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The effect of private investment on landlord port authorities' cost efficiency: The Spanish case

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A R T I C L E I N F O

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A B S T R A C T

This article examines the impact of private investments in port facilities and equipment on the cost efficiency of Spanish port authorities operating under the landlord model. Using panel data from 26 Spanish port authorities between 2001 and 2018, we estimate a short-run variable cost frontier based on Wang's (2002) normal-truncated normal stochastic frontier model. This method allows the cost inefficiency component to depend on exogenous covariates, including private investment, traffic concentration, and port reforms. Our findings indicate that higher private investment and traffic concentration are associated with lower cost inefficiency. However, the efficiency gains from private investment have diminished since the enactment of Law 33/2010, with diminishing marginal returns at higher investment levels.

1. Introduction

Recent Spanish port legislation has aimed to enhance the competitive position of the Spanish port system within an open and globalized market. According to the preamble of Law 48/2003, the increase in private investment in port facilities and equipment, encouraged by clear and stable economic regulation over time, allowing for the financial planning of these long-term investments, would reduce the costs of the Spanish port system. This would enhance competitiveness and the investment capacity of infrastructure, as it is an economically self-sufficient system. Law 33/2010 has amended the previous Law 48/2003, reinforcing private participation in Spanish ports while adapting the system to improve competitiveness and align with EU regulations. Additionally, it has given public port authorities greater flexibility to adjust fees based on market conditions. This has helped to attract private operators by allowing ports to offer more competitive rates, fostering a dynamic business environment.

Then, a major goal of both port reforms has been related to lower port system costs by fostering competition among private port operators and minimizing reliance on public funds. This has been aligned with the principle of financial self-sufficiency for port authorities, meaning ports had to generate their own revenue from fees and private investments.

In the Spanish port system, port authorities operate under business-oriented criteria, coordinated by Puertos del Estado, a public entity under the Spanish Ministry of Public Works. The Spanish port system follows the landlord model, in which the PA goes beyond merely providing port land and infrastructure or regulating public domain use; they also play an active role in guiding port activities. However, private port operators remain the principal actors in this model, primary responsible for cargo and passenger management, superstructure development, and commercial operations. Fig. 1 shows the structure for the Spanish landlord port management system.

To facilitate port investments, Public-Private Partnerships—primarily through concession agreements—have served as a key mechanism for joint projects between port authorities and private port operators. These partnerships support the development of new terminals, logistics hubs, and specialized infrastructure, addressing capital investment needs, distributing risks, and leveraging the private sector's expertise in operational efficiency (Cabrera et al., 2015).

In this research, we test whether the preamble of Law 48/2003 is right or not. In other words, we want to address the influence of private investment on port authorities' cost inefficiency. Our hypothesis is that the transference of some risks through the PPP formula might lead to a higher port authorities' performance. This issue is relevant given that the higher port authorities' cost efficiency, the higher the possibility of lowering port fees, making investment more attractive for private port operators. To our knowledge, this is the first study that tries to analyze the influence of the effect of port private investment on the economic performance of landlord port authorities.

The results highlight that growth in private investment is generally

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associated with lower cost inefficiency in port authorities, particularly at lower investment levels. However, this efficiency-enhancing effect has weakened since the implementation of Law 33/2010, suggesting that institutional changes introduced by the reform may have reduced the effectiveness of private sector participation. Additionally, the analysis shows that greater traffic concentration within ports contributes to lower inefficiency, while the marginal effect of private investment diminishes in ports with higher concentration levels.

The paper's structure is as follows. Section 2 reviews the literature on port efficiency and investment. Section 3 outlines the investment framework and recent investment trends in the Spanish port system. Section 4 details the methodology and econometric models used. Section 5 describes the data and variables. Finally, Sections 6 and 7 present the results and conclusions, respectively.

2. Literature review

Research on port efficiency drivers is crucial within maritime economics literature. It offers insights into the factors that enhance or hinder port performance. In this sense, port investment is assumed to play a crucial role in shaping efficiency, competitiveness, and long-term development. This section reviews the existing literature on port investment and efficiency, distinguishing between theoretical contributions and empirical evidence. First, we examine the main theoretical models that analyze investment strategies in ports, often rooted in game theory or industrial organization. We then present empirical studies focused on the economic and political determinants of port investment and those that explicitly assess the impact of investment on port efficiency. Finally, we identify existing research gaps, particularly regarding the role of private sector participation in improving the performance of public landlord ports.

2.1. Theoretical models of port investment

Investment in port literature has often been approached through theoretical frameworks rooted in game theory or industrial organization models; the literature on port investment decisions provides theoretical foundations for understanding the strategic choices made by stakeholders. By synthesizing these theoretical perspectives, this section aims to illustrate the prevailing discourse on investment strategies in the port sector.

De Borger et al. (2008) investigate the dynamics of port pricing and public investment in port and hinterland capacities under duopolistic competition, showing that port capacity investment reduces port congestion and prices but increases hinterland congestion. Anderson et al. (2008) provide a game-theoretic analysis focusing on the investment effects on competition between the ports of Busan and Shanghai for container port hub status. Their main findings suggest that investments can lead to significant competitive advantages. However, the benefits are contingent on the rivals' investment decisions. Luo et al. (2012) analyze port capacity expansion and pricing strategies within a duopolistic framework, focusing on the interaction between a monopolistic incumbent port and a new entrant. They find that capacity expansion can significantly influence the incumbent's market position and profitability and deter competing ports' entry or expansion. Ishii et al. (2013) explore how ports set their service charges and decide the timing for expanding port capacity under competition and demand uncertainty. This analysis reveals that ports should ideally set lower charges when demand elasticity is high and when capacity expansions are undertaken almost simultaneously by competing ports. Cheng and Yang (2017) investigate the equilibrium conditions of port investments in China's multi-port regions, considering two scenarios: profit-driven investment by port companies and GDP-driven investment by port cities. Their results suggest that when GDP-driven investments are carried out, there may be potential over-investment or strategic misalignments.

The series of articles by Balliauw et al. (2019a, 2019b, 2020 and 2021) explores strategic port capacity investment decisions under varying conditions of uncertainty and competition. Balliauw et al. (2019a) introduce a framework for competitive port capacity expansion, highlighting the impact of uncertainty and customer aversion to delay on investment timing and size. Balliauw et al. (2019b) advocate for real options (RO) modeling to better capture managerial flexibility under uncertainty, identifying key sources of uncertainty affecting port investment decisions. In Balliauw et al. (2020), authors extend the discussion to consider a single port operator facing uncertainty and congestion, finding that ports benefit from delaying investments to accommodate larger future expansions, applicable to both private and public port operators. Finally, Balliauw et al. (2021) focus on the timing and scale of port capacity expansion investments, incorporating construction times into the RO analysis. From a qualitative and descriptive approach, Meersman (2005) explores the complexities of port investments under conditions of uncertainty. This author emphasizes the mix of public and private involvement due to large capital requirements and long payback periods, discusses the challenges posed by uncertainty

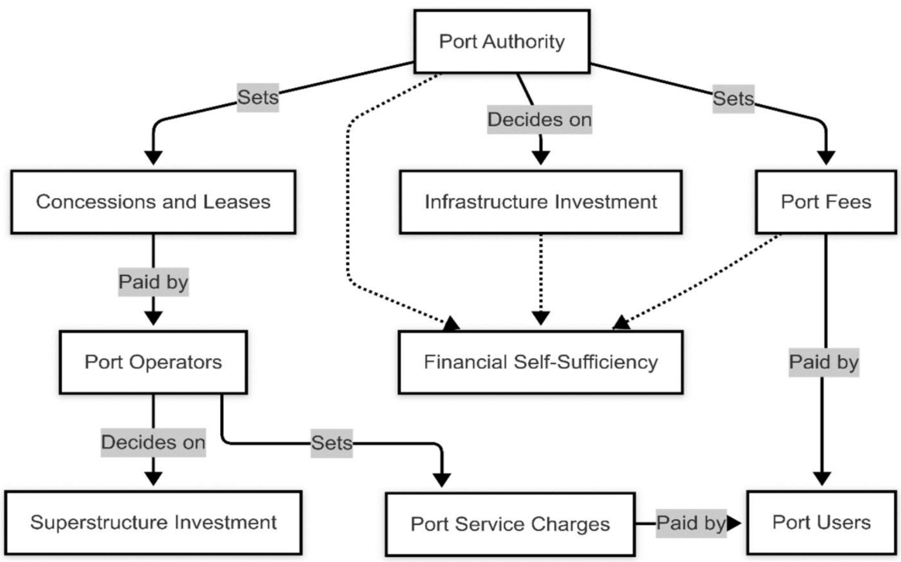

Fig. 1. Structure for the Spanish landlord port management system. Source: Own elaboration.

and irreversibility on investment decisions, and highlights the use of real options theory to manage investment timing under uncertainty.

Xiao et al. (2015) examine port investment decisions for coastal and marine disaster prevention, developing a model to assess how uncertainties affect investment timing. Immediate investment is recommended for high-probability disasters and delayed investment for low-probability ones. The study also finds that coordinated strategies can mitigate under-investment but may lead to overinvestment when disaster probabilities are low. Wang and Zhang (2018) examine the effects of uncertain disaster occurrence probabilities on port adaptation strategies, considering both inter-port competition and intra-port cooperation. They find that higher expectations of disaster occurrence probability encourage port adaptation investments, while higher variances in this probability discourage them. Randrianarisoa and Zhang (2019) use a two-period real options game model to study optimal investment timing for ports adapting to climate change under uncertainty and competition. They find that intensified competition prompts earlier investments, while low competition or significant potential for information gain suggests delaying investments. The model's insights apply to private and public ports, highlighting the strategic importance of timing in adaptation investments to enhance resilience and competitiveness, with broader impacts on social welfare and regional economies. Xia and Lindsey (2021) investigate strategic decision-making for ports facing climate change, focusing on the optimal timing and scale of investments in capacity and protection measures under uncertainty. They use a dynamic model to analyze how different port ownership types should balance immediate investment needs against the benefits of waiting for more information. The study finds that ports may delay or expedite investments based on expected changes in disaster frequency and demand uncertainty.

2.2. *Empirical studies of port investment*

2.2.1. *Political and economic determinants of port investment*

The studies by Castillo-Manzano & Fageda (2014) and Nuñez-Sanchez & Hidalgo-Gallego (2024) analyze the factors that affect port investment decisions within the Spanish port system, highlighting the interplay between economic and political factors. The key distinction between these studies lies in the use of regional data by Castillo-Manzano & Fageda (2014) versus a more disaggregated port-level data employed by Núñez-Sánchez & Hidalgo-Gallego (2024). Additionally, the latter distinguishes between two types of public investment: (i) infrastructure and capacity; (ii) logistics and intermodal transport.

Castillo-Manzano & Fageda (2014) reveal the influence of port usage and political decentralization on investment. In this sense, they find that economic performance in terms of technical efficiency or specialization in containers influence the allocation of port investments. Moreover, Spanish port reform processes at greater political but not financial decentralization allow a more important role to political criteria. For instance, the political alignment in both the regional and local governments.

Núñez-Sánchez & Hidalgo-Gallego (2024) confirm the significant role of both economic criteria and political alignment in port investment decisions. However, the relevance of the political factors differs by the type of port investment. On the one hand, the partisan alignment between local and national governments shows higher public port investment related to infrastructure and capacity. On the other hand, the coincidence between the incumbent political party in the central and regional governments affects logistics and intermodal transport investment.

2.2.2. *Port investment and efficiency*

Few studies have explicitly considered port investments when examining port efficiency despite the critical role of investment decisions in port management. Two exceptions are the contributions conducted by Díaz-Hernández et al. (2014) and Tovar & Wall (2017) stand out within this context. Both studies propose an evaluation of port efficiency within a dynamic framework. On the one hand, Díaz-Hernández et al. (2014) apply a non-parametric DEA model to estimate cost efficiency, considering quasi-fixed inputs as outputs and their lags as inputs. Conversely, Tovar & Wall (2017) utilize a directional distance function and a cost frontier to estimate technical and economic efficiency, respectively. In the directional distance function, investment is incorporated as a regressor, enabling the determination of maximum input contraction and maximum investment expansion while keeping outputs and quasi-fixed inputs constant, thus achieving technical efficiency for a given level of quasi-fixed input. Regarding the cost frontier, once optimal cost is estimated, it accounts for the cost effects resulting from changes in quasi-fixed inputs, considering the difference between gross investment and existing capital depreciation, and the time cost effects. Finally, Garcia-Alonso & Martin-Bofarull (2007) aim to analyze the impact of port investment on efficiency and the capacity to attract traffic, focusing on the Ports of Bilbao and Valencia in Spain. They apply Data Envelopment Analysis (DEA) to measure efficiency changes and study traffic distribution from the land side. Once efficiency scores are obtained, these authors compare investment levels, efficiency changes, and traffic attraction capabilities of both ports, which have seen divergent results from similar levels of investment. Garcia-Alonso & Martin-Bofarull (2007) find that investment does not guarantee enhanced port efficiency or an increased ability to attract traffic, highlighting differences in outcomes between the two ports and suggesting the need for strategic investment beyond just increasing infrastructure spending. Table 1 summarizes these studies about port investment and efficiency.

2.3. *Existing research gaps for port private sector participation on port efficiency*

Ownership and private sector involvement emerge as critical determinants of port efficiency, with studies presenting mixed findings (Table 2). For instance, while some research indicates no significant efficiency differences between privately and publicly owned ports (Liu, 1995; Tongzon & Heng, 2005; Cullinane et al., 2005), others suggest that private ownership positively affects efficiency (Wanke, 2013; Niavis & Tsekeris, 2012; Serebrisky et al., 2016; Suárez-Alemán et al., 2016; Wanke & Barros, 2015; Chang & Tovar, 2017; López-Bermúdez et al., 2019; Yuen et al., 2013). Another pivotal area of focus is the impact of legal reforms, often leading to efficiency improvements through enhanced autonomy and private participation. Within the works that find positive impacts of port reforms on port efficiency, we find Núñez-Sánchez & Coto-Millán (2012), Coto-Millán et al. (2016), Cheon et al. (2010). However, the studies of Trujillo (2008), Rodríguez-Álvarez and Tovar (2012) and Hidalgo-Gallego et al. (2022) suggest mixed or context-specific effects of port reforms.

Table 1
Summary table of empirical studies about port investment and efficiency.

Study	Focus Area	Methodology	Key Findings
Díaz-Hernández et al. (2014)	Port investment and cost efficiency	DEA (Data Envelopment Analysis)	Cost efficiency is analyzed using quasi-fixed inputs and their lag effects.
Tovar & Wall (2017)	Investment impact on technical and economic efficiency	Directional distance function and cost frontier	Investment affects efficiency by optimizing input contraction and investment expansion.
Garcia-Alonso & Martin-Bofarull (2007)	Port investment and its impact on efficiency and traffic attraction	DEA and traffic distribution analysis	Investment does not guarantee improved efficiency or increased traffic attraction.

Source: Own elaboration.

Table 2
Summary table of key studies about private participation, legal reforms and economic efficiency.

Author	Data	Model	Efficiency determinant related to port devolution	Effect on efficiency
Liu (1995)	28 UK port authorities. 1983–1990	SFA	Ownership	No effect
Cullinane et al. (2005)	30 container ports worldwide. 1992–1999	DEA	Ownership	No effect
Tongzon and Heng (2005)	25 terminals in Asia. 1999	SFA	Private participation	U-shape effect
Niavis and Tsekeris (2012)	30 container ports. South-Eastern Europe. 2008	DEA	Private operation	Positive effect
Wanke (2013)	27 Brazilian ports. 2011	DEA	Ownership	Positive effect
Serebrisky et al. (2016)	63 container ports in Latin America and the Caribbean. 1999–2009	SFA	Private participation in port operations	Positive effect
Suárez-Alemán et al. (2016)	203 ports in developing countries. 2000–2010	SFA	Private participation	Positive effect
Wanke and Barros (2015)	27 Brazilian ports. 2011	DEA	Public-private partnership	Positive effect
Chang et al. (2014)	14 terminals in Chile and Peru. 2004–2014	DEA	Private management	Positive effect
López-Bermúdez et al. (2019)	20 Brazilian port authorities. 2008–2017	SFA	Private operation	Positive effect
Yuen et al. (2013)	21 container terminals in China. 2003–2007	DEA	Foreign ownership	Positive effect
Cheon et al. (2010)	98 major world ports. 1991–2004	DEA	Port reforms	Positive effect
Núñez-Sánchez and Coto-Millán (2012)	27 Spanish port authorities. 1986–2005	SFA	Port reforms	Positive effect
Coto-Millán et al. (2016)	27 Spanish port authorities. 1986–2012	SFA	Port reforms	Positive effect
Trujillo (2008)	27 Spanish port authorities. 1990–2002	SFA	Port reforms	Individual significant effects
Rodríguez-Álvarez and Tovar (2012)	27 Spanish port authorities. 1993–2007	SFA	Port reforms	Individual significant effects
Hidalgo-Gallego et al. (2022)	26 Spanish port authorities. 1992–2016	SFA	Port reforms	Context-specific effects

Source: Own elaboration.

Despite the fact that the port devolution process began decades ago, there are still no studies that have analyzed the influence of increased private investment in port operations on the performance of publicly owned ports. One of the fundamental reasons has been the absence of homogeneous data from private port operators for publicly owned ports. In the specific case of Spain, the public entity Puertos del Estado has been publishing both public and private port investment statistics since 2001. To our knowledge, this is the first study that attempts to determine the influence of investment by port operators on the performance of public port authorities.

3. Investments in the Spanish port system

The management and development of Spanish ports involve two main types of investment: public and private, reflecting the Public-Private Partnership (PPP) model of landlord port systems. Public investment focuses on the provision and maintenance of basic infrastructure, such as docks, access channels, storage areas, and land transport connections (Puertos del Estado, several years). An example is the expansion of the port of Sagunto (2002–2013), managed by the Port Authority of Valencia. This project involved the construction of a new dock to alleviate congestion. Otherwise, private investment, carried out mainly by port operators and concessionaires, is directed towards superstructure and handling equipment, including cranes, container terminals, and specialized warehouses (World Bank, 2007). An example of private investment in the Spanish port system is the Port Nou Terminal in the Port of Barcelona (2004), developed by TCB Group (Terminal Catalunya). This project involved the construction of a specialized container terminal, incorporating advanced cranes and handling systems to improve efficiency and capacity.

Between 2001 and 2018, nearly 20 billion euros were invested in the Spanish port system, with more than 12 billion euros concentrated in the period from 2004 to 2011. Public investment peaked in 2008, exceeding 10 billion euros, while private investment reached its highest level in 2005, surpassing 9 billion euros. As shown in Fig. 2, following the enactment of Act 48/2003, private investment grew at a faster pace than public investment. However, both types of investment declined sharply after the 2008 financial crisis. In recent years, private investment has not returned to previous levels, whereas public investment has shown a slight recovery.

Fig. 3 shows the distribution of private and public investment across ports authorities. It reveals considerable disparities. Valencia and Barcelona received the highest levels of total investment, followed by Bilbao, Cartagena, and Huelva, whereas Pasajes, Melilla, Vilagarcía and Ceuta had the lowest investment levels. In general terms, investment tends to be more concentrated in ports with high cargo traffic. This suggests that it could be necessary to analyze investment in relative terms, for instance, the average investment per ton moved by the port authority as in Fig. 4.

The analysis of investment per ton of cargo highlights significant differences among Spanish ports. Port authorities such as Vigo, Málaga, and Alicante exhibit the highest levels of investment per ton,

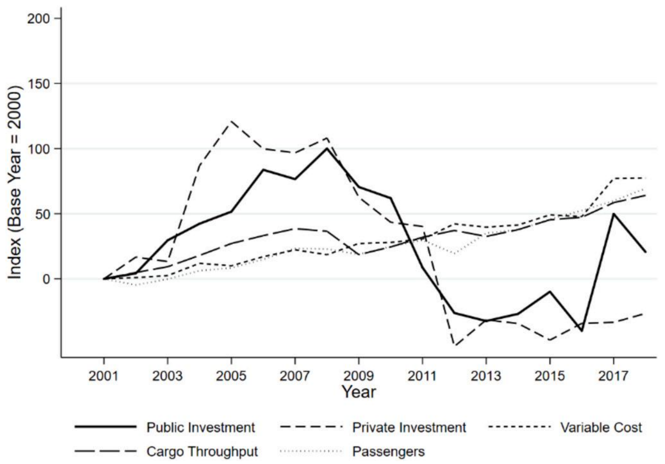

Fig. 2. Trend of private and public investment.

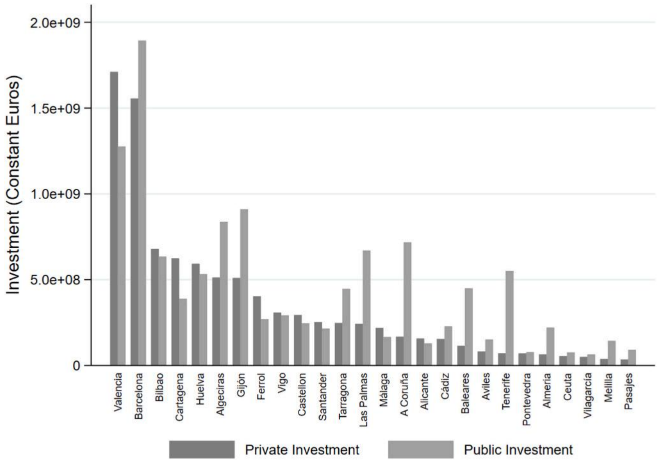

Fig. 3. Allocation of private and public investment across ports (constant €).

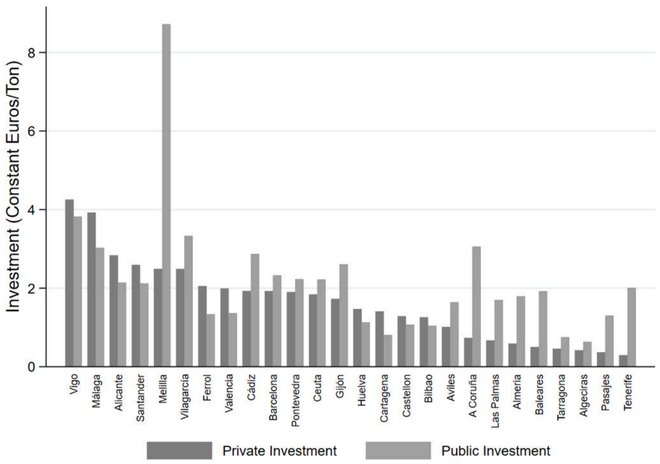

Fig. 4. Average investment per ton moved by port (constant € per ton).

particularly from private sources, indicating greater private sector involvement in specialized infrastructure. Melilla stands out with exceptionally high public investment per ton, suggesting strong government support due to strategic regional importance. Ports like Valencia, Barcelona, Cádiz, and Ferrol display a more balanced mix of public and private investment, reflecting strong public–private collaboration. In contrast, Pontevedra, Gijón, and Huelva rely more on public investment. Meanwhile, ports such as Tarragona and Algeciras, specialized in container traffic, exhibit relatively low investment per ton, possibly due to efficient infrastructure utilization.

4. Methodology

4.1. Empirical specification

In this work, we estimate a stochastic cost function, an approach particularly suitable for analyzing firms whose behavior is assumed to be cost minimizing. Unlike production frontier models, which focus solely on technical efficiency, the cost frontier function framework allows for the estimation of economic or cost efficiency, which includes technical and allocative efficiency, providing a broader measure of overall economic performance. This is especially relevant when firms operate under different input price structures, as it captures not only how efficiently inputs are transformed into outputs but also how well input combinations align with their relative prices. Within this framework, the research investigates the effects of port investments on the economic inefficiency of Spanish port authorities. The stochastic cost frontier, economic inefficiency, and the impact of investment on inefficiency levels are estimated in a one-step procedure using Maximum Likelihood Estimation (MLE). Employing this one-step approach helps avoid the biases (Wang and Schmidt, 2002) and inconsistencies (Chang and Tovar, 2014) that are often associated with two-step estimation methods.

To appropriately model the operating environment of port authorities, it is also necessary to consider the nature of their inputs. Infrastructure components such as linear meters of quays or storage areas cannot be easily or quickly adjusted in response to changes in demand, due to their indivisibility, budgetary constraints, and the bureaucratic processes typical of the public sector. As a result, these infrastructure elements must be treated as quasi-fixed inputs. Such inputs justify the estimation of a short-run variable cost function, which reflects a setting in which port authorities minimize their variable costs subject to existing levels of quasi-fixed infrastructure. This specification better captures the operational constraints faced by port authorities and aligns with the economic environment in which their decisions take place.

Subsequently, a short-run cost function is specified to estimate port authorities' inefficiencies. The variable cost function, $VC(\boldsymbol{w}_{it}, \boldsymbol{y}_{it}, k_{it})$, is defined as the minimum variable cost required to produce the output vector $\boldsymbol{y}_{it}$ given the variable input prices $\boldsymbol{w}_{it}$ and the quasi-fixed input k_{it}. This definition entails identifying the technically feasible combination of variable inputs that allows for the minimization of variable costs in producing $\boldsymbol{y}_{it}$ given $\boldsymbol{w}_{it}$ and k_{it} (1) (Coelli et al., 2005).

$$VC^{*}_{it}(\boldsymbol{w}_{it}, \boldsymbol{y}_{it}, k_{it}) = min_{\boldsymbol{x}_{it}} \sum_{r=1}^{R} w_{rit} x_{rit} \; such\, that \; T(\boldsymbol{x}_{it}, \boldsymbol{y}_{it}, k_{it}) = 0 \qquad (1)$$

where $VC^{*}_{it}(\boldsymbol{w}_{it}, \boldsymbol{y}_{it}, k_{it})$ represents the variable cost function, $\boldsymbol{w}_{it}$ is the vector of variable input prices, $\boldsymbol{y}_{it}$ is the vector of outputs,k_{it} is the quasi-fixed input, $\boldsymbol{x}_{it}$ is the vector of variable inputs that minimizes variable costs. The subscript i refers to the $i-th$ port authority and t refers to the period.

In equation (2), variable cost inefficiencies occur when the observed variable cost (VC_{it}) exceeds the minimum variable cost,$VC^{*}_{it}(\boldsymbol{w}_{it}, \boldsymbol{y}_{it}, k_{it})$

$$VC_{it}(\bullet) = VC^{*}_{it}(\boldsymbol{w}_{it}, \boldsymbol{y}_{it}, k_{it}) + v_{it} + u_{it} \qquad (2)$$

where $VC^{*}_{it}(\boldsymbol{w}_{it}, \boldsymbol{y}_{it}, k_{it})$ is the variable cost function, $\boldsymbol{w}_{it}$ is the vector of inputs, $\boldsymbol{y}_{it}$ is the vector of outputs, k_{it} is the quasi-fixed input, i refers to the $i-th$ port authority and t refers to the period. The error component v_{it} represents the random disturbance, which is independently and identically distributed (*iid*) as normal with a mean of zero; and u_{it} captures the cost inefficiencies that are assumed to follow a non-negative truncated normal distribution, $u_{it} \sim iidN^{+}(\mu_{it}, \sigma_{uit})$.

Moreover, we assume that exogenous determinants ($\boldsymbol{z}_{it}$) affect the inefficiency distribution through its mean, μ_{it} (Belotti et al., 2013). Following Lovell (1993), we consider in $\boldsymbol{z}_{it}$ those variables beyond the decision maker's control during the study period. These determinants include the investments undertaken by private port operators operating under the port authority.

$$\mu_{it} = \mu(\boldsymbol{z}_{it}) \qquad (3)$$

Therefore, as we said above, the model formed by (2) and (3) is estimated using Maximum Likelihood Estimation (MLE). Additionally, Wang (2002) proposes a formulation to compute the non-monotonic effects of the investment variables included in (3). This procedure can be implemented after the joint estimation of (2) and (3).

4.2. Econometric model

We employ a translog short-run variable cost frontier to analyze the cost performance of port authorities for several reasons. In the landlord port model, outputs are exogenous to port authorities, which means their main decision variables are limited to variable inputs and quasi-fixed inputs. Specifically, in the short run, port authorities cannot adjust their quasi-fixed input—measured as the linear meters of quay—and must focus on minimizing variable costs, in line with their legal and institutional constraints. The flexible multiproduct translog functional form is particularly suitable for this setting, as it allows for varying cost elasticities across port authorities, capturing potential heterogeneity in behavior and performance. In contrast, more restrictive functional forms such as Cobb-Douglas would impose uniform elasticities and limit the model's ability to reflect port-specific cost structures.

In the proposed specification, all the variables centered around their means. Consequently, first-order coefficients can be interpreted as elasticities at the sample mean. The final specification of the model is presented below, where efficiency is expressed as a function of the exogenous inefficiency determinants, which includes private operators' investments:

$$lnVC_{it} = \alpha_0 + \sum_{r=1}^{R}\alpha_r lnw_{rit} + \sum_{m=1}^{M}\beta_m lny_{mit} + \frac{1}{2}\sum_{r=1}^{R}\sum_{s=1}^{R}\alpha_{rs} lnw_{rit} lnw_{sit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn} lny_{mit} lny_{nit} + \sum_{r=1}^{R} \times \sum_{n=1}^{M}\gamma_{rm} lnw_{rit} lny_{mit} + \gamma_k lnk_{it} + \frac{1}{2}\gamma_{kk} lnk_{it} lnk_{it} + \sum_{r=1}^{R}\gamma_{rk} lnw_{rit} lnk_{it} + \sum_{m=1}^{M}\gamma_{mk} lny_{mit} lnk_{it} + v_{it} + u_{it} \quad (4)$$

$$\mu_{it} = \psi_0 + \psi_1 lnpoi_{it} + \psi_2 hhi_{it} + \psi_3 lnpoi_{it} {}^* d_{2010} + \psi_4 lnpoi_{it} {}^* hhi_{it} + \omega_{\mu it} \quad (5)$$

where VC_{it} is the variable cost of port authority i in year t, w_{rit} is the price of the variable input r for port authority i in year t, y_{mit} is the volume of cargo m handled by port authority i in year t, k_{it} is the quasi-fixed input of port authority i in year t, poi_{it} is the amount of private investment in port i in year t, hhi_{it} is the level of traffic concentration of port i in year t and d_{2010} is a dummy variable taking a value one for the year 2010 and onwards, and zero otherwise. The error component v_{it} represents random disturbances that are identically, independently and normally distributed with a mean of zero and u_{it} represents cost inefficiencies identical and independently distributed following a truncated normal distribution with mean μ_{it}. Finally, $\omega_{\mu it}$ is a random variable that is not necessarily identically distributed.

The variable cost function must satisfy several regularity properties: homogeneity of degree one in variable input prices, non-decreasing behavior in outputs, non-decreasing behavior in variable input prices, and concavity in variable input prices. Homogeneity of degree one can be enforced in the translog functional form by imposing the following parameter restrictions: $\sum_{r=1}^{R}\alpha_r = 1; \sum_{r=1}^{R}\alpha_{rs} = 0; \sum_{r=1}^{R}\gamma_{rm} = 0; \sum_{r=1}^{R}\gamma_{rk} = 0$. Additionally, symmetry is ensured by stipulating that: $\alpha_{rs} = \alpha_{sr}$, $\beta_{mn} = \beta_{nm}$ and $\gamma_{rm} = \gamma_{mr}$.

From the estimation of equation (4), we can obtain the variable cost elasticities for each output through logarithmic differentiation of the variable cost function (6), the short-run marginal costs (7), and the short-run economies of capacity utilization, SE_{it}^{Sr}, defined as the maximum growth rate of outputs achieved when all variable inputs expand in the same proportion for a given level of capacity (8).

$$\varepsilon_{mit}^{VC} = \left(\beta_m + \sum_{n=1}^{M}\delta_{mn} lny_{nit} + \sum_{j=1}^{J}\lambda_{mj} lnw_{jit} + \theta_{mk} lnk_{it}\right) \quad (6)$$

$$MC_{mit}^{Sr} = \varepsilon_{mit}^{VC}\frac{VC_{it}}{y_{mit}} \quad (7)$$

where STC_{it} is $VC_{it} + r_{it}K_{it}$, being VC_{it} the variable cost, r_{it} the price of the quasi-fixed input and K_{it} the quasi-fixed input.

$$SE_{it}^{Sr} = \frac{VC_{it}}{\sum_m \frac{\partial VC}{\partial Q_m} Q_{mit}} = \frac{1}{\sum_m \varepsilon_{mit}^{VC}} \quad (8)$$

5. Data

Data from 26 Spanish port authorities observed from 2001 to 2018 has been gathered to estimate the previously mentioned empirical specification. The Spanish port system includes 28 port authorities; however, our study excludes Seville and combines the port authorities of Almería and Motril into a single entity. Seville is omitted due to its unique status as a river port, while Almería and Motril, which were managed by the same port authority until their separation in 2005, are considered together. Financial and traffic data were sourced from the annual reports published by the state-owned entity 'Puertos del Estado' and the respective port authorities. Additional statistical information was obtained from the Spanish Statistics Institute (INE). Detailed descriptive statistics of the variables used in the model are presented in Table 3.

To estimate the translog short-run variable cost frontier in equations (6) and (7), we constructed the following variables: The dependent variable in equation (6) is the variable cost (*vc*), which includes labor, capital and intermediate consumption expenses. The independent variables in the cost frontier model include output, the prices of variable inputs, and a quasi-fixed input. Reflecting the diverse nature of port operations, we incorporate five types of outputs into the model: liquid bulk (*lb*), solid bulk (*sb*), containerized general cargo (*cgc*), non-containerized general cargo (*ogc*), and passenger traffic (*pax*). Input prices comprise labor price (pl), price of variable capital (*pvc*) and intermediate consumption price (pic). Labor price (pl) is calculated as the ratio of labor expense to the number of workers employed by the port authority. The capital price (*pvc*) has been approximated by multiplying the building index price of public works (obtained from the reports of the Confederación Nacional de la Construcción, SEOPAN) by the sum of the long-term interest rate and the depreciation rate of the port's property and equipment. The depreciation rate is calculated as the annual depreciation expenditure of each port authority divided by the total assets. The intermediate consumption price (*pic*) is defined as the ratio resulting from dividing the intermediate consumption expense by the tons of intermediate supplies used by the port authority. The port authorities' linear meters of quays (*k*) proxy the quasi-fixed input.

Since the main objective of this study is to assess the impact of private investment on the cost efficiency of port authorities, equation (5) includes the natural logarithm of total investment carried out by private operators (*lnpoi*) as the core determinant under analysis.[1] To better

[1] Although private investments are made by entities other than the port authority, for the sake of simplicity, we denote the investments undertaken by the private sector in port authority i during period t as $lnpoi_{it}$. Another reason for using this notation is that data on these private investments are collected and published by the port authority and by Puertos del Estado in their annual reports and official publications.

Table 3
Descriptive statistics.

Variable	Description	Units	Mean	Std. Dev.	Min	Max
vc	Variable cost	Constant euros	2.35E + 07	1.88E + 07	3,409,897	1.14E + 08
lb	Liquid bulk	Tons	5,762,024	7,613,212	0	3.18E + 07
sb	Solid bulk	Tons	3,590,414	3,719,947	3425	1.97E + 07
cgc	Containerized general cargo	Tons	5,106,492	1.18E + 07	0	6.06E + 07
ogc	Non-containerized general cargo	Tons	2,128,868	2,616,988	681	1.41E + 07
pax	Passenger	People	1,018,131	1,715,279	0	8,942,434
pl	Price of labor	Constant euros	33,123.26	5,064.48	18915.56	57397.51
pvc	Price of variable capital	Rate	6.11	2.32	1.384523	11.9779
pic	Price of intermediate consumptions	Constant euros	64.26	76.42375	2.79468	830.6668
k	Quays	Linear meters	12588.47	9132.623	2634	50,751
poi	Private operators' total investment	Million constant euros	1.97E + 07	3.56E + 07	0	2.99E + 08
hhi	Traffic concentration index		1.42E + 07	2.42E + 07	0	1.58E + 08
D2010	Dummy Act 33/2010		1,308,007	3,134,602	0	3.25E + 07

isolate the effect of this investment on port authorities' cost performance, we control for an exogenous port characteristic as traffic concentration. Specifically, we use the Herfindahl-Hirschman Index (*HHI*), calculated as the sum of the squares of the shares of each of the four types of cargo in the total volume handled by a port in a given year:

$$HHI_{it} = \sum_{j=1}^{M-1} s_{mit}^2 \tag{9}$$

where $s_{mit} = \frac{y_{mit}}{\sum_{j=1}^{M-1} y_{mit}}$ represents the share of cargo type m in the total cargo handled by the port authority i in year t.

Additionally, to explore how regulatory changes may influence the relationship between private investment and port authorities' cost efficiency, we include an interaction term between private investment and a dummy variable associated with Act 33/2010 (D_{2010}). This dummy takes a value of one from 2010 onwards and zero for the previous years, capturing potential structural breaks or shifts in the institutional context introduced by the reform. Furthermore, since port-specific characteristics such as traffic concentration may also condition the effectiveness of private investment, we include interaction terms between private investment and the Herfindahl-Hirschman Index. This allows us to assess whether the degree of cargo specialization or diversification within a port alters the impact of private capital on port authorities' cost-efficiency outcomes.

6. Results

Based on the econometric specifications outlined earlier, we have estimated the short-run cost frontier and the inefficiency effects model using the maximum likelihood method. The analysis is conducted across two distinct specifications to address different aspects of investment and its impacts on port efficiency. Specification 1 includes investments made by private agents, the interaction between private operators' investment and a dummy variable capturing the effect of Act 33/2010, and a measure of port authorities' traffic concentration as a control for port authorities' characteristics. Additionally, Specification 2 includes the interaction between private investment and traffic concentration to capture how port characteristics influence the effect of private investment on port authorities' cost inefficiencies.

Table 4 provides the estimates for both specifications of the variable cost frontier model. The results appear robust across the two specifications. Each model satisfies the short-run cost function's regularity conditions, exhibiting homogeneity of degree one in input prices, non-decreasing behavior in input prices and outputs, and concavity in input prices. The standard errors of these estimations are presented in brackets to the right of each coefficient. Moreover, the first-order coefficients can be interpreted as elasticities, evaluated at the data average since each variable has been standardized by its respective geometric mean. This adjustment allows for a direct comparison of elasticities across different outputs.

Table 4
Maximum likelihood estimates of the short-run cost frontier and the inefficiency model.

VARIABLE	Specification 1	Specification 2
Frontier		
pl	0.848***	0.846***
	(0.0268)	(0.0263)
pvc	0.118***	0.122***
	(0.0248)	(0.0243)
pic	0.034**	0.033**
	(0.0154)	(0.0152)
k	0.229***	0.227***
	(0.0425)	(0.0419)
lb	0.0430***	0.0424***
	(0.0106)	(0.0105)
sb	0.107***	0.108***
	(0.0171)	(0.0171)
cgc	0.0210***	0.0191**
	(0.00810)	(0.00804)
ogc	0.285***	0.285***
	(0.0269)	(0.0264)
pax	0.0779***	0.0795***
	(0.0112)	(0.0109)
Constant	−0.114***	−0.118***
	(0.0390)	(0.0380)
Second order coefficients[a]	Yes	Yes
Mean of the inefficiency term		
lnpoi	−0.542**	−0.884***
	(0.271)	(0.298)
lnpoi*D2010	0.511*	0.333*
	(0.272)	(0.175)
hhi	−10.07***	−8.357***
	(3.383)	(3.193)
lnpoi *hhi		1.781***
		(0.592)
Constant	3.078***	2.655***
	(0.955)	(0.929)
Variance of the inefficiency term		
Constant	−3.413***	−4.174***
	(0.684)	(0.669)
Variance of the error term		
Constant	−3.520***	−3.559***
	(0.0692)	(0.0690)
Log-Likelihood function	146.70	151.30

[a]The full set of estimation results, including second-order coefficients, is provided in Annex 1.

Table 4 shows that the estimated first-order coefficients for both models display the expected signs and are statistically significant. According to Shephard's Lemma, the elasticities of variable input prices in the short-run translog cost function reflect the contributions of each input to the total variable costs. The price of labor has the highest elasticity coefficient, indicating that labor costs constitute a significant proportion of the total variable costs. Regarding outputs, non-

Table 5
Cost elasticities, marginal costs, short-run total cost elasticity and economies of capacity utilization (Specification 1).

	Liquid bulk	Solid bulk	Containerized general cargo	Non −containerized general cargo	Passengers
Cost elasticities	0.0430***	0.107***	0.0210***	0.285***	0.0779***
Marginal costs	0.1753***	0.6970***	0.0963***	3.1389***	1.7953***
Economies of capacity utilization	1.8751***				

containerized general cargo exhibits the highest cost elasticity, while container traffic shows the lowest. This suggests distinct operational dynamics among cargo types. General non-containerized cargo can be shipped in various forms: as individual units like rolls of paper, using pre-slung systems for materials such as iron or wood, or on pallets and vehicles. Handling techniques also vary depending on the type of cargo and the volume of inputs required for movement (Jara-Díaz et al., 2006). These variations may partially explain the higher cost elasticity associated with this type of traffic. In contrast, containerized cargo is more standardized, which allows for greater flexibility and efficiency in both handling and storage. The mechanization and technological advancements in container handling have also enabled economies of scale, making these operations less sensitive to small fluctuations in input prices. Economies of capacity utilization have been identified and calculated as the inverse of the sum of the coefficients related to the five outputs considered. This suggests efficiency gains in port operations as output increases. Table 5 shows the cost elasticities, marginal costs, short-run total cost elasticity, and economies of capacity utilization for the output considered in Specification 1.[2] The quasi-fixed input, proxied by the linear meters of quays, shows a positive coefficient in both models. This indicates that an increase in quay length necessitates higher input usage, thereby increasing variable costs.

Similar to cost elasticities, the estimated marginal costs reveal substantial differences across cargo types. Non-containerized general cargo shows the highest marginal cost, which is consistent with its heterogeneous nature and the complexity involved in its handling. In contrast, containerized general cargo presents the lowest marginal cost, reflecting the efficiency gains from standardization, mechanization, and economies of scale. Solid bulk and liquid bulk fall somewhere in between, with solid bulk being relatively more costly, probably because of additional handling and storage requirements. Passenger traffic also exhibits a relatively high marginal cost, likely due to its labor-intensive and service-oriented characteristics.

After discussing the results associated with the estimation of the cost frontier, we now turn to the analysis of the determinants of cost inefficiency, as captured by the inefficiency term in the stochastic frontier model. The results suggest that higher levels of private investment and greater traffic concentration are associated with lower cost inefficiency, as indicated by the negative and statistically significant coefficients of the logarithm of private port operators' investment and the Herfindahl-Hirschman index. However, the interaction between private investment and the time dummy variable associated with the enactment of Law 33/2010 is positive and statistically significant, suggesting that the efficiency gains from private investment have diminished since the implementation of the reform. While Law 33/2010 aimed to deepen the liberalization and competitiveness of the Spanish port system, some of the institutional changes it introduced may have reduced the effectiveness of private investments in improving efficiency. In particular, the reorganization of the port labor system created a period of legal and operational uncertainty, likely introducing rigidities that limited private operators' ability to plan or carry out investments efficiently. However, it is also worth noting that the decline in the efficiency gains from private investment observed after 2010 may not be solely attributable to the institutional changes introduced by Law 33/2010. As shown in Fig. 2, public and private port investment dropped sharply starting in 2008–2009, reflecting the impact of the global financial crisis and subsequent fiscal constraints. This overlap complicates the identification of the reform's effect, as the diminished impact of private investment on cost efficiency may also partly result from reduced investment volumes and broader macroeconomic factors. Moreover, the interaction between private investment and traffic concentration is also positive and statistically significant, implying that the marginal effect of private investment on reducing inefficiency is smaller in ports with higher concentration. One possible explanation for this result is that higher concentration may reflect lower levels of intra-port competition, reducing the pressure on private operators to invest in efficiency-enhancing activities. In such environments, private firms may face weaker incentives to improve performance, especially if market dominance allows them to extract rents without necessarily improving operational efficiency. These results highlight the complex interplay between private investment, market structure, macroeconomic conditions and regulatory changes. While private sector participation can be an effective tool to reduce inefficiency, its effectiveness depends on the broader institutional, the prevailing economic environment and the degree of competitive pressure within the port system.

Including private investment as a cost-efficiency determinant allows for further insights by computing the marginal effects. These effects will improve the comprehension of the relationship between port authorities' cost inefficiency and port operators' investment, making the results more informative (Wang, 2002). Two variables having a non-monotonic relationship imply that their values are not the same along the sample. Still, they can be related differently in different parts of the sample. In this sense, the effect of investment on port cost inefficiency may not be the same for the different levels of investment.

Fig. 5 shows the marginal effects of private port agents' investment on the expected inefficiency of port authorities over the period studied. Since the vertical axis represents cost inefficiency, negative marginal effects imply a performance improvement. The results indicate that private investment tends to reduce inefficiency, especially at lower investment levels, although the magnitude of this effect is highly

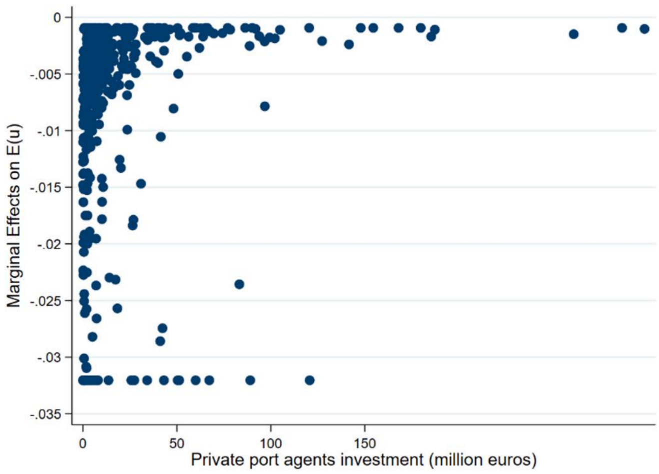

Fig. 5. Marginal effect of private operators' investment.

[2] Cost elasticities, marginal costs, short-run total cost elasticity, and economies of capacity utilization have not been calculated for Specification 2, as the coefficient values of the cost frontier are very similar between the two specifications.

dispersed. For higher levels of investment (above 100 million euros), the marginal effects approach zero, suggesting diminishing returns of private investment. Importantly, there is no evidence that private investment increases inefficiency. Overall, while private investment contributes to improving efficiency in the port system, its impact seems not to be systematic.

7. Conclusions

This paper has examined the relationship between private investment and cost efficiency in the Spanish port system, motivated by the legislative reforms aimed at enhancing port competitiveness and promoting financial self-sufficiency. Specifically, we assessed whether the objectives stated in the preamble of Law 48/2003—mainly the idea that private investment, supported by regulatory stability, would reduce port system costs—are empirically supported. Given the landlord port model in Spain, where private operators play a central operational role, the research focused on evaluating whether greater private participation, implemented through Public-Private Partnership, contributes to improved economic performance of port authorities. Therefore, we tested the hypothesis that private investment helps reduce cost inefficiency. We estimate a translog short-run stochastic cost frontier and the effect of exogenous inefficiency determinants to assess the impact of private investment on the Spanish port authorities' cost efficiency. This methodological approach is well-suited to the Spanish port system context, where port authorities are assumed to operate under cost-minimizing behaviour and a limited flexibility to adjust infrastructure in the short run. The exogenous inefficiency determinants evaluated include private investment, traffic concentration, and regulatory changes. Data from 2001 to 2018 from 26 Spanish port authorities has been analyzed, ensuring a comprehensive evaluation over a significant period.

The results confirm that private investment by port operators contributes to improving the cost efficiency of Spanish port authorities, particularly at lower levels of investment. The estimation reveals a negative and statistically significant relationship between private investment and cost inefficiency, suggesting that increasing the involvement of private capital helps to reduce port authorities' inefficiencies. Traffic concentration also appears to enhance port authorities' efficiency, although the marginal benefit of private investment diminishes in more concentrated ports, likely due to reduced competitive pressure. However, the analysis also indicates that the efficiency gains from private investment have weakened since the implementation of Law 33/2010. This may be partly attributed to institutional uncertainties introduced by the reform, as well as broader economic conditions such as the global financial crisis, which constrained both public and private investment. Furthermore, marginal effects analysis shows that the efficiency-enhancing impact of private investment is strongest at moderate investment levels, with diminishing returns beyond certain thresholds. These findings point to a non-linear and context-dependent relationship between private investment and port authority performance, influenced by regulatory frameworks, market structure, and investment intensity. Therefore, this research underlines the importance of institutional settings and competitive pressure in shaping the effectiveness of private sector participation in port infrastructure.

Annex 1. Full maximum likelihood estimates of the short-run cost frontier and the inefficiency model.

Variable	Specification 1	Specification 2
Variable cost frontier		
pl	0.848***	0.846***
	(0.0268)	(0.0263)
pvc	0.118***	0.122***
	(0.0248)	(0.0243)
pic	0.034**	0.033**
	(0.0154)	(0.0152)
k	0.229***	0.227***
	(0.0425)	(0.0419)
lb	0.0430***	0.0424***
	(0.0106)	(0.0105)
sb	0.107***	0.108***
	(0.0171)	(0.0171)
cgc	0.0210***	0.0191**
	(0.00810)	(0.00804)
ogc	0.285***	0.285***
	(0.0269)	(0.0264)
pax	0.0779***	0.0795***
	(0.0112)	(0.0109)
pl*pl	0.00870	0.00571
	(0.110)	(0.110)
pvc*pvc	−0.143	−0.137
	(0.0913)	(0.0904)
pic*pic	0.013	0.019
	(0.0197)	(0.0197)
lb*lb	0.0423***	0.0414***
	(0.0145)	(0.0142)
sb*sb	0.0685***	0.0673***
	(0.0194)	(0.0189)
cgc*cgc	0.0124**	0.0126**
	(0.00607)	(0.00595)
ogc*ogc	0.0661***	0.0660***
	(0.0155)	(0.0153)
pax*pax	−0.00650	−0.00373
	(0.0114)	(0.0112)
k*k	−0.811***	−0.807***
	(0.150)	(0.148)
pl*pvc	0.0738	0.0748
	(0.0947)	(0.0940)
pl*pic	−0.083**	−0.081**
	(0.0360)	(0.0354)
pl*lb	−0.0201	−0.0179
	(0.0201)	(0.0198)
pl*sb	0.0296	0.0233
	(0.0313)	(0.0308)
pl*cgc	0.00441	0.000361
	(0.0145)	(0.0144)
pl*ogc	0.0606	0.0686
	(0.0435)	(0.0430)
pl*pax	−0.0365*	−0.0357*
	(0.0200)	(0.0196)
pl*k	−0.0802	−0.0731
	(0.1000)	(0.0982)
pvc*pic	0.0692**	0.062*
	(0.0326)	(0.0321)
pvc*lb	−0.00133	−0.00359
	(0.0193)	(0.0190)
pvc*sb	−0.0506*	−0.0468
	(0.0299)	(0.0293)
pvc*cgc	0.0241*	0.0273**
	(0.0130)	(0.0128)
pvc*ogc	−0.0392	−0.0470
	(0.0404)	(0.0403)
pvc*pax	−0.0101	−0.0131
	(0.0187)	(0.0184)
pvc*q	0.0664	0.0672
	(0.0862)	(0.0851)
pic*lb	0.021**	0.021**
	(0.0108)	(0.0106)
pic*sb	0.021	0.024*
	(0.0137)	(0.0136)
pic*cgc	−0.029***	−0.028***
	(0.0087)	(0.0085)
pic*ogc	−0.021	−0.022
	(0.0250)	(0.0244)
pic*pax	0.047***	0.049***
	(0.0117)	(0.0114)
pic*k	0.014	0.006
	(0.0540)	(0.0536)
lb*sb	0.0192	0.0219
	(0.0138)	(0.0136)
lb*cgc	−0.0254***	−0.0248***

(continued on next page)

(*continued*)

Variable	Specification 1	Specification 2
	(0.00484)	(0.00481)
lb*ogc	−0.0104	−0.0101
	(0.0113)	(0.0112)
lb*pax	−0.00388	−0.00409
	(0.00717)	(0.00707)
lb*k	0.0750**	0.0717**
	(0.0331)	(0.0326)
sb*cgc	0.0436***	0.0448***
	(0.00942)	(0.00927)
sb*ogc	−0.0564**	−0.0598**
	(0.0265)	(0.0260)
sb*pax	−0.0257**	−0.0250**
	(0.0114)	(0.0113)
sb*k	−0.168***	−0.163***
	(0.0408)	(0.0399)
cgc*ogc	−0.00369	−0.00282
	(0.0104)	(0.0103)
cgc*pax	−0.00411	−0.00397
	(0.00462)	(0.00455)
cgc*k	0.0673***	0.0628***
	(0.0227)	(0.0225)
ogc*pax	−0.00577	−0.00998
	(0.0160)	(0.0158)
ogc*k	0.128**	0.127**
	(0.0602)	(0.0596)
pax*k	−0.0173	−0.0130
	(0.0297)	(0.0291)
Constant	−0.114***	−0.118***
	(0.0390)	(0.0380)
Mean of the inefficiency term		
lnpoi	−0.542**	−0.884***
	(0.271)	(0.298)
lnpoi*D2010	0.511*	0.333*
	(0.272)	(0.175)
hhi	−10.07***	−8.357***
	(3.383)	(3.193)
lnpoi *hhi		1.781***
		(0.592)
Constant	3.078***	2.655***
	(0.955)	(0.929)
Variance of the inefficiency term		
Constant	−3.413***	−4.174***
	(0.684)	(0.669)
Variance of the error term		
Constant	−3.520***	−3.559***
	(0.0692)	(0.0690)
Log-Likelihood function	146.70	151.30

CRediT authorship contribution statement

Soraya Hidalgo-Gallego: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ramón Núñez-Sánchez:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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