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An empirical study of the impacts of operating and market conditions on container-port efficiency and benchmarking

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A B S T R A C T

Despite the growing amount of research on container-port efficiency and benchmarking, the literature on the subject is yet to provide stable and consistent results across researchers and in relation to dynamic operating and market conditions. In this paper, we formulate a number of operational hypotheses to test the sensitivity of benchmarking results to port market and operating conditions namely production scale, cargo mix, transhipment ratio, operating configurations, and working procedures. A series of data envelopment analysis (DEA) models are used to measure the operational efficiency of 420 container terminal decision-making units from 2004 till 2010. The results show that variations in operating conditions highly impact terminal efficiency and that future work on container-port performance and benchmarking should take into account the structure and mechanisms underpinning the operations of container ports and terminals.

1. Introduction

In the last decade or so, there has been a growing amount of research into port performance and benchmarking. A review of the contemporary literature on the subject shows an increasing use of frontier methods, notably data envelopment analysis (DEA) and stochastic frontier analysis (SFA), for measuring and benchmarking port performance and efficiency. For a review of the main approaches and techniques for port performance and benchmarking, see for instance Gonzalez and Trujillo (2009), Jara-Diaz, Tovar, and Trujillo (2007), Panayides, Maxoulis, Wang, and Ng (2009), and Bichou (2012).

Too often though, relevant work on the relationship between a port's efficiency and its operating and organisational conditions shows a great degree of discrepancy and divergence across port researchers. This is particularly the case for studies looking at the role of the institutional structure and type of ownership as a determinant of port efficiency, the relationship between scale economies and port efficiency, and the impact of port reform on port efficiency. For instance, when investigating the relationship between port efficiency and the type of port ownership, Cullinane, Song, and Gray (2002) and Tongzon and Hang (2005) found that private sector participation would improve port efficiency. On the other hand, Cullinane et al. (2002), Liu (1995) and Notteboom, Coeck, and Van-Den Broeck (2000) have all found that the type ownership does not have a significant effect on port efficiency. The literature on the impact of port size on port efficiency also shows inconsistent results. Studies by Martinez-Budría, Díaz-Armas, Navarro-Ibañez, and Ravelo-Mesa (1999) and Wang, Cullinane, and Song (2005) found that port's scale positively influences the level of port efficiency. These results contradict the findings of Tongzon (2001) and Bonilla, Medal, Casacus, and Salas (2002) who concluded that the impact of size on port efficiency is not significant. Conflicting views also exist regarding the impact of port reform on port efficiency. Studies by Barros (2003), Estache, Tovar, and Trujillo (2004) and Gonzalez and Trujillo (2009) have shown that port reforms in Mexico, Portugal, and Spain, respectively, have generated significant improvements in port efficiency. In contrast, Baird (2000), Coto-Millan, Banos-Pino, and Rodriguez-Alvarez (2000) and De Monie (1996) have all argued that the combination of decentralization and deregulation would have a negative influence on port efficiency.

This wide divergence in the port performance literature raises the question as to whether there is something wrong with the techniques applied so far or simply whether something is not captured by the available literature on the subject. In this paper, we focus on the latter issue by examining the relationship between port efficiency and the operating environment, focussing in particular on market and operating conditions of container ports and terminals. Data envelopment analysis (DEA) is used to benchmark the efficiency of 420 container terminal decision-making

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units (DMUs), and test whether changes in certain operating conditions have an impact on port efficiency.

The remainder of the paper is structured as follows. Section 2 highlights the importance of market and operating conditions in shaping port efficiency, focussing in particular on the limitations of the container-port literature for overlooking the variations in market conditions and operating configurations. In Section 3, we present research hypotheses, formalise DEA models, and specify the sampling frame variables' selection. Section 4 presents the empirical results for testing and analysis, while Section 5 concludes with a summary and suggestions for future research.

2. Market and operating conditions for container terminals

A basic requirement for any reliable performance benchmarking exercise is the appropriate definition and selection of homogenous decision-making units (DMUs). For ports, this usually implies disaggregating port systems into homogenous operational units of similar trade and traffic type although this may not be sufficient to ensure homogeneity. For container ports, sources of non-homogeneity could stem from several factors such as different handling technologies, dissimilar operating procedures, and/or diverse types and proportions of container categories. In the next sections, we briefly describe the variations in container terminal handling systems and procedures and argue that there is a need to incorporate the differences in non-controllable factors when attempting to measure or benchmark container-port efficiency.

2.1. Terminal configurations and handling systems

Modern port configurations and operating systems are increasingly designed to serve a particular trade or ship's type, although many ports around the world still operate multipurpose facilities. Nevertheless, even within a single port type, terminals may be designed, operated and managed differently. In addition to physical constraints such as quay length, berth draught and terminal size, much of the operational features of modern container terminals are determined by the typologies and configurations of quay and yard handling systems.

2.1.1. Quay crane performance and technology

A container quay crane is the main equipment used for ship loading and unloading. It can be either mounted on the ship (ship-mounted crane) or located on the quay (ship-to-shore -STS-cranes), the latter being widely used in modern container ports and terminals. STS cranes come in different types, shapes and configurations (See Table 1).

Driven by the increases in ship size and technology, STS cranes have also developed in different sizes and types. A first prerequisite of increased ship size is the requirement for increased crane's height, outreach, and lifting capacity as shown in Table 2. Evidence therefore suggests that STS crane's productivity varies greatly depending on the crane's type, size, and technology.

2.1.2. Yard configuration and handling systems

As with the variations in STS crane technology, modern container yard configurations depict a variety of cargo handling, transfer and stacking typologies, the aggregation of which results into three generic cargo-handling systems, each with different operating technology and performance levels as shown in Table 3

1. The tractor-chassis or wheeled system (as opposed to the grounded system). Automated container terminals operating through automated guided vehicles (AGV) fall under the same category.
2. The straddle carrier (SC) and stacking handler systems, which can be based either on a direct system or in combination with internal trucks (relay system).
3. Yard gantry systems generally using rubber- gantry (RTG) or rail-mounted gantry (RMG) cranes. Similar yard configurations using other equipment such as bridge cranes or automated stacking cranes (ASC) also fall under the same category.

One of the main shortcomings of the contemporary literature on port efficiency is that the variations in crane technology and handling configurations are hardly captured in the benchmarking dataset.

Table 1
Types and characteristics of modern STS cranes.

STS crane type		Description
Shape		
A-frame		A-shaped crane that can be either simple or articulated
Low profile		Minimum height cranes used for reduced visual impact
Configuration		
Cycle mode	Single	Crane travels back empty from shore to ship or vice versa
	Dual	Crane travels full in each direction
Trolley	Rope-towed	The trolley drive, main hoist and boom hoist are located in the machinery house on the frame.
	Machinery-type	The trolley and main hoist drives are located on board
Hoist	Single	One hoist is operating for both waterside/ship and landside/apron operations
	Dual	Two hoists, one for the waterside and the other for the landside, are exchanging containers in a single cycle-mode shuttle system.
Lifts	Single 20ft	The crane spreader can only handle one 20ft (TEU).
	Twin twenties	The crane spreader can handle one 40ft/FEU container or two 20ft at once
	Tandem 40ft/two twin 20ft	Tandem containers are handled by one head block and two spreaders The spreaders can handle two 40ft, four 20ft, or each of both.
	Triple 40ft	Tandem containers are handled by one head block and three spreaders

Table 2
Sizes of modern container ships and the requirements for STS cranes.

Containership generation	Ship name (Year launched)	Capacity (TEU)	Dimensions (metres) LOA × Beam × draft	Arrangements (rows) under-below-across
Panamax-Max	ZIM Savannah	5070	294 × 32 × 12.5	8-6-13
Post Panamax	Hamburg S,d Rio Negro	5900	287 × 40 × 10	9-5-16
	Sovereign Maersk (1997)	8500	347 × 44 × 11.8	9-6-18
New Panamax	COSCO Oceania (2006)	10,062	349 × 45.6 × 11.5	10-6-19
	MSC Danit (2009)	14,000	366 × 51 × 16	10-6-20
ULCS: ultra-large container ships	Emma Maersk (2006)	15,500	397 × 56.4 × 15.5	10-6-22
	Maersk triple E (2013–15)	18,000	400 × 59 × 17.5–18	13-8-23

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