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Abstract

Purpose – The purpose of this paper is to focus on answering the following research question: "How efficient are deep-sea ports in the Hamburg-Le Havre (HLH) range compared with each other?"

Design/methodology/approach – Input-oriented (and output-oriented) Data Envelopment Analysis (DEA) results demonstrate that the deep-sea port of Vlissingen is perfectly efficient and also that the port of Amsterdam is quite efficient. These DEA results are underligned by the single-point benchmarking results.

Findings – The Dutch deep-sea ports are the most efficient ports in the HLH range. Finally, relatively smaller deep-sea ports (with a market share of about 5 percent, such as Amsterdam, Vlissingen, and Zeebrugge) are relatively more efficient than larger deep-sea container ports (such as Antwerp, Hamburg, and Rotterdam). It can be observed that especially in these larger ports, the container sector is (very) important as compared with the smaller ports. Furthermore, Dutch ports are relatively more efficient and receive the lowest subsidies, suggesting efficiency improvement opportunities for the Belgium, German, and French ports.

Originality/value – The originality of the paper is in its focus on all deep-sea ports in the HLH range (and not on container ports only) and in the combination of methods (DEA and single-point benchmarking).

Keywords Competitiveness, Industrial performance, Data Envelopment Analysis, Logistics, Corporate strategy

Paper type Research paper

1. Introduction

In recent years, deep-sea ports in the Hamburg-Le Havre (HLH) range have changed from public utilities that focus on transport activities to companies that also focus on more advanced commercial activities (such as value-added logistics and industries) and profits. These changes have been caused by port privatizations, rapid growth in freight volume, congestion in and around ports, possible development of global port groups, and port market deregulation efforts by the European Commission. These developments resulted in increased competition between deep-sea ports in the HLH range and this typically results in improved efficiency and altered financial connections between government(s) and the deregulated company. As a result of increased demand for accountability, port benchmarking to assess the results of deregulation and analyze competition has received greater attention. Port performance is increasingly important, as deep-sea container carriers and container terminal operators are becoming larger and more integrated (Soppe *et al.*, 2009). This means that efficiency of existing ports will also become more important, and mergers and port acquisitions (by other ports or

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by deep-sea container carriers) might be expected as well. Gonzalez and Trujillo (2009) researched the empirical evidence of efficiency measurements in the port industry. Their analysis revealed that data collection must be improved and, that it is necessary to be clear about the port activities when measuring efficiency. In our analysis, we focus on efficiency of deep-sea ports (not only container ports) in the HLH range. In this paper, we pose the question of how efficient deep-sea ports in the HLH range are compared with one another? To answer this question, publicly available data were used because private data sources are confidential. The paper consists of four additional sections. First, we describe deep-sea ports in the HLH range. Second, we review performance theory benchmarking, and Data Envelopment Analysis (DEA). Third, we analyze the performance (i.e. efficiency) of deep-sea ports in the HLH range. We close the paper with a number of relevant conclusions.

2. Deep-sea ports in western Europe

2.1 Deep-sea ports in the –HLH range

The major deep-sea ports located in the north of the western European continent are known as the HLH range (see Figure 1 and Table I).

Source: Drawn by Itziar Lasa-Epelde

Figure 1. The Hamburg-Le Havre range

Table I. Market shares and tons handled by deep-sea ports in the HLH range (2007)

Port	Tons (million)	Market share (%)
Amsterdam	65.4	5.9
Antwerp	182.9	16.6
Bremen	69.2	6.3
Dunkirk	57.1	5.2
Ghent	25.1	2.3
Hamburg	140.4	12.8
Le Havre	78.9	7.2
Rotterdam	407.0	37.0
Vlissingen	33.0	3.0
Wilhelmshaven	0.0	0.0
Zeebrugge	42.1	3.8
Total	1,101.1	100

In the HLH range, competition for cargo between ports is fierce. Competition is further intensified by globalization of production and consumption, which stimulates economic growth and trade. Important factors that determine competition between ports are availability of hinterland connections, reasonable tariffs, and proximity of consumers (Wiegmans *et al.*, 2008). Port competition can occur between (Verhoef, 1981; Meersman and van de Voorde, 1994; Robinson, 2002): port undertakings; ports; port clusters; port ranges; routes or trades; and chains. In this paper, we focus on competition between port undertakings.

The most important ports in the HLH range are (in alphabetical order) Amsterdam, Antwerp, Bremen, Dunkirk, Ghent, Hamburg, Le-Havre, Rotterdam, Vlissingen, Wilhelmshaven, and Zeebrugge. Important sectors in the port of Amsterdam are: energy, food, the cruise sector, the building sector, general cargo, and containers; however, the size of the container sector is relatively limited. The Amsterdam Container Terminal, formerly known as the Ceres terminal, closed in 2012 but had a capacity of 1 million TEUs and a capacity extension option of approximately 2 million TEUs. The mineral oil and container sectors in the port of Antwerp are most important. Antwerp has increased its container handling capacity considerably, to 12 million TEUs, and if the Deurganck Dock is fully operational the total container terminal throughput capacity will equal 15.5 million TEUs. In the port of Bremen, containers are the most important sector. The Eurogate container terminal in Bremen has a capacity of 6 million TEUs and there are no plans for further development of container handling capacity. Important sectors for the port of Dunkirk are ores and scrap, Ro-Ro, and coal. The transshipment of containers is limited but growing in this port. The port of Ghent can be characterized by the steel, automotive, foodstuffs, paper, energy and chemical sectors. Important sectors for the port of Hamburg are containers and, to a smaller extent, ores and scrap. In Hamburg, four deep-sea container terminals operate with a combined capacity of approximately 9.4 million TEUs. Space for further extension is limited and the maximum future capacity for Hamburg is estimated at approximately 13.5 million TEUs. The current container handling capacity of the port of Le-Havre amounts to approximately 3 million TEUs. An extension is under way that will bring the capacity, in phases, up to 6.3 million TEUs. The port of Rotterdam is one of the world's largest ports and oil, containers, ores and scrap, and chemicals are important sectors in this port. In Rotterdam, extensions of container handling capacity add up to a capacity increase from 8.6 million TEUs in 2004 to 16 million TEUs in 2014. Furthermore, an extension of the port area Maasvlakte 2 is currently being built, that will bring the container capacity up to 32 million TEUs. In the port of Vlissingen, the major types of goods that are transshipped include petroleum products, solid mineral fuels (i.e. coal), and transport equipment (i.e. cars). The total containerized cargo volume handled in 2007 amounted to an estimated 70,000 TEUs. Vlissingen recorded a total throughput of 19 million tons in 2007 and, in the HLH-port range, its market share was about 2 percent. Currently, three development plans to construct container terminals in Vlissingen, with a combined initial capacity of approximately 5.5 million TEUs, are underway (Wiegmans *et al.*, 2008). Important sectors for the port of Wilhelmshaven are crude oil and mineral oil products. In Wilhelmshaven, a new container port is planned (JadeWeser port). The terminal, with a capacity of 2.7 million TEUs, has been operational since 2012. Important sectors for the port of Zeebrugge are containers, Ro-Ro, and mineral oil products. The container handling capacity of Zeebrugge could be extended to approximately 3 million TEUs by 2020.

3. Efficiency: benchmarking and DEA performance techniques

Companies use different performance management techniques to obtain insight into the quality, cost-effectiveness, and profitability of their operations. According to Kim and Marlow (2001), "efficiency refers to how well the resources expended are used." Ockwell (2001) suggests that efficiency is either a minimizer or a maximizer concept. Minimizing would then be applied to inputs (i.e. costs), whereas maximizing would be applied to outputs (i.e. sales). This definition is particularly suitable for the aim of our research, which analyzes the performance of deep-sea ports in terms of efficiency of the inputs (variables = employees, depreciation, and material/service costs) and outputs (variables = ships, throughput (tons), sales, and profits). Next to the container port sector, also the rail freight sector and airports have already been studied quite well in terms of efficiency. For example, Cantos and Maudos (2001) showed that rail freight companies that are more efficient in costs behave inefficiently with regard to revenue. Their conclusions are in line with Ockwell's (2001) efficiency concept. Wilson (1997) found that due to deregulation the US railroad industry had impressive cost savings and large productivity gains. Also among port authorities a privatization tendency can be observed. Research by Asmild *et al.* (2009) revealed that the reform initiatives in the railway systems in Europe have had a positive impact on efficiency of both material and staff costs (i.e. technical efficiency has improved). In this paper, the conceptual framework for the efficiency analysis (both inputs and outputs) of the deep-sea ports consists of two elements, namely: single-measure benchmarking; and DEA.

3.1 History and characteristics of benchmarking: literature review

In order to determine the level of efficiency, a benchmark is needed. Sinclair (1992) defines a benchmark as, "something whose quality, quantity, or capability is known and which can therefore be used as a standard with which other things can be compared." To be beneficial to management, the benchmark concepts must be translated into meaningful indicators (Martland, 1992). Benchmarking determines who is the best, who sets the standard, and what that standard is. Essential elements of benchmarking are that it is continuous, systematic, implementable, and best practice (Sheffield Hallam University, 2003). Benchmarking has advantages such as opportunities for improvement, but also disadvantages such as loss of sensitive data to competitors or the costly failure of implementing someone else's best practice effectively. Furthermore, the benchmarking process itself carries considerable costs associated with data collection and analysis. The aim of benchmarking is to search outside the organization concerned, in this case a deep-sea port authority, for information that will offer a competitive advantage and that can subsequently be incorporated into the organization's own repertoire of best practices (Francis *et al.*, 2002).

Historically, benchmarking has developed in different stages (Watson, 1998): benchmarking of products; benchmarking of competitors, third, benchmarking of processes; strategic benchmarking; and global benchmarking. Benchmarking of products focusses on the analysis of competitor's products. Benchmarking of competitors builds on the analysis of products but also adds competitor processes to the benchmarking process. Process benchmarking focusses on analysis of processes of companies in different sectors. This enables in-depth sharing of information. Quality is often the focus and the process consists of different stages from inspection of final products, prevention of mistakes, and partnership of business units, with customer satisfaction being the overall focus. Strategic benchmarking is a systematic process that evaluates alternatives in order to implement strategies and improve performance by adapting successful external strategies. Global benchmarking deals with international differences in doing business, culture, and business processes. Often this type of benchmarking concerns unique country and/or government services that can only be found at the country level. As an alternative to stages, benchmarking can be classified on three levels (Shang and Marlow, 2005): internal benchmarking; competitive benchmarking; and non-restricted/cooperative/generic/functional benchmarking. Internal benchmarking focusses on the performance of internal business units involved in similar operations. Two advantages are information availability and ease of implementing improvements; however, a disadvantage is the limited potential for a significant breakthrough. External (or competitive) benchmarking has to do with comparing performance to industry standards or to those of competitors. Non-restricted/cooperative/generic/functional benchmarking compares the organization with other companies in different industries on particular aspects of selected business operations. Functional benchmarking focusses on a certain function within a company (e.g. the purchase of inputs) compared with its competitors in a specific sector. A different, additional perspective on efficiency of port authorities comes from DEA.

3.2 Deep-sea port benchmarking by using DEA: literature review

One of the important ways to benchmark efficiency is by using DEA. Generally, the models differ in their "orientation" (output-orientation vs input-orientation) and "returns to scale" (constant, variable, increasing, decreasing). DEA is an extreme point method that compares each producer with only the "best" producers. A fundamental assumption in such a method is that, if a given company is capable of producing X (output) with Y (inputs), then other companies should be able to produce exactly the same. For the deep-sea ports in this analysis, the difference in operations (containers and/or bulk) is very important. This is why it is also necessary to include the "slacks" for each input and output factor in order to see where differences occur and how these differences, compared with the "best" virtual producer, might be explained. The heart of DEA analysis for each real producer lies in finding the "best" virtual producer. This "best" virtual producer is often the cost leader. However, not all port authorities have the ambition to be a cost leader. DEA assumes that outputs can be fully explained from the inputs (i.e. as well as the potential inefficiency and there are no random fluctuations in the output). Any deviation from the efficiency frontier is stated as inefficient. The distinguishing factor of DEA is the absence of assumptions regarding the underlying functional form relating the independent and dependent variables (Charnes *et al.*, 1994). Some limitations and problems may occur when using DEA (Coelli *et al.*, 1999). Specifically, the shape and position of the frontier may be influenced by measurement error and other noise. Outliers may also influence the results and the exclusion of an important input or output may result in biased results. The efficiency scores obtained are only relative to the best firm(s) in the sample. When one has only a few observations and many inputs and/or outputs, many of the firms will appear on the frontier. Treating inputs and outputs as homogeneous when they are actually heterogeneous may bias the results. Not accounting for environmental differences may give misleading indications of relative managerial competence. Finally, standard DEA does not account for either multi-period optimization or risk in management decision making. DEA is useful to analyze port efficiency because the calculations are non-parametric, it can handle multiple outputs, and it does not require explicit distinction between inputs and outputs. Furthermore, DEA does not require the development of a standard, against which efficiency is benchmarked. In addition, ports produce different outputs, which makes DEA a suitable technique to use for measuring efficiency. The output- and input-oriented models will estimate the same frontier, and therefore, identify the same set of deep-sea ports as being efficient. It is only the efficiency measures associated with inefficient deep-sea ports that might differ between the two methods.

In the scientific literature, deep-sea container port and container terminal performance – as compared to the "general" ports including container ports that we analyze in this paper from the port authority perspective – have been studied extensively. Although the focus in this paper is on the position of port authorities of ports in general (including container ports), it is important to discuss the most influential and recent scientific papers in container port efficiency. Wang und Cullinane conclude from their analysis of 104 European container terminals that terminals in the British Isles and in western Europe are the most efficient. For our analysis this means that the relatively more efficient container ports are included. Turner *et al.* (2004) found that scale economies exist at the container terminal level in container ports. A more recent finding is from Schøyen and Odeck (2013). In their analysis of Norwegian container ports they find that the ports need to increase their scale due to the container port operations performing under increasing returns to scale. In our analysis this suggests that larger container ports are more efficient than smaller ones. Tongzon and Heng (2005) and Wanke (2013) show that private sector involvement in the port industry can, to some extent, improve container port and terminal operational efficiency. Haralambides *et al.* (2001) conclude that a level playing field among competing "commercial" seaports is needed. Cullinane and Wang (2010) implemented panel data approaches in order to be able to implement medium- and long-term efficiency analysis. They found that efficiency levels of container ports vary (sometimes drastically) over time. Research by Figueiredo de Oliveira and Cariou (2011) revealed that also for iron ore and coal ports, scale efficiency is a main source of inefficiency. In this paper, we aim to combine these findings from the container port industry with ports in general in order to analyze the internal port authority structures relatively to measures characterizing port operations efficiency by comparing benchmarking and DEA results. In the next section, the port performance is benchmarked on a factor-by-factor basis (see Tables III and IV), and then, input and output DEA is performed and "slacks" are presented and explained.

4. Deep-sea port performance analysis: benchmarking and DEA

4.1 Definition of variables

The data we were able to collect per port authority are tons, ships, employees, hectares, quay length, depreciation, personnel costs, material costs, sales, profit, rent, and port dues (see Table II). Port authorities' performance is depending on the efficient use of labor, land, and equipment. Therefore, inputs for port authorities are employees, depreciation of land and equipment, and material costs linked to equipment and the authority. Employees provide all port services and ensure that ships are handled well by the port authority. Depreciation and material costs indicate the resources needed to produce the port authority outputs (throughput, ships, sales, and profits). Throughput (tons handled in the port) and ships are important outputs for a port area because they indicate the total port authority service production. Furthermore, two important financial output indicators for port authorities are sales and profits. See Table II for an overview of inputs and outputs used in the DEA model.

4.2 Data sources

The most common method we used to gather data were by reviewing annual reports of the deep-sea ports concerned (Port Authorities, 2003-2009). European experts were also contacted in order to determine whether they could provide additional data or suggest sources. Finally, the port authorities themselves were contacted but, as the results show, this was not successful for all ports. In the data collection set-up and execution the goal was to get the database over a period of time (2003-2007) in order to capture the efficiency trends over time. However, due to limited data availability the final application had to be limited to a single period model.

4.3 Benchmarking the HLH range deep-sea ports through single-measures

For performance benchmarking of the deep-sea ports in the HLH range, we first used the single measure analysis method. When performing relative efficiency analysis, it is important to choose a relevant benchmark and then find the most similar company in terms of efficiency (Gonzalez and Alvarez, 2001). For the benchmarking analysis, we chose to develop as many options for benchmarking as possible given the available data (see also Tables III and IV). This is necessary because one single measure does not suffice for the performance benchmarking, partly due to the selection of "best practice" (Zhu, 2003). The single measure ignores interactions, trade-offs, and substitutions among various performance benchmarks, but this is partly dealt with in the DEA analysis. According to Tortosa-Austina (2002), in the context of major changes primarily due to deregulation, the estimation of efficiency depends heavily on output specification. So far, deregulation efforts in the deep-sea port sector in Europe have been limited. In Table III, the focus is on depreciation costs, personnel costs, and material and service costs. The depreciation costs show that the port of Amsterdam has the highest depreciation cost per ton, ship, and per employee. The main cause of these high depreciation costs are the high investments in the Ceres container terminal that are now fully embedded in the exploitation of the port undertaking. Depreciation cost per ton and per ship are comparable in Antwerp and Rotterdam. Per employee these costs are considerably lower, caused by a relatively higher number of employees. Overall, lowest depreciation costs are found in Bremen which is attributable to close ties between the port authority and its government owners. Overall, the variance in depreciation costs per ton, ship, and employee appears to be considerable.

Personnel costs show a mixed picture. The best practice in terms of lowest costs is clearly the Port of Vlissingen which is very efficient in terms of employees. The highest personnel costs per ton, ship, and employee vary between the largest container ports of Hamburg, Antwerp, and Rotterdam, respectively. The personnel cost per employee depict that the larger the port the higher the pay. Material and service costs are the

DEA variable	Number of cases	Minimum	Maximum	Mean	In/output
Employees	8	66	1,638	405	Input
Depreciation (million euros)	7	0.2	87.0	28.1	Input
Material costs (million euros)	6	0	133	2.5	Input
Tons (million)	10	25.1	407.0	65.4	Output
Ships (no.)	9	3,172	40,000	9,449	Output
Sales (million euros)	8	24.2	488.0	77.6	Output
Profit (million euros)	8	0.1	114	12.6	Output

Table II.
DEA variable descriptive statistics

Table III. Overview of input performance per port for 2007 (in €)

Port	Depreciation/ton	Depreciation/ship	Depreciation/employee	Personnel costs/ton	Personnel costs/ship	Personnel costs/employee	Material and service costs/ton	Material and service costs/ship	Material and service costs/employee
Amsterdam	0.882	10,240	181,447	0.33	3,826	67,800	0	0	0
Antwerp	0.209	2,294	23,396	0.53	5,846	59,621	0.25	2,731	27,856
Bremen	0.003	20	494	0.29	2,026	50,123	0.04	250	6,173
Dunkirk	0.000	0	0	0	0	0	0	0	0
Ghent	0.506	4,005	80,380	0.44	3,469	69,620	0.15	1,198	24,051
Hamburg	0.200	703	17,155	0.63	2,208	53,907	0.70	2,463	60,134
Le Havre	0.000	0	0	0	0	0	0	0	0
Rotterdam	0.214	2,345	73,356	0.21	2,345	73,356	0.33	3,585	112,142
Vlissingen	0.176	883	87,879	0.08	396	39,394	0.13	639	63,636
Wilhelmshaven	0.000	0	0	0	0	0	0	0	0
Zeebrugge	0.000	0	0	0	0	0	0	0	0

Table IV.
Overview of output performance per port for 2007 (in €)

Port	Sales/ ton	Sales/ ship	Sales/ employee	Profit/ ton	Profit/ ship	Profit/ employee	Rent/ ton	Rent/ ship	Rent/ employee	Port dues/ tone	Port dues/ ship	Port dues/ employee
Amsterdam	2.40	27,862	493,711	0.72	8,305.24	147,170	0.97	11,251	199,371	0.55	6,424	113,836
Antwerp	1.65	18,106	184,667	0.54	5,941.54	60,599	0.55	6,052	61,723	0.47	5,114	52,156
Bremen	0.35	2,416	59,753	0	9.98	247	0	0	0	0	0	0
Dunkirk	1.36	10,977	0	0	0	0	0.39	3,190	0	0.68	5,492	0
Ghent	1.14	9,051	181,646	0.27	2,176	43,671	0.48	3,816	76,582	0.50	3,942	79,114
Hamburg	2.73	9,568	233,639	0	2.50	61	0	0	0	0	0	0
Le Havre	0	0	0	0	0	0	0	0	0	0	0	0
Rotterdam	1.20	13,155	411,467	0.28	3,073.02	96,121	0.48	5,283	165,261	0.68	7,494	234,401
Vlissingen	0.97	4,884	486,364	0.38	1,917.22	190,909	0.41	2,054	204,545	0.41	2,054	204,545
Wilhelmshaven	0	0	0	0	0	0	0	0	0	0	0	0
Zeebrugge	0	0	0	0.35	1,545.14	99,320	0	0	0	0	0	0

lowest in Bremen, although these data must be treated with care due to close ties with the government owners. Also the port of Vlissingen scores quite well in terms of material and service costs per ton and per ship. The highest costs per ship are found in Rotterdam and Hamburg. Overall, it can be concluded that the port of Amsterdam has high depreciation costs due to the investment in the container terminal and the port of Vlissingen performs well in terms of personnel costs due to its efficient operations.

In Table IV, the focus is on benchmarking the output performance (sales, profits, rents, and port dues) of the deep-sea ports in the HLH range. In sales, a good overall performance can be observed for the port of Amsterdam, whereas the port of Bremen performs the worst in overall deep-sea port sales in the HLH range. The highest sales per ton are found in the port of Hamburg followed by the port of Amsterdam. The lowest sales per ton are found in Bremen followed by the port of Vlissingen. In sales per ship, Amsterdam is the top performer followed by Antwerp and Rotterdam. Low sales per ship are found in Bremen and Vlissingen. Sales per employee are high in Amsterdam, Vlissingen, and Rotterdam which signals that the Dutch port are efficient in terms of sales per employee. The lowest sales per employee are found in Bremen. In terms of profits, good overall performances can be found in the ports of Amsterdam (per ton and per ship), and Vlissingen (per employee). The performance of Vlissingen is extremely good, given its good performance on the input variables. Typically, companies perform well on either the input side (minimizer) or the output side (maximizer), but Vlissingen is able to realize efficiency performance in both input and output variables. The lowest profits are found in the ports of Hamburg (per ship and per employee) and Rotterdam (per ton). For rents, good performances can be found in the ports of Amsterdam (per ton and per ship) and in Vlissingen (per employee). The worst performances in rents are found in the port of Dunkirk (per ton), Vlissingen (per ship), and Antwerp (per employee). In terms of port dues, good performances can be found in the ports of Dunkirk (per ton) and Rotterdam (per ton, ship, and employee). Lower performances in port dues are found in the ports of Antwerp (per employee) and Vlissingen (per ton and per ship). This means that Vlissingen delivers good value for money, while at the same time operating efficiently.

Benchmarking of non-financial performance measures is also important. In this respect, throughput, ships, and employees are relevant. The tons handled per ship vary considerably over the ports in the HLH range (see Figure 2). This variable is low in the ports of Hamburg and Zeebrugge. Handled tons per ship are the highest in Rotterdam, Antwerp, and Amsterdam, with an average of more than 10,000 tons per ship. In particular, the low performance of Hamburg and the high performance of Amsterdam should be noted. One would expect higher numbers for the port of Hamburg because of its important position in the deep-sea container trades. However, next to these container trades, large numbers of feeder ships to and from the Baltic area reduce the average number of tons per ship, but highlight its important position as a hub. For Amsterdam, one would expect lower numbers because of its limited involvement in container trade. However, the port of Amsterdam is strong in manufacturing of raw materials brought to the port by sea. These materials are carried by relatively large, deep-sea ships.

The tons handled per employee are high in the ports of Vlissingen and Rotterdam (see Figure 3). Low performance in tons per employee was observed in the ports of Antwerp and Hamburg. This might be caused by a relatively large number of employees as compared with other deep-sea ports (Figure 4).

It could be expected that Antwerp, Hamburg, and Rotterdam would have a good performance in the number of ships per employee due to their scale advantages.

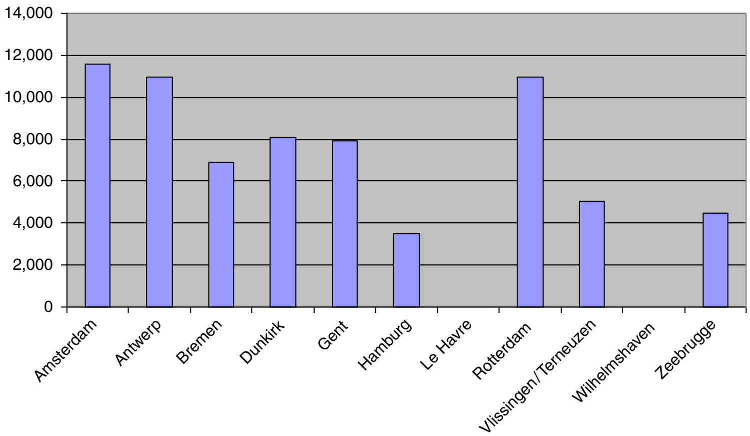

Figure 2.
Tons handled per ship for deep-sea ports in the HLH range in 2007

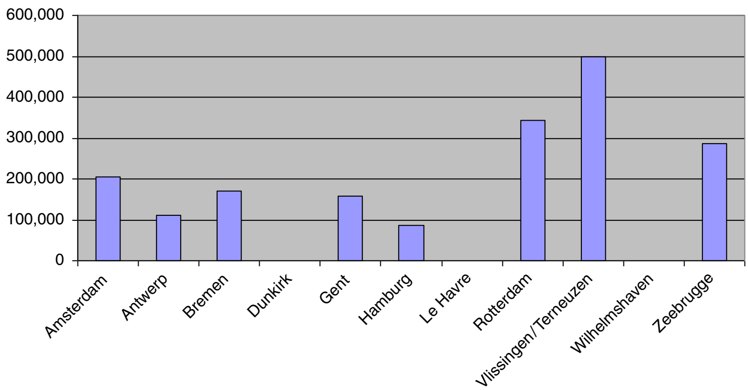

Figure 3.
Tons handled per employee for deep-sea ports in the HLH range in 2007

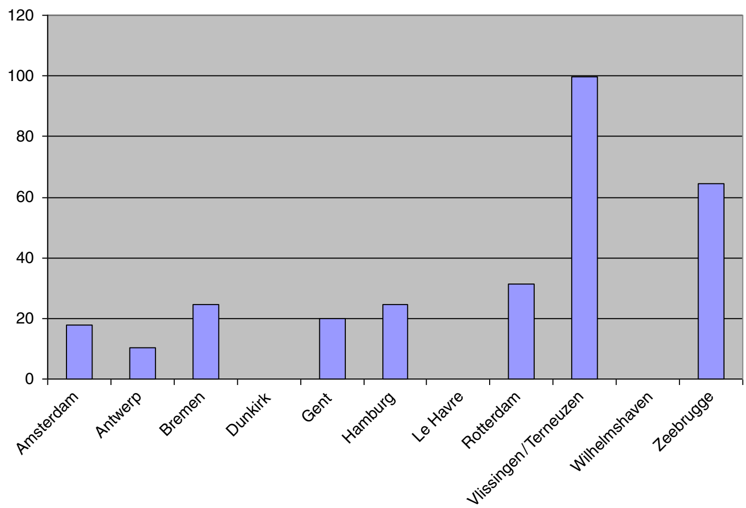

Figure 4.
Ships per employee for deep-sea ports in the HLH range in 2007

However, Vlissingen and Zeebrugge have a large number of ships per employee. The other ports have comparable numbers, but Antwerp is a little lower (about 12 ships per employee) and Rotterdam is a little higher (about 30 ships per employee). The high number in Vlissingen is caused by efficient operations, but the cause of the high number in Zeebrugge is unknown.

4.4 Efficiency of the deep-sea ports in the HLH range: input-oriented DEA

We have chosen to both execute the input and output analysis while for ports in general it is not immediately clear if those ports are efficient in inputs or in outputs. Furthermore, some ports might be efficient in inputs while other ports might be efficient in outputs. Therefore, the analysis of both has been performed. In the tables, we present all ports in the range to give a complete overview, although for the ports of Dunkirk, Le Havre, and Wilhelmshaven the data are missing. In Table V, the DEA results for deep-sea ports in the HLH range are given for the input-oriented analysis. From the DEA results it appears that the deep-sea port of Vlissingen is perfectly efficient and that the port of Amsterdam is also efficient. Zeebrugge and Rotterdam achieve scores of around 50 percent efficiency. For the rest of the deep-sea ports, the efficiency scores are quite disappointing (Antwerp and Ghent) or lacking due to insufficient data (Bremen and Hamburg). Overall, the Dutch deep-sea ports appear to be among the more efficient ports in the HLH range. Furthermore, relatively smaller deep-sea ports, with a market share of about 5 percent, such as Amsterdam, Vlissingen, and Zeebrugge appear to be more efficient than larger deep-sea ports (focussing on containers) such as Antwerp and Rotterdam. Most of the deep-sea ports operate under decreasing returns to scale. Most of these ports have relatively low efficiencies, which suggest that in order to increase efficiency, their input (employees) could be reduced while realizing the same or improved outputs leading to higher efficiency.

In Table VI, the output slacks show a mixed picture. Different ports (Amsterdam, Ghent, and Rotterdam) could – given their input – increase their throughput and number of ships handled to increase their efficiency. The ports of Bremen, Hamburg, and Zeebrugge could increase their sales and throughput. Given the characteristics of these ports this means that under their current conditions they could increase their performance by realizing more throughputs and realize more sales. The port of Vlissingen does not have the ability to become much more efficient; there are some possibilities in increasing throughputs and sales. However, an increase in overall size might open up new opportunities for growth.

Deep-sea ports	Market share (%)	Efficiency	Scale orientation
Port of Amsterdam	5.9	0.77089	Decreasing
Port of Antwerp	6.6	0.31742	Decreasing
Port of Bremen	6.3	0.00129	Decreasing
Port of Dunkirk	5.2	No data	No data
Port of Ghent	2.3	0.22544	Increasing
Port of Hamburg	12.8	0.00032	Decreasing
Port of Le Havre	7.2	No data	No data
Port of Rotterdam	37.0	0.50349	Decreasing
Port of Vlissingen	3.0	1.00000	Constant
Port of Wilhelmshaven	0.0	Not operating	Not operating
Port of Zeebrugge	3.8	0.52025	Decreasing

Table V. DEA results for the HLH deep-sea ports: input-oriented VRS

4.5 Efficiency of the deep-sea ports in the HLH range: output-oriented DEA

From the output-oriented DEA results in Table VII, it shows that the deep-sea ports of Amsterdam and Vlissingen and Zeebrugge are efficient. The ports of Ghent, Antwerp, and Rotterdam have the potential for more outputs, given their characteristics. The deep-sea ports of Hamburg and Bremen are very inefficient in terms of outputs. The ports of Dunkirk, Le Havre, and Wilhelmshaven do not provide sufficient data to be able to analyze their efficiency. Overall, it could be expected that if their efficiency was great, they would be proud of that and more than willing to provide the input and output data and show their excellent performance. However, up to now that is not the case.

From the output-oriented DEA it can be concluded that relatively smaller deep-sea ports (Zeebrugge, Vlissingen, Amsterdam) are the most efficient ports in the HLH range. In general, the deep-sea ports operate under either constant or decreasing returns to scale. The ports with decreasing returns to scale have relatively low efficiencies; this suggests that they should increase their outputs in order to become more efficient. However, given the current financial crisis, this might not be an option and the deep-sea ports might be better off reducing their inputs (Table VIII).

In the output-oriented DEA analysis, slacks are found for the large container ports in the input variable material/service inputs. However, this is not strange given their large investments in ever larger container terminals requiring huge investments. In terms of output variables, no slacks are found for the deep-sea ports of

Table VI. Slacks for DEA results for the HLH deep-sea ports: input-oriented VRS

Deep-sea ports	Sales	Throughput	Profit	Ships
Port of Amsterdam	0.00000	84.97404	0.00000	22,216.40116
Port of Antwerp	0.00000	113.40133	0.00000	39,562.03280
Port of Bremen	85.44489	11.58128	0.00000	0.00000
Port of Dunkirk	No data	No data	No data	No data
Port of Ghent	0.00000	1.08326	0.00000	1,412.20626
Port of Hamburg	56.04253	182.62192	0.00000	0.00000
Port of Le Havre	29.59012	0.00000	0.00000	9,765.41251
Port of Rotterdam	0.00000	36.99888	0.00000	40,363.43297
Port of Vlissingen	0.00000	0.00000	0.00000	0.00000
Port of Wilhelmshaven	No data	No data	No data	No data
Port of Zeebrugge	57.32424	10.95455	0.00000	0.00000

Table VII. DEA results for the HLH deep-sea ports: output-oriented VRS

Deep-sea ports	Market share (%)	Efficiency	Scale orientation
Port of Amsterdam	5.9	1.00000	Constant
Port of Antwerp	16.6	2.04137	Decreasing
Port of Bremen	6.3	404.32935	Decreasing
Port of Dunkirk	5.2	No data	No data
Port of Ghent	2.3	3.40103	Decreasing
Port of Hamburg	12.8	1919.72203	Decreasing
Port of Le Havre	7.2	No data	No data
Port of Rotterdam	37.0	1.82865	Decreasing
Port of Vlissingen	3.0	1.00000	Constant
Port of Wilhelmshaven	0.0	No data	No data
Port of Zeebrugge	3.8	1.00000	Constant

Deep-sea ports	Employees	Depreciation	Material/ service	Sales	Throughput	Profit	Ships
Port of Amsterdam	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Port of Antwerp	0.00000	0.00000	17.86552	0.00000	486.76653	0.00000	123,434.49092
Port of Bremen	0.00000	0.00000	2.35517	34,390.83004	4,652.63848	0.00000	0.00000
Port of Dunkirk	No data	No data	No data	No data	No data	No data	No data
Port of Ghent	0.00000	0.00000	0.00000	0.00000	4.86820	0.00000	3,966.16683
Port of Hamburg	0.00000	0.00000	78.15172	107,072.01676	350,485.08342	0.00000	0.00000
Port of Le Havre	No data	No data	No data	No data	No data	No data	No data
Port of Rotterdam	0.00000	0.00000	70.00000	0.00000	109.31205	0.00000	80,774.05604
Port of Vlissingen	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Port of Wilhelmshaven	No data	No data	No data	No data	No data	No data	No data
Port of Zeebrugge	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Table VIII. Slacks for DEA results HLH deep-sea ports: output-oriented VRS

Amsterdam and Vlissingen. The deep-sea ports of Antwerp, Ghent, and Rotterdam show slacks in throughput and ships. This means that, with their current characteristics, they are able to increase throughput and ships. The deep-sea ports of Bremen and Hamburg could increase their sales and throughput, given their other input and output variables. However, given their characteristics and current market conditions it is more efficient for them to reduce their inputs in order to balance their inputs and outputs and become more efficient.

5. Conclusions and policy implications

In this paper, we focus on answering the research question:

RQ1. How efficient are deep-sea ports in the HLH range compared with one another?

We answer this question using benchmarking and DEA. From the benchmarking analysis, based on the single measure benchmark, it can be concluded that – in term of inputs – the port of Vlissingen possesses quite often the lowest scores in inputs meaning that it is quite efficient in inputs. Inefficient in inputs are the port of Amsterdam (especially depreciation), the port of Antwerp (personnel cost), and the port of Rotterdam (material and service cost). In benchmarking the output performance (sales, profits, rents, and port dues) of the deep-sea ports in the HLH range, we found that the deep-sea port of Amsterdam performs quite well on most single benchmarks. The port of Rotterdam performs very well in port dues, signaling that it is able to charge a relatively high price. Inefficient in output performance is the port of Antwerp, especially indicators related to employees (signaling a too large labor force). The port of Vlissingen also scores low on most output performance indicators. However, when these output indicators are related to employees, the performance is very good. Overall, smaller deep-sea ports, with limited or no container handling, appear to perform better than larger deep-sea ports where containers are an important market segment. From the DEA results, it appears that the deep-sea port of Vlissingen is perfectly efficient and that the port of Amsterdam is quite efficient. The ports of Zeebrugge and Rotterdam achieve scores of around 50 percent efficiency. The remaining deep-sea ports have low efficiency scores compared to Vlissingen, Amsterdam, Zeebrugge, and Rotterdam.

Overall, three main conclusions can be drawn that are new to the literature. First, we conclude that Dutch deep-sea ports appear to be the most efficient ports in the HLH range and they perform significantly better than their Belgian and German competitors. Second, we conclude that relatively smaller deep-sea ports, with a market share of about 5 percent, such as Amsterdam, Vlissingen, and Zeebrugge are more efficient than larger deep-sea container ports such as Antwerp, Hamburg, and Rotterdam. This is clearly the result of a lack of large container handling terminals. Third, a port is either very efficient in inputs (the port of Vlissingen) or very efficient in outputs (the port of Rotterdam). A final remark is about further research. The findings from our paper can be further elaborated upon by including port data for a certain time period. Furthermore, the number of ports in the analysis could be increased as to include other port ranges as well.

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