



The impact of governance on the technical efficiency of container ports

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ABSTRACT

We examine the impact of ownership, competition and regulation on the technical efficiency of container ports, with a focus on governance-related factors. We employ stochastic frontier analysis to investigate the interplay between privatization levels, hinterland and transshipment competition and economic regulators across the Far East and Asian regions. Our findings suggest that independent regulators foster higher technical efficiency compared to regulation by government ministries or port authorities. Moreover, majority privately owned ports demonstrate higher technical efficiency than those with minority private ownership. Additionally, our results reveal that transshipment competition positively affects container port efficiency. Perhaps surprisingly, the independence of the economic regulator is more critical to technical efficiency than hinterland competition. We recommend that policymakers promote the independence of regulators and encourage privatization to enhance the technical efficiency of container ports, thereby strengthening global supply chains.

1. Introduction

The covid-19 crisis has resulted in serious congestion at some of the world's largest ports, causing significant delays and supply chain disruptions. This congestion has been caused by the stockpiling of freight and containers at seaport terminals, as well as vessels experiencing long wait times to access berths at the seaports. In many cases, vessels and trucks have diverted their goods to nearby ports, suffering less severe congestion and delays. According to [Gui et al. \(2022\)](#), major factors contributing to congestion and delays at seaports during the pandemic include interruptions to railway and barge services, shortages of skilled labour at ports and a shortage of truck drivers and drayage trucks. [Komaromi et al. \(2022\)](#) report that the supply chain crisis caused by the covid-19 pandemic has led to an increase in port tariffs ranging from 0.9 to 3.1 %. Additionally, they find that delays caused by the crisis have surpassed 1.5 days on average, equating to a 25 % increase in global travel times. These statistics highlight the crucial role of efficient seaports in mitigating the adverse consequences of global supply chain crises. Given that Asian ports have been among the most impacted by the pandemic, their efficiency is of particular significance, which is the primary focus of this paper.

Containerization has revolutionized global supply chains and shipping, mainly by unitizing break-bulk cargo. Since its inception in

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1956, container trade has grown significantly due to its facilitation of mechanized cargo handling, which has improved the performance of seaports and supply chains. Containers enable efficient door-to-door delivery as they can be transferred easily between different modes of transport, such as ships, rail, and trucks, without the need for additional cargo handling, including the packing and unpacking of cargo contained within the containers. Containerization has been the most dynamic aspect of globalization, exceeding the growth in the value of exports and GDP (Guerrero and Rodrigue, 2014). Rodrigue and Notteboom (2009) state that no other technical improvement has contributed more to globalization than containerization. Seaports handling containers have realized improved efficiency, higher service quality and reduced vessel turnaround times compared to ports handling break-bulk cargo. Transport companies, such as shipping lines, railway firms and trucking companies benefit from economies of scale due to containerization. For these reasons, containerized trade has expanded faster than other forms of cargo, with volumes increasing at an annual average rate of 8 % between 1980 and 2018 (UNCTAD, 2019), and there is further potential for growth.

Seaports play a crucial role in container trade value chains because most containers transit through seaports on their way to their final destination. As a result, the performance of seaports in handling containers significantly impacts the time and cost associated with the delivery of the container. This is particularly relevant for mature seaports, which face increasing competition from secondary markets (Hayut, 1981), land and capacity constraints (Notteboom and Rodrigue, 2009) and the consequences of containerization waves (Guerrero and Rodrigue, 2014). Given these external changes, port governance has become increasingly crucial for port efficiency, and one of the roles of port authorities is to enhance efficiency (Goss, 1990). The port authority plays a key role in port governance as it is responsible for the administration and management of port infrastructure and the coordination and control of activities of the different stakeholders at the port (Notteboom and Haralambides, 2020). Vieira et al. (2014) provide a systematic review of forms of port governance and performance studies up to 2013.

According to the World Bank (2007), four governance models exist linked to port ownership: the service, tool, landlord and private service seaport model. The former two models serve the interests of the public, whereas the latter is intended to benefit private shareholders. On the other hand, the landlord seaport model strikes a balance between public and private interests. The evolution of port governance has been influenced by the growth in private investment, which has resulted in increased competition, productivity and cost efficiency (Notteboom and Haralambides, 2020). Private participation in seaports has also increased, with the private sector playing a significant role in providing a broad range of services. Brooks and Cullinane (2006) surveyed 42 ports worldwide and observed that only four ports operate as fully public, while one is fully private. Hence, the majority of ports operate under a public-private partnership agreement. Specialized private terminal operators often operate container terminals globally and achieve higher total factor productivity (Cheon et al., 2010). State involvement in port governance may be beneficial, particularly when ports receive support from the government for transportation infrastructure. Furthermore, governments may prefer to maintain control over their seaports, which may, in turn, lead to higher cost efficiency (Zheng and Yin, 2015). Public participation may also be advantageous, as public stakeholders possess knowledge of the upstream and downstream markets (Yuen et al., 2013). Combining these factors suggests that a public-private partnership agreement may enhance container port performance.

In addition to ownership form, governance-related factors affect port performance, including competition and economic regulation. Dappe and Suarez-Aleman (2016) show that container ports facing higher inter- and intra-port competition tend to be more efficient. However, excessive entry and overcapacity from excess competition can negatively impact efficiency. In cases where there is local monopoly power with no effective competition, private participation may necessitate economic regulation. The most commonly applied regulatory practices include rate-of-return and price-cap regulation. There are also hybrid regulatory systems that incorporate both pricing elements and profit caps (Tovar et al., 2004; Defilippi and Flor, 2008).

Regarding institutional factors, economic regulation may be imposed by multiple levels of government, a port authority, an independent regulatory body or it may be market-based without explicit economic regulation (see Ferrari et al. (2022) for case studies on seaport regulation). We note that an independent regulator is a body separate from both the government and the container ports, accountable solely to the national parliament. For example, India's Tariff Authority for Major Ports (TAMP) serves as such an institution, economically regulating the major Indian seaports. To assess the impact of regulation, Zheng and Negenborn (2014) employ principal-agent theory and dynamic game theory to analyse the port of Shanghai in China. The study finds that a decentralized, market-based pricing regime leads to higher demand, efficiency and social welfare than centralized government regulation. Additionally, the authors find that the decentralized model will likely lead to lower tariffs due to competition from locally owned terminal operators. Sauri and Robuste (2012) employ principal-agent theory to analyse the concession agreement between a private container terminal operator and the port authority, modelling it as a moral hazard problem with hidden information. They demonstrate that the private container terminal operator could be incentivized to increase productivity and reduce tariffs by imposing an annual fee to mirror a competitive market scenario. The port authority should set the fee based on the estimated costs of the container terminal working in a competitive market. This finding highlights the potential for port authority regulation to be potentially efficiency-enhancing.

Overall, the effectiveness of economic regulation in enhancing port performance appears to depend on several factors. Market-based pricing may promote efficiency in the presence of effective competition. Otherwise, independent regulation may help increase technical efficiency. However, economic regulation by a government ministry may lead to lower efficiency due to regulatory capture. The efficiency implications of economic regulation by the port authority remain unclear, as it may be efficiency-enhancing but also susceptible to regulatory capture. If the port authority is involved in port operations or earns rent as a function of the terminal operator's revenues or profits, it is no longer an independent regulator. Therefore, a nuanced approach is necessary to ensure that the appropriate regulatory framework is in place to promote efficient port operations.

This concise review underscores the significant role that container port efficiency plays in global supply chains. With the trend towards devolved port governance, there is a need to assess the efficiency implications of the governance structure. Private participation in ownership and operations and hinterland and transshipment competition may have changed the economic and regulatory

requirements. However, without effective competition, economic regulation may remain necessary to prevent container ports from abusing market power. Consequently, empirically testing the effectiveness of the regulatory institutions in promoting container port efficiency is highly relevant, given their diverse motivations and incentives. Accordingly, this research aims to analyse the isolated and combined impact of ownership form, levels of competition and institutional regulation on the technical efficiency of container ports. In line with the devolution and deregulation observed in the port sector, we include container ports in our sample that are not subject to economic regulation. As a result, these ports are effectively deregulated, with market-based pricing established through negotiation with stakeholders like shipping lines. Our study is on Asia because there are many container seaports in this region, indeed nine of the ten largest cargo-handling seaports are located on this continent. To achieve this goal, we estimate production frontiers for an unbalanced panel dataset of 43 container ports from the Far East and Asian region between 1986 and 2010. While previous studies have examined the technical efficiency of seaports (e.g., [Yan et al., 2009](#); [Medda and Liu, 2013](#)), to the best of our knowledge, we are the first to empirically study the sources of technical efficiency of container ports in the Far East and Asian region.

The remainder of the paper is organized as follows: [Section 2](#) provides a literature review and generates hypotheses. [Section 3](#) specifies the data collected and the stochastic frontier analysis models applied. [Section 4](#) presents the findings of the stochastic frontier analysis models, examining both the individual and combined effects of the variables and providing answers to the research hypotheses. In [Section 5](#) we draw conclusions and provide directions for future research.

2. Literature Survey

Data envelopment analysis (DEA) and stochastic frontier analysis (SFA) are common methodologies used to study the efficiency and performance of seaports. For surveys of DEA and SFA studies on port productivity, refer to [Gonzalez and Trujillo \(2009\)](#), [Panayides et al. \(2009\)](#) and [Odeck and Brathen \(2012\)](#). In this research, we employ SFA to explore the technical efficiency of container ports in the Far East and Asian regions. The choice of SFA over DEA is motivated by the need to accommodate potential errors in variables due to statistical noise and the possibility of estimating a production function. Additionally, SFA also permits the computation of technical change and elasticities using an unbalanced panel dataset, which are not readily accessible with DEA. [Appendix A](#) presents an overview of the literature published to date that utilizes SFA to understand the impact of governance on seaport performance. Based on the literature review, we develop hypotheses regarding the effects of governance determinants on the technical efficiency of container ports.

First, we examine the impact of private sector participation and seaport autonomy on performance. There is clear evidence that seaport reforms that allow for increased private sector participation lead to enhanced technical efficiency (see [Estache et al., \(2002\)](#) for an analysis of Mexican ports; [Gonzalez and Trujillo \(2008\)](#), [Nunez-Sanchez and Coto-Millan \(2012\)](#) and [Coto-Millan et al., \(2016\)](#) for Spain; [Bergantino and Musso \(2011\)](#) for Southern Europe; [Trujillo et al., \(2013\)](#) for Africa; [Chang and Tovar \(2014a\)](#) for Chile and Peru; [Nguyen et al., \(2018\)](#) for Vietnam; and [Lopez-Bermudez et al., \(2019a\)](#) for Brazil). However, the effectiveness of these reforms depends on the level of autonomy granted.

While seaport reform-induced changes in privatization have been shown to enhance technical efficiency, findings related to the level of private ownership are mixed. Both [Liu \(1995\)](#), who studied 28 trust, municipal and private British ports, and [Notteboom et al. \(2000\)](#), who examined 36 European container terminals and four Asian container terminals, do not find a significant impact of ownership on technical efficiency. On the other hand, most studies do find that higher private-sector participation is generally associated with improved technical efficiency. These studies include [Tongzon and Heng \(2005\)](#) for container ports in Asia, Europe and North America; [Cullinane et al. \(2006\)](#) for 30 of the world's top container ports; [Wanke et al. \(2011\)](#) for Brazil; [Chang and Tovar \(2014b\)](#) for Chile and Peru; [Serebrisky et al. \(2016\)](#) for Latin America and the Caribbean; and [Lopez-Bermudez et al. \(2019b\)](#) for Argentina.

Studies suggest that there may be diminishing returns from full privatization as the benefits of private ownership tend to fade out after the private shareholder holds the majority position. [Tongzon and Heng \(2005\)](#) find that privatization at around 80 % is the most conducive to the technical efficiency of container ports in Asia, Europe and North America. Similarly, [Zheng and Yin \(2015\)](#) find that Chinese ports with less than 50 % private ownership achieve higher cost-efficiency. Studies on the landlord port model, where the port authority is the landlord and private entities operate and manage the terminals, show that this ownership pattern generally improves technical efficiency (see [Trujillo et al. \(2013\)](#) for Africa; [Wang et al. \(2013\)](#) for US ports; [Sarriera et al.'s \(2013\)](#) insignificant results for Latin America and the Caribbean; [Serebrisky et al. \(2016\)](#) on Latin America and the Caribbean; and [Suarez-Aleman et al. \(2016\)](#) for developing countries). Based on this literature, we propose.

Hypothesis 1. (impact of private participation and the landlord seaport model on port performance): Private participation and the landlord seaport model positively impact technical efficiency.

Although ownership structure is important, [Vickers and Yarrow \(1988\)](#) argue that market competition and the regulatory environment are more important for generating efficiency. [Verhoeff \(1981\)](#) identifies three hierarchies of port competition; the first is related to transshipment competition, and the second and third to hinterland competition. He concludes that even though port competition is complex and public authorities play a crucial role in this complexity, port competition should be based on the real costs of port services, which reflect the natural advantages and disadvantages of the competing ports. The main argument is that the impacts of competition are complicated. Only a few studies focus on factors that affect port competitiveness (see [Appendix A](#)). [Tongzon and Heng \(2005\)](#) argue that technical efficiency, port selection preferences of carriers and shippers, and landside accessibility are the most significant factors. Hinterland competition occurs when ports or terminal operators compete for traffic originating from the same hinterland or catchment area. This is the most prevalent form of competition between ports and terminal operators. [Dappe and Suarez-](#)

Aleman (2016) suggest that competition will likely improve quality, for example, shorter turnaround time at ports. Merkel (2018) analyses 77 large European container ports and finds that an increase in inter-port competition, defined by the Herfindahl-Hirschman Index (HHI) within a 300-kilometre radius, improves technical efficiency. However, Lopez-Bermudez et al. (2019a) attribute the decline in the estimated technical efficiency of Brazilian terminals to competitive effects. Furthermore, competition in an increasing returns-to-scale setting may lead to excessive entry and over-capacity, which could harm efficiency. Anderson et al. (2008) argue that the excessive investment in transshipment capacity in East Asia has driven down prices to the point of endangering cost recovery. Notteboom et al. (2000) argue that European and Asian container terminals have spare terminals to address competition, which has led to over-capacity. While the results on inter-port competition are mixed, evidence suggests that intra-port competition improves technical efficiency (see Perez et al. (2016) for container port analysis in Latin America and the Caribbean; Notteboom et al. (2000) for Europe). Despite this mixed evidence, we propose:

Hypothesis 2. (impact of hinterland competition on port performance): *Container ports facing substantial hinterland competition are more technically efficient than those facing weak hinterland competition.*

Most studies have found a positive association between transshipment competition and technical efficiency. For example, Cullinane et al. (2006) report such an association for the world's largest container terminals, Notteboom et al. (2000) in Europe and Sarriera et al. (2013) in Latin America and the Caribbean. Similarly, Suarez-Aleman et al. (2016) find that the ports in developing countries benefit from transshipment competition. In contrast, Perez et al. (2016) find that transshipment ports in Latin America and the Caribbean are less technically efficient than non-transshipment ports. Therefore, we propose the following hypothesis:

Hypothesis 3. (impact of transshipment competition on port performance): *Transshipment competition positively impacts the technical efficiency of container ports.*

Private participation may require economic regulation if there is limited competition (Dappe and Suarez-Aleman, 2016; Defilippi, 2004), particularly in the case of captive traffic (Tovar et al., 2004). Economic regulation of ports is either access or price regulation. Access regulation sets the conditions under which competing firms may use the facilities controlled by the monopolist, while efficient prices are determined by market forces. Regulators use the essential facilities doctrine to ensure fair access to the facilities under reasonable conditions (Defilippi and Flor, 2008).

Price regulation can take the form of rate-of-return, price-caps or hybrid systems, all of which have been applied to seaports (Tovar et al., 2004; Defilippi and Flor, 2008). Rate-of-return regulation reduces capital risks as profits are guaranteed. However, it does not incentivize the terminal operator to be efficient, and it may lead to the Averch-Johnson effect. Moreover, it may also result in regulatory capture due to the high degree of discretion available to the regulator for purposes of implementation (Tovar et al., 2004; Defilippi and Flor, 2008). The advantage of price-cap regulation is that it incentivizes the container-terminal operator to minimize costs, but it may lead to insufficient quality due to under-investment. Furthermore, although a port-wide price cap could lead to Ramsey prices, predatory pricing may result when some of the markets supplied by the monopolist are contestable (Defilippi and Flor, 2008).

Hybrid regulatory systems combine the advantages of rate-of-return and price caps while preserving product and environmental quality. Even without competition, heavy-handed regulation may be unnecessary when there is potential competition. In this case, the regulator could impose periodic price controls to prevent collusion among competitors (Tovar et al., 2004).

The theoretical literature posits that economic regulation of ports may potentially enhance efficiency. However, empirical studies such as Cullinane et al. (2002) find that privatization and deregulation positively impacted the technical efficiency of Asian container ports and terminals. Cullinane and Song (2003) confirm these findings by showing improved efficiency at two Korean and three British container terminals following deregulation. Based on these empirical studies, our hypothesis regarding the impact of regulation on performance is as follows:

Hypothesis 4. (impact of economic regulation on port performance): *Deregulation positively impacts the technical efficiency of container ports.*

Stochastic frontier analyses have consistently revealed that private participation and the landlord seaport model contribute to seaport performance, regardless of the region. Nevertheless, the combined impacts of hinterland and transshipment competition, together with economic regulation, on the efficiency of seaports have not been extensively explored and require further research. To date, only two studies have explicitly analysed the impact of ownership, competition and regulation on the efficiency of seaports, but neither differentiates between hinterland and transshipment competition. Tongzon and Heng (2005) measure the impact of private participation and regulation in a first-stage efficiency analysis and second-stage principal component analysis to identify the factors affecting port competitiveness. Coto-Millan et al. (2016) focus on the Spanish reform programs and establish a connection between the reforms and port efficiency. Our research contributes to the literature by measuring the direct impact of governance, hinterland and transshipment competition, and institutional regulation on the technical efficiency of seaports. We also examine the impact of private participation and the landlord seaport model on seaports' technical efficiency. Finally, we estimate the individual and the combined effects of the governance-related contextual variables on the technical efficiency of seaports in the Far East and Asian regions. Our hypothesis concerning the combined impact of ownership, hinterland competition and economic regulation is as follows:

Hypothesis 5. (combined performance impact of ownership, hinterland competition and economic regulation): *A majority, privately-owned container port that competes to serve the hinterland without price regulation is relatively technically efficient.*

3. Stochastic frontier analysis models and dataset

In this section, we first discuss the SFA modelling approach employed in the research, including a discussion of panel data and the analysis of contextual variables. Subsequently, we describe the dataset collected and the computations required to develop the contextual variables.

3.1. Methodology

The SFA model permits us to test hypotheses and handle statistical noise (Coelli et al., 2005). The SFA production frontier model consists of three key components: the production function, an asymmetrically distributed inefficiency term and a random error component. Aigner et al. (1977) and Meeusen and van den Broeck (1977) developed the fundamental concepts of SFA, which assume that the production process involves producer-level random variations. The assumptions concerning the random effect term include non-negativity, independence of the random error component and inputs, and being independently and identically distributed across producers. While earlier studies used the Cobb-Douglas (1928) production function to model the production process, more recent research has applied the translog production function due to its greater flexibility.

Given the panel dataset, we apply the SFA model proposed by Battese and Coelli (1995). Their model formulates a stochastic production frontier that accounts for (unbalanced) panel data and assumes technical inefficiency is a function of time and contextual variables. The inefficiency effects are defined by a truncated normal distribution with constant variance and mean that are linear functions of the contextual variables. The model simultaneously estimates the coefficients of the stochastic frontier and contextual variables, the technical change and the time-varying technical inefficiencies. Specifically, for N firms over T time periods, we define output Y_{it} and the random effect term U_{it} as follows:

$$Y_{it} = f(x_{it}; \beta) \exp(V_{it} - U_{it})$$

and

$$U_{it} = z_{it}\delta + W_{it}$$

where Y_{it} is the output of firm i in period t ; $f(x_{it}; \beta)$ is a production function with inputs x_{it} , associated with firm i in period t ; β is the vector to be estimated; V_{it} are iid $N(0, \sigma_v^2)$ random errors; U_{it} are non-negative random variables that are independently distributed with a truncated normal distribution and mean $z_{it}\delta$ and variance σ^2 ; z_{it} is a vector of contextual variables associated with technical inefficiency; δ is a vector of the coefficients of the contextual variables which are to be estimated; and W_{it} has a truncated normal distribution with zero mean and variance σ^2 such that $W_{it} \geq -z_{it}\delta$. As a result, U_{it} has a non-negative, truncated distribution, $N(z_{it}\delta, \sigma^2)$,

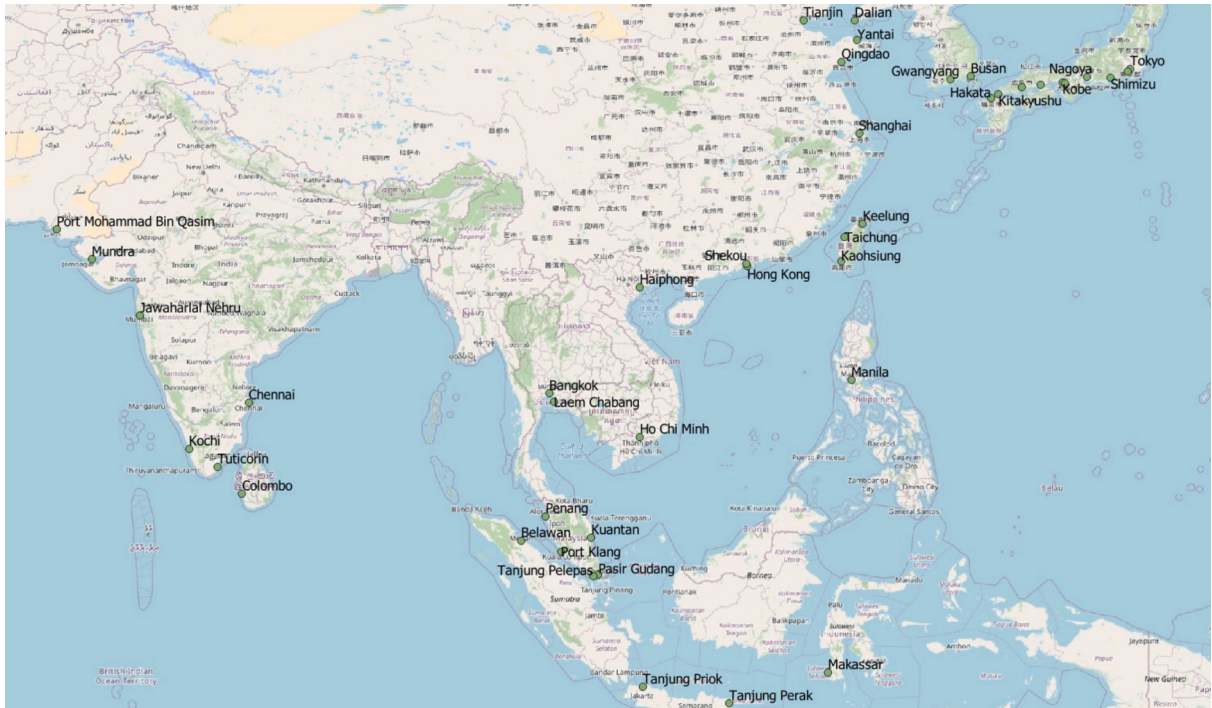


Fig. 1. Map of ports in the dataset.

and the technical efficiency of firm i in period t equals $TE_{it} = \exp(-z_{it}\delta - W_{it})$. The simultaneous estimation of the coefficients is achieved using maximum likelihood estimation.

We apply the Battese and Coelli (1995) model to an unbalanced panel dataset of 43 Asian container ports observed between 1986 and 2010. The data is sourced from the Containerisation International Yearbooks (1988-2012). We have collected data on container ports from 12 Asian countries spanning 25 years. The container ports are in China, India, Indonesia, Japan, Malaysia, Pakistan, Philippines, South Korea, Sri Lanka, Taiwan, Thailand and Vietnam. The dataset contains 591 observations, and Fig. 1 presents a map of the ports in the dataset.

The SFA model is as follows:

$$\ln y_{it} = TL(\ln x_{k,it}, t; \beta) + \nu_{it} - u_{it}$$

$$u_{it} = |N(m_{it}, \sigma_u^2)| \text{ where } m_{it} = \delta_0 + \sum_j \delta_j z_{j,it}$$

Model (2) includes individual contextual variables ($z_{j,it}$) which cover ownership form, hinterland and transshipment competition and the type of regulation, in order to study hypotheses 1 to 4. Since our main focus is on the interaction of the contextual variables, Model (3) includes the combined effects of the contextual variables as determinants of technical inefficiency.

Country-fixed effects are included in all models to account for country-level heterogeneity and to estimate the average output level per country. Post estimation, we compute the elasticities of the output with respect to each input ($\varepsilon_{k,it}$), returns-to-scale (RTS) and technical change (TC) as follows:

$$\varepsilon_{k,it} = \beta_k + \beta_{kt}t + \sum_j \beta_{jk} \ln x_{j,it}$$

$$RTS = \sum_k \bar{\varepsilon}_{k,it}$$

$$TC = \beta_t + \beta_{t^2}t + \sum_k \beta_{kt} \ln x_{k,it}$$

The output elasticity is computed as the partial derivative of the output with respect to each input. The returns-to-scale are calculated as the summation of the individual elasticities of the output with respect to each input. The technical change is derived from the partial derivative of the output with respect to time. The β s in the equations are the coefficients estimated using a maximum likelihood estimation of the SFA models.

3.2. Dataset

The Containerisation International Yearbooks report some data at the terminal level and others at the berth level. As there is no consistent data at the terminal level, we aggregate to the level of the container port. The output y_{it} represents the total number of Twenty-Foot Equivalent Units (TEU) handled by a container port i in year t , which is the output that has most often been included in analyses of container port technical efficiency. Following Trujillo et al. (2013), we collect data on three inputs. The first input is the total berth length at the level of the container port, which is a proxy for capital. The second input is the total terminal area, which serves as an indicator of the land available. We include the berth length and the terminal area because the former accounts for operations on the sea-side and the latter for land-side operations. The third input is the total number of cranes, which is a proxy for labour and variable inputs such as energy. The use of the number of cranes as a proxy is supported by previous research (Cullinane and Song, 2006; Cullinane et al., 2006; Merkel, 2018; Notteboom et al., 2000; Tongzon and Heng, 2005; Sarriera et al., 2013; Serebrisky et al., 2016; Trujillo et al., 2013). As a sensitivity analysis, given the increasing productivity of cranes over time, we test the aggregate crane capacity (in tons) at the port level as an input. The results for these models, presented in Appendix D, show that our main findings remain qualitatively consistent with the base models reported in Table 6.

Table 1 contains descriptive statistics of the inputs and the output. An average port in the dataset handles around 2.5 million containers annually with a berth length of 3 km, a terminal area of one million square meters and 68 cranes. The significant dispersion in the data shows small ports handling 100,000 containers and the largest port handling 29 million containers annually. As a result, the dataset is a good representation of the set of container ports present in Asia. Table 2 presents the correlation matrix of the inputs and the output. It shows that the number of cranes is closely correlated to the TEU handled; hence, there will be a higher elasticity for the number of cranes than for the other inputs. Regarding the within-input correlations, we observe a high correlation between the number of cranes and the terminal area. Nevertheless, as the value is below 0.9, using both inputs to estimate the production frontiers is

Table 1
Descriptive statistics of the output and the inputs.

Variable	Shorthand	Unit	Mean	Median	Std. Dev.	Min.	Max.
TEU Handled	TH	count	2,565,581	1,348,383	4,180,936	100,700	29,069,000
Berth Length	BL	m	3,172	2,370	2,724	350	14,610
Terminal Area	TA	m ²	1,050,836	740,000	1,137,798	90,000	8,569,837
Number of Cranes	NC	count	67.93	44	83.46	5	497

Table 2
Correlation matrix of the output and the inputs.

Variable	Shorthand	TH	BL	TA	NC
TEU Handled	TH	1	–	–	–
Berth Length	BL	0.65	1	–	–
Terminal Area	TA	0.81	0.79	1	–
Number of Cranes	NC	0.95	0.75	0.84	1

justifiable. Although the threshold of 0.9 is somewhat subjective, the literature indicates that high correlations often lead to statistically insignificant coefficients (Castano and Gallon, 2017). As shown in Table 6, the significance of most parameters further justifies the decision to include all three inputs in the SFA models. Moreover, the three inputs capture distinct aspects of container port operations. Berth length relates to the handling of vessels, terminal area to land-side handling and storage and cranes to the physical movement of containers.

The contextual variables include ownership form, competition levels and regulation types. We include these variables individually in Model (2) to assess their specific effects, as compared to Model (1) where the production function is estimated without accounting for contextual variables. In Model (3), we examine the combined impact of these contextual factors. For ownership, we measure private participation by creating a ratio of the number of private operators out of the total number of operators. Zero indicates no private participation and one indicates that all terminal operators are private firms. The dataset includes both extremes, as reflected in Table 3, with a mean value for private participation of 51 %, highlighting significant and increasing private participation in Asian container ports over time. For the analysis, we classify container ports as majority private with more than 50 % private operators and minority private, with 50 % or more public operators.

We note that the private operator count relative to the total does not necessarily reflect the market share. For example, a single large public operator alongside numerous small private operators would mean that private operators appear to have a higher ownership share. Capacity or capital investment might offer a more accurate reflection of the bargaining power of the operators, which will in turn impact port operations and efficiency. Therefore, we construct an alternative measure of private participation based on the input share of the private operators by equally weighting the berth length, terminal area and cranes in order to obtain an input-weighted measure of private participation. Results using this input-weighted measure are detailed in Appendix E and largely mirror those presented in the subsequent section. In the combined effects model (Model 3), the evidence for an efficiency-enhancing impact of independent regulators is even stronger for high-competition ports. Given that the individual effects model demonstrates that independent regulators foster technical efficiency compared to other forms, we conclude that our results are broadly consistent with those obtained in our base model results discussed in the next section.

Inter-port competition is classified as hinterland and transshipment competition, as defined in the Containerisation International Yearbooks. Hinterland competition occurs when container ports compete for traffic whose final destination is within a radius of 1,000 km of the port (Oliveira and Cariou (2015)). We assume that ports on separate islands do not compete for hinterland traffic. Hinterland competition is defined as low if there are up to five container ports within this radius and as high if there are more than five container ports. This definition is chosen because 1,000 km is a relatively large radius, and ports have a larger degree of substitutability owing to the modes of surface transport in the hinterland. As seen in Table 4, 19 container ports face low hinterland competition, and 33 ports face high competition. For robustness, we perform sensitivity analyses with different definitions of hinterland competition. From the sensitivity analyses, we learn that our base models are quite robust to alternative specifications of hinterland competition.

Ports engage in transshipment competition when competing to attract cargo transfers. Transshipment competition is assumed to occur between container ports that handle Post Panamax II vessels. Until 2010, these were the largest container vessels, with a maximum capacity of 8,500 TEU. Container ports with a berth length of at least 340 m and a draft of at least 15 m are assumed to be potential transshipment ports. We employ this definition of transshipment competition due to the absence of data on transshipment flows within our sample. The approach is justifiable because handling larger vessels, such as Post Panamax II, necessitates specific infrastructure. Ports must possess appropriately sized cranes and may have undertaken dredging in order to accommodate the deeper drafts and wider beams of the larger vessels. Consequently, although direct transshipment flows are unobserved, the infrastructure capacity required to handle Post Panamax II vessels provides a strong proxy for the ability of a port to accommodate transshipment operations. As shown in Table 4, 16 ports in the dataset are assumed to compete for transshipment traffic. No container port in the dataset faced transshipment competition prior to 1995.

While ideally, hinterland and transshipment competition would be measured through capacity or market share, the lack of such data for all container ports in the Far East and Asian region necessitates the use of a more parsimonious measure for which data is accessible. We acknowledge that employing capacity or market share-based measures of competition represents a valuable avenue for future research.

Table 3
Descriptive statistics of the ownership structure.

Variable	Mean	Std. Dev.	Min.	Max.
% Private Operators	0.51	0.42	0	1
% Public Operators	0.49	0.42	0	1

Regarding economic regulation, rate-of-return regulation is the most frequently applied at Asian container ports. Three types of regulators have been identified: the Ministry of Transport or Shipping (MOT/S) of the respective country, a port authority (PA) or an independent regulatory institution (IR). In 18 cases, no a-priori regulation (NR) exists hence the ports practice market-based pricing or negotiate with the shipping lines on port charges and levels of service quality offered, as shown in Table 4.

In Model (3), we assess the combined impact of the contextual variables and Table 5 presents the number of observations per combination. We note that one cell is empty in this case.

4. Results

Table 6 presents the results of the SFA regressions. Model (1) estimates the translog production function model, Model (2) adds individual contextual variables and Model (3) incorporates their combined effects as controls to the translog function. Model (3) is preferred because it includes the full characteristics of the ports as contextual variables. The coefficients of the translog production function inputs remain stable across models, except for berth length. According to Model (2), the mean output elasticity with respect to berth length is 0.08 (meaning a 1 % increase in berth length leads to a 0.08 % increase in output), the terminal area is 0.34 and the number of cranes is 0.57. Model (3) yields similar elasticities, confirming the robustness of the results. The 25-year timeframe of our analysis, during which all factors of production have changed across all container ports, indicates that these elasticities represent long-run effects.

Appendix B depicts the elasticities from Models (2) and (3) plotted against the respective input. The graphs show that output elasticity with respect to berth length and terminal area is downward sloping and also becomes negative for larger berth lengths. This suggests that elasticities are lower for larger berth lengths and terminal areas. The output elasticity with respect to the number of cranes is upward-sloping, suggesting that larger ports have a higher elasticity. Overall, these trends indicate diminishing returns to berth length and terminal area at larger scales, while crane investment remains beneficial as port size grows.

The elasticities from the individual and combined effects models estimate returns to scale. In Model (2), the returns-to-scale value is 0.99, indicating that container ports exhibit constant to mildly decreasing returns-to-scale. From Model (3), the returns-to-scale value is 0.92, also indicating mildly decreasing returns-to-scale. These values reflect long-run returns to scale because all factors of production for the container ports vary during the 25 years considered in our analysis. The results align with the findings of Liu (1995), Yan et al. (2009), and Medda and Liu (2013), who find that ports operate with decreasing returns-to-scale, given the large infrastructure required.

The coefficients of time, t , can be used to estimate the technical change experienced by the ports. Our findings indicate weak technical change over time, with an annual average rate of 0.02 % from both Models (2) and (3). Nevertheless, Fig. 2 shows that this rate of change is not constant. The left panel in Fig. 2 presents the rate of change in output with respect to time as downward sloping, meaning that output is increasing at a decreasing rate over time. The right panel in Fig. 2 plots the technical change with respect to output, showing that technical change decreases with output. Technical change has slightly decreased at the larger ports and it is also decreasing in TEU handled. As a result, we conclude that smaller ports have achieved a higher level of technical change on average over the 25 years analysed.

After accounting for the governance effects, the mean technical efficiency estimates are 69 % in Model (2) and 68 % in Model (3). Fig. 3 presents the average annual technical efficiency, showing a clear upward trend over time. This increase in technical efficiency likely reflects improvements in the competitive and regulatory environment, which would appear to have contributed to improved efficiency in port operations.

Fig. 4 presents box plots of the efficiencies of the ports classified by model. We observe no significant variation in the rankings of container ports between the models, which is an indication that the models are robust. Additionally, port efficiencies do not appear to be country-specific, as performance is dispersed across countries, suggesting that factors beyond the national context influence efficiency levels.

With respect to the type of regulator, the Ministry of Transport or Shipping (MOT/S) consistently results in lower technical efficiency compared to all alternative regulatory frameworks, regardless of ownership type or level of competition. This could be due to regulatory capture or alternative policy objectives, such as maximising output or employment at container ports. Unfortunately, we are

Table 4
Number of ports and observations per classification.

Classification	Number of Ports	Number of Observations
<i>Hinterland Competition</i>		
Low	19	217
High	33	374
<i>Transshipment Competition</i>		
Yes	16	133
No	39	458
<i>Type of Regulation</i>		
Ministry of Transport / Shipping	10	137
Port Authority	11	147
Independent Regulator	6	45
No Regulation	18	262

Table 5

Number of observations per combination of contextual variables.

Ownership	Hinterland Competition	MOT/S	PA	IR	NR	Total
Majority & Fully Public	Low	82	47	17	4	150
	High	0	9	15	169	193
Majority & Fully Private	Low	16	37	8	6	67
	High	39	54	5	83	181
Total		137	147	45	262	591

Table 6

SFA Results (Note: *p < 0.05; ** p < 0.01; *** p < 0.001).

Dep. Variable: ln(TEU handled)			Model 1		Model 2		Model 3		
			Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	
Frontier (Translog): Input variables									
x intercept			1.694	1.75	−6.429**	2.164	−11.578***	3.09	
ln(Berth Length)			−3.202**	0.947	−0.028	0.895	0.166	0.885	
ln(Terminal Area)			2.6***	0.586	1.967**	0.634	2.919***	0.752	
ln(Cranes)			2.487***	0.625	2.09***	0.552	1.071*	0.618	
ln(Berth Length)*ln(Term. Area)			0.885***	0.108	0.473***	0.112	0.489***	0.101	
ln(Berth Length)*ln(Cranes)			−0.467***	0.107	−0.169	0.105	−0.314***	0.1	
ln(Terminal Area)*ln(Cranes)			−0.084	0.064	−0.157**	0.06	−0.008	0.066	
(ln(Berth Length)) ²			−0.807***	0.148	−0.679***	0.17	−0.648**	0.149	
(ln(Terminal Area)) ²			−0.688***	0.098	−0.362***	0.101	−0.484***	0.107	
(ln(Cranes)) ²			0.695***	0.114	0.472***	0.085	0.463***	0.082	
t			0.104*	0.055	0.078*	0.047	0.124***	0.043	
t ²			−0.004***	0.001	−0.003***	0.001	−0.003***	0.001	
t*ln(Berth Length)			−0.051***	0.007	−0.024**	0.007	−0.03***	0.006	
t*ln(Terminal Area)			0.026***	0.006	0.01*	0.006	0.008*	0.005	
t*ln(Cranes)			0.011*	0.006	0.01**	0.005	0.017***	0.005	
Contextual Variables – Inefficiency									
z Intercept					−1.357**	0.532	−3.794***	0.868	
Transshipment Comp.		No			Base Case		Base Case		
		Yes			−1.271***	0.326	−0.523***	0.159	
Ownership		Minority private			0.567***	0.163			
		Majority private			Base Case				
Hinterland Comp.		Low			0.372*	0.208			
		High			Base Case				
Regulation		MOT/ S ^{a)}			0.606***	0.211			
		PA ^{b)}			−0.955***	0.334			
		IR ^{c)}			−3.692***	1.152			
		NR ^{d)}			Base Case				
Minority Private	LowComp.	MOT/S					4.216***	0.824	
		PA					2.945***	0.704	
		IR					2.915***	0.733	
		NR					5.627***	0.901	
	High Comp.	MOT/S					—		
		PA					4.268***	0.858	
		IR					2.169**	0.718	
		NR					4.163***	0.809	
MajorityPrivate	Low Comp.	MOT/S					5.134***	0.870	
		PA					3.531***	0.808	
		IR					−6.932**	2.003	
		NR					1.192	0.983	
		High Comp.	MOT/S					3.988***	0.843
			PA					3.747***	0.784
			IR					−0.873	0.955
			NR					Base Case	
σ ² ^{e)}		0.572***	0.075	0.895***	0.197	0.417***	0.044		
γ ^{f)}		0.86***	0.027	0.962***	0.01	0.946***	0.013		
Country Fixed Effects			Yes		Yes		Yes		
Observations			591		591		591		
Log likelihood value			−170.12		−257.07		−194.1		
Average efficiency			0.638		0.694		0.676		

Note: *p < 0.05; ** p < 0.01; *** p < 0.001. A negative coefficient for a contextual variable in the efficiency model indicates a reduction in inefficiency.

a) MOT/S federal regulation (Ministry of Transport). b) PA Port Authority Regulator c) IR Independent regulator. d) NR No regulation. e) Sum of variances of noise and efficiency. f) ratio of the variance of the inefficiency term to the total variance. There are no ports fitting the category Minority Private, High. Comp and MOT/S.

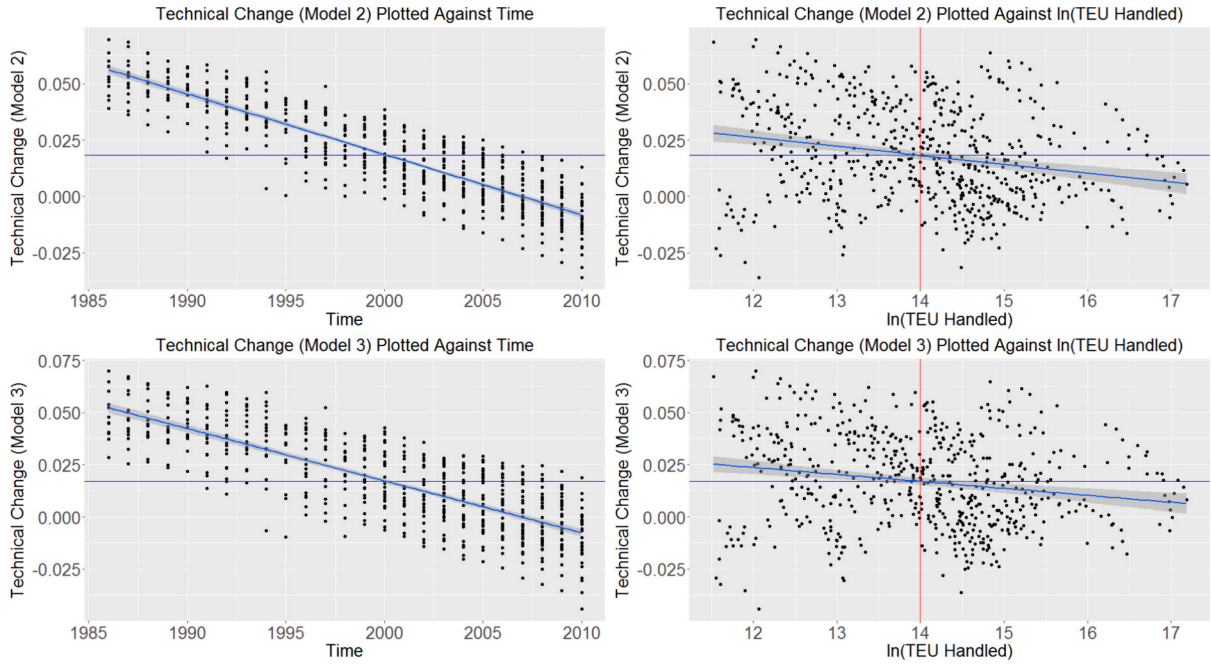


Fig. 2. Technical change plotted against time and TEU handled.

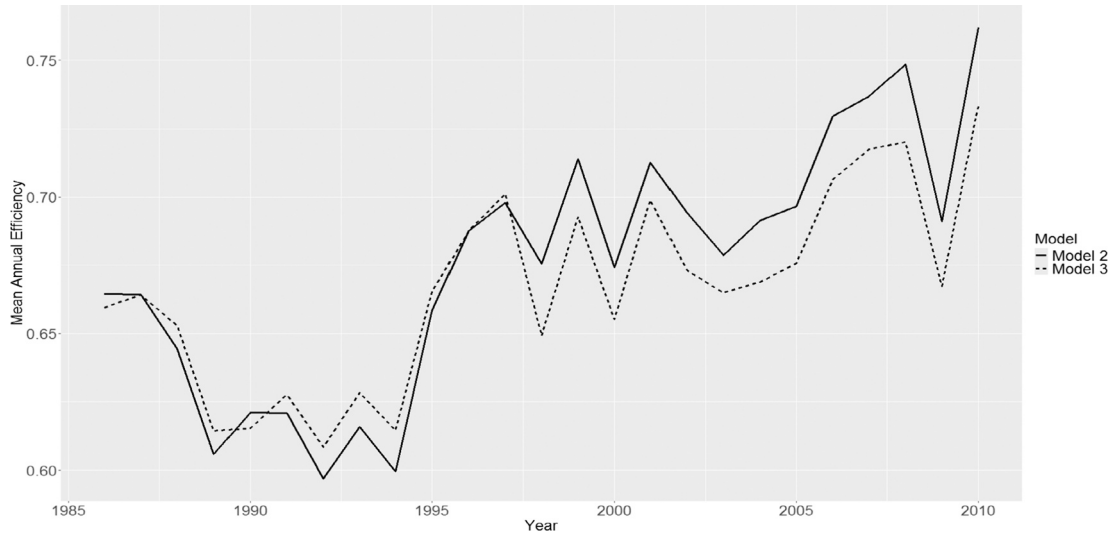


Fig. 3. Average annual technical efficiency.

unable to test the direct impact of the type of regulation on technical efficiency because cost-based regulation alone has been implemented at the ports in the dataset.

Returning to the hypotheses specified in Section 2, the results of Model (2) confirm Hypotheses 1, 2 and 3. *Hypothesis 1* posits that private participation and the landlord seaport model promote technical efficiency, a finding consistent with the work of Cullinane et al. (2006), Chang and Tovar (2014b), Wanke et al. (2011) and Lopez-Bermudez et al. (2019a). *Hypothesis 2* suggests that ports facing hinterland competition are more technically efficient in comparison to those that do not face hinterland competition and our results are in line with those of Merkel (2018), Cullinane and Song (2003), Coto-Millan et al. (2016) and Estache et al. (2002). *Hypothesis 3* suggests that transshipment competition contributes to enhanced efficiency, which aligns with the conclusions of Cullinane et al. (2006), Notteboom et al. (2000), and Sarriera et al. (2013). In contrast, *Hypothesis 4* is rejected. *Hypothesis 4* is rejected as our findings indicate that regulation by an independent regulator is associated with higher efficiency than other forms of regulation, contradicting the findings of Cullinane et al. (2002) and Cullinane and Song (2003). In conclusion, the results suggest that deregulation is beneficial only under competitive conditions.

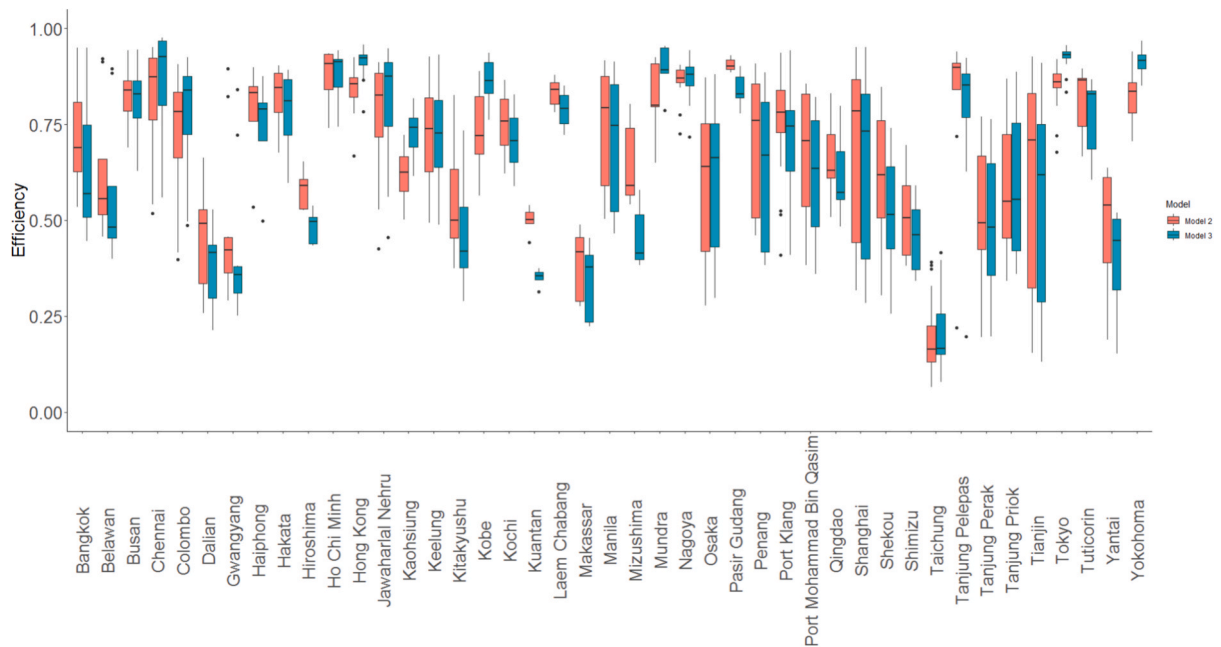


Fig. 4. Efficiency by port.

The primary objective of this research is to provide a more precise understanding of the impact of port governance on technical efficiency by examining the interaction between ownership, competition and economic regulation. In Model (3), the base-case scenario represents an unregulated, majority privately owned port facing competition. With one exception, all other combinations of contextual variables lead to the same or lower technical efficiency compared to the base case. The findings indicate that an independent regulator is preferable to other forms of regulation in encouraging technical efficiency. [Hypothesis 5](#), which states that an unregulated, majority privately owned container port facing hinterland competition is relatively technically efficient, is only partially supported. While majority privately owned ports tend to achieve relative technical efficiency, the presence of an independent regulator appears to contribute positively to efficiency, regardless of the level of competition. One possible explanation for this outcome is excessive entry or capacity expansion, which may lead to overcapacity and reduced efficiency. This finding aligns with the theory of excessive entry ([Mankiw and Whinston, 1986](#)), which suggests that new entrants may divert business from incumbents, lowering output per firm and reducing both firm efficiency and overall social welfare. Under these conditions, independent regulation emerges as the more effective governance mechanism to enhance technical efficiency. These findings should be interpreted with caution, as the dataset used in this study does not include information on costs. As a result, the potential cost of regulation has not been considered, which may influence

Table 7

Sensitivity analysis across hinterland competition measures.

radius (km) / # competitors				500/0	500/1	500/3	500/5	1000/0	1000/1	1000/3	1000/5
1	Minority Private	Low Competition	MOT/S	3.23	3.44	2.88	3.55	4.18	4.11	4.18	4.22
2			PA	1.93	2.41	1.86	2.31	2.11	2.07	2.64	2.95
3			IR	−3.34	2.45	1.89	2.31	—	—	3.22	2.92
4			NR	3.70	4.02	3.62	3.80	—	—	—	5.63
5		High Competition	MOT/S	3.06	3.73	—	—	4.01	4.02	—	—
6			PA	2.64	3.62	3.38	4.02	3.54	3.56	4.04	4.27
7			IR	2.03	2.27	−2.50	—	2.66	2.64	1.70	2.17
8			NR	3.11	3.49	2.76	3.40	4.19	4.20	4.20	4.16
9	Majority Private	Low Competition	MOT/S	3.91	4.02	3.8	4.46	5.05	4.94	5.24	5.13
10			PA	3.05	3.48	2.59	3.10	4.02	4.00	3.22	3.53
11			IR	−3.44	−5.75	−2.26	−2.77	—	—	—	−6.92
12			NR	—	—	Insig	Insig	—	—	Insig	Insig
13		High Competition	MOT/S	3.94	5.01	4.33	—	4.56	4.65	3.9	3.99
14			PA	2.53	3.02	1.98	Insig	3.41	3.45	3.82	3.75
15			IR	Insig	Insig	—	—	−2.93	−2.95	−4.93	Insig
16			NR	Base case							

SFA coefficient results for combined contextual variables under differing definitions of hinterland competition. Model 1000/5 is applied in [Table 6](#) where low competition is defined as, at most, five ports within a distance of 1000 km from observed port. Model 500/0 defines a port subject to low competition if there are no competitors in the catchment area of 500 km. “Insig” means insignificant. “—” means no observations.

the overall assessment of regulatory effectiveness, particularly in a competitive market with substantial private participation.

For purposes of sensitivity analysis, we test the results of Model (3) with varying definitions of hinterland competition. The base case defines low hinterland competition as a port with at most five competitors within a 1000 km distance. This definition is ad hoc because we lack the necessary data to calculate Herfindahl indices for hinterland market concentration. We perform sensitivity analyses to test the robustness of our results to changes in the definition of hinterland competition, reducing the number of competitors and the catchment area. Table 7 presents the coefficients of the contextual variables related to hinterland competition (the full results are presented in Appendix C). The results are generally consistent with the base model, with only minor differences in the interaction effects, confirming the robustness of our estimates. There is clear and robust evidence that independent regulation (IR) encourages at least as high technical efficiency as ports with no a-priori regulation, independent of ownership form or the competition level (rows 3 vs. 4, 7 vs. 8, 11 vs. 12 and 15 vs. 16).

5. Conclusions and future directions

We examine the impact of governance structures on the technical efficiency of container ports, with a focus on the interaction between ownership, competition and economic regulation. We apply stochastic frontier analysis on an unbalanced panel dataset of 43 Asian ports observed between 1986 and 2010. Our findings indicate that the sample container ports exhibit slightly decreasing returns-to-scale, with mean efficiency estimates of around 68 %, suggesting substantial potential for efficiency improvement. Technical change also appears to be weak, with output increasing at a diminishing rate over time, reinforcing concerns about stagnating productivity growth in the port sector.

The findings confirm that private participation, hinterland competition and transshipment competition significantly enhance the technical efficiency of container ports, supporting the case for increased private sector involvement in port operations and governance. The landlord seaport model, where the public sector owns the infrastructure while private firms operate the terminals, emerges as an effective governance framework. The findings suggest that decision-makers should encourage policies that combine public oversight with private sector efficiency incentives. In particular, the results highlight the positive role of independent regulation in enhancing technical efficiency. Independent regulators outperform other forms of regulation, particularly ministerial oversight, which appears to be associated with lower efficiency levels, potentially due to regulatory capture or conflicting policy objectives. This would suggest that ports operating in markets with limited competition require strong, independent regulatory institutions to mitigate monopolistic behaviour. Therefore, we suggest establishing independent regulatory bodies to address issues related to the market power of privately owned ports and terminal operators.

Another key insight from the analysis is that deregulation alone does not guarantee higher efficiency. While some ports without formal regulation achieve reasonable levels of efficiency, the presence of an independent regulator appears to be at least as effective as deregulation. This contradicts earlier research in which deregulation appears to universally enhance efficiency and suggests that governance structures ought to be tailored to market conditions.

Our findings on competition indicate that transshipment competition has a stronger positive impact on technical efficiency compared to hinterland competition. This is partly attributable to Asia's role as a global transshipment hub. In 2010, our definition identified 25 transshipment ports in the Far East and Asia, including Busan, Hong Kong and Singapore, highlighting the intense competition within this sector. This competitive environment appears to have driven these ports to push the efficiency frontier, as evidenced by their preparedness for larger container vessels. For example, Busan and Hong Kong developed maximum draughts of 17 and 15.5 m respectively in 2010, alongside berths capable of handling these larger ships. A draft of 15 m is sufficient to handle Post Panamax II vessels but as can be seen, many transshipment ports in the Far East and Asian region had deeper draughts and were well prepared to handle larger vessels that are used for transshipment. This proactive adaptation suggests that transshipment ports in the region were positioning themselves to compete effectively in the future container shipping market, post the Panama Canal Expansion Project.

This research has several limitations that could be addressed in future research. We note that the lack of access to cost data has prevented an evaluation of the cost efficiency trade-offs associated with the governance models. This limits our ability to assess whether the efficiency gains from privatization or independent regulation outweigh the potential administrative and regulatory costs. Future research could incorporate cost frontier models or detailed financial data on port operations to provide a more complete picture. Collecting data at the container terminal level could also be valuable by deepening our understanding of the production process of container ports. Additionally, future studies could better assess the impact of competition on technical efficiency by conducting route-level analyses to measure route overlap between container ports or terminals. Other promising research areas include estimating cost frontiers for the same sample of container ports and evaluating the effects of improved port efficiency and effectiveness on surrounding regions and overall economic welfare. The data has been collected from the Containerisation International Yearbook, which was last published in 2012, including data up to 2010. To the best of our knowledge, there is no alternative standardized data source for container ports. Were such data to become available, it would be of interest to analyse more recent time periods, for example to study how the covid-19 pandemic impacted container port efficiency and performance. However, the data would need to be made publicly available for such analyses to be performed. In addition, future research could further explore the role of independent regulators. Our current sample includes six ports, located in India and Vietnam. By including country fixed effects, the positive estimation of the impact of independent regulators captures the residual effects of institutional regulation. However, expanding the sample to encompass a greater number of container ports under independent economic regulation would enhance the generalizability of these findings. Future research should also examine how regulatory frameworks interact with broader economic policies, trade agreements, and environmental regulations. Given the increasing focus on sustainable port operations, future studies could explore how green

policies, carbon pricing mechanisms or environmental regulations impact port efficiency and competitiveness.

CRedit authorship contribution statement

Nicole Adler: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Georg Hirte:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Shravan Kumar:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hans-Martin Niemeier:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

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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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Appendix

Appendix A. . Literature Survey of SFA studies on governance of seaports

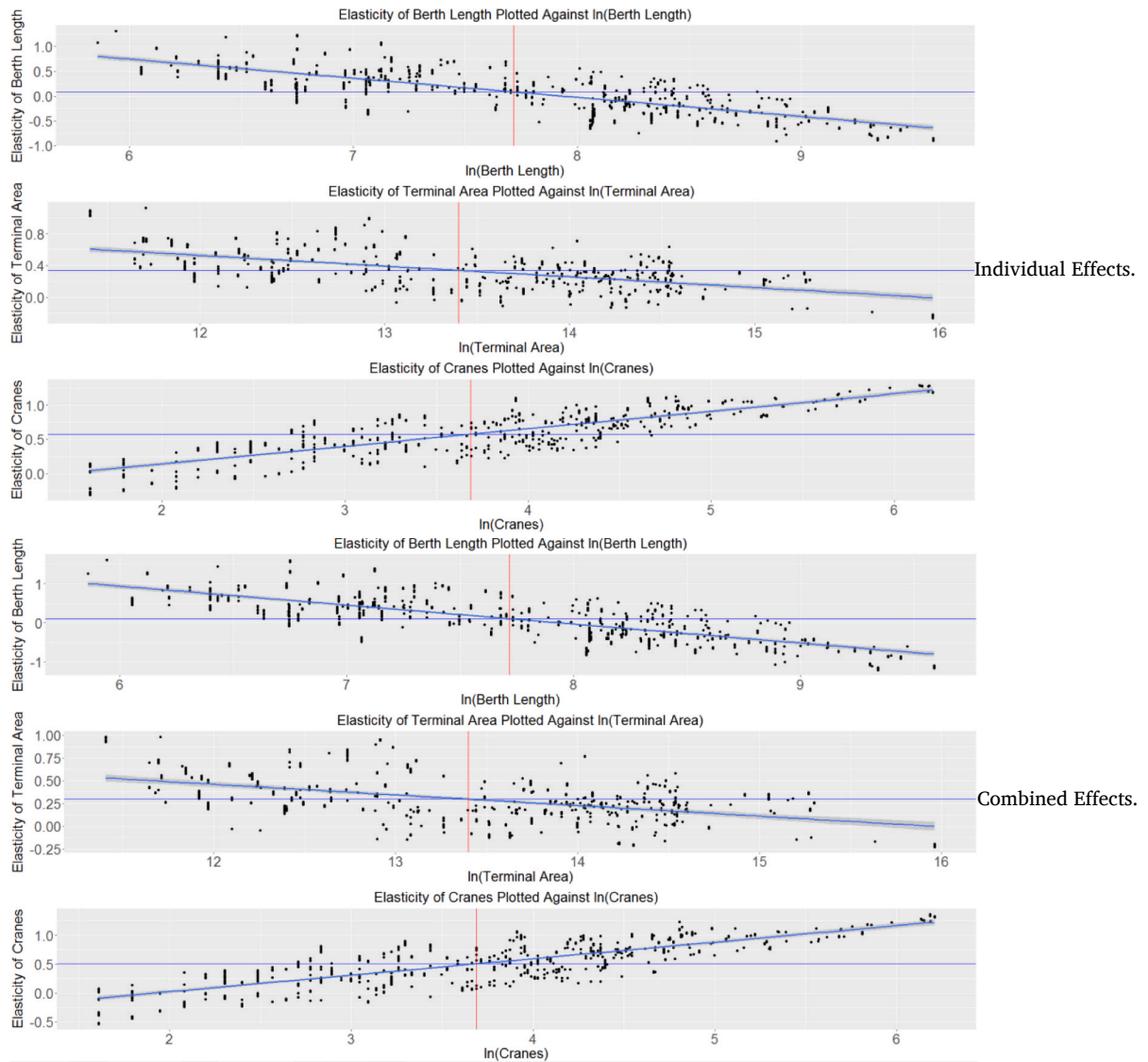
Reference	Region	Timeframe	Explicit Effects	Relevant Results
Autonomy Bergantino and Musso (2011)	Southern Europe	1995–2007	Yes	Seaport autonomy positively affects the reduction of the input slack
Coto-Millan et al. (2000)	Spain	1985–1989	No	Greater autonomy of Spanish seaports leads to a higher economic inefficiency
Reform programs Gonzalez and Trujillo (2008)	Spain	1990–2002	No	The first two seaport reform programs in Spain have had a positive impact on technological change with a catching up of poor performers
Nguyen et al. (2018)	Vietnam	2015	No	Corporatization and commercialization can improve the technical efficiency of Vietnamese ports
Nunez-Sanchez and Coto-Millan (2012)	Spain	1986–2005	No	Spanish seaport reform programs of 1992, 1997, and 2003 were responsible for an increase in total factor productivity
Rodriguez-Alvarez and Tovar (2012)	Spain	1993–2007	No	Spanish seaport reform programs of 1992 and 1997 positively impacted cost efficiency
Ownership Chang and Tovar (2014a)	Chile & Peru	2004–2010	No	The dynamic port reform process attracted higher private sector participation in Chilean port terminals leading to higher investment in infrastructure and technology hence enhancing efficiency

(continued on next page)

(continued)

Reference	Region	Timeframe	Explicit Effects	Relevant Results
Chang and Tovar (2014b)	Chile & Peru	2004–2010	Yes	Privately operated Chilean and Peruvian port terminals are more technically efficient than publicly operated terminals
Liu (1995)	United Kingdom	1983–1990	Yes	Ownership has little to no impact on the technical efficiency of the British ports
Lopez-Bermudez et al. (2019b)	Argentina	2012–2017	Yes	Private terminal operators are more efficient than public terminal operators
Trujillo et al. (2013)	Africa	1998–2007	Yes	Port reforms in Africa enhance technical efficiencyLandlord ports are the most efficient in Africa and have the highest service quality compared to tool and service ports
Wang et al. (2013)	United States	1997–2006	Yes	Landlord ports in the US are more profitable than limited-operating and operating ports
Wanke et al. (2011)	Brazil	2008	Yes	Private Brazilian port terminals are more efficient than public terminals
Zheng and Yin (2015)	China	1998–2011	No	More than 50 % of state-owned ports have a higher cost-efficiency
Hinterland Competition Merkel (2018)	Europe	2002–2012	Yes	Inter-port competition within a proximity of 300 km leads to an increase in the technical efficiency of the container ports
Regulation Rodriguez-Alvarez et al. (2007)	Spain	1991–1999	No	Labour-related regulations negatively affect allocative efficiency limiting the terminal operators' flexibility
Ownership and hinterland competition Cullinane and Song (2003)	South Korea and United Kingdom	1978–1996	No	A higher degree of privatization and deregulation leads to higher technical efficiencyHigher competition will lead to higher technical efficiency
Lopez-Bermudez et al. (2019a)	Brazil	2008–2017	Yes	Private terminal operators such as Tecon, Libra, and APM Terminals are more technically efficient than their public counterpartsCompetition leads to a drop in efficiency
Ownership and transshipment competition Cullinane et al. (2006)	Worldwide	2001	No	Higher private sector participation leads to a higher technical and scale efficiencyTransshipment ports are more technically efficient than gateway ports
Sarriera et al. (2013)	Latin America & the Caribbean	1999–2009	Yes	Landlord ports are more efficient in comparison to the other portsTransshipment ports are more technically efficient than ports that do not handle transshipment traffic
Serebrisky et al. (2016)	Latin America & the Caribbean	1999–2009	Yes	Private sector participation and the landlord seaport model result in higher technical efficiency
Suarez-Aleman et al. (2016)	Developing Countries	2000–2010	Yes	Landlord ports are significantly more technically efficient than ports not operating under the landlord port modelTransshipment ports have a significantly higher output than ports that are not transshipment hubs
Ownership and regulation Cullinane et al. (2002)	Asia	1989–1998	No	Privatization and deregulation positively impact the technical efficiency of the ports or terminals
Hinterland competition and transshipment competition Perez et al. (2016)	Latin America & the Caribbean	2000–2010	Yes	Ports with three or four container terminals are more technically efficient than ports with one or two container terminalsTransshipment ports are less technically efficient than non-transshipment ports
Ownership, hinterland competition and transshipment competition Notteboom et al. (2000)	Europe and Asia	1994	No	Ownership structure has no significant impact on technical efficiency levels Container terminals over-invest in capacity to address competition. However, small terminals located at larger container ports achieve higher technical efficiency levels due to intra-port competitionHub port terminals achieve a higher level of technical efficiency than feeder port container terminals
Ownership, hinterland competition and regulation Coto-Millan et al. (2016)	Spain	1986–2012	Yes	Autonomy, private sector participation through public–private partnerships, and competition promote the technical efficiency of Spanish ports
Estache et al. (2002)	Mexico	1996–1999	No	Decentralization, privatization, and competition have a significant positive impact on the performance of the Mexican ports
Tongzon and Heng (2005)	Asia, Europe & North America	1999	Yes	Privatization at the level of around 80 % is the most conducive to container port technical efficiency

Appendix B. . Elasticities plotted against respective input



Appendix C. . Full Regression Tables across hinterland competition measures

Table C1

Sensitivity analysis of different definitions of hinterland competition (500 km).

Dep. Variable: ln(TEU handled)	Model 500/0		Model 500/1		Model 500/3		Model 500/5	
	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
Frontier (Translog): Inputs								
x intercept	-6.435	1.615	-10.182	2.837	-6.444	1.576	-7.619	1.933
ln(Berth Length)	0.22	0.913	-1.45	0.92	-1.119	0.879	-0.423	0.928
ln(Terminal Area)	1.937	0.595	3.491	0.788	2.675	0.564	2.528	0.65
ln(Cranes)	1.927	0.499	1.664	0.558	1.992	0.501	1.623	0.514
ln(Berth Length)*ln(Terminal Area)	0.515	0.107	0.729	0.11	0.653	0.103	0.549	0.11
ln(Berth Length)*ln(Cranes)	-0.331	0.102	-0.396	0.101	-0.445	0.099	-0.397	0.098
ln(Terminal Area)*ln(Cranes)	-0.08	0.056	-0.033	0.063	-0.039	0.055	-0.023	0.058
(ln(Berth Length)) ²	-0.679	0.148	-0.806	0.151	-0.693	0.14	-0.632	0.141

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Table C1 (continued)

Dep. Variable: ln(TEU handled)			Model 500/0		Model 500/1		Model 500/3		Model 500/5	
			Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
(ln(Terminal Area)) ²			−0.414	0.101	−0.664	0.117	−0.558	0.097	−0.488	0.107
(ln(Cranes)) ²			0.532	0.08	0.571	0.08	0.604	0.079	0.539	0.079
t			0.099	0.042	0.11	0.045	0.098	0.043	0.122	0.044
t ²			−0.004	0.001	−0.004	0.001	−0.003	0.001	−0.003	0.001
t*ln(Berth Length)			−0.035	0.007	−0.036	0.007	−0.033	0.007	−0.033	0.007
t*ln(Terminal Area)			0.014	0.005	0.014	0.005	0.012	0.005	0.01	0.005
t*ln(Cranes)			0.017	0.004	0.016	0.005	0.016	0.005	0.017	0.005
<u>Contextual variables</u>										
z Intercept			−2.591	0.515	−2.941	0.584	−2.237	0.369	−2.94	0.593
<i>Transshipment Competition</i>										
No					Base Case		Base Case			
Yes			−0.537	0.152	−0.599	0.141	−0.357	0.134	−0.334	0.127
Majority Private	Low Comp.	MOT/S	3.911	0.557	4.022	0.673	3.796	0.483	4.457	0.664
		PA	3.052	0.55	3.477	0.638	2.592	0.389	3.099	0.583
		IR	−3.443	1.113	−5.751	1.704	−2.256	0.898	−2.767	1.005
		NR					0.541	0.95	0.814	0.88
	High Comp.	MOT/S	3.94	0.598	5.009	0.677	4.329	0.545		
		PA	2.528	0.475	3.019	0.609	1.983	0.44	0.659	0.879
		IR	0.17	0.948	−0.648	0.964				
		NR					Base Case			
	Low Comp.	MOT/S	3.227	0.533	3.443	0.63	2.881	0.414	3.549	0.616
		PA	1.931	0.479	2.408	0.571	1.864	0.392	2.31	0.525
		IR	−3.341	1.24	2.447	0.598	1.894	0.402	2.311	0.547
		NR	3.697	0.661	4.021	0.667	3.615	0.407	3.797	0.587
	High Comp.	MOT/S	3.055	0.52	3.725	0.65				
		PA	2.641	0.496	3.622	0.646	3.378	0.461	4.02	0.647
		IR	2.031	0.467	2.271	0.635	−2.497	1.15		
		NR	3.109	0.483	3.491	0.57	2.759	0.36	3.402	0.567
σ ²					3.109	0.483	3.491	0.57	2.759	0.36
γ					0.364	0.034	0.29	0.025	0.268	0.023
Country Fixed Effects			Yes		Yes		Yes		Yes	
Observations			591		591		591		591	
log likelihood value			−210.42		−198.55		−189.04		−198.85	
Average Efficiency			0.642		0.644		0.634		0.640	

Table C2

Sensitivity analysis of different definitions of hinterland competition (1000 km).

Dep. Variable: ln(TEU handled)			Model 1000/0		Model 1000/1		Model 1000/3		Model 1000/5	
			Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
<u>Frontier (Translog): Inputs</u>										
x intercept			−9.218	2.543	−10.065	2.545	−12.035	3.299	−11.58	3.09
ln(Berth Length)			0.849	0.883	0.741	0.905	0.652	0.905	0.166	0.885
ln(Terminal Area)			2.204	0.648	2.416	0.625	2.76	0.787	2.919	0.752
ln(Cranes)			1.107	0.568	1.037	0.611	0.868	0.62	1.071	0.618
ln(Berth Length)*ln(Terminal Area)			0.484	0.103	0.491	0.104	0.452	0.102	0.489	0.101
ln(Berth Length)*ln(Cranes)			−0.263	0.097	−0.278	0.099	−0.265	0.1	−0.314	0.1
ln(Terminal Area)*ln(Cranes)			−0.036	0.057	−0.022	0.06	−0.012	0.068	−0.008	0.066
(ln(Berth Length)) ²			−0.741	0.143	−0.733	0.143	−0.661	0.148	−0.648	0.149
(ln(Terminal Area)) ²			−0.426	0.1	−0.45	0.099	−0.452	0.109	−0.484	0.107
(ln(Cranes)) ²			0.441	0.082	0.442	0.084	0.42	0.081	0.463	0.082
t			0.126	0.043	0.121	0.043	0.14	0.043	0.124	0.043
t ²			−0.004	0.001	−0.004	0.001	−0.004	0.001	−0.003	0.001
t*ln(Berth Length)			−0.034	0.007	−0.033	0.007	−0.034	0.007	−0.03	0.006
t*ln(Terminal Area)			0.01	0.005	0.01	0.005	0.009	0.005	0.008	0.005
t*ln(Cranes)			0.02	0.005	0.02	0.004	0.02	0.005	0.017	0.005
<u>Contextual variables</u>										
z Intercept			−3.727	0.859	−3.714	0.781	−3.828	0.859	−3.794	0.868
<i>Transshipment Competition</i>										
No					Base Case		Base Case			
Yes			−0.787	0.162	−0.775	0.168	−0.589	0.16	−0.523	0.159
Majority Private	Low Comp.	MOT/S	5.047	0.877	4.938	0.786	5.244	0.862	5.134	0.87
		PA	4.016	0.816	3.997	0.76	3.224	0.802	3.531	0.808
		IR							−6.932	2.003
		NR					0.372	0.95	1.192	0.983
	High Comp.	MOT/S	4.557	0.802	4.647	0.741	3.9	0.815	3.988	0.843

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Table C2 (continued)

Dep. Variable: ln(TEU handled)		Model 1000/0		Model 1000/1		Model 1000/3		Model 1000/5	
		Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
Minority Private	PA	3.408	0.74	3.453	0.694	3.824	0.761	3.747	0.784
	IR	−2.933	1.109	−2.946	1.032	−4.934	1.436	−0.873	0.955
	NR					Base Case			
	MOT/S	4.184	0.819	4.105	0.713	4.18	0.788	4.216	0.824
	PA	2.11	0.694	2.073	0.613	2.641	0.657	2.945	0.704
	IR					3.224	0.757	2.915	0.733
	NR							5.627	0.901
	MOT/S	4.011	0.8	4.021	0.74				
	PA	3.542	0.751	3.557	0.701	4.044	0.804	4.268	0.858
	IR	2.658	0.663	2.637	0.588	1.697	0.608	2.169	0.718
High Comp.	NR	4.194	0.8	4.195	0.738	4.225	0.806	4.163	0.809
	σ^2	0.469	0.055	0.453	0.05	0.475	0.053	0.417	0.044
	γ	0.957	0.01	0.955	0.011	0.957	0.011	0.946	0.013
	Country Fixed Effects	Yes		Yes		Yes		Yes	
Observations		591		591		591		591	
log likelihood value		−210.49		−221.97		−201.02		−194.1	
Average Efficiency		0.665		0.663		0.670		0.676	

Appendix D. . SFA models with Crane capacity in tons as an input

Dep. Variable: ln(TEU handled)		Model 1		Model 2		Model 3	
		Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
<i>Frontier (Translog): Input variables</i>							
x intercept		−1.84	2.81	−12.01***	0.97	−15.05***	1.38
ln(Berth Length)		−1.98*	0.80	0.41	0.80	1.60	0.82
ln(Terminal Area)		2.40**	0.73	2.68***	0.44	3.34***	0.49
ln(Crane Capacity)		1.26	0.73	0.59	0.58	−0.96	0.58
ln(Berth Length)*ln(Term. Area)		0.93***	0.11	0.50***	0.12	0.46***	0.12
ln(Berth Length)*ln(Crane Capacity)		−0.63***	0.11	−0.17	0.13	−0.35**	0.12
ln(Terminal Area)*ln(Crane Capacity)		−0.20	0.11	−0.16	0.086	0.062	0.084
(ln(Berth Length)) ²		−0.67***	0.16	−0.71***	0.18	−0.62***	0.16
(ln(Terminal Area)) ²		−0.61***	0.13	−0.39***	0.10	−0.53***	0.11
(ln(Crane Capacity)) ²		0.92***	0.12	0.46***	0.11	0.43***	0.10
t		0.025	0.049	0.038	0.045	0.093*	0.040
t^2		−0.004***	0.000	−0.003***	0.000	−0.0036***	0.00089
t^* ln(Berth Length)		−0.044***	0.007	−0.017*	0.008	−0.020*	0.0080
t^* ln(Terminal Area)		0.030***	0.007	0.0091	0.006	0.0029	0.0063
t^* ln(Crane Capacity)		0.0019	0.006	0.0041	0.005	0.012	0.0067
<i>Contextual Variables – Inefficiency</i>							
z Intercept				−0.55*	0.25	−2.34***	0.51
Transshipment Comp.	No			Base Case		Base Case	
	Yes			−0.83***	0.22	−0.45**	0.15
Ownership	Minority private			0.30*	0.14		
	Majority private			Base Case			
Hinterland Comp.	Low			0.57**	0.21		
	High			Base Case			
Regulation	MOT/ S ^{a)}			0.39	0.21		
	PA ^{b)}			−0.95***	0.27		
	IR ^{c)}			−2.35***	0.53		
	NR ^{d)}			Base Case			
Minority Private	Comp.					2.87***	0.48
	MOT/S					1.58***	0.45
	PA					1.88***	0.49
	IR					4.29***	0.61
	NR					—	
	MOT/S					2.91***	0.55
MajorityPrivate	PA					0.70	0.61
	IR					2.83***	0.49
	NR					3.73***	0.52
	MOT/S					2.36***	0.51
						−5.20***	1.49

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Dep. Variable: ln(TEU handled)		Model 1		Model 2		Model 3	
		Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
<i>Frontier (Translog): Input variables</i>							
x intercept		−1.84	2.81	−12.01***	0.97	−15.05***	1.38
ln(Berth Length)		−1.98*	0.80	0.41	0.80	1.60	0.82
ln(Terminal Area)		2.40**	0.73	2.68***	0.44	3.34***	0.49
ln(Crane Capacity)		1.26	0.73	0.59	0.58	−0.96	0.58
ln(Berth Length)*ln(Term. Area)		0.93***	0.11	0.50***	0.12	0.46***	0.12
ln(Berth Length)*ln(Crane Capacity)		−0.63***	0.11	−0.17	0.13	−0.35**	0.12
ln(Terminal Area)*ln(Crane Capacity)		−0.20	0.11	−0.16	0.086	0.062	0.084
(ln(Berth Length)) ²		−0.67***	0.16	−0.71***	0.18	−0.62***	0.16
(ln(Terminal Area)) ²		−0.61***	0.13	−0.39***	0.10	−0.53***	0.11
(ln(Crane Capacity)) ²		0.92***	0.12	0.46***	0.11	0.43***	0.10
t		0.025	0.049	0.038	0.045	0.093*	0.040
t ²		−0.004***	0.000	−0.003***	0.000	−0.0036***	0.00089
t*ln(Berth Length)		−0.044***	0.007	−0.017*	0.008	−0.020*	0.0080
t*ln(Terminal Area)		0.030***	0.007	0.0091	0.006	0.0029	0.0063
t*ln(Crane Capacity)		0.0019	0.006	0.0041	0.005	0.012	0.0067
<i>Contextual Variables – Inefficiency</i>							
z Intercept				−0.55*	0.25	−2.34***	0.51
<i>Transshipment Comp.</i>				Base Case		Base Case	
Ownership	No			−0.83***	0.22	−0.45**	0.15
	Yes			0.30*	0.14		
	Minority private						
	NR					1.25	0.98
	MOT/S					2.60***	0.51
	PA					2.44***	0.47
	IR					−3.00*	1.27
	NR					Base Case	
σ ² e)		0.71***	0.070	0.59***	0.082	0.35***	0.035
γ f)		0.88***	0.015	0.94***	0.016	0.93***	0.020
Country Fixed Effects		Yes		Yes		Yes	
Observations		591		591		591	
Log likelihood value		−167.77		−266.13		−202.11	
Average efficiency		0.61		0.68		0.67	

Note: *p < 0.05; **p < 0.01; ***p < 0.001. A negative coefficient for a contextual variable in the efficiency model indicates a reduction in inefficiency. a) MOT/S federal regulation (Ministry of Transport). b) PA Port Authority Regulator c) IR Independent regulator. d) NR No regulation. e) Sum of variances of noise and efficiency. f) ratio of the variance of the inefficiency term to the total variance. There are no ports fitting the category Minority Private, High. Comp and MOT/S.

Appendix E. . SFA models with an input weighted measure of ownership

Dep. Variable: ln(TEU handled)		Model 2		Model 3	
		Coeff.	s.e.	Coeff.	s.e.
<i>Frontier (Translog): Input variables</i>					
x intercept		−4.71***	1.32	−10.12**	3.18
ln(Berth Length)		0.14	0.90	1.22	0.92
ln(Terminal Area)		1.59**	0.55	2.18**	0.78
ln(Cranes)		2.21***	0.52	0.71	0.66
ln(Berth Length)*ln(Term. Area)		0.46***	0.11	0.42***	0.10
ln(Berth Length)*ln(Cranes)		−0.16	0.10	−0.16	0.10
ln(Terminal Area)*ln(Cranes)		−0.17**	0.056	−0.037	0.068
(ln(Berth Length)) ²		−0.68***	0.16	−0.72***	0.15
(ln(Terminal Area)) ²		−0.32**	0.099	−0.38***	0.11
(ln(Cranes)) ²		0.47***	0.085	0.32***	0.092
t		0.076	0.047	0.16***	0.045
t ²		−0.003***	0.000	−0.0040***	0.00076
t*ln(Berth Length)		−0.024***	0.006	−0.034***	0.0068
t*ln(Terminal Area)		0.0099	0.005	0.0064	0.0052
t*ln(Cranes)		0.011*	0.004	0.025***	0.0048
<i>Contextual Variables – Inefficiency</i>					
z Intercept		−0.77**	0.28	−2.00***	0.46
<i>Transshipment Comp.</i>		No	Base Case	Base Case	

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Dep. Variable: ln(TEU handled)			Model 2		Model 3	
			Coeff.	s.e.	Coeff.	s.e.
Ownership	Yes		−1.01***	0.24	−0.38*	0.15
	Minority private		0.41**	0.14		
	Majority private		Base Case			
Hinterland Comp.	Low		0.33	0.19		
	High		Base Case			
Regulation	MOT/ S		0.49*	0.21		
	PA		−0.75**	0.27		
	IR		−2.58***	0.67		
	NR		Base Case			
Minority Private	Comp.	MOT/S			2.48***	0.43
		PA			1.45***	0.38
		IR			−0.53	0.99
		NR			3.88***	0.55
		MOT/S			—	
MajorityPrivate		PA			2.38***	0.45
		IR			0.62	0.58
		NR			2.41***	
		MOT/S			3.37***	0.47
		PA			1.80***	0.44
		IR			0.80	0.45
		NR			−1.05	0.93
		MOT/S			2.06***	0.46
High Comp.		PA			2.00***	0.40
		IR			−0.58	0.98
		NR			Base Case	
					0.42***	0.052
σ^2			0.70***	0.11	0.96***	0.015
γ			0.96***	0.013		
Country Fixed Effects			Yes		Yes	
Observations			591		591	
Log likelihood value			−258.53		−205.48	
Average efficiency			0.68		0.66	

Data availability

Data will be made available on request.

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