THE IMPACT OF PUBLIC REFORMS ON THE PRODUCTIVITY OF THE SPANISH PORTS: A PARAMETRIC DISTANCE FUNCTION APPROACH

RAMÓN NÚÑEZ-SÁNCHEZ
PABLO COTO-MILLÁN

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The impact of public reforms on the productivity of the Spanish ports: a parametric distance function approach

Ramón Núñez-Sánchez*
Pablo Coto-Millán**

Abstract

This paper tries to analyse the evolution of total factor productivity and its decomposition between 1986 and 2005 in the Spanish port authorities using a parametric distance function approach. Panel data for different outputs and inputs for the last 20 years have been constructed. During this period, the Spanish port authorities suffered three important regulatory changes. The results show that technical progress and scale efficiency gains contributed to improve total factor productivity whereas pure technical efficiency affected negatively. The change in the model of port management from a service port model to a landlord port model, the adoption of certain technologies and the possible existence of overcapacity caused by an increasing port competition, could explain these results.

Keywords: Ports; Malmquist Decomposition; Technical Efficiency; Distance Functions.
JEL classification: L92, D24, L52.

* **Corresponding Author:** Departamento de Economía. Universidad de Cantabria. Avda. Los Castros, s/n, 39005. Santander (Spain). E-mail address: nunezr@unican.es. Tel.: +34942201285 Fax: +34942201603.
** Departamento de Economía, Universidad de Cantabria, Avda. Los Castros, s/n, 39005, Santander (Spain), e-mail address: cotop@unican.es

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1. Introduction

As remarked by the EU Commission, short-sea shipping and inland waterway transport are the two modes which could provide a means of coping with the congestion of certain road infrastructure and the lack of railway infrastructure in Europe. Nowadays, both these modes are underused. The creation of motorways of the sea could be a way to strengthen short-sea shipping. This will require better connections between ports and the rail and inland waterway networks together with improvements in the efficiency of port services (EU Commission, 2001).

In Spain, maritime transport is the most important transport mode in terms of international trade. The overall port system moves 59% of total Spanish exports and 82% of total imports, which represent 53% of Spanish international trade with other EU countries and 96 % of third countries (Puertos del Estado, 2008).

The present work examines the productivity changes of Spanish port authorities during the period 1986-2005 using a parametric multiproduct distance function approach. This type of analysis has rarely been used in the assessment of port efficiency literature. Only few exceptions have been found, which use a parametric approach (Baños-Pino et al., 1999; Rodriguez-Alvarez et al., 2007; González and Trujillo, 2008). However, none of these references have estimated a Total Factor Productivity (TFP) measure. As shown in Section 3, the most extended method for port productivity analysis has been the Data Envelopment Analysis (DEA).

This paper has the following objectives. First, the estimation of a multiproduct translog input-oriented distance function in order to obtain a technical efficiency measure. This function allows calculating a Malmquist index of the Total Factor Productivity (TFP) and decomposing it into Technical Efficiency Change (TEC), Technical Change (TCH) and Scale Efficiency Change (SEC). The second objective of the paper is to study the impact of public reforms carried out during the period 1986-2005 in Spain. The question addressed by this paper is how these legal changes have impacted on the evolution of Total Factor Productivity (TFP), Technical Efficiency Change (TEC), Technical Change (TCH) and Scale Efficiency Change (SEC).

The paper is structured as follows. First, in Section 2 the Spanish port system during the period 1986-2005 is described. In Section 3, a literature review on port

technical efficiency analysis is undertaken. Section 4 establishes the definition and econometric estimation of the input-oriented distance function. Section 5 presents the descriptive analysis of the data and the results of the estimation. Finally Section 6 offers some conclusions.

2. Description of Spanish port system (1986-2005)

During the period 1986-2005, the Spanish port system has suffered some important regulatory changes[1]. Law 27/1992, Law 62/1997 and Law 48/2003 of General Interest Ports have produced important changes in the management structure of the Spanish ports. Thus, before 1992 the port system was characterized by the existence of two different management models. Most of the ports were managed by "Juntas del Puerto" (Port Assemblies), organizations characterized by having a centralized and bureaucratic structure, dependent on Ministerio de Obras Públicas (Spanish Ministry of Public Works). On the other hand, some of the largest ports (Barcelona, Bilbao, Valencia and Huelva) were defined as "Puertos Autónomos" (Autonomous Ports) with a greater autonomy level. Additionally, from 1986 the Spanish Ministry of Public Works, through the 2546/1985 Act, set a minimum rate of return based on the net investment of fixed assets for the entire port system, in order to control the current expenditures and improve the internal management of the port assemblies.

Law 27/1992 created the "Ente Público Puertos del Estado" (State-owned Enterprise of National Ports) and transformed the ports assemblies and autonomous ports into new public entities, less centralized, called "Autoridades Portuarias" (Port Authorities). Independent business criteria management with individual budgets and the abolition of direct public subsidies were some of the features of these new entities. One of the aims of these reforms was the encouragement of inter-port competition among the different port authorities. On the other hand, the State-owned Enterprise of National Ports was the responsible of coordination and efficiency control for the entire system. As remarked by Castillo-Manzano et al. (2008), after 1992, Spanish ports had more flexibility to manage the port community of their hinterland. This reform achieved the change in the port model, from a public system based on strictly administrative criteria to

[1] Other papers which study the Spanish port reform during the 1990s are Coto-Millán (1996) and Castillo-Manzano et al. (2008)

a commercial understanding of port services. Moreover, the new legislation established the creation, in every port, of a "Sociedad Estatal de Estiba y Desestiba" (State-owned stevedore company), trying to de-regulate the composition of work teams for port services, such as port cargo handling. This way, the Law allowed the replacement of the civil servants by private sector workers.

The other two public regulation reforms took place in 1997 (Law 62/1997) and 2003 (Law 48/2003). The reform in 1997, established that public Regional Governments were allowed to name members of a port authority governing board. Moreover, "Ente Público Puertos del Estado" gained autonomy from the Ministerio de Fomento (Spanish Public Works Ministry). The second one, in 2003, encouraged private investment in port infrastructures, trying to improve the intra-port competition and the competitive position of Spanish ports.

It is important to stress that, from 1992, the Spanish port system is based on financial self-sufficiency for port authorities, not receiving any direct subsidy from the national government. This way, both current and investment expenditures are financed by current incomes, EU special subsidies and, occasionally, by external debt.

Within this framework, the General Interest Ports are intended to respond to the landlord model, where the port authority just provides the port land and infrastructure and regulates the use of this public property, whereas port services are essentially provided by private sector operators under an authorization or concession regime.

3. A survey on port efficiency and regulatory changes

The estimation of productivity and efficiency measures in the port industry is relatively new and scarce. However, in recent years significant progress has been made in studies related to this topic[2]. Some of these contributions are summarized in Table 1. Cheon et al. (2009) point out the importance of distinguishing two types of ports studies, those related to infrastructure and navigation services of ports (Liu (1995); Baños-Pino et al. (1999); Coto-Millán et al. (2000); Barros(2003); Estache et al. (2004); González and Trujillo (2008)),

[2] A good survey related to productivity and efficiency measurement in the port industry comes from González and Trujillo (2009).

and those related to private terminals or cargo handling firms (Culliname et al. (2002); Rodríguez-Álvarez et al. (2007); Díaz-Hernández et al. (2008a); Díaz-Hernández et al. (2008b)).

Some of these studies use a parametric approach (Liu (1995); Baños-Pino et al. (1999); Coto-Millán et al. (2000); González and Trujillo (2008); Culliname et al. (2002); Rodríguez-Álvarez et al. (2007) and Díaz-Hernández et al. (2008b)), and some of them use a non-parametric approach (Barros(2003); Estache et al. (2004); Díaz-Hernández et al. (2008a)).

Liu (1995) studies the performance of the British port transport industry, evaluating the determinants of relative efficiency from the different ports. It concludes that neither the form of ownership nor size are important factors which can explain technical inefficiency.

Baños-Pino et al. (1999) use both the cost function approach and its dual approach, the input-oriented distance function, to demonstrate the existence of allocative inefficiency in the Spanish port authorities. The study shows that Spanish ports do not minimize their costs and also the existence of a quasi-fixed input amount higher than the optimal one, considering this optimal amount as the quasi fixed input amount if ports were allocative efficient.

Coto-Millán et al. (2000) estimate the economic efficiency of Spanish port authorities using a stochastic cost frontier. Their results show: the relatively larger ports are more economically inefficient, the existence of large economies of scale and the inexistence of technical progress during the last 80's.

Barros (2003) analyses the technical and allocative efficiencies of Portuguese port authorities in order to investigate if the state's policy is achieving its objective of regional development. The analysis concludes that the incentive regulation carried out by the government's regulatory body, based on direct subsidies for non-profitable ports, is not achieving the improvement of economic efficiency.

Estache et al. (2004) evaluate the sources of efficiency gains after the port reforms, based on the liberalization and decentralization of the port system. The study shows that the public reforms facilitated the improvement of technical change through the adoption of new technologies.

Table 1. Summary of port efficiency studies

Authors	Activity	Model [1]	Data	Variables [2]	Measures [3]	Observations
Liu (1995)	Provision infrastructure	SPF	28 British Port Authorities 1983-1990	Output: income services(m) Inputs: labour(p), capital(m) Other: trend	TE	Explain TE through OLS model. Explanatory variables: size, location, ownership, capital intensity
Baños et al. (1999)	Provision infrastructure	SCF i-DF	27 Spanish Port Authorities 1985-1995	Output: total cargo(p) Inputs: labour(p), capital(m), intermediate consumption(m), linear meters(p) Price inputs:labour price(m), capital price(m), intermediate consumption price(m) Other: variable cost(m), trend	TE AE	Estimate the optimal level of the quasi-fixed input
Coto-Millan et al. (2000)	Provision infrastructure	SCF	27 Spanish Port Authorities 1985-1989	Output: total cargo(p) Price inputs: labour price(m), capital price(m), intermediate consumption price(m) Other: total cost(m), trend	EE	Explain EE through OLS model Explanatory variables: organization, size
Estache et al. (2002)	Provision infrastructure	SPF	11 Mexican Port Authorities 1996-1999	Output: total cargo(p) Inputs: labour(p), capital(p)	TE	
Culliname et al. (2002)	Handling	SPF	15 Asian Ports/Terminals 1989-1998	Output: turnover(m) Inputs: quay length(p), terminal area(p), cargo handling equipment(p)	TE	
Barros (2003)	Provision infrastructure	DEA	5 Portuguese Port Authorities 1999-2000	Outputs: ships(p), movement of freight(p), tonnage(p), market share(%), break-bulk cargo(p), containerised cargo(p), roll-on/roll-off (ro/ro) traffic(p), dry bulk(p), liquid bulk(p), net income(m) Inputs: labour(p), capital(m) Input prices: labour price(m), capital price(m)	TE AE EE	
Estache et al. (2004)	Provision infrastructure	DEA	11 Mexican Port Authorities 1996-1999	Output: total cargo(p) Inputs: labour(p), capital(p)	TE TCh SE TFP	
Tongzon and Heng (2005)	Handling	SPF	25 International Terminals Cross-sectional	Output: container throughput(p) Inputs: terminal length(p),terminal area(p), number of quay cranes(p)	TE	Explain TE through second-step estimation Explanatory variables: size, location, private sector participation
Rodríguez-Alvarez et al. (2007)	Handling	i-DF	3 Spanish Terminals 1992-1999	Outputs: containers(p), ro-ro cargo(p), general break-bulk cargo(p) Inputs: ordinary port workers(p), special port workers(p), capital(m), intermediate consumption(m), terminal area(p)	TE AE TCh	Calculate the degree of substitutability between inputs by means of Morishima elasticities of substitution

Table 1 (cont). Summary of port efficiency studies

Authors	Activity	Model [1]	Data	Variables [2]	Measures[3]	Observations
González and Trujillo (2008)	Provision infrastructure	o-DF	9 Spanish Port Authorities 1990-2002	Outputs: containers(p), liquid bulk(p), other cargo(p), passengers(p) Inputs: labor(p), berths(p), surface(p) Other: trend	TE TCh	Include some environmental variables: existence oil refineries, location
Díaz-Hernández et al. (2008)	Handling	DEA	21 Spanish Stevedore Companies 1994-1998	Outputs: containerised general cargo(p), non containerised general cargo(p), solid bulk(p) Inputs: labour(p), crane hours(p)	TE TCh SE TFP	
Cheon et al. (2009)	Provision infrastructure	DEA	98 International Ports 1991 and 2004	Output: containers(p) Inputs: berth length(p),terminal area(p), container crane(p)	TE TCh SE TFP	Study the effects of changes on corporate structure and ownership structure of terminal assets on productivity change

Notes: (1) SPF=Stochastic Production Function; SCF=Stochastic Cost Function; i-DF=Input-oriented Distance Function;DEA=Data Envelpment Analysis;o-SF=Output-oriented distance function.
(2) (p)=physical measure; (m)=monetary measure.
(3) TE=Technical Efficiency; AE=Allocative Efficiency; EE=Economic Efficiency; TCh=Technical Change; SE=Scale Efficiency; TFP=Total Factor Productivity.

Culliname et al. (2002) apply a model to analyse the administrative and ownership structures of the terminals of the main container ports in Asia. The results of the analysis conclude that the size of a port or terminal is closely correlated with its efficiency, and that both existence of programmes in Asian ports, which aim at attracting private capital, and the level of market deregulation, improve economic efficiency.

Rodríguez-Álvarez et al. (2007) present a model to calculate both the technical and the allocative efficiency in cargo handling firms in a Spanish port. This model is applied to a frontier input-oriented distance system. The results obtained show a positive relationship between firm size and technical efficiency, and the existence of allocative inefficiency, which suggests that the port labour-specific regulatory environment hinders adjustments which are needed by operators.

González and Trujillo (2008) analyze the extent to which port reforms, which took place in the 90's, had an impact on the technical efficiency in port infrastructure provision in the major Spanish port authorities involved in container traffic. Their results show that technical efficiency has changed little on average, even though there is a significant movement of efficiency within ports over time as a result of reforms.

Díaz-Hernández et al. (2008) evaluate the deregulation process which took place in port cargo handling sector in Spain during the 90's. This work found that technical change is the element that has caused the increase in productivity, as technical efficiency has remained constant. Moreover, ports with a relatively large traffic volume exhibit efficiency index and rates of technical change higher than the average

Finally, Cheon et al. (2009) evaluate how port institutional reforms influenced efficiency gains between 1991 and 2004, using a panel data for 98 major world ports. Their results show that restructuring ownership contributed to total factor productivity gains.

4. Definition and estimation of an input-oriented distance function

4.1. Definition of an input-oriented distance function

The use of distance functions has, basically, three advantages with regard to the use of traditional cost functions. Firstly, it is not necessary to assume that port authorities minimize costs regarding input market prices. This feature is

especially important in the context of Spanish Port System, which is characterized by being a highly regulated state-owned sector. In this sense, the main objective of port authorities is the creation of employment and regional development in its hinterland (Puertos del Estado, 2008). Secondly, input-oriented distance functions do not assume the exogeneity on input prices. Thus, the existence of price regulation and monopsonistic markets in some inputs makes important this feature for the estimation of efficiency in the infrastructure services of Spanish ports.

On the other hand, the choice of an input-oriented distance function, instead of an output distance function can be justified by the conditions under which port authorities develop their activities. It has been considered that port authorities do not have control over the traffic of cargo using their facilities. However, the managers have most control over inputs such as: labour, capital and intermediate consumption.

Before specifying the input-oriented distance function, it is necessary to define the input set. The input associated with a given output vector y , is defined as the set:

$$L(y) = \{x : x \text{ can produce } y\} = \{x : (x, y) \in S\} \quad (1)$$

where *S* is the technology set. The input set consists of all inputs vectors, *x*, that can produce a given output vector, *y*.

An input-oriented distance, which involves the scaling of the input vector, is defined on the input set, $L(y)$, as:

$$D_I(x, y) = \max_{\delta} \{\delta : (x/\delta) \in L(y)\} \quad (2)$$

that is, the largest scalar by which all outputs can be proportionally divided and still the same amount of output be obtained. A value of $D_I(x, y)$ equal to 1 implies that production is technically efficient, whereas a value of $D_I(x, y)$ over 1 will indicate the existence of technical inefficiency.

Input-oriented distance functions are required to satisfy some theoretical properties: homogeneity of degree 1 in inputs, non-increasing in outputs, non-decreasing in inputs and concave in inputs.

4.2. Estimation of an input-oriented distance function

For the estimation of the input-oriented distance function, a flexible functional form has been chosen, the multiproduct translog input-oriented distance function. The translog form is based upon a second-order Taylor series expansion around the mean values:

$$\ln D_{lit} = \alpha_0 + \sum_{r=1}^{M} \beta_r \ln y_{rit} + \frac{1}{2} \sum_{r=1}^{M} \sum_{s=1}^{M} \beta_{rs} \ln y_{rit} \ln y_{sit} + \sum_{j=1}^{N} \gamma_j \ln x_{jit} + \frac{1}{2} \sum_{j=1}^{N} \sum_{h=1}^{N} \gamma_{jh} \ln x_{jit} \ln x_{hit} + \sum_{r=1}^{M} \sum_{j=1}^{N} \rho_{rj} \ln y_{rit} \ln x_{jit} + \lambda_1 T + \lambda_{11} T^2 + \sum_{j=1}^{N} \delta_j T \ln x_{jit} + \sum_{r=1}^{M} \varphi_r T \ln y_{rit} \quad (3)$$

where D_{lit} is the short-run input-oriented distance function, *y* is the output vector, *x* is the input vector, *i* relates to the *i*-th port authority and *t* relates to the time period. *T* is a time trend representing technical change. Given that the time trend *T* interacts with input and output variables, the model allows studying non-neutral technical change.

As explained before, an input-oriented distance function has to be homogeneous of degree 1 of inputs:

$$\sum_{j=1}^{N} \gamma_j = 1, \quad \sum_{\mathrm{h=1}}^{N} \gamma_{\mathrm{jh}} = 0, \quad \sum_{\mathrm{j=1}}^{\mathrm{N}} \rho_{\mathrm{rj}} = 0 \qquad \forall r = 1,.....,M \,, \sum_{\mathrm{j=1}}^{N} \zeta_{\mathrm{fj}} = 0 \quad (4)$$

The symmetry condition is also imposed:

$$\beta_{\mathrm{rs}} = \beta_{\mathrm{sr}}, \quad \gamma_{\mathrm{jh}} = \gamma_{\mathrm{hj}}, \; \zeta_{\mathrm{fj}} = \zeta_{\mathrm{jf}}, \quad \zeta_{\mathrm{fr}} = \zeta_{\mathrm{rf}}, \quad \rho_{\mathrm{rj}} = \rho_{\mathrm{jr}} \quad (5)$$

Coelli and Perelman (2000) impose these conditions by normalizing the input-oriented distance function with one of the inputs. Using this methodology, the input-oriented distance function remains:

$$-\ln\left(x_{Nit}\right) = \alpha_0 + \sum_{r=1}^{M} \beta_r \ln y_{rit} + \frac{1}{2} \sum_{r=1}^{M} \sum_{s=1}^{M} \beta_{rs} \ln y_{rit} \ln y_{sit} + \sum_{j=1}^{N-1} \gamma_j \ln x^*_{jit} + \frac{1}{2} \sum_{j=1}^{N-1} \sum_{h=1}^{N-1} \gamma_{jh} \ln x^*_{jit} \ln x^*_{hit} + \sum_{r=1}^{M} \sum_{j=1}^{N-1} \rho_{rj} \ln y_{rit} \ln x^*_{jit} + \lambda_1 T + \lambda_{11} T^2 + \sum_{j=1}^{N-1} \delta_j T \ln x^*_{jit} + \sum_{r=1}^{M} \varphi_r T \ln y_{rit} - \ln\left(D_{lit}\right) \quad (6)$$

where $x^*_{jit} = x_{jit} / x_{Nit}$. The $-\ln\left(D_{lit}\right)$ is a non-observable component interpreted as an error term which captures the technical inefficiency. Adding a symmetric

error component v_{it} and replacing $-\ln(D_{lit})$ with u_{it}, equation (6) can be estimated by maximum likelihood.

$$-ln(x_{Nit}) = TL(y_{it}, x_{it}/x_{Nit}, \beta, \gamma, \rho, \lambda, \delta, \varphi) + v_{it} - u_{it} \quad (7)$$

The u_{it} component represents the magnitude of technical inefficiency, which is allowed to vary across different port authorities, and v_{it} represents a statistical noise. Following Aigner et al. (1977), it has been assumed that v_{it} follows a $N(0, \sigma_v^2)$ distribution and u_{it} follows a $|N(0, \sigma_u^2)|$ distribution.

The value of the input-oriented distance, $D_{lit} = \exp(-u_{it})$ is not directly observable, given that u_{it} is just one of the two components of the composed error, $\varepsilon_{it} = v_{it} - u_{it}$. However, it is possible to obtain estimates of u_{it} using the expression suggested by Battese and Coelli (1988).

Following the approach outlined in Orea (2002) to measure the total factor productivity change relative to the estimated input-oriented distance function, the input-oriented Malmquist productivity index has been calculated to measure and decompose productivity change in the following way:

$$\ln(TPF_{i1}/TPF_{i0}) = \ln(TE_{i1}/TE_{i0}) + 0.5[(d_{i1}/t) + (d_{i0}/t)] + 0.5\sum_{r=1}^{M}[(SF_{i0}\theta_{ri0} + SF_{i1}\theta_{r1i})(y_{ri1} - y_{ri0})] \quad (8)$$

The first term on the right-hand-side is the technical efficiency change (TEC). The technical efficiency measure (TE_{it}), is the technical efficiency prediction of the *i*-port authority in the *t*-th period, which is defined as $TE_{it} = E(exp(-u_{it}) | \varepsilon_{it})$. This measure varies between 0 and 1. The second term is the technical change measure (TC), defined as the mean of the technical change measures evaluated at the period 0 and period 1 data points.

$$\frac{ln\, D_{it}}{T} = \lambda_1 + \lambda_{11} T + \sum_{s=1}^{M} \varphi_r \, ln\, y_{sit} + \sum_{j=1}^{N} \delta_j \, ln\, x_{jit} \quad (9)$$

The final term measures the change in scale efficiency (SEC). This measure requires the calculation of production elasticities:

$$\theta_{rit} = \frac{ln\, D_{it}}{ln\, y_{rit}} = \beta_r + \sum_{s=1}^{M} \beta_{rs} \, ln\, y_{sit} + \sum_{j=1}^{N} \rho_{rj} \, ln\, x_{jit} + \varphi_r T \quad (10)$$

for each output and each observation, and the calculation of the scale factors $SF_{it} = (\theta_{it} + 1)/\theta_{\mathrm{it}}$ at each data point, where $\theta_{it} = \sum_{r=1}^{M} \theta_{rit}$ is equal to the negative of the inverse of the standard returns to scale elasticity.

5. Empirical results

5.1. Data description

The sample consists on 27 port authorities, management entities of 50 ports considered as being of general interest in Spain. Annual data from 1986 until 2005 are available, being the complete panel data set of 540 observations. The data were gathered from the annual reports of Puertos del Estado (several years). Other studies which have been used were Baños-Pino et al. (1999), Coto-Millan et al. (2000), Jara et al. (2002), González and Trujillo (2008).

The explanatory variables of the multiproduct translog input-oriented distance function for the infrastructure services of Spanish ports comprise five outputs, three inputs and one quasi-input.

The output variables of ports represent the movements of solid bulk (*sol*) and liquid bulk (*li*), containerized general cargo (*cont*), non-containerized general cargo (*ncont*) and passengers (*pas*). Regarding input variables, labour (*l*) is defined as the total annual number of employees. Capital (*k*) is calculated as annual depreciation expenses. Finally, intermediate consumption (*ci*) is defined as annual consumption expense, services externally provided plus other expenses[3]. The stocking surface (*sup*) includes both open air and closed areas and, in this model, it is considered as a quasi-fixed input. Following the *landlord* model, port authorities grant this area under concession to private sector operators.

Table 2 shows the mean of each variable previously defined for every port during the period 1986-2005. Considering the aggregated product volume, Algeciras is the largest port authority, followed by Barcelona, Tarragona, Bilbao and Valencia. The study of the percentages of the different cargo over the total shows heterogeneity among the different Spanish port authorities. Thus, for some ports, solid bulk represents more than 85% of the total cargo as in Gijón, Ferrol and

[3] As we pointed on Section 2, in 1985 the Spanish Ministry of Public Works set a rate of return based on the net investment of fixed assets for the port system (4 per cent).

Almería. On the other hand, Cartagena and Castellón present a percentage of liquid bulk larger than 75%. Containerized general cargo is relatively important in Valencia, Algeciras and Barcelona, with percentages larger than 35%, whereas in Melilla, Baleares and Pasajes non-containerized general cargo is the most relatively important cargo, with more than 40% of the total. Finally, Algeciras, Tenerife, Ceuta and Baleares move an important annual number of passengers.

On the other hand, Valencia is the port authority with the highest number of employees, followed by Bilbao, Palmas, Barcelona and Cadiz. The largest ports in terms of capital are Barcelona, Bilbao and Valencia and the port authorities with the highest intermediate consumption are: Bilbao, Valencia, Tarragona and Palmas. Regarding the quasi-input, the port authorities of Barcelona and Valencia have the largest stocking areas during 1986-2005, with approximately 2 M of square meters. On the other hand, Melilla and Ceuta present the lowest stocking areas, with less than 51,000 square meters.

Table 2. Descriptive statistics of inputs and outputs

Port Authority	l	ci	k	li	sol	cont	ncont	pas	sup
	Number	Constant euros	Constant euros	Ton	Ton	Ton	Number	Percentage	Squared-meters
Algeciras	279	5,565,810	9,465,956	17,641,267	2,085,527	14,877,273	2,722,740	3,868,498	483,878
Alicante	176	2,105,828	2,882,790	445,609	1,224,339	648,075	353,453	163,436	166,719
Almeria	145	1,677,317	2,803,638	730,988	6,804,416	4,128	464,076	520,234	243,115
Aviles	155	2,092,553	2,434,448	597,070	1,919,288	16,045	1,326,956	0	228,646
Cadiz	297	2,775,912	6,716,675	466,106	1,243,748	758,724	1,376,868	95,082	1,301,110
Barcelona	561	17,702,237	19,196,856	8,354,769	4,141,577	9,117,752	3,321,178	1,004,169	2,081,122
Bilbao	344	11,405,452	17,418,157	14,957,604	5,074,894	3,204,266	3,034,014	89,216	1,392,806
Cartagena	191	2,051,484	4,900,580	11,479,832	2,463,293	274,924	294,616	5,131	285,410
Castellon	97	1,478,808	2,530,585	6,880,731	1,072,555	224,800	394,907	0	291,271
Ceuta	135	1,871,733	2,862,241	2,160,714	53,149	49,516	740,714	2,367,858	50,084
Ferrol	146	849,992	1,579,028	493,715	4,903,436	957	331,867	848	141,713
Gijon	398	5,321,173	10,284,181	1,343,887	13,167,304	76,581	383,692	460	756,330
Huelva	219	4,431,093	7,357,229	8,848,630	4,764,411	17	557,231	506,740	228,657
A Coruna	207	3,082,139	5,982,527	8,360,716	2,851,077	3,468	349,617	20,184	285,030
Palmas	299	6,057,936	11,121,080	3,599,856	1,007,969	4,490,037	2,514,003	823,412	522,727
Malaga	194	2,286,935	4,882,437	4,724,861	1,188,346	45,818	463,441	269,363	165,753
Melilla	83	897,774	1,596,859	432,866	107,823	116,793	456,711	388,109	27,186
Baleares	285	4,069,025	8,479,100	2,166,628	1,373,572	1,427,307	3,488,017	1,814,459	233,015
Pasajes	245	3,574,125	4,834,664	419,547	2,071,853	61,446	1,760,793	43	420,923
Pontevedra	121	849,579	1,659,645	10,904	555,561	210,634	397,834	18,403	85,183
Tenerife	219	5,076,732	9,815,523	8,043,373	1,152,531	2,268,498	2,368,548	3,217,397	454,339
Santander	242	3,935,852	6,343,766	498,492	3,140,994	27,542	911,255	127,414	614,321
Sevilla	249	3,501,355	5,712,072	238,367	2,353,133	464,034	602,633	1,624	240,349
Tarragona	315	6,135,939	8,903,090	17,786,746	7,815,066	269,788	550,051	6,055	653,865
Valencia	363	9,604,792	13,469,980	1,531,568	4,176,822	10,273,131	3,787,144	286,260	1,998,228
Vigo	223	3,793,209	5,135,533	431,813	498,301	1,012,017	1,165,724	23,114	447,989
Vilagarcía	90	532,807	1,221,168	178,433	330,416	0	167,393	2,879	147,902
Mean	233	4,175,096	6,651,474	4,549,077	2,871,904	1,849,021	1,269,832	578,533	516,580

5.2. Estimation of the multiproduct translog input-oriented distance function

The study has estimated the equation (6) by means of the maximum-likelihood procedure[4]. The variables have been divided by the geometric mean. Therefore, the first-order coefficients can be interpreted as elasticities at the sample mean. As shown in Table 3, the regularity conditions are satisfied: it is non-decreasing and quasi-concave in variable inputs, non-increasing in outputs and homogeneous of degree 1 in variable inputs.

It can be seen that every first-order coefficient is statistically significant and has the right sign with the exception of the deposit area (*sup*) coefficient. The parameters of variable inputs are positive and significant, showing that capital is the most important input in the production process of port authorities, at the sample mean. The sum of the first-order output coefficients is less than one in absolute value, indicating the presence of increasing returns to scale. This observation coincides with results obtained in other empirical ports analyses. On the other hand, the deposit area coefficient (*sup*) is negative and statistically significant. This means that the marginal productivity of deposit area is negative. Other studies related to port infrastructure obtain that this marginal productivity is negative but not statistically significant (Rodríguez-Álvarez et al. (2007)). These authors justify that due to the fact that port deposit area has an indivisibility nature, it is not possible to enlarge a deposit area in a continuous way. In this process, ports authorities have more total area than previously needed. In this sense, Baños-Pino et al. (1999) estimate the deviation between the optimal quasi-fixed input[5] if ports were allocative efficient and also the amount of input which is really used in the short-run. The results obtained showed that during the 1985-97 period Spanish ports were allocative inefficient, with an amount of the quasi-fixed input larger than the optimal.

[4] For the estimation, Stata 10.0 has been used, which includes the standard errors related to the numeraire variable derived from the asymptotic theory.

[5] Baños et al. (1999) considered as quasi-input number of lineal meters a port land surface of more than 4 meters, instead of total deposit area. However, with the data used for this study, both variables are highly correlated.

Table 3. Input-oriented distance function estimation

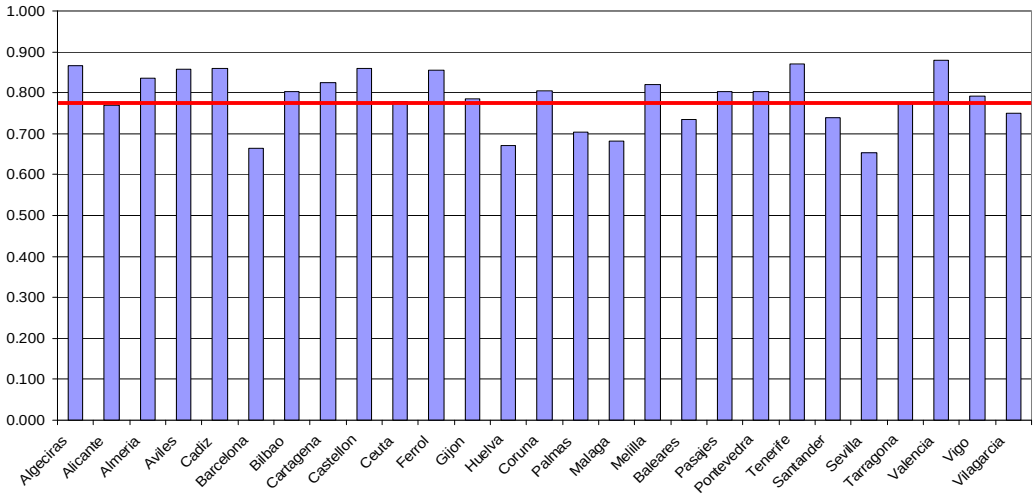
Variable	Coef.	Std. Err.	z	P>z
Constant	0.218	0.042	5.220	0.000
L(l)	0.381	0.035	11.020	0.000
L(k)	0.436	0.032	13.510	0.000
L(ci)	0.183	0.030	6.040	0.000
L(sol)	-0.101	0.016	-6.350	0.000
L(li)	-0.043	0.008	-5.650	0.000
L(cont)	-0.030	0.007	-4.250	0.000
L(ncont)	-0.164	0.022	-7.290	0.000
L(pas)	-0.012	0.004	-3.090	0.002
L(sup)	-0.358	0.025	-14.290	0.000
L(sol)*L(sol)	0.125	0.020	6.320	0.000
L(li)*L(li)	0.006	0.003	2.250	0.025
L(cont)*L(cont)	-0.004	0.002	-2.640	0.008
L(ncont)*L(ncont)	-0.033	0.038	-0.870	0.385
L(pas)*L(pas)	0.003	0.002	1.830	0.068
L(sup)*L(sup)	0.263	0.040	6.630	0.000
L(l)*L(l)	-0.217	0.074	-2.930	0.003
L(k)*L(k)	-0.089	0.130	-0.680	0.494
L(ci)*L(ci)	-0.374	0.089	-4.200	0.000
L(l)*L(k)	-0.034	0.089	-0.380	0.703
L(l)*L(ci)	0.251	0.067	3.760	0.000
L(k)*L(ci)	0.123	0.086	1.430	0.154
L(sol)*L(li)	-0.027	0.007	-3.830	0.000
L(sol)*L(sup)	-0.184	0.026	-7.170	0.000
L(sol)*L(cont)	0.010	0.004	2.260	0.024
L(sol)*L(ncont)	0.052	0.026	2.030	0.042
L(li)*L(cont)	0.007	0.001	4.830	0.000
L(li)*L(ncont)	0.022	0.009	2.330	0.020
L(li)*L(sup)	0.020	0.011	1.770	0.077
L(sup)*L(cont)	-0.015	0.008	-1.840	0.065
L(sup)*L(ncont)	-0.080	0.036	-2.250	0.024
L(cont)*L(ncont)	0.011	0.005	2.270	0.023
L(pas)*L(li)	-0.012	0.001	-9.310	0.000
L(pas)*L(sol)	0.013	0.002	5.520	0.000
L(pas)*L(cont)	0.000	0.001	0.560	0.575
L(pas)*L(ncont)	-0.004	0.004	-1.010	0.313
L(pas)*L(sup)	0.020	0.006	3.410	0.001
L(l)*L(sol)	0.064	0.027	2.400	0.016
L(l)*L(li)	0.010	0.016	0.620	0.537
L(l)*L(cont)	-0.013	0.008	-1.660	0.098
L(l)*L(ncont)	-0.099	0.046	-2.170	0.030
L(l)*L(pas)	0.016	0.006	2.660	0.008
L(l)*L(sup)	-0.017	0.048	-0.350	0.725
L(k)*L(sol)	-0.074	0.031	-2.410	0.016
L(k)*L(li)	-0.006	0.017	-0.350	0.728
L(k)*L(cont)	0.005	0.008	0.620	0.538
L(k)*L(ncont)	0.021	0.048	0.450	0.655
L(k)*L(sup)	0.105	0.053	1.970	0.049
L(k)*L(pas)	-0.010	0.007	-1.560	0.118
L(ci)*L(sol)	0.010	0.022	0.470	0.641
L(ci)*L(li)	-0.004	0.016	-0.230	0.817
L(ci)*L(cont)	0.008	0.007	1.030	0.304
L(ci)*L(ncont)	0.078	0.042	1.840	0.066
L(ci)*L(sup)	-0.088	0.042	-2.100	0.036
L(ci)*L(pas)	-0.006	0.005	-1.100	0.273

Table 3 (cont). Input-oriented distance function estimation

Variable	Coef.	Std. Err.	z	P>z
t	0.016	0.003	6.080	0.000
t*t	0.005	0.001	4.710	0.000
t*L(l)	0.009	0.008	1.100	0.270
t*L(k)	-0.008	0.008	-1.090	0.274
t*L(ci)	-0.001	0.007	-0.110	0.914
t*L(sol)	0.000	0.002	0.020	0.986
t*L(li)	0.001	0.001	0.490	0.622
t*L(cont)	-0.001	0.001	-0.930	0.351
t*L(ncont)	-0.006	0.004	-1.430	0.152
t*L(sup)	0.014	0.004	3.370	0.001
t*L(pas)	-0.004	0.000	-8.790	0.000
lnsig2v	-4.227	0.307	-13.780	0.000
lnsig2u	-2.248	0.170	-13.230	0.000
sigma_v	0.121	0.019		
sigma_u	0.325	0.028		
sigma2	0.120	0.014		
lambda	2.690	0.044		

In Figure 1 the technical efficiency index (TE_i) is presented following Section 3.2, which is estimated to be on average at 78.6% for the overall of port authorities for the period 1986-2005. The most efficient port authority is Valencia (88%), followed by Tenerife (87%), and Algeciras (86%). Other port authorities which show higher values than the average are: Almeria, Aviles, Cadiz, Bilbao, Cartagena, Castellon, Ferrol, Coruna, Melilla, Pasajes, Pontevedra and Vigo. The least efficient port authorities are Sevilla (65%), Barcelona (66%) and Huelva (67%).

Figure 1. Average technical efficiency of port authorities. 1986-2005



5.3. Decomposition of productivity change

As pointed out in Section 3.2, the estimation of an input-oriented distance function enables authors to calculate a Malmquist productivity index to measure and

decompose productivity change in different components: technical efficiency change, technical change and the change in scale efficiency.

In Table 4 it is possible to analyze the mean of technical efficiency change (TEC), technical change (TCH) and the change in scale efficiency (SEC) for each port authority. It has been observed that the annual average TFP growth rate for the whole port system over the period was equal to 2.82%, and that this was due to technical change (TCH), with an annual average growth rate of 1.58%, and scale efficiency change (SEC), with 1.43%. On the other hand, the annual average technical efficiency growth rate was negative equal to -0.19%.

Ferrol, Cartagena, Gijon and Tarragona were those port authorities with the highest annual average TFP growth rate, mainly due to technical change (TCH). In contrast, Melilla, Ceuta, Malaga and Almeria presented a negative TFP growth rate.

Table 4. Decomposition of Malmquist index. Summary of port authorities' means

Port Authority	TEC	TCH	SEC	TFP
Algeciras	-0.422	-1.649	2.599	0.528
Alicante	1.126	0.027	1.519	2.672
Almeria	-2.345	0.314	0.953	-1.078
Aviles	0.232	4.577	0.096	4.905
Cadiz	0.497	1.949	2.705	5.152
Barcelona	0.382	0.923	2.225	3.531
Bilbao	-1.083	2.172	0.817	1.905
Cartagena	0.319	3.600	3.465	7.384
Castellon	1.381	4.995	2.147	8.523
Ceuta	-0.952	-3.386	0.695	-3.644
Ferrol	1.521	3.972	2.016	7.509
Gijon	0.305	5.530	0.954	6.788
Huelva	1.747	2.260	0.856	4.863
Coruna	0.579	2.025	1.676	4.280
Palmas	-0.496	-1.007	2.005	0.502
Malaga	-1.044	-0.336	-0.430	-1.810
Melilla	-1.735	-3.211	-0.573	-5.519
Baleares	0.231	-2.208	2.617	0.639
Pasajes	-3.123	4.622	0.589	2.088
Pontevedra	0.033	3.020	0.323	3.376
Tenerife	0.180	-1.464	2.764	1.480
Santander	-0.169	1.020	0.673	1.523
Sevilla	0.023	2.387	0.729	3.139
Tarragona	-0.463	4.220	2.855	6.613
Valencia	0.001	1.053	2.745	3.798
Vigo	-1.860	3.314	0.828	2.282
Vilagarcia	-0.183	4.153	0.801	4.770
Mean	-0.197	1.588	1.431	2.822
Standard dev.	1.146	2.578	1.086	3.373
Max	1.747	5.530	3.465	8.523
Min	-3.123	-3.386	-0.573	-5.519

5.4. Regulatory periods, productivity and efficiency change

Figure 2 illustrates the weighted average TFP, TEC, TCH and SEC growth rates for every regulatory regime, defined in Section 2[6]. For period 1986-1992, where the two management models coexist, the TFP weighted average growth rate is positive

[6] Weighted averages have been determined for every measure in order to control the different size of port authorities.

(1.31%), mainly due to positive TEC and SEC growth rates (1.28% and 1.17%, respectively). Only the TCH is negative in this period (-1.15 %).

Table 5 compares changes in technical efficiency, technical change, scale efficiency and productivity between entities characterized by having centralized and bureaucratic structures (Port Assemblies), and those characterized by being more autonomous (Autonomous Ports). From 1986 to 1992, Autonomous Ports show higher TFP than Port Assemblies. The means of both groups are statistically different from the 10% according to ANOVA (F=3.64, p-value=0.058), although Welch' test does not confirm this result (-1.23, p-value=0.2284). TEC presents statistically significant differences between Autonomous Ports and Port Assemblies, based on ANOVA (F=7.87, p-value=0.005) but again, the Welch' test does not confirm this result (-1.57, p-value=0.1277). Whereas, TCH and SEC do not present differences according to ANOVA (TCH: F=0.25, p-value=0.62; SEC=0.09, p-value=0.76). These results show that more autonomous ports presented higher PTF growth rates, mainly due improvements on technical efficiency.

Figure 2. Decomposition of Malmquist index. Summary of regulatory periods' means

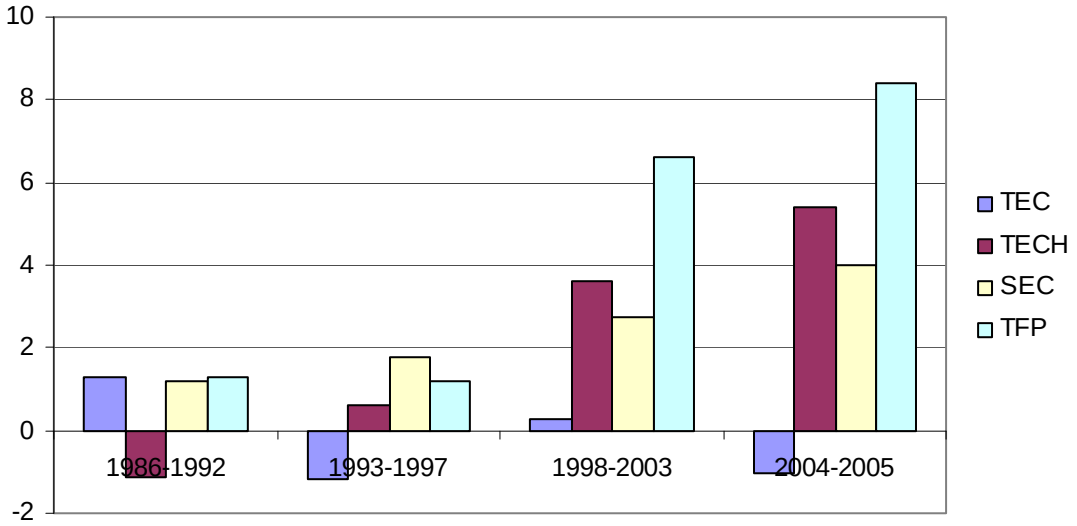


Table 5. TEC, TCH, SEC and TFP for the period 1986-1992

		Mean	Std. Dev.	Freq.
TEC	Port Assemblies	0.487	6.507	138
	Autonomous Ports	5.878	16.525	24
	Total	1.286	8.873	162
TCH	Port Assemblies	-1.090	3.824	138
	Autonomous Ports	-1.517	4.231	24
	Total	-1.153	3.876	162
SEC	Port Assemblies	1.216	3.494	138
	Autonomous Ports	0.964	5.335	24
	Total	1.179	3.803	162
TFP	Port Assemblies	0.615	9.474	138
	Autonomous Ports	5.329	18.289	24
	Total	1.314	11.268	162

For the next period, 1993-1997, in which the State-owned Enterprise of National Ports is created and the Ports Assemblies and Autonomous Ports are transformed into Port Authorities, the latter characterized by being less centralized, the weighted average TFP growth rate is positive and equal to 1.21 %. TCH and SEC weighted growth rates are positive (0.61 % and 1.76 %, respectively). However, TEC growth rate becomes negative (-1.15%), particularly during the years following the implementation of the reform. These results show that during the first years of the decentralization process of port authorities in Spain, scale-efficiency gains and especially, technical change gains were improved. Nevertheless, this first reform was not effective in terms of TEC gains. As Cheon et al. (2009) point out technical efficiency changes in ports focus on improvement in managerial and operational practices. One possible explanation for this result could be the important managerial changes suffered by ports during the implementation of Law 27/1992, especially for those ports with a centralized management structure (Ports Assemblies).

During the next two periods, 1998-2003 and 2004-2005, in which the decentralization process becomes more important through both the participation of regional governments in Port Authorities' governing board, and the encouragement of intra-port competition among the different ports' operators, the weighted average TFP growth rate rises (6.62 % and 8.38 %, respectively), due to the improvement of both SEC (2.73% and 3.99%, respectively) and TCH (3.6% and 5.42%, respectively). In addition, during the period 2004-2005 the TEC acts again as a negative factor affecting the TFP growth. Scale efficiency changes (SEC) are influenced by changes in external demand driven by the economic growth of ports' hinterlands (Estache et al., 2004). The growth of international trade from 1998 to 2005 and the change of the Spanish port model, from a public system based on strictly administrative criteria to a commercial understanding of port services could have helped port authorities to reach closer-to-optimum production scales.

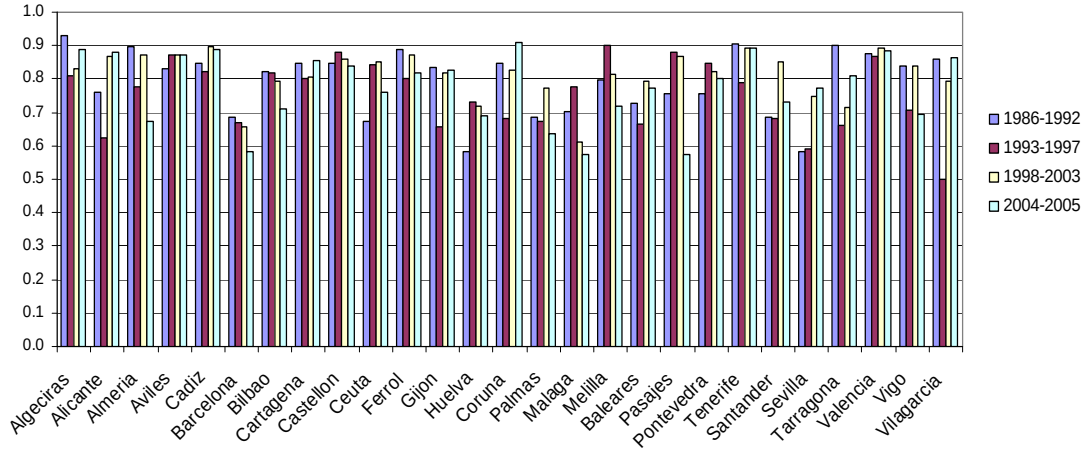
On the other hand, technical change (TCH) could be induced by the adoption of new technologies such as information and communication technologies which had allowed port authorities to shift the production frontier upwards for period 1998-2005. Finally, the possible existence of overcapacity, caused by an increasing inter-port competition, could explain the result of negative growth rates of TEC for the period 2004-2005[7]. However, this last result cannot hide the beneficial effects of the public reforms for the Spanish port system as a whole.

In order to examine technical efficiency differences among port authorities throughout the four different regulatory periods, Figure 3 shows the evolution of technical efficiency during the period 1986-2005. When comparing the first two regulatory regimes it is possible to observe that, in general terms, those ports with a centralized management structure suffered technical efficiency losses, while the technical efficiency of ports considered autonomous remained constant, except for the case of Huelva, where technical efficiency improved. Therefore, the transformation of ports assemblies into port authorities negatively affected technical efficiency, especially during the first years after the implementation of Law 27/1992. On the hand, it is important to stress that technical efficiency decreases during the last regulatory period. Thus, the port authorities as Barcelona, Bilbao or Las Palmas present relevant negative growth rates.

Finally, it has been tested whether there are significant differences on TEC, TCH, SEC and TFP among the four different regulatory periods. In this way, both ANOVA and F* tests show that there are only differences for TCH ($F^*=52.069$, p-value=0.00) and TFP ($F^*=3.002$, p-value=0.0305). However, neither TEC ($F^*=0.677$, p-value=0.5666) nor SEC ($F^*=1.836$, p= 0.1407) present statistical differences.

[7] The participation of regional governments in port authorities' governing boards (Law 62/1997) transforms Spanish ports into important tools for regional development policies. Thus, investment in ports' capacity is the most important strategic variable for the inter-port competition, given that port fees are uniform in the whole Spanish port system. This kind of inter-port competition could lead to overcapacity (Yoshihiro et al., 2009) and technical efficiency losses.

Figure 3. Regulatory periods and technical efficiency of port authorities



6. Conclusions

In this paper technical efficiency measures in the infrastructure services of Spanish ports during 1986-2005 have been calculated. Such years coincide with a period of public reforms which affected the structure of the sector. It has been possible to estimate a multiproduct translog input-oriented distance function using data of 27 port authorities from 1986 to 2005, being the final panel data set of 540 observations. This type of analysis has rarely been used in the assessment of port productivity literature.

The heterogeneity among the different port authorities has been shown, in terms of traffic, stock of capital, and deposit capacity.

The empirical evidence shows the existence of increasing returns to scale in variable inputs, but a negative marginal productivity of the deposit area. This result could be explained due to the fact that the port deposit area has an indivisibility nature, so it is not possible to enlarge a deposit area in a continuous way. In this process, ports authorities have a more extensive total area than previously needed. One of the reasons for the existence of overcapacity could be the increasing port competition between port authorities in order to enlarge their hinterlands.

The technical efficiency index has been on average 78.6% for the overall set of port authorities for the period 1986-2005. The most efficient port authority has been Valencia, followed by Tenerife and Algeciras. The least efficient port authorities have been Sevilla, Barcelona and Huelva.

In general terms, it has been found that the annual average TFP growth rate for the whole port system over the period was equal to 2.82 %, being this fact due to technical change (TCH), with an annual average growth rate of 1.58 %, and scale efficiency change (SEC), with 1.43 %. On the other hand, the annual average technical efficiency

growth rate was negative equal to -0.19 %. In this sense, it has been demonstrated that technical change is the most important source of TFP growth rate. This result is similar to those in the literature review (González and Trujillo, 2008; Díaz-Hernández et al., 2008). Moreover, the importance of considering scale efficiency change has been shown in port productivity analysis.

In general terms, the results show that the restructuring of port corporate structure in 1992, 1997 and 2003 was effective in creating a higher total factor productivity. However, it is important to stress, as a shortcoming of these public reforms, the negative growth rates of the technical efficiency change for the periods 1993-1997 and 2004-2005. An extension of this work could be to empirically test whether the inter-port competition among different port authorities leads to overcapacity and technical efficiency losses.

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