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Efficiency of inland waterway container terminals: Stochastic frontier and data envelopment analysis to analyze the capacity design- and throughput efficiency

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ABSTRACT

Although terminal efficiency has been thoroughly studied for deep-sea container ports and terminals, up till now, there has been little scientific literature on the efficiency of inland waterway container terminals (IWTs). This paper therefore focuses on determining and analyzing terminal characteristics that influence efficiency. Our analysis led to a number of conclusions. First, there exist important differences between IWTs and maritime terminals in terms of design capacity and thus also in operations. Different combinations of inputs and output have been tested with the SFA and DEA methodologies. Important terminal inputs turned out to be yard and crane, but also terminal operating hours and terminal area are important. When capacity is excluded as an input it turns out that the importance of inputs becomes more diverse under SFA. Furthermore, when the inputs and output are varied it shows that this leads to a variation in best and worst performers (the efficiency depends on defined inputs and output). Finally, terminal operating hours are an important input for IWTs which is an important difference with maritime terminals which are open 24/7. In terms of how efficiency is defined, there arises a considerable difference between design efficiency (capacity) and the operational efficiency (terminal throughput).

1. Introduction

The European Union (EU) envisions a greater importance of inland waterway (IWW) transportation, as that would mean a shift towards a more environmentally-friendly transport sector (Caris et al., 2014). Despite the urgency stressed by the EU, the modal shift is not taking place as fast as was set in the European Commission's policy goals (Jonkeren et al., 2011). Therefore, there is a need for further research into the efficiency of IWW transport and container terminals. Inland waterway container terminals (IWTs) are playing an increasingly significant role within the intermodal transport chain due to ongoing globalization and growing containerized freight flows. This results in larger container flows between continents, fast growing container ports (such as Shanghai, Antwerp, Rotterdam), and thus also growing container hinterland transportation by inland waterways. The growing flows in the hinterland transportation systems also imply increasing requirements for IWTs along the main rivers (e.g. the river Rhine in Europe). For these IWTs, requirements for being efficient and delivering high quality services at a competitive price are becoming ever more important. For maritime container terminals efficiency has been thoroughly studied (e.g. Cullinane et al., 2002, 2006; Tongzon, 1995, 2001).

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However, up till now, there has been very little scientific literature on the efficiency of IWTs. Given the growing importance of IWTs in policy and practice as described above, scientific attention to their efficiency and to policy implications for cities and regions is needed. IWTs differ in a number of ways from maritime terminals and this influences terminal designs and terminal efficiencies. First, the locations in inland ports are suboptimal in size and lay-out leading to inefficient terminal designs as compared to maritime container terminals. Maritime terminals are often constructed on new locations that are tailor-made to the design requirements. Secondly, once IWTs are started it is often difficult to expand them because the location does not offer expansion possibilities, whereas this is often the case for maritime terminals. Thirdly, IWTs often start small and, when volumes allow, grow larger by adding more equipment, more labor, implementing better equipment or by extending the opening hours while keeping the area of the IWT the same. This means that the design capacity and the operations are much more flexible when compared to maritime terminals. Fourthly, often the smaller IWTs have difficulties in growing towards larger volumes due to limited demand. Finally, when terminals cannot expand further either the terminal has to move (disinvestments need to be made) or second locations are opened which is also suboptimal.

The focus in this paper is on the design efficiency (capacity) and also the operational efficiency (throughput) of the various IWTs. This paper uses an analytical approach based on two methodologies: Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). In Section 2, a literature review on the topic of inland terminal efficiency is introduced. As scientific literature on the efficiency of inland terminals is scarce, also the literature on seaport terminals is studied. In Section 3, the materials and methods used in the analysis are presented. Subsequently, a brief description of Stochastic Frontier Analysis (SFA) and data envelopment analysis (DEA) is given. In Section 4, the dataset is discussed. Then, the results of the analysis are presented in Section 5. Finally, in Section 6, the conclusions are presented, followed by the implications for policy and practice, and recommendations for further research.

2. Literature review: inland waterway terminal efficiency

Efficiency can be defined as the quality of being able to do a task successfully and without wasting time or energy (Sinclair, 1992). Kim and Marlow (2001) present a similar definition: ‘efficiency refers to how well the resources expended are used’. Efficiency is often linked to input, process, and output. Input then consists of resources, such as land, labor and capital, that are given to something such as a machine or a project to make it work. Process refers to resources consumed in the process. Output is the ability of a process to deliver products or services according to specifications or the amount of something that they make or produce. Efficiency can then be measured by comparing the amount or value of goods (output) with the time and money spent on producing them and the number of workers who produce them (input). According to Ockwell (2001), efficiency is either a minimizer or a maximizer concept. Minimizing is then applied to inputs, whereas maximizing is applied to outputs. In addition to this, Cantos and Maudos (2001) proved that rail freight companies that are more efficient in costs behave inefficiently with regard to revenue. This means that companies that are efficient in minimizing inputs (cost efficient) tend to be inefficient in maximizing outputs.

Because the scientific attention to the efficiency of IWTs is limited, the literature review has been broadened to also include several papers regarding maritime terminal efficiency. On the operational side of maritime terminals, Tongzon (1995) analyzed the determinants of container port and terminal efficiency and performance, and found the following factors: container mix, work practices, crane efficiency, vessel size and cargo exchange. These factors play a much more limited role when analyzing the efficiency of IWTs, except for the crane efficiency due to the much more flexible operation of the IWT. Cullinane et al. (2002, 2006) found that the efficiency of terminals is closely related to their size. For IWTs growth in size is much less a given factor caused by smaller customer bases limiting the growth potential of IWTs. Tongzon (2001) also found that the terminal area is one of the main variables that influences the efficiency of a port. This places the IWT at a disadvantage as these terminals often operate on not optimally configured terminal areas. If a terminal already operates at its ideal level, further improved efficiency can only be achieved by large investments in increased capacity (Kozan, 1997). The same tendency can be observed for IWTs although the area extension is often prohibited and the expansion is more concentrated on more or different handling equipment and additional labor.

When analyzing efficiency of IWTs, it should be borne in mind that certain factors are in control and some are outside the control of the terminal operator. Factors in control of the terminal operator are mostly decisions related to the terminal infrastructure and to terminal operational characteristics. In this respect, the efficiency of a container terminal depends on the efficient design (capacity) and use (operations) of labor, land and equipment. Given the flexibility in the design capacity of IWTs (e.g. large changes in handling equipment possible, large changes in operating hours possible, changes in labor), analyzing the efficiency of the IWT design capacity is needed. In most cases, maritime terminals possess an efficient terminal design and analyzing the efficiency of the terminal design is not needed. However, to IWTs certain suboptimal conditions might apply.

Factors outside the control of the terminal operator could be (Wiegmans et al., 2004):

1. Network productivity: relates to the size and load factor of vessels, the arrival pattern of vessels, and the number of containers exchanged per call. Although terminal operators are increasingly involved in inland waterway transport and information technology projects both resulting in more accurate information on container flows and thus possibly decreasing this type of inefficiency.
2. Actor productivity relates to subjects such as exporters who provide containers according to vessel schedules. If containers are late (from the exporter) this might cause the terminal operator to wait for the container to arrive at the terminal and tranship it onto the waiting inland waterway vessel. An alternative might be to reschedule it for a next inland waterway vessel which also influences actor productivity.