Deep-sea port performance in the Hamburg-Le Havre range: Explorative benchmarking and Data Envelopment Analysis

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Abstract

In this paper, the focus is on answering the following research question: 'How efficient are deep-sea ports in the Hamburg-Le Havre range compared with each other?' Input-oriented (and output-oriented) DEA results demonstrate that the deep-sea port of Vlissingen is perfectly efficient and also that the port of Amsterdam is quite efficient. Furthermore, 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 per cent, such as Amsterdam, Vlissingen, and Zeebrugge) are relatively more efficient than larger deep-sea container ports (such as Antwerp, Hamburg, and Rotterdam). For European port policy this might suggest that subsidies should be limited to further increase efficiency. A level playing field could contribute to increased efficiency of deep-sea port operations and to lower port subsidies by the governments of Belgium, Germany, and the Netherlands.

KEYWORDS: deep-sea ports, efficiency, benchmarking, DEA

1. Introduction

In recent years, increasingly deep-sea ports in the Hamburg-Le Havre (HLH) range have been changing from being public utilities focusing on operations to businesses focusing also on profits and commercial activities. This has been caused by: port privatizations (plans); the rapid growth in freight volumes; congestion in and around ports; the possible development of global port groups; and port market deregulation efforts. These developments have resulted in increased competition between the deep-sea ports in the HLH range for cargo and container handling. In general, deregulation results in better efficiency and also in changed financial connections between the government(s) and the deregulated company. Therefore, benchmarking is receiving greater attention from the Port Authorities as a result of the increased competition between them. In the scientific literature, deep-sea container port and container terminal performance has been studied, but, as for as we are aware, efficiency (in terms of either minimizing inputs or maximizing outputs) analysis of deep-sea ports in a certain port range has not been undertaken. Turner et al. (2004) find that for container ports, scale economies also exist at the container terminal level. Tongzon and Heng (2005) 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. They approach the subject of port financing and pricing from both the theoretical and the political point of view. This level playing field has still not been achieved, and the results of our analysis again confirm the conclusion of Haralambides et al. (2001), but from the efficiency point of view. Port performance is increasingly important, as the deep-sea container carriers and the container terminal operators are becoming larger and are also integrating (Soppe et al., 2009). This means not only that the efficiency of existing ports will be more important but also that mergers and acquisition of ports by other ports (or maybe even by deep-sea container carriers) might be expected. The competition between port authorities (inter-port competition at port authority level) and their respective efficiencies take centre stage in this article. The challenge is to examine to what extent regulations might influence the performance of deep-sea Port Authorities. Efficiency performance refers to either minimizing the inputs used or maximizing the outputs produced by the deep-sea port companies. The research question posed in this article is: *How efficient are deep-sea ports in the Hamburg-Le Havre range compared with each other?*

To answer this question only publicly available data have been used. First, the article will describe the deep-sea ports in the HLH range. Secondly, performance theory will be described, and benchmarking and Data Envelopment Analysis (DEA) will be briefly described and reviewed. Thirdly, the performance (efficiency) of deep-sea ports in the HLH range will be compared. The article will close with a number of conclusions.

2. Deep-sea ports in Western-Europe

2.1 Deep-sea ports in the Hamburg-Le-Havre range

The major deep-sea ports located in the North of the Western European continent are also known as the Hamburg-Le Havre range. This range already has a long history of economic importance in freight transport, and this will continue for the foreseeable future. For an overview of the main characteristics of the HLH range, see also Figure 1 and Table 1.

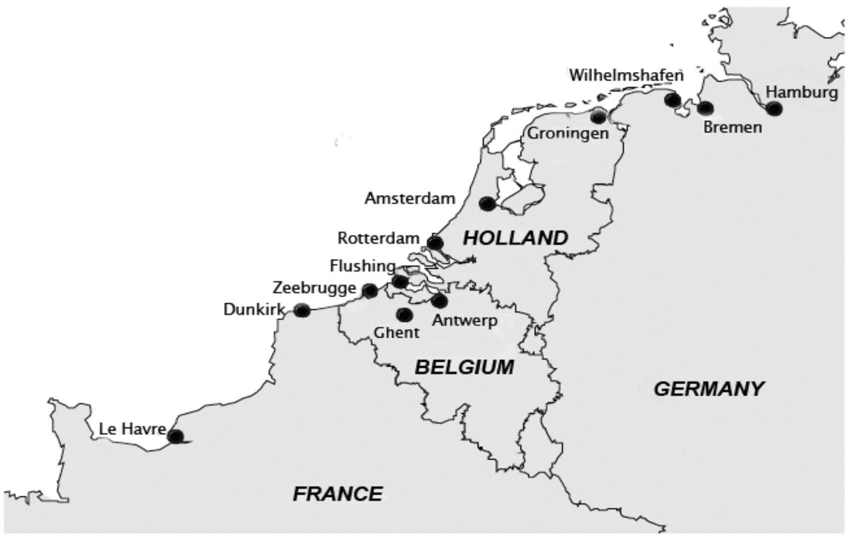

Figure 1. The Hamburg-Le Havre range
Source: Drawn by Itziar Lasa-Epelde.

Table 1. Market shares and tonnes handled by deep-sea ports in the HLH-range (2007)

Port	Tonnes	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	1101.1	100%

Sources: Deep-sea port companies annual reports, 2008.

In the HLH range, competition between the ports for container and bulk freight handling is fierce. Competition between deep-sea ports has further been intensifying as a result of the globalization of production and consumption, which has stimulated economic growth and trade. Important factors that determine competition between the ports are: availability of hinterland connections; reasonable tariffs; and proximity of consumers (Wiegmans et al., 2008). Port competition can occur between (Verhoeff, 1981; Meersman and van de Voorde, 1994; Robinson, 2002): 1) port undertakings; 2) ports; 3) port clusters; 4) port ranges; 5) routes (or trades) ; and 6) chains. 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. Sectors that are important in *the port of Amsterdam* and might contribute to the challenges for the coming years are: energy, food, the cruise sector, the building sector, general cargo, and containers. The container sector is growing in importance, but is still relatively limited. The Ceres terminal has a capacity of 1 million TEUs and an extension of capacity by approximately 2 million TEUs is possible. For *the port of Antwerp* the sectors mineral oil and containers are important. Antwerp has increased its container handling capacity considerably to 12 million TEUs, and, if the Deurganck Dock is entirely operational in 2010, then the total container terminal throughput capacity will amount to 15.5 million TEUs. The most important sector for *the port of Bremen* is containers, and a small volume of ores and scrap is handled. The Eurogate container terminal in Bremen has a capacity of 6 million TEUs. In Bremen, 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 in this port. 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 has been 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 the 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 planned, which will bring the container capacity up to 32 million TEUs. In *the port of Vlissingen*, the major types of goods transshipped are petroleum products, solid mineral fuels (coal) and transport equipment (cars). The total containerized cargo volume handled in 2007 amounted to an estimated 70,000 TEUs. Vlissingen recorded a total throughput of 19 million tonnes in 2007 and in the HLH-port range its market share was about 2 per cent. At the moment, 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, is expected to become operational in 2010. Important sectors for *the port of Zeebrugge* are containers, Ro-Ro, and mineral oil products. In the port of Zeebrugge, current container handling capacity can be extended to approximately 3 million TEUs in 2020.

3. Efficiency: benchmarking and DEA performance techniques

Different performance management techniques are used by companies 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'. According to Ockwell (2001), efficiency is either a minimizer or a maximizer concept. Minimizing would then be applied to inputs (costs), whereas maximizing could be applied to outputs (sales). This definition is particularly suitable for the aim of this research which is to analyze the performance of deep-sea ports in terms of efficiency of inputs (variables are employees, depreciation, and material/service costs) and outputs (variables are ships, throughput (tonnes), sales, and profits). The rail freight sector and airports have already been studied quite well in terms of efficiency. 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 the efficiency concept of Ockwell (2001). Wilson (1997) found for the US railroad industry that – due to deregulation – cost savings were impressive, and productivity gains were large. Research by Asmild et al. (2009) revealed that all the reform initiatives in the railway systems in Europe have had a positive impact on the efficiency of both material and staff costs (the technical efficiency has improved). This might also result from changed regulation in the deep-sea port industry in Europe.

3.1 The characteristics of benchmarking

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). In benchmarking, it is determined who is the very 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 not only advantages (opportunities for improvement) but also disadvantages. It carries risks such as loss of sensitive data to competitors or the costly failure to implement someone else's best practice effectively. Furthermore, the benchmarking process itself might carry considerable costs through data collection and data analysis. The aim of benchmarking is to search outside the organization concerned (in this case a deep-sea port authority) for, and subsequently incorporate best practice into the organizations' own repertoire in order to gain competitive advantage (Francis at al., 2002).

In history, benchmarking has developed in different stages (Watson, 1998): 1) benchmarking of products; 2) benchmarking of competitors; 3) benchmarking of processes; 4) strategic benchmarking; and, 5) global benchmarking. Benchmarking of products focuses on the analysis of the products of competitors. The benchmarking of competitors builds on the analysis of products but also adds the processes of the competitors to the benchmarking process. Process benchmarking focuses on the analysis of the processes of the companies in different sectors. This enables the in-depth sharing of information. Quality is often the focus and the process consists of different stages running from inspection of final products, prevention of mistakes, partnership of business units, to customer satisfaction as the overall focus. Strategic benchmarking is a systematic process to evaluate alternatives, to implement strategies, and to improve the performance by adapting successful external strategies. Global benchmarking deals with the international differences in doing business, culture, and business processes. Often this concerns unique (country and/or government) services that can only be found on the country level. As an alternative to stages, benchmarking can be classified in three levels (Shang and Marlow, 2005): 1) internal benchmarking; 2) competitive benchmarking; and, 3) non-restricted/cooperative/generic/functional benchmarking. Internal benchmarking focuses on the performance of internal business units involved in similar operations. Two advantages are: information availability, and ease of implementing improvements. But a disadvantage is the limited potential for a significant breakthrough. External (or competitive) benchmarking has to do with comparing the performance to industry standards or to that 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 focuses on a certain function within a company (e.g. the purchase of inputs) as compared with its competitors in a certain sector.

3.2 Benchmarking by using DEA

One of the important ways to benchmark efficiency is by using DEA. Since it was first introduced, many different DEA-models have been developed. Generally, the models differ in their 'orientation' (output-orientation versus input-orientation), and 'returns to scale' (constant, variable, increasing, decreasing). DEA evaluates the efficiency of a number of producers. DEA is an extreme point method and 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 produce the same if the companies operate efficiently. For the deep-sea ports in this analysis, the difference in operating characteristics (containers versus 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 as 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 the cost leader. DEA uses a sequence of linear programming problems, in order to create a piecewise linear frontier. DEA assumes that outputs can be fully explained from the inputs (i.e. as well as the (potential) inefficiency, there are no random fluctuations in the output). Any deviation from the efficiency frontier is stated as inefficient. The degree of efficiency of each port is evaluated against this frontier. This means that the efficiency of a port is evaluated by comparing it with the performance of the other deep-sea ports in the HLH-range. The distinguishing factor of DEA is the absence of any assumption about 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). The shape and position of the frontier may be influenced by measurement error and other ‘noise’. Outliers may 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 heterogeneous may bias 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 the explicit distinction between inputs and outputs. Furthermore, DEA does not require the development of a ‘standard’ against which the efficiency is benchmarked. Finally, ports produce different outputs, which makes DEA a suitable technique to use for efficiency measurement. When the objective is to produce maximum output, given the input, an output-oriented model should be used. When the objective is to produce a given level of output with a minimum of inputs, an input-oriented model should be used. 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 next section, first, the port performance is benchmarked on a factor-by-factor basis (see Tables 3 and 4). Next, input and output DEA is performed and ‘slacks’ are presented and explained.

4. Deep-sea port performance analysis

The main method that has been used to gather data is through the annual reports of the deep-sea ports concerned (Port Authorities, 2003-2009). Furthermore, European experts were contacted in order to see if they were able to provide additional data or could suggest sources. Finally, the Port Authorities themselves were contacted, but, as the results show, this was not successful for all ports. The data that have been collected are tonnes, ships, employees, hectares, quay length, depreciation, personnel costs, material costs, sales, profit, rent, and port dues. Not all variables have been used because of limited data availability (See Table 2).

Table 2. DEA variable descriptive statistics

DEA Variable	Number of cases	Minimum	Maximum	Mean
Tonnes	10	25.1	407.0	65.4
Ships	9	3172	40000	9449
Employees	8	66	1638	405
Depreciation	7	0.2	87.0	28.1
Material costs	6	0	133	2.5
Sales	8	24.2	488.0	77.6
Profit	8	0.1	114	12.6

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

For the performance benchmarking of the deep-sea ports in the HLH-range, we use 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 this analysis, we have chosen to develop as many options for benchmarking as possible, given the available data (see also Tables 3 and 4). This is necessary because one single measure can not suffice for the performance benchmarking as it only partly selects ‘best practice’ (Zhu, 2003). The single measure ignores any interactions, trade-offs, and substitutions among various performance benchmarks, but this is 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 the output specification. So far, deregulation efforts in the deep-sea port sector in Europe have been limited. In the HLH-range, the competition between the deep-sea ports is raking place within given boundaries. But if several deep-sea ports operate on the ‘maximum subsidy’ boundary (German, Belgian, and French) and others on the ‘minimum subsidy’ boundary (the Netherlands), then port policy is implemented correctly, but competition is still unfair.

In Table 3, the focus is on depreciation costs, personnel costs, and material and service costs. The *depreciation cost* show that the port of Amsterdam has the highest depreciation cost per tonne, ship, and per employee. One of the causes of these high depreciation costs might be the high investments in the Ceres container terminal that are now fully embedded in the exploitation of the port company. The lowest depreciation costs are found in Bremen. However, this might be attributed to the close ties between the Port Authority and its (government) owners. The variance in depreciation costs per tonne, ship, and employee appears to be considerable. The cost structure of the ports of Antwerp and Rotterdam is more or less the same for depreciation, although per employee the difference is considerable due to the higher number of employees in the port of Antwerp.

Table 3. Overview of input performance per port for 2007

Port	Depreciation/ Tonne	Depreciation/ ship	Depreciation/ employee	Personnel costs/tonne	Personnel costs/ship	Personnel costs/employee	Material & service costs/tonne	Material & service costs/ship	Material & service costs/employee
Amsterdam	0.882	10240	181447	0.33	3826	67800	0	0	0
Antwerp	0.209	2294	23396	0.53	5846	59621	0.25	2731	27856
Bremen	0.003	20	494	0.29	2026	50123	0.04	250	6173
Dunkirk	0.000	0	0	0	0	0	0	0	0
Ghent	0.000	0	0	0.00	0	0	0	0	0
Hamburg	0.200	703	17155	0.63	2208	53907	0.70	2463	60134
Le Havre	0.000	0	0	0	0	0	0	0	0
Rotterdam	0.214	2345	73356	0.21	2345	73356	0.33	3585	112142
Vlissingen	0.176	883	87879	0.08	396	39394	0.13	639	63636
Wilhelmshaven	0.000	0	0	0	0	0	0	0	0
Zeebrugge	0.000	0	0	0	0	0	0	0	0

Sources: Annual reports, 2008.

Table 4. Overview of output performance per port for 2007

Port	sales/tonne	sales/ship	sales/ employee	profit/ tonne	profit/ ship	profit/ employee	rent/tonne	rent/ship	rent/employee	Port dues/ tonne	Port dues/ ship	Port dues /employee
Amsterdam	2.40	27862	493711	0.72	8305.24	147170	0.97	11251	199371	0.55	6424	113836
Antwerp	1.65	18106	184667	0.54	5941.54	60599	0.55	6052	61723	0.47	5114	52156
Bremen	0.35	2416	59753	0	9.98	247	0	0	0	0	0	0
Dunkirk	1.36	10977	0	0	0	0	0.39	3190	0	0.68	5492	0
Ghent	0	0	0	0	0	0	0	0	0	0	0	0
Hamburg	2.73	9568	233639	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	13155	411467	0.28	3073.02	96121	0.48	5283	165261	0.68	7494	234401
Vlissingen	0.97	4884	486364	0.38	1917.22	190909	0.41	2054	204545	0.41	2054	204545
Wilhelmshaven	0	0	0	0	0	0	0	0	0	0	0	0
Zeebrugge	0	0	0	0.35	1545.14	99320	0	0	0	0	0	0

Sources: Annual reports, 2008.

The *personnel cost*s show a mixed picture. The best practice in terms of lowest costs is clearly the Port of Vlissingen. The highest personnel cost per tonne, ship, and employee vary between the (largest container) ports of Hamburg, Antwerp, and Rotterdam, respectively. The *material and service costs* are the lowest in Bremen, although these data must be treated with care due to the ties with the government owners. The highest costs are found in Rotterdam and Hamburg. Overall, it can be concluded that the port of Amsterdam has high depreciation costs, and the port of Vlissingen performs very well in terms of personnel costs.

In Table 4, the focus is on benchmarking the output performance (sales, profits, rents, and port dues) of the deep-sea ports in the HLH-range. For the *sales* a good performance can be observed for the port of Amsterdam, whereas the port of Bremen performs less well in overall deep-sea port sales in the HLH-range. The highest sales per tonne are found in the port of Hamburg. In terms of *profits*, good performances can be found in the ports of Amsterdam (per tonne and per ship) and Vlissingen (per employee). The performance of Vlissingen is extremely good, given its good performance on the input variables. Usually companies perform well on either the input side (minimizer) or output side (maximizer). The lowest profits are found in the ports of Hamburg (per ship and per employee) and Rotterdam (per tonne). For *rents*, good performances can be found in the ports of Amsterdam (per tonne and per ship) and in Vlissingen (per employee). The worst performances in rents are found in the port of Dunkirk (per tonne), Vlissingen (per ship), and Antwerp (per employee). In terms of *port dues*, good performances can be found in the ports of Dunkirk (per tonne) and Rotterdam (per tonne, ship, and employee). Less good performances in port dues are found in the ports of Antwerp (per employee) and Vlissingen (per tonne and per ship). For the port of Vlissingen this means that this port delivers good value for money, while at the same time operating very efficiently.

Next, benchmarking of the non-financial performance measures is important. In this respect, throughput, ships, and employees are relevant.

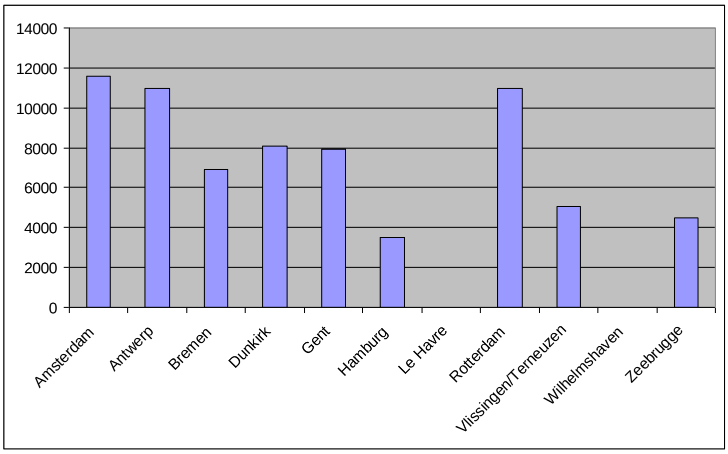

Figure 2. Tonnes handled per ship for deep-sea ports in the HLH-range for 2007

The handled tonnes per ship vary considerably over the ports in the HLH-range (see Figure 2). The variable is low in the ports of Hamburg and Zeebrugge. The handled tonnes per ship are the highest in Rotterdam, Antwerp and Amsterdam, with an average of more than 10,000 tonnes 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 to its important position in the deep-sea container trade. For Amsterdam, one would expect lower numbers because of its limited involvement in container trade. However, the port of Amsterdam is strong in the manufacturing of raw materials brought to the port by sea (as mentioned earlier in the paper). These materials are carried by relatively large deep-sea ships.

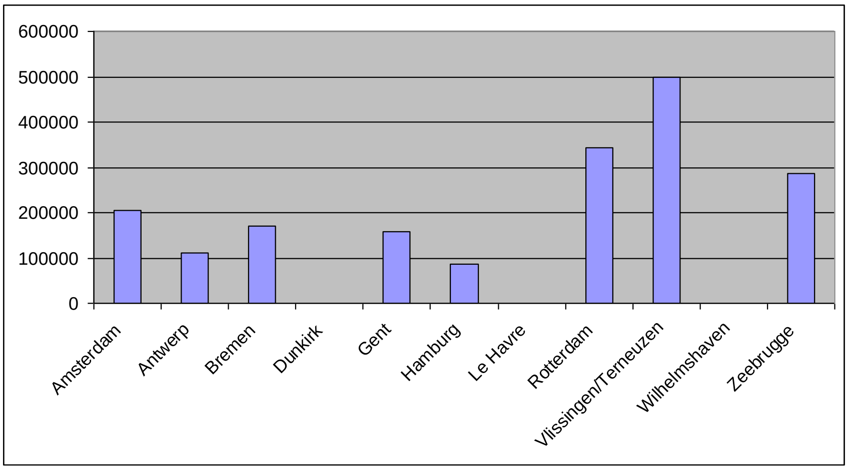

Figure 3. Tonnes handled per employee for deep-sea ports in the HLH-range for 2007

The handled tonnes per employee are high in the ports of Vlissingen and Rotterdam (see Figure 3). Low performance in tonnes per employee can be 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.

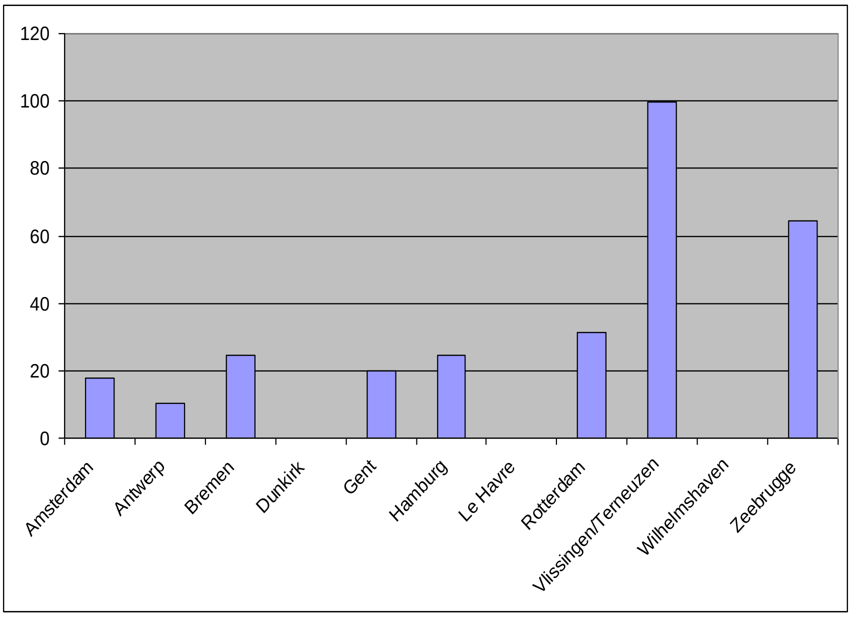

Figure 4. Ships per employee for deep-sea ports in the HLH-range for 2007

The ports of Vlissingen and Zeebrugge have a large number of ships per employee. The other ports have more or less comparable numbers, but Antwerp is a little lower with about 12 ships per employee, and Rotterdam a little higher with about 30 ships per employee. The high number in Vlissingen follows from its efficient operations, but the cause of the high number in Zeebrugge is unknown.

4.2 Efficiency of the deep-sea-ports in the HLH-range: Input oriented DEA

In Table 5, the DEA results for the 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 also the port of Amsterdam is quite efficient. The ports of Zeebrugge and Rotterdam achieve scores of around 50 per cent efficiency. For the rest of the deep-sea ports, the efficiency scores are quite disappointing (and, for some, the scores can not be calculated). Overall, it can be concluded that the Dutch deep-sea ports are among the most efficient ports in the HLH-range. Furthermore, it could also be concluded that relatively smaller deep-sea ports (with a market share of about 5 per cent, such as Amsterdam, Vlissingen, and Zeebrugge) are relatively more efficient than larger deep-sea ports (such as Antwerp, Hamburg, 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 their efficiency, their input (employees) should be reduced while realizing the same or improved outputs.

Table 5. DEA results for the HLH deep-sea ports: Input-Oriented CRS

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%	0.00000	Constant
Port of Ghent	2.3%	0.22544	Increasing
Port of Hamburg	12.8%	0.00032	Decreasing
Port of Le Havre	7.2%	0.00000	Constant
Port of Rotterdam	37.0%	0.50349	Decreasing
Port of Vlissingen	3.0%	1.00000	Constant
Port of Wilhelmshaven	0.0%	0.00000	Increasing
Port of Zeebrugge	3.8%	0.52025	Decreasing

In Table 6, 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. For the port of Vlissingen there are no opportunities to become more efficient, just an increase in size might open up new opportunities for growth.

Table 6 Slacks for DEA results for the HLH deep-sea ports: Input-Oriented CRS

Deep-sea ports	**Sales**	**Throughput**	**Profit**	**Ships**
Port of Amsterdam	0.00000	84.97404	0.00000	22216.40116
Port of Antwerp	0.00000	113.40133	0.00000	39562.03280
Port of Bremen	85.44489	11.58128	0.00000	0.00000
Port of Dunkirk	0.00000	0.00000	0.00000	0.00000
Port of Ghent	0.00000	1.08326	0.00000	1412.20626
Port of Hamburg	56.04253	182.62192	0.00000	0.00000
Port of Le Havre	29.59012	0.00000	0.00000	9765.41251
Port of Rotterdam	0.00000	36.99888	0.00000	40363.43297
Port of Vlissingen	0.00000	0.00000	0.00000	0.00000
Port of Wilhelmshaven	0.00000	0.00000	0.00000	0.00000
Port of Zeebrugge	57.32424	10.95455	0.00000	0.00000

4.3 Efficiency of the deep-sea-ports in the HLH-range: Output-oriented DEA

From the output-oriented DEA results in Table 7, it appears that the deep-sea ports of Amsterdam and Vlissingen are efficient. Dunkirk, Le Havre and Wilhelmshaven are also shown to be efficient. However, the data for these deep-sea ports are incomplete, and therefore these efficiency numbers must be treated with care. The other previous efficiency scores also do not indicate that these ports are 'very' efficient. The ports of Zeebrugge, Antwerp and Rotterdam have the potential to have more outputs, given their characteristics. The deep-sea ports of Hamburg and Bremen are very inefficient in terms of outputs.

Table 7. DEA results for the HLH deep-sea ports: Output-Oriented CRS

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%	1.00000	Constant
Port of Ghent	2.3%	3.40103	Decreasing
Port of Hamburg	12.8%	1919.72203	Decreasing
Port of Le Havre	7.2%	1.00000	Constant
Port of Rotterdam	37.0%	1.82865	Decreasing
Port of Vlissingen	3.0%	1.00000	Constant
Port of Wilhelmshaven	0.0%	1.00000	Constant
Port of Zeebrugge	3.8%	1.00000	Constant

Overall, from the output-oriented DEA it can also be concluded that the Dutch deep-sea ports are the most efficient ports in the HLH-range. The deep-sea ports operate under either constant or decreasing returns to scale. The ports with decreasing returns to scale have relatively low efficiencies which suggests that they should increase their outputs in order to become more efficient. But, given the current financial crisis, this might not be an option, and maybe the deep-sea ports should reduce their inputs.

Table 8. Slacks for DEA results HLH deep-sea ports: Output-Oriented CRS

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	123434.49092
Port of Bremen	0.00000	0.00000	2.35517	34390.83004	4652.63848	0.00000	0.00000
Port of Dunkirk	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Port of Ghent	0.00000	0.00000	0.00000	0.00000	4.86820	0.00000	3966.16683
Port of Hamburg	0.00000	0.00000	78.15172	107072.01676	350485.08342	0.00000	0.00000
Port of Le Havre	0.00000	0.00000	0.00000	29.59012	0.00000	0.00000	9765.41251
Port of Rotterdam	0.00000	0.00000	70.00000	0.00000	109.31205	0.00000	80774.05604
Port of Vlissingen	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Port of Wilhelmshaven	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Port of Zeebrugge	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

In the output-oriented DEA analysis, slacks are found for the large container ports in the input variable material/service inputs. In terms of output variables, no slacks are found for the deep-sea ports of Amsterdam and Vlissingen. Several other ports also show no slacks, but lack of data for these deep-sea ports prevents ’firm’ conclusions. 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.

5. Conclusions and policy implications

In this paper, the focus has been on answering the following research question: ‘*How efficient are deep-sea ports in the Hamburg-Le Havre range compared with each other?*’ Overall, from the single measure benchmark, it can be concluded that the port of Amsterdam has high depreciation costs and the port of Vlissingen performs very well in terms of personnel costs. Overall, in benchmarking the output performance (sales, profits, rents, and port dues) of the deep-sea ports in the HLH-range, it was found that the deep-sea ports of Vlissingen and Amsterdam perform quite well. Furthermore, smaller deep-sea ports (with limited or no container handling) appear to perform better than the larger deep-sea ports where containers are an important market segment. In the non-financial benchmark, the deep-sea port of Vlissingen also performs well, as do the other Dutch deep-sea ports.

From the input-oriented DEA results it appears that the deep-sea port of Vlissingen is perfectly efficient and also that the port of Amsterdam is quite efficient. The port of Zeebrugge and Rotterdam achieve scores of around 50 per cent efficiency. For the rest of the deep-sea ports, the efficiency scores are quite disappointing. The majority of these conclusions are confirmed by the output-oriented DEA analysis. Another conclusion from the DEA analysis is that the Dutch deep-sea ports are the most efficient ports in the HLH-range.

They perform significantly better than their Belgian and German competitors. If regulations were to be equalized, the Dutch deep-sea ports might be able to further increase their performance and market share as compared with their competitors. Finally, relatively smaller deep-sea ports (with a market share of about 5 per cent, such as Amsterdam, Vlissingen, and Zeebrugge) are relatively more efficient than larger deep-sea container ports (such as Antwerp, Hamburg, and Rotterdam).

For European port policy this suggests that limiting financial subsidies could increase efficiency and might therefore be a desirable goal. Differences in subsidy levels still exist between the deep-sea ports in the Hamburg-La Havre range. Limiting subsidies could create a level playing field for port competition, benefit tax-payers in the respective countries, and force deep-sea container carriers to invest more in their preferred deep-sea port. The level playing field could contribute to the increased efficiency of deep-sea port operations and to lower port subsidies by the governments of Belgium, Germany, and the Netherlands.

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