EFFICIENCY MEASUREMENT OF CONTAINER PORTS – A NEW OPPORTUNITY FOR HINTERLAND INTEGRATION

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Abstract Changes in international production networks and maritime transport lead to a growing importance of container ports as nodes in international supply chains. Based on technology development and time-critical global production patterns ports are confronted with rising expectations on the performance of their sea and land side operations as well as on the seamless distribution of goods to the hinterland. In order to assess the comparative performance of ports in supply chains it has been accepted that efficiency ratings determined through benchmarking can be powerful tools. Next to simple key performance indicators complex production functions have experienced approval due to their ability to compare independent multiple input and output criteria. To benchmark container terminals the frontier function *Data Envelopment Analysis* (DEA) has been applied frequently in the past ten years. But as the sea leg is in the main focus of past studies, measuring the efficiency of port hinterland connections still needs further clarification in the context of integrated supply chains.

Paper type: Research paper

1. INTRODUCTION TO MARITIME AND PORT LOGISTICS

The theory of logistics and supply chain management gained popularity as an academic research field in the past decades underlined by a growing amount of book and journal publications. As one partial aspect of logistics the terminology of maritime and port logistics still needs further clarification. Primarily, maritime logistics is the concept of physical, economic/strategic or organisational/relational integration (Panayides, 2006, p. 5) and comprises planning, design, execution and management of material and information flows alongside the maritime supply chain from ship to port to the hinterland and vice versa. Port-centric logistics is defined as the provision of distribution and other value-adding logistics services at ports (Mangan, Lalwani & Fynes, 2008, p. 36) whereas port services need to fit into door-to-door supply chains and terminal operators as well as port authorities increasingly play a role in hinterland transport (de Langen, 2007, p. 1). Based on the concept of integrated logistics and supply chains, ports are no longer valid to be considered as separate entities or within isolated markets (Bichou & Gray, 2005, p. 83). Thus, ports play an important role in the management and co-ordination of materials and information and are regarded as a cluster of organizations in which different logistics operators are involved in bringing value to the final customers (Carbone & de Martino, 2003, p. 306).

Strategic, tactical and operational changes in the container port industry are intensely affected by competition taking place between supply chains. The competitive position of a port is not only determined by its cargo handling ability but also by its link in the supply chain implying that external coordination and control of the whole chain determines a port's competitiveness (Carbone & de Martino, 2003, p.306). At large, port performance is regarded to be vital for the prosperity of whole regions and nations. This involves that measurement of port competitiveness relative to competitors becomes crucial to determine indicators for plausible improvements in port management and operational planning (Munisamy, 2011, p. 1397); (Cullinane & Wang, 2007, p. 518). In order to determine significant strengths and weaknesses and to recognize crisis and opportunities, evaluating the efficiency enables adoption of appropriate response measures (Liu, 2008, p. 1741). As a result, efficiency ratings determined through benchmarking can be a powerful tool (Park & De, 2004, pp. 55-56); (Min & Park, 2008, p. 651).

2. EFFICIENCY MEASUREMENT OF CONTAINER PORTS

The ability to collect relevant data quickly and to use basic calculations led to a dominance of applying simple *key performance indicators* (KPIs) to measure efficiency in the port sector. Nevertheless, due to their simplicity KPI-models are not able to display complex relationships which do not have a direct impact on each

other. That is why efficiency measurement with complex production functions expanded and among others *Data Envelopment Analysis* (DEA) and *Stochastic Frontier Analysis* (SFA) found their way into comparing efficiencies in the port industry based on their ability to compare independent multiple input/output criteria. To give an overview of methods of efficiency measurement and their classification (Hammerschmidt, 2006, p.105) developed a model differencing between KPIs and production functions (Fig. 1). Supporting the model of Hammerschmidt (2006, p. 105), Bichou (2006, pp. 569-579) proposed a similar structure on approaches to benchmark performance in ports excluding economic impact studies from performance metrics and index methods.
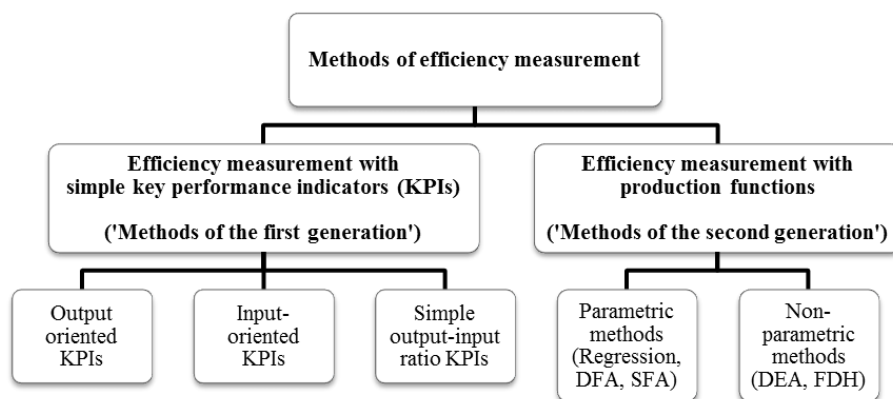

Fig. 1 Methods of efficiency measurement (Hammerschmidt 2006, p.105)

2.1. Simple key performance indicators

In regard to single output criteria, the throughput of container terminals in TEU is a popular indicator to display maritime business rankings, exemplary the "Top 50 World Container Ports" (World Shipping Council 2011), "World's 10 busiest ports" (Barros 2006, p.150) or the "World Container Terminal Ownership Ranking" (Drewry Shipping Consultants Limited 2011).

Single-input criteria are less widespread but for example the number of ship arrivals at a port is utilized to demonstrate a port's development over time (see Hafen Hamburg Marketing 2010).

Furthermore, simple output-input KPI ratios are frequently applied to measure efficiency of container ports. When it comes to academic modelling, Marlow & Paixão Casaca (2003) suggest a set of new port performance indicators that measure lean ports performance and finally try to sustain the subsequent development of agile ports and present a port performance theoretical framework for measuring lean ports. In addition, Tongzon, Chang & Lee contributed 2009 to the empirical

literature by considering the port of Incheon as a case in point and by measuring the degree of its supply chain orientation based on certain valid indicators drawn from current literature. Criticizing the rejection of externally generated KPIs, Pallis & Vitsounis (2008) examined the potential of using externally generated information as a decisive tool towards the evaluation of port performance and found that ports continue to be preoccupied with the measurement of internally collected indicators, in order to assess operational efficiency.

In regard to hands-on application in the present container port business, the *Container Terminal Quality Indicator* (CTQI) standard has been introduced by Germanischer Lloyd Certification GmbH in cooperation with the Global Institute of Logistics in 2008. By annual audits of the container terminal performance and supply chain interfaces benchmarks are set and the facilitation of the supply chain integration is motivated (Germanischer Lloyd SE, 2010). To highlight, the set of KPIs used in determining the CTQI are according to Ring (2007):

1. Generic Indicators (absolute figures as basic input e.g. container moves, quay productivity, terminal and storage area productivity),
2. KPIs measuring operational effectiveness and efficiency (ship productivity, gross crane productivity, berth occupancy, berth working index), and
3. KPIs measuring service quality for users (average ship turnaround time at terminal, ship service quality index, road service quality index, rail service quality index, average barge waiting time, barge service quality index).

Another practical approach of setting up a standard of port performance indicators is undertaken by the European Sea Ports Organisation. The project "Port Performance Indicators – Selection and Measurement" is funded by the European Commission and plans to publish a Port Sector Performance Dashboard by the end of 2011 (European Sea Ports Organisation, 2011). Additionally, private corporations (e.g. Drewry Shipping Consultants) set up individual container terminal performance benchmarks including customized KPI ratios regularly.

2.2. Production functions

With reference to production functions, the parametric methods regression, *deterministic parametric frontier analysis* (DFA) and SFA base on functional specifications and on known relationships between input/output criteria. Parameters of known production functions are economically estimated (Cantner, Krüger & Hanusch, 2007, p.60). As opposed to this, the non-parametric approaches DEA and *Free Disposable Hull* (FDH) both do not impose any functional form a priori on the data and can handle independent multiple input/output criteria. They base on the construction of frontier functions which envelop empirically determined observation points through linear optimisation (Cantner, Krüger & Hanusch, 2007, p.68).

To highlight advantages and disadvantages of the variety of methods for measuring container port efficiency González & Trujillo (2009) and Park & De (2004)

performed literature reviews comparing parametric and non-parametric frontier approaches. SFA and DEA are widely used in contemporary literature on container-port performance and efficiency (Haralambides, Hussain, Barros & Peypoch, 2010, pp.79-80) and therefore, the evaluation of DEA and SFA has been in the centre of academic debate (González & Trujillo, 2009), (Haralambides, Hussain, Barros & Peypoch, 2010), (Cullinane, Wang, Song & Ji, 2006). SFA has been applied by Tongzon & Heng (2005) to show whether port privatization is a necessary strategy for ports to gain a competitive advantage, or by Cullinane & Song (2003) who assessed if port privatization and/or deregulation policies increase the productive efficiency of Korean container terminals. In contrast, DEA has been deployed by Itoh (2002) to analyse efficiency changes of the eight international container ports in Japan during the period 1990-1999, and by Liu (2008) to evaluate the changes in efficiency that have taken place between 1998 and 2001 in 10 ports in the Asia-Pacific region. Both frontier models SFA and DEA allow the estimation of productive efficiency, relatively to a point of reference – the frontier – representing best practices (Haralambides, Hussain, Barros & Peypoch, 2010, p.79-80) and therewith benchmarking and the initialisation of interfering activities is possible.

Beyond, several studies focus on other or mixed-method approaches (including DEA or SFA). Regression analysis as a statistical tool to determine the relationship between variables has been applied in the container port industry by Lun & Cariou (2009) in combination with DEA to develop a reference for terminal operators to evaluate their operational performance, or by Tongzon & Heng (2005) linked with SFA to investigate the quantitative relationship between port ownership structure and port efficiency. A detailed comparison of DEA and FDH has been performed by Cullinane, Song & Wang (2005).

Production functions are established methods beeing transfered to the multi-production nature of the port sector. By applying DEA it is possible to estimate potential improvements that can be made by inefficient ports (Barros, 2006, p.348). In particular, the advantages of DEA lead to its acceptance as a meaningful method to measure efficiency of several container terminals (González & Trujillo, 2009, p.157; Cullinane, Song, Ji & Wang, 2004, p.185).

3. EFFICIENCY MEASUREMENT OF CONTAINER TERMINALS WITH DEA

DEA is "a nonparametric approach to weigh the inputs/outputs and measure the relative efficiency of *decision making units* (DMUs)" (Ablanedo-Rosas & Ruiz-Torres, 2009, p.279). In the past, common DEA use cases have been related to health care, education, insurance or banking with hospitals, universities, insurance companies or banking institutions as decision making units. In regard to Cantner, Krüger & Hanusch (2007, p.77), the basic DEA model of Charnes, Cooper & Rho-

des of 1978, called *Charnes Cooper Rhodes-model* (CCR-model), is founded on a combination of ideas by Farrell (1957) in terms of step-by-step linear approximation of production functions and it is based on the transformation of Charnes & Cooper (1962) which enables linear approximation of tangible data through a comparison of productivities. The main advantage of DEA which makes its transference to the complex port industry worthwhile is its ability to include multiple input/output criteria (Ablanedo-Rosas & Ruiz-Torres, 2009, p.278); (González & Trujillo, 2009, p.157). Thus, if container port terminals are defined as the relevant DMUs possible input criteria could be exemplary quay length, terminal area, number of quayside gantry cranes, number of yard gantry cranes and number of straddle carriers. Possible output criteria would be number of ship calls and total throughput. Nevertheless, it is stressed by Barros & Athanassiou (2004, p.126) and underlined by Cullinane & Wang (2007, p.535) and Liu (2008, p.1737) that the identification and precise definition of input/output variables and the completeness of the data gathered is as difficult as it is crucial.

Starting with the pioneering work by Roll & Hayuth in 1993, DEA has been increasingly applied to analyse container port efficiency and forms today a main stream of container port performance evaluation (Ablanedo-Rosas & Ruiz-Torres 2009, p.278); (Wu, Yan & Liu, 2010, p.216). Next to different input/output factors the most important differentiation criteria of studies are the total number and geographical location of terminals. Attention of past DEA research projects has been drawn to the main container ports worldwide with respect to total throughput, e.g. studies performed by Cullinane & Wang (2010), Wu, Yan & Liu (2010), Cheon (2009), Cullinane & Wang (2007), Cullinane, Ji & Wang (2005), Cullinane, Song & Wang (2005), Lee, Chou & Kuo (2005), Cullinane, Song, Ji & Wang (2004), Valentine & Gray (2000), Roll & Hayuth (1993).

Additionally, efficiency measurement of geographical regions took place for Middle East and African ports (Al Eraqi, Mustafa, Khader & Barros, 2008), Asian Pacific ports (Lin & Tseng, 2007); (Liu 2008), South American ports (Rios 2006), and European ports (Wang & Cullinane, 2006). A single country's container terminal efficiency has been analysed for Spain (Bonilla, Casasus, Medal & Sala, 2004); (Diaz Hernandez, Martinez-Budria & Jara-Diaz 2008), Italy (Stadtler & Kilger, 2010); (Ferrari & Basta, 2009), Korea (Min & Park, 2008); (Park & De, 2004), Australia (Geweke & Busse, 2011), Japan (Itoh, 2002), Mexico (Ablanedo-Rosas & Ruiz-Torres, 2009), Portugal or Greece (Barros & Athanassiou, 2004).

The majority of past DEA research projects dealt with seaside operations of container port terminals. As an exeption Bichou (2011) incorporated the landside link integrating gate and yard operations. The author focuses on a supply chain perspective capturing the internal structure of terminal operating export processes in order to measure both the individual and aggregate performances of container terminal sites by defining 70 different decision making units.

4. FUTURE OF DEA APPLICATION IN PORT SUPPLY CHAINS

Competitive advantage of terminal operators is increasingly based on the ability to integrate in logistics networks, to enhance the efficiencies within these and to extract value from them instead of solely focussing upon operational efficiency or location (Jacobs & Hall, 2007, p.328). As a result, performance and competitiveness of a seaport container terminal is highly dependent on the quality of inbound and outbound hinterland transport systems (Geweke & Busse, 2011, p.305). This quality perspective receives growing attention in the research field (de Langen & Chouly, 2004, p. 362); (Gouvernal & Daydou, 2005, p. 558) but although improvement of hinterland transport coordination and cooperation are at centre stage in many projects, efficiency measurement of container terminal hinterland connections is scarce (de Langen & Douma, 2010, p. 262). Approving, Bichou (2006, p. 578) criticises that the majority of frontier applications in ports solely focus on sea access, other processes of the port operating system are overlooked and the interests of other members of the port's supply chain network are ignored. The analysis of Bichou in 2011 is one of the first attempts to transfer the concept of integrated supply chains to the container port business employing DEA.

Subsequently, to initiate further research on DEA application in efficiency measurement of container terminal hinterland networks a structural model of the port hinterland stakeholder relationships needs to be developed inheriting information flows, processes and supporting technical systems. A dedicated stakeholder perspective could be selected such as the requirements of terminal operators, port authorities, forwarding agents, logistics service providers, and rail or barge operators. Incorporating practical knowledge of stakeholder representatives, a comprehensive set of input/output criteria has to be determined. Comparison of input and output criteria of KPIs measuring the service quality of users established by the CTQI standard may be of value - relevant indexes deal with road service quality, rail service quality, average barge waiting time, or barge service quality. After access to appropriate panel data is assured, calculation runs can start applying available DEA software tools. Finally, reflecting benchmarks with stakeholders and deriving possible action scenarios would enable further research on efficiency improvement of the container terminal hinterland network.

5. CONCLUSION

With the rise of containerization changes in maritime transport networks necessitated the incorporation of logistics strategies into the port industry in order to stay competitive and/or gain competitive advantage. Notably, container terminal operators are subject to fiercly contested business environments. To meet user demands on time, cost and service, evaluating efficiency of container terminals has

been recognized to enable the adoption of appropriate response measures leading to a growing attention of different ways to measure efficiency. Next to simple KPIs, DEA has been established as an appropriate method to benchmark terminals. However, past applications mainly focused on the sea leg of terminal operations and partly neglected the terminal-hinterland perspective. To bridge this gap, one possible approach has been presented and further research at the link of container port and hinterland is stipulated.

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BIOGRAPHICAL NOTES

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