost has been calculated by adding the accounting depreciation for the period and the return on the active capital for the period. This rate of return comprises the compensation earned by risk-free capital, which is made up of bank interest, plus a risk premium. The return for both concepts amounted to 8% per annum over the sample period. The price of capital (w_{CAP}) is calculated as the ratio of the capital costs over the active capital of the period (net fixed assets under exploitation for a given period).

All productive factors which are not included in the above categories, such as office supplies, water and electricity have been aggregated to form an input which we call Intermediate inputs (*SUPP*). The price of electricity has been used as an indicator of the price of intermediate consumption (w_{SUPP}). Some descriptive statistics of the variables used are presented in Table 1 below.

This data set is particularly relevant for the purposes of our study. Firstly, it has been used by Rodríguez-Álvarez et al. (2010) in their study of the effect of demand uncertainty on port terminal costs, and demand uncertainty was found to be an important issue for these terminals' costs. Secondly, the data set has already been used by Jara-Díaz et al. (2005) to study economies of scale and scope. These authors found significant evidence of economies of scale and scope and their results can be used as a benchmark to check whether the introduction of demand uncertainty affects these estimates and whether the policy conclusions of that study change in any way.

Table 1. Descriptive statistics of variables used in estimations

	Variable	Units	Mean	Std Dev	Min.	Max.
Full sample						
Costs	Total costs (C)	1000 pesetas	94783	34820	56512	279569
Outputs	Containers (Y_{CON})	1000 Tons	59.15	41.57	14.85	309.86
	General cargo (Y_{GC})	1000 Tons	5.60	6.35	0.00	29.50
	Roll-on/Roll-off (Y_{RO})	1000 Tons	2.09	2.36	0.00	11.22
Input prices	Non-port personnel (w_{LNP})	Pesetas/month	484344	63420	60151	925544
	Payroll port workers (w_{LP1})	Pesetas/hour	10975	3128	2594	28897
	Other port workers (w_{LP2})	Pesetas/hour	9306	1080	6524	14874
	Intermediate inputs (w_{SUPP})	Pesetas/kwh	25420	2380	22000	30380
	Land (w_{LAND})	1000 pesetas/m^2	0.113	0.021	0.088	0.212
	Capital (w_K)	Return/peseta	0.023	0.004	0.013	0.033
Terminal 1						
Costs	Total costs (C)	1000 pesetas	73631	8114	56512	88821
Outputs	Containers (Y_1)	1000 Tons	53.12	9.72	32.21	73.99
	General cargo (Y_{GC})	1000 Tons	0.56	0.78	0.00	3.04
	Roll-on/Roll-off (Y_{RO})	1000 Tons	0.98	0.71	0.02	3.08
Input prices	Non-port personnel (w_{LNP})	Pesetas/month	486006	69460	373711	925544
	Payroll port workers (w_{LP1})	Pesetas/hour	10846	2907	2594	19874
	Other port workers (w_{LP2})	Pesetas/hour	9496	1537	7860	14874
	Intermediate inputs (w_{SUPP})	Pesetas/kwh	25680	2120	23070	29340
	Land (w_{LAND})	1000 pesetas/m^2	0.107	0.009	0.097	0.143
	Capital (w_K)	Return/peseta	0.023	0.002	0.020	0.028
Terminal 2						
Costs	Total costs (C)	1000 pesetas	81943	11966	60742	107906
Outputs	Containers (Y_1)	1000 Tons	33.46	7.45	14.85	61.64
	General cargo (Y_{GC})	1000 Tons	9.87	7.39	0.00	29.50
	Roll-on/Roll-off (Y_{RO})	1000 Tons	0.80	0.86	0.00	3.84
Input prices	Non-port personnel (w_{LNP})	Pesetas/month	506006	48645	410860	613214
	Payroll port workers (w_{LP1})	Pesetas/hour	9645	1543	6204	14317
	Other port workers (w_{LP2})	Pesetas/hour	9157	946	6524	12946
	Intermediate inputs (w_{SUPP})	Pesetas/kwh	25390	2650	22000	30380
	Land (w_{LAND})	1000 pesetas/m^2	0.105	0.007	0.092	0.124
	Capital (w_K)	Return/peseta	0.023	0.006	0.013	0.033
Terminal 3						
Costs	Total costs (C)	1000 pesetas	129423	42236	86826	279569
Outputs	Containers (Y_1)	1000 Tons	97.36	54.36	48.55	309.86
	General cargo (Y_{GC})	1000 Tons	4.42	3.12	0.31	13.84
	Roll-on/Roll-off (Y_{RO})	1000 Tons	4.69	2.50	0.06	11.22
Input prices	Non-port personnel (w_{LNP})	Pesetas/month	455068	63928	360151	567154
	Payroll port workers (w_{LP1})	Pesetas/hour	12796	3878	2779	28897
	Other port workers (w_{LP2})	Pesetas/hour	9333	677	7545	11594
	Intermediate inputs (w_{SUPP})	Pesetas/kwh	25250	2230	22530	29340
	Land (w_{LAND})	1000 pesetas/m^2	0.128	0.031	0.088	0.212
	Capital (w_K)	Return/peseta	0.022	0.003	0.014	0.027

Note: 166.386 pesetas = 1€

4. Cost models: empirical specification

As we are estimating two systems of equations comprising the total cost function and the factor demand equations with and without demand uncertainty, we need an estimate of demand uncertainty. To capture the effects of demand variability on costs we therefore estimate a demand forecast equation following Rodríguez-Álvarez et al. (2010). These authors note that the simplest form of the forecast equation is to relate present demand to the demand realized in the previous period i.e. an AR(1) process. As demand is not directly observed, actual output is used as a proxy. Output and demand are expected to coincide except when the terminal is operating at maximum capacity. Denoting the total demand faced by the terminal in period t as y_t^d, the demand forecast equation to be estimated is specified as:

$$y_t^d = \alpha_i D_i + \alpha_t D_t + \alpha_d y_{t-1}^d + \varepsilon_t \quad (18)$$

where D_i and D_t are port terminal and month dummy variables. The fit of this equation is our estimate of the demand forecast and we use the errors from this equation to estimate the standard error of demand. The R^2 from the estimation of (18) was over 0.9 which shows good predictive power.

Following Harvey (1976) we estimate a variance function where we regress the log of the squared error from (18) on the firm and month dummies and the lag of demand, using the antilog of the fitted values of this regression as our estimate of the standard error of demand (σ_y). This estimated standard error of forecasted demand will then be introduced into the long-run cost function and input demand equations. Their parameter estimates can then be used to test the hypothesis of whether demand uncertainty affects long-run port terminal costs according to our long-run model and will show how terminals' input choices are influenced.

To ensure that the demand uncertainty variable enters the factor demand equations, in the cost system we will include this variable not only by itself but also cross it with the factor prices. This ensures that the factor demands are expressed as a function of the demand uncertainty variable, as these demands can be obtained through Shephard's Lemma by differentiating the cost function with respect to the input prices. We follow Jara-Díaz et al. (2005) and specify a linear quadratic functional form for the cost function, which provides a second-order approximation to any arbitrary function. For a

model with m outputs and n inputs, the empirical counterparts of the cost function and demand equation system (10)-(11) to be estimated are:

$$C_i = \alpha_i + \sum_{j=1}^{m} \alpha_j y_j + \sum_{j=1}^{n} \beta_j w_j + \frac{1}{2}\sum_{j=1}^{m}\sum_{k=1}^{m} \delta_{jk} y_j y_k + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} \gamma_{jk} w_j w_k$$

$$+ \sum_{j=1}^{n}\sum_{k=1}^{m} \pi_{jk} w_j y_k + \theta t + \rho t^2 + \sum_{j=1}^{m} \lambda_j y_j t + \sum_{j=1}^{n} \rho_j w_j t + \omega \sigma_y + \sum_{j=1}^{n} \mu_j w_j \sigma_y \quad (19)$$

$$x_j \left(\equiv \frac{\partial C}{\partial w_j} \right) = \beta_j + \gamma_{jj} w_j + \sum_{k \neq j}^{n} \gamma_{jk} w_k + \sum_{k=1}^{m} \pi_{jk} y_k + \rho_j t + \mu_j \sigma_y \quad (20)$$

where the w_j are input prices, y_j are outputs, t is a time trend, σ_y is the demand uncertainty variable and the α_i are individual firm-specific effects. The parameter estimates from the cost system (19)-(20) will be used to test the effect of demand uncertainty and to estimate economies of scale and scope. To check the effects of including demand uncertainty in the cost system we will compare these estimated scale and scope economies with those obtained from estimating a system where demand uncertainty is omitted.

5. Results and discussion

The results from the estimation of the system formed by the cost function and the six input expenditure equations (19)-(20) are reported in Table 2. To account for the panel nature of the data, the Within estimator is used. Two sets of estimates are reported: Model 1 is the system without demand uncertainty and Model 2 includes demand uncertainty. The estimates were carried out using Zellner's Iterative SURE, which is equivalent to maximum likelihood estimation. Heteroskedasticity-robust standard errors are reported. The results for Model 1 are basically the same as those reported by Jara-Díaz et al. (2005), with differences being due to the different number of observations used as we have dropped the first observation for each terminal as there is no demand variable for these three observations.

Table 2. Estimates of cost system with and without demand uncertainty

Dependent variable: Total cost

	MODEL 1 No Demand Uncertainty			MODEL 2 With Demand Uncertainty		
Variable	*Estimate*	*S.E.*	*p-value*	*Estimate*	*S.E.*	*p-value*
Constant	96724	744.51	0.000	96820	703.86	0.000
$D_{TERMINAL1}$	-2458.2	284.08	0.000	-2473.2	287.26	0.000
$D_{TERMINAL2}$	-2580.2	468.88	0.000	-2599.2	469.02	0.000
y_{CON}	735.94	33.359	0.000	578.08	45.277	0.000
y_{GC}	1988.9	153.95	0.000	1826.8	149.52	0.000
y_{RO}	1259.6	350.40	0.000	1322.4	352.34	0.000
w_{L1}	1.5747	0.0257	0.000	1.5756	0.0261	0.000
w_{L2}	2.3406	0.0532	0.000	2.3449	0.0491	0.000
w_{SUPP}	982.71	11.187	0.000	982.76	11.166	0.000
w_{LAND}	61549	486.69	0.000	61595	457.55	0.000
w_{CAP}	583613	14624	0.000	584452	14657	0.000
w_{LNP}	0.0219	0.0003	0.000	0.0220	0.0003	0.000
y_{CON}^2	-0.0593	0.0476	0.213	-0.0421	0.0440	0.339
$y_{CON} \cdot y_{GC}$	0.7201	0.4992	0.149	0.8269	0.4960	0.096
$y_{CON} \cdot y_{RO}$	4.6419	1.5263	0.002	4.7161	1.3991	0.001
$y_{CON} \cdot w_{L1}$	0.0099	0.0009	0.000	0.0102	0.0013	0.000
$y_{CON} \cdot w_{L2}$	0.0199	0.0025	0.000	0.0071	0.0033	0.032
$y_{CON} \cdot w_{SUPP}$	5.7548	0.5125	0.000	5.6827	0.7131	0.000
$y_{CON} \cdot w_{LAND}$	183.98	62.309	0.003	69.946	60.345	0.246
$y_{CON} \cdot w_{CAP}$	7646.4	576.62	0.000	7749.5	846.04	0.000
$y_{CON} \cdot w_{LNP}$	0.0003	1×10^{-05}	0.000	0.0002	1×10^{-05}	0.000
$y_{CON} \cdot t$	0.1099	0.1316	0.404	0.0619	0.1294	0.632
y_{GC}^2	-0.8956	1.0675	0.401	-1.0976	1.0735	0.307
$y_{GC} \cdot y_{RO}$	-6.5857	9.8966	0.506	-7.6040	9.8371	0.440
$y_{GC} \cdot w_{L1}$	0.0372	0.0061	0.000	0.0380	0.0061	0.000
$y_{GC} \cdot w_{L2}$	0.0784	0.0115	0.000	0.0638	0.0112	0.000
$y_{GC} \cdot w_{SUPP}$	8.8916	2.3211	0.000	8.7942	2.4377	0.000
$y_{GC} \cdot w_{LAND}$	-115.52	148.42	0.436	-261.42	139.79	0.061
$y_{GC} \cdot w_{CAP}$	18260	3011.5	0.000	18825	3029.7	0.000
$y_{GC} \cdot w_{LNP}$	0.0005	0.0001	0.000	0.0004	0.0001	0.000
$y_{GC} \cdot t$	-0.4267	0.6031	0.479	-0.3439	0.6046	0.569
y_{RO}^2	-47.248	12.883	0.000	-45.226	12.818	0.000
$y_{RO} \cdot w_{L1}$	0.0388	0.0120	0.001	0.0411	0.0124	0.001
$y_{RO} \cdot w_{SUPP}$	23.440	8.2981	0.005	23.315	8.3061	0.005
$y_{RO} \cdot w_{LAND}$	-628.83	539.88	0.244	-610.28	497.36	0.220
$y_{RO} \cdot w_{CAP}$	-1220.5	8228.3	0.882	21.567	8276.5	0.998
$y_{RO} \cdot w_{LNP}$	0.0008	0.0002	0.000	0.0009	0.0002	0.000
$y_{RO} \cdot t$	-0.0948	1.7673	0.957	0.4307	1.7283	0.803
w_{L1}^2	-7×10^{-06}	1×10^{-06}	0.000	-7×10^{-06}	1×10^{-06}	0.000
$w_{L1} \cdot w_{L2}$	-2×10^{-05}	9×10^{-06}	0.026	-1×10^{-05}	8×10^{-06}	0.039
$w_{L1} \cdot w_{SUPP}$	0.0091	0.0048	0.059	0.0079	0.0046	0.087
$w_{L1} \cdot w_{LAND}$	-0.3006	0.1969	0.127	-0.2263	0.1861	0.224
$w_{L1} \cdot w_{CAP}$	6.1221	3.4962	0.080	5.7579	3.4898	0.099
$w_{L1} \cdot w_{LNP}$	1×10^{-07}	6×10^{-08}	0.002	2×10^{-07}	6×10^{-08}	0.001
$w_{L1} \cdot t$	-0.0156	0.0015	0.000	-0.0158	0.0015	0.000
w_{L2}^2	-2×10^{-05}	7×10^{-06}	0.003	-2×10^{-05}	7×10^{-06}	0.000
$w_{L2} \cdot w_{SUPP}$	0.0300	0.0071	0.000	0.0335	0.0069	0.000
$w_{L2} \cdot w_{LAND}$	0.8176	0.5196	0.116	0.6533	0.4913	0.184
$w_{L2} \cdot w_{CAP}$	-9.4977	5.6661	0.094	-9.8561	5.6246	0.080

Table 2 continued						
	Estimate	*S.E.*	*p-value*	*Estimate*	*S.E.*	*p-value*
$w_{L2} \cdot w_{LNP}$	1×10^{-07}	1×10^{-07}	0.359	1×10^{-07}	1×10^{-07}	0.489
$w_{L2} \cdot t$	0.0101	0.0030	0.001	0.0120	0.0029	0.000
w_{SUPP}^2	-15.687	2.2567	0.000	-16.525	2.2923	0.000
$w_{SUPP} \cdot w_{LAND}$	928.79	376.31	0.014	1011.83	373.72	0.007
$w_{SUPP} \cdot w_{CAP}$	3433.0	2803.9	0.221	3993.0	2753.9	0.147
$w_{SUPP} \cdot w_{LNP}$	0.0001	0.0001	0.388	0.0001	0.0001	0.291
$w_{SUPP} \cdot t$	1.1548	0.7345	0.116	1.0486	0.7506	0.162
w_{LAND}^2	-12761	20774	0.539	-7630	19317	0.693
$w_{LAND} \cdot w_{CAP}$	-186500	181410	0.304	-257772	184919	0.163
$w_{LAND} \cdot w_{LNP}$	-0.0455	0.0126	0.000	-0.0478	0.0128	0.000
$w_{LAND} \cdot t$	205.63	57.377	0.000	229.97	56.754	0.000
w_{CAP}^2	-1475990	1277620	0.248	-1397830	1262550	0.268
$w_{CAP} \cdot w_{LNP}$	0.2268	0.0626	0.000	0.2147	0.0593	0.000
$w_{CAP} \cdot t$	173.77	808.76	0.830	102.28	806.89	0.899
w_{LNP}^2	-5×10^{-09}	1×10^{-09}	0.000	-5×10^{-09}	1×10^{-09}	0.000
$w_{LNP} \cdot t$	-0.0001	1×10^{-05}	0.000	-0.0001	1×10^{-05}	0.000
t	-63.869	41.626	0.125	-47.177	39.844	0.236
t^2	0.1770	0.1214	0.145	0.1554	0.1222	0.204
σ				1519.9	317.61	0.000
$\sigma \cdot w_{L1}$				-0.0034	0.0106	0.749
$\sigma \cdot w_{L2}$				0.1234	0.0226	0.000
$\sigma \cdot w_{SUPP}$				0.7403	4.6047	0.872
$\sigma \cdot w_{LAND}$				938.61	415.28	0.024
$\sigma \cdot w_{CAP}$				-127.28	6239.7	0.984
$\sigma \cdot w_{LNP}$				0.0006	0.0002	0.000
No. observations	261			261		
R^2 Cost function	0.905			0.916		

Heteroskedasticity-robust estimates
Likelihood ratio test Model 1 v. Model 2: Test statistic = 90.06. p = 0.000

The models perform well, with the first order coefficients on the input price variables all being positive and highly significant. Comparing Model 2 to Model 1, it can be seen that the magnitudes of the estimated parameters change but the signs and significance of the parameter estimates are virtually unchanged. As the model without uncertainty is a restricted version of the model with uncertainty, we tested the validity of the restrictions using the likelihood ratio test. This soundly rejected the restricted model so demand uncertainty should be included in the specification of costs.

While the cost function performs well overall, our main interest is in the estimates of the demand uncertainty variables. The parameter on the demand uncertainty variable (σ_y) is positive and highly statistically significant. This indicates that for a given level of output, greater demand variability translates into higher terminal costs. As the

parameter should be interpreted holding all other variables constant, these costs may be attributable to managerial or organizational factors. Regarding the cross terms between the demand uncertainty variable and input prices, ($\sigma_y w$) three of them are positive and significant: non-payroll port workers, land and non-port workers. This implies that companies increase the use of these three inputs in response to demand uncertainty. Of particular interest is the fact that of the two types of port personnel, terminals tend to increase the use of non-payroll personnel in response to demand uncertainty. In concrete, an one-unit increase in the uncertainty (standard deviation) of demand (i.e., an increase of 1000 tons) leads to an increase of 123 non-payroll port worker hours per month. This is in line with the fact that this type of personnel is cheaper to employ.

Using the parameters obtained from the estimations of the cost systems, we calculate various measures of economies of scale. We calculate global scale economies at the overall sample mean and for each individual terminal, and product-specific scale economies for each of the three outputs. We then compare the estimates from both models to check whether the inclusion of demand uncertainty affects these measures. The results are reported in Table 3 below.

It can be seen that the scale economies at the overall sample mean increase when demand uncertainty is included in the estimation. Moreover, on the basis of a chi-squared test the difference is significant with a p-value of 0.005. The scale economies for each individual terminal also increase when demand uncertainty is included and the difference is strongly statistically significant in each case.

Table 3. Global and product-specific economies of scale

	Model 1 No uncertainty		Model 2 With uncertainty		H_0: Equal estimates
Scale economies	Estimate	Std. Error	Estimate	Std. Error	p-value
At sample mean					
Global	1.644	0.063	1.998	0.126	0.005
Containers	1.005	0.004	1.004	0.005	0.921
General cargo	1.003	0.003	1.003	0.003	0.799
Ro-ro cargo	1.078	0.030	1.072	0.027	0.797
By terminal					
Global T.1	2.273	0.088	2.868	0.202	0.003
Global T.2	2.124	0.100	2.514	0.166	0.019
Global T.3	1.074	0.039	1.307	0.079	0.003

The product-specific scale economies, however, do not change from one estimation to the other. The product specific degrees of scale economies are all close to unity, which suggests that the reason for the difference between the global figures on scale are due to the possible presence of economies of scope, which magnifies scale. This is confirmed by our estimates of economies of scope, which are presented in Table 4.

Table 4. Economies of scope

	Model 1 No uncertainty		Model 2 With uncertainty		H_0: Equal estimates
Scope economies	Estimate	Std. Error	Estimate	Std. Error	p-value
SC	0.782	0.046	0.999	0.062	0.001
SC_{CON}	0.386	0.023	0.495	0.031	0.001
SC_{GC}	0.393	0.023	0.502	0.031	0.001
SC_{RO}	0.390	0.023	0.498	0.031	0.000

Based on the estimated parameters, all relevant orthogonal partitions of the product vector are analysed. All SC estimates are within the theoretically expected range (-1,1) and all of them are significant. Importantly, in each case the estimates of the

economies of scope increase when demand uncertainty is included, and the differences are all highly statistically significant. Being faced with demand uncertainty therefore reinforces the advantages of joint production, in line with our discussion in Section 2. In particular, the increased use of common inputs, in our case non-payroll port workers, land and non-port workers, to provide a target provision of service probability has increased the benefits of joint production.

Finally, it is interesting to note how policy implications may change depending on whether or not demand uncertainty is included in the cost function. When demand uncertainty is not included (Model 1) terminals 1 and 2 show high increasing returns to scale (2.27 and 2.12 respectively) whereas the largest firm, terminal 3, has very slight increasing returns (1.07). This indicates that unifying the two smaller firms, terminals 1 and 2, could be desirable from a cost perspective as it would permit taking advantage of these scale economies.[8] The port would therefore contain two firms, which would permit a certain degree of competition in the market. However, when demand uncertainty is introduced into the model the conclusions change dramatically. The estimated scale economies of all three terminals increase substantially to 2.86, 2.51 and 1.3. This suggests that a single operator would be cost-efficient, implying in turn that price regulation should be imposed in order to avoid monopoly power abuse.

6. Conclusions

We have estimated a system comprising a cost function and input demand equations for a panel data set of three Spanish port container terminals in order to check whether demand variability influences measures of economies of scale and scope. Comparing the estimates of economies of scale and scope with those obtained from a system which does not include demand uncertainty, we find that demand variability affects firm input choices and costs. In particular, our results show that estimated global economies of scale and scope are higher when demand uncertainty is included.

The implication of our research is that studies of port terminals' economies of scale and scope should check for the effects of demand uncertainty as failure to do so may generate misleading regulatory policy recommendations. In our empirical study, for example, we found that when demand uncertainty is taken into account the policy

[8] This would be possible in practice because the terminals are located in neighboring sites.

recommendation would be to merge the three operators, whereas if demand uncertainty is ignored the recommendation would be to merge only the two smaller ones.

While our study has focused on port terminals, these conclusions apply in principle to any service firm which needs sufficient service capacity to satisfy uncertain demand in all but exceptional cases. This provides a potentially interesting future research agenda in empirical studies in the transport sector.

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