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Comparative Port Performance Analysis of Italian Ports

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Abstract : *Recently, the fierce competitions in the shipping industry and the global economic downturn have heavily influenced ports' operational strategies. In order for port authorities to remain competitive at an international level and to provide more accurate information to develop National policies, ports are required to analyse and improve operations' efficiency. In this paper, the efficiency of 19 Italian ports in 2013, handling different types of cargoes, is assessed through the application of Data Envelopment Analysis (DEA), with constant return to scale (CRS) and variable return to scale (VRS). The purpose of this study is to analyze the efficiency of Italian ports and evaluate whether differences in size and specialization of each port (or cargo handled) are directly correlated with ports' efficiency.*

Key words : *port efficiency, Data Envelopment Analysis (DEA), Ialian ports, CCR, CSR, VRS*

1. Introduction

Ports play an increasingly key role in international trade as part of vast supply chains. For this reason, ports are not only influencing the efficiency of transportation networks, but also the strategic role, the connectivity and the competitiveness of countries. (De Oliveira & Cariou, 2011). However, due to the global economic downturn, competition has risen steady and ports are now required to be as efficient as possible; performance measurement is deemed to be a powerful management tool for port terminal operators.

The concepts of production and efficiency are essentially different. Production is defined as "*the process through which inputs are combined, transformed and turned into outputs*" (Case and Fair, 1999). On the other hand, efficiency is illustrated as "*the relative productivity over time or space, or both*". The efficiency can be broadly divided into intra-and inter-firm efficiency measures. The intra-firm efficiency is related to the use of a firm's own production potential through the productivity level over time relative to a firm's specific production frontier, defined as "*the maximum set of outputs subject to the different level of inputs*". The inter firm efficiency measures the performance of a firm compared to the best competitor(s) operating in the industry (Lansink et al, 2001).

Since ports need to measure their efficiency relative to their competitors, there is a need to set a reliable performance standard measurement and the introduction of the concept of benchmarking is necessary to analyze and develop a reliable assessment tool.

As Min and Galle(1996) suggested in their study, benchmarking is necessary because it is a progressive quality improvement process through which strengths and weakness can be analyzed. Competitive advantages of competitors can be assessed and the results can be successfully implemented into a strategic plan to gain a better market position.

More specifically, there are several useful information that can be collected by performance measurements; for example "*the identification of best practices, the most productive operating scale, the efficiency savings in resources use, to exploit the model for an inefficient unit to emulate to improve its performance, the marginal rates of substitution between the factors of production; and the productivity change over time by each operating unit and by the most efficient of the operating units at each point in time*" (Thanassoulis, 2001).

Port efficiency has been widely studied due to its impact

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on international trade (De Oliveira & Cariou, 2011). However, most of the recent studies have focused on the efficiency of container terminals and very few on the efficiency of dry bulk terminals. In this paper an alternative approach is suggested and the study focuses on Italian ports efficiency taking into account the total volume handled regardless of the cargo type (container, liquid bulk, dry bulk and general cargo). Italian ports were selected in the study in order to give a contribution to the country ports′ sector , which takes on a great strategic importance in the national economy yet, very few papers have focused on this matter. In fact, Italian ports have been either taken into account in a very fragmented way as part of European ports′ studies (Niavis & Tsekeris, 2012). Only a single paper published by Barros in 2006 provides a more comprehensive analysis through a DEA methodology but the selected data of each DMU is at present a bit out-dated as it refers to the years 2002-2003(Barros, 2006). The study aims at filling this gap by providing a study mainly focused at measuring the efficiency of Italian ports in the year 2013.

The importance of Italian ports to the national economy can be partially explained by volume of cargo types handled. In 2013, the 23 major Italian port have handled a total cargo volume of over 453 million tons. About 179 million tons or 40% of the total is represented by liquid bulk, 109 million tons or 24% is represented by containers, 70 million tons or 16 % is represented by solid bulk and another 74 million tons or 16% by Ro-Ro cargo. In terms of cargo volume handled, Trieste ranks first with over 56 million tons handled and the majority of cargo is represented by crude oil. Genova, with 48 million tons follows up and the biggest percentage of cargo handled is given by solid bulk. In third position, with over 35 million tons, there is Cagliari where again liquid bulk is the main cargo handled whilst Gioia Tauro, with a total of 33 million tons handled is the main container port in Italy, with over 3 million TEU moved. The smallest ports are represented by Marina di Carrara, Piombino, Bari, Catania, Palermo and Ancona with less than 7 million tons handled in 2013. (Direzione Generale per i porti, 2013). Nevertheless, in the following study only 19 ports have been considered due to data limitation, in particular concerning the quay length and the investment cost.

The originality of this paper lies on the application of a DEA model taking into account the total cargo handling volume (measured in tons) as output in the major Italian ports for the year 2013 and not a specific cargo type (container, bulks, general cargo) as the greatest majority of previous studies analyzed. Therefore, ports handling different types of cargo are included in the study and, through the application of general standardized indicators, the paper aims at analyzing what factors (port size, specialization, position) are more likely to influence the port's efficiency.

2. Literature Review

In previous studies, Data Envelopment Analysis (DEA) has been utilized to measure the operational efficiency in several business sectors. Examples are given by the research conducted by Thanassoulis in 1999 to measure efficiency of banks (Thanassoulis, 1999), hospitals (Valdamanis, 1992), airports (Sarkis, 2000), airport quality (Adler and Berechman, 2001), trucking firms (Min and Joo, 2003) and regional freight logistics (He et al., 2006).

In relation to seaports, DEA has been mostly applied limiting the objective of the study to container terminals. Roll and Hayuth(1993) analyzed the theoretical rate of the efficiency of ports using as inputs manpower, capital and cargo uniformity and as outputs cargo throughput, level of service, user's satisfaction and ship calls(Roll and Hayunth, 1993). Tongzon(2001) tested the various factors which influence the performance and efficiency of ports. Valentine and Gray(2001) went further and compared port efficiency to determine a relationship between ownership and organizational structure with efficiency. Ryoo(2006) focused on the efficiency measurement of major container terminals in Asia and container terminal operations in Busan and Kwangyang ports(Ryoo, 2005). Wang, et al.(2003) analyzed the container terminal efficiency using two different techniques, Data Envelopment Analysis (DEA) and Free Disposal Hull (FDA). The same methodology was also applied by Kaisar, Pathomsiri and Haghani in 2006. A similar study, but with the application of a different methodology, was carried out by Lin and Tseng who applied data Envelopment Analysis and Stochastic Frontier Analysis (SFA) to evaluate the efficiency of 27 international container ports (Lin and Tseng, 2005).

Min and Park(2008) proposed a hybrid Data Envelopment Analysis simulation model aimed at evaluating the relative efficiency of container terminal operators.

A few studies have also evaluated the efficiency of dry bulk ports using DEA. De Oliveira and Cariou(2011) examined the efficiency of 122 iron ore and coal ports in 2005 while Merk and Dang(2012) calculated the efficiency scores of world ports according to cargo handled, including containers and bulk cargoes.

3. Research Methodology

3.1 Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a non-parametric method for measuring the efficiency of a Decision Making Unit,(DMU) or also called Unit of Assessment (Thanassoulis, 2001) which was first introduced in 1978, (Charnes et al, 1978) and have multiple inputs and multiple outputs. Among the advantages of using DEA, it should be mentioned that this methodology does not impose any functional form to the production function or on the shape of returns to scale and that it enables dealing with multiple output process(Park, 2006). On the other hand, DEA has also some weaknesses such as its deterministic property which does not allow random measurement errors to be separated from the pure efficiency.

Different efficiency indicators can be determined through the application of DEA and are called CCR-CRS, under constant return to scale, BCC-VRS, under variable return to scale and super efficiency (S_CRS). In this paper, the model selected for assessing the efficiency of 22 Italian ports in 2013 are CCR and BCC.

The CCR model, developed by Charnes, can be expressed as:

$$Model\,CCR\begin{cases}\min\theta-\varepsilon\left(\sum_{i=1}^{m}s_i+\sum_{r=1}^{s}s_r\right)\\ sc\sum_{j=1}^{n}\lambda_j x_{ij}+s_i=\theta\chi_{io} & i=1,....,m;\\ \sum_{j=1}^{n}\lambda_i y_{rj}+s_r=y_{ro} & r=1,....,s;\\ \lambda_j,s_i,s_i\geq 0 & \forall\, j,i,r\end{cases}$$

$$Model\,BCC\left\{\sum_{j=1}^{n}\lambda_j=1\right.$$

In which n is defined as the number of DMU that are represented by the Italian ports. Each DMU (j=1,⋯.,n) uses m inputs x_{ij} (i=1,⋯,m) to produce s outputs y_{rj} (r= 1,⋯.,s).

θ optimal value represents the DMU0 relative efficiency index. The symbol ε ($\varepsilon > 0$) reflects a non-Archimedean element as the smallest real positive number and its importance is given by the recognition of any potential slacks (s_j and s_r) or excess for each input considered. The symbol λj is the total weight of all the efficient entities used for a DMU under evaluation. In the BCC model, variable return to scale, there is an additional constraint introduced; it is the sum of Lambdas to be equal to 1. The model can operate respectively under different return to scale, constant, increasing or decreasing.

Within a DEA application measurement there are three different efficiency that can be identified: overall efficiency, technical efficiency and scale inefficiencies. The first one, overall efficiency, is obtained by the application of a DEA-CCR model. It is assumed that a variation in production size or scales have no influence on efficiency scoring which means that both small and big ports can operate efficiently. Technical efficiency allows outputs to vary unproportionally with only a marginal increase in inputs. This type of efficiency is calculated by a DEA-BCC with variables return to scale(Park et al., 2007; Ryoo, 2005). Neutralizing the scale inefficiencies, the relative differences between smaller and bigger ports are removed and purely operational efficiency is reflected.

Finally, whenever there is an inappropriate (above or below optimal level) scale of production, a scale inefficiencies occur and is calculated by the following ratio:

SE=CRS/VRS and where SE<1

When SE=1 it implies that port are efficient operating at the optimal level at which they are designed. On the hand, if SE<1, it means that the port is inefficient with higher overall inefficiency compared to technical inefficiency.

3.2 Research Data and Descriptive Statistics

The assessment of ports' operational efficiency through a DEA model starts with the selection of an appropriate number of inputs and outputs that can be combined into a composite index of overall performance standards(Song and Sin, 2005). Data selection, in this sense, must be given great attention and particularly towards the choice of inputs and outputs. The homogeneity of data attributed to container operations for outputs and expressed in TEU is not applicable in this analysis.

The standard inputs utilized, like for instance the number of cranes used, the technology and the m^2 of the container yard, cannot also be taken into account. Similarly, for the dry cargo traffic, in which factors such as draught, stockpile and loading/discharging rates are key elements, in this paper cannot be utilized when analysing several cargo types' inflows.

An example of the port performance indicators is proposed by UNCTAD as shown in Table 1 below:

Table 1 Summary of performance indicators suggested by UNCTAD

Financial indicators	· Tonnage worked · Berth occupancy revenue per ton of cargo · Cargo handling revenue per ton of cargo · Labour expenditure · Capital equipment expenditure per ton of cargo · Contribution per ton of cargo · Total contribution
Operational indicators	· Arrival late · Waiting time · Service time · Turn-around time · Tonnage per ship · Fraction of time berthed ships worked · Number of gangs employed per ship per shift · Tons per ship-hour in port · Tons per ship hour at berth · Tons per gang hours · Fraction of time gangs idle

Source : UNCTAD(1976)

It has been decided to rather focus on productivity indicators which are standardized for every types of cargo handled by the port; for the inputs, the productivity indicators selected are the yard capacity expressed in m^2, and quay length expressed in meter. One financial indicator, the investment cost, is also used as input in Model 2 of the data analysis and it is expressed in Euro (€) invested in the port in 2013. The selected outputs are the total cargo volume handled by the port(tons) and the value added. It has been decided to select the total tons handled by the port because it represents a common objective to all ports: traffic maximization. It was chosen not to take into account profit maximization due to the fact that usually dry and liquid cargo terminals are owned by private companies and the terminals cannot be deemed as a profit centers but rather more as part of wider supply chains(De Oliveira and Cariou, 2011). The aforementioned variables were retrieved from the Italian ports' status annul report(Direzione Generale per i porti, 2013) and from individual port authorities' web sites.

Another output is represented by the added value. It is very interesting to note how this indicator was calculated. First of all, the total tons per cargo type handled by each Italian port in 2013 were analysed. The categories considered were: Ro-Ro, containers, liquid bulk, dry bulk and general cargo. In the study conducted by Merk and Dang titled "the competitiveness of global port-cities" it was calculated the added value per cargo type surveying 150 major international ports. The added value of each Ton of cargo taken into account respectively are: 45 USD for liquid bulk, 20 USD for dry bulk, 90 USD for containers, 220 USD for Ro-Ro and 60 USD for general cargo. The added value per cargo type was then multiplied by the total tons handled by the port (Merk, 2010).

Table 2 presents some detailed statistics of the 19 Italian ports taken into consideration in the analysis. It includes average, minimum, maximum and standard deviation calculated for the inputs and outputs.

Table 2 Descriptive Statistics of the Selected Input & Output

	Yard Capacity (m^2)	Quay Length (m)	Investment Cost(€)	Cargo Handling Volume (Tons)	Value Added (€)
Max	2,582,314	24,000	34,921,117	56,585,708	4,321,251,520
Min	3,612	1,160	1,074,696	26,946	260,416,275
Average	467,776	7,833	12,679,398	19,130,319	1,681,941,636
SD	672,284	6,702	11,004,626	15,293,773	1,143,972,990

Source : Author's calculation

4. Data Analysis

In order to assess the overall efficiency and the scale efficiency two models are utilized: CCR(CRS) and BCC (VRS). An input model interpretation was selected for this case study, in order for ports to improve efficiency by reducing inputs. However, in the port sector, this may be rather hard as the inputs are found to be the yard capacity and the quay length. On the other hand, the investment cost may be easily reduced. Nevertheless, the reduction in space of a yard terminal could be also interpreted as a different port's operational strategy, for example by utilizing some of the area for different port activities, consequently reducing the total area.

A further distinction was made among 2 models: model 1, which takes into account 2 inputs namely yard capacity, quay length and as outputs total tons and value added and Model 2, with same inputs and outputs as Model 1 but adding as input the investment cost. This approach was selected because the investment cost in each port can vary significantly each year and it is therefore interesting to analyze how efficiency varies when taking it into account and when not. The first interesting result is given by the average score, which appears to be higher in the VRS model (0,75 and 0,84 respectively in Model 1 and Model 2) than CRS model (0,57 and 0,72). Additionally, the differences between the average score in Model 1 and Model 2 is higher for CRS, which may suggest that investment cost is mainly related to scale efficiency.

In Model 1, it is found that there are 6 technically efficient ports in VRS but not under CRS, showing a scale inefficiency for Genova, Napoli, Salerno, Gioia Tauro, Trieste and Catania. However, there are 5 ports found to be efficient in both CRS and VRS, Piombino, Brindisi, Ravenna, Augusta and Cagliari. The characteristics of these ports suggest that the biggest ports are not necessarily the most efficient in both models whist small-medium sized ports are the most efficient. It is also interesting to note that these ports all handle mixed cargoes but with a predominance of liquid and dry bulk.

In Model 2 there are 9 ports efficient in both CRS and VRS and 4 ports efficient under VRS but not under CRS namely Genova, Napoli, Bari and Trieste. Similarly to Model 1, it appears that the most efficient ports are those small-mid-sized and handling different cargoes with a higher percentage in the dry-wet bulk sector. It also appears that these ports are mostly concentrated in the South part of Italy, suggesting a slight predominance of efficiency ports by geographical region.

Table 3 Model 1 – 2 Inputs

	Port	CRS	VRS	SE
1	SAVONA-VADO	0.173127356	0.175769613	0.984967
2	GENOVA	0.214714532	1	0.214715
3	LA SPEZIA	0.311756668	0.337721265	0.923118
4	LIVORNO	0.368985352	0.748805584	0.492765
5	PIOMBINO	1	1	1
6	CIVITAVECCHIA	0.106523149	0.181018322	0.588466
7	NAPOLI	0.72713382	1	0.727134
8	SALERNO	0.888560394	1	0.88856
9	GIOIA TAURO	0.516705818	1	0.516706
10	TARANTO	0.23113337	0.274458189	0.842144
11	BRINDISI	1	1	1
12	BARI	0.406263156	0.467764626	0.86852
13	ANCONA	0.28235171	0.283437376	0.99617
14	RAVENNA	1	1	1
15	TRIESTE	0.483611735	1	0.483612
16	CATANIA	0.778328274	1	0.778328
17	AUGUSTA	1	1	1
18	PALERMO TERMINI	0.496671016	0.806944063	0.615496
19	CAGLIARI-SARROCH	1	1	1

Source : Author's calculation

Table 4 Model 2 – 3 Inputs

	Port	CRS	VRS	SE
1	SAVONA-VADO	0.256087	0.271194717	0.944293144
2	GENOVA	0.233104	1	0.233103617
3	LA SPEZIA	0.32379	0.337721265	0.958748566
4	LIVORNO	0.395243	0.748805584	0.52783107
5	PIOMBINO	1	1	1
6	CIVITAVECCHIA	0.149141	0.181018322	0.823900413
7	NAPOLI	0.831831	1	0.831831092
8	SALERNO	1	1	1
9	GIOIA TAURO	1	1	1
10	TARANTO	1	1	1

11	BRINDISI	1	1	1
12	BARI	0.711191	1	0.711190728
13	ANCONA	0.557075	0.663281727	0.83987654
14	RAVENNA	1	1	1
15	TRIESTE	0.671899	1	0.671898685
16	CATANIA	1	1	1
17	AUGUSTA	1	1	1
18	PALERMO TERMINI	0.567811	0.806944063	0.703655733
19	CAGLIARI-SARROCH	1	1	1

Source : Author's calculation

5. Conclusion

The paper intended assessing the efficiency of Italian port through a DEA model but using a different approach, by taking into account the total cargo handling volume (measured in tons) as output in the major 19 Italian ports for the year 2013 and not a specific cargo type (container, bulks, general cargo). The objective of this study is to analyze what factors (port size, specialization, position) are more likely to influence port's efficiency.

The results, under the two different models, have suggested that the most efficient ports share some similar characteristics in terms of size and cargo handling/specialization. In fact, biggest ports are not necessarily the most efficient whilst small-medium sized ports are found to be the most efficient. In this sense, examples are given by small-sized ports such as Piombino, Brindisi and Salerno which are found to be efficient whilst bigger ports like Trieste, Genova, Gioia Tauro and Livorno are found to be not efficient under Model 1.

In the second model, the one in which an additional input (investment cost) has been added, it seems there are some similarities with Model 1. Once again, the most efficient ports are those small-mid sized and handling heterogenous cargo like Brindisi, Taranto, Salerno, and Catania. On the other hand, Trieste, Genova and Livorno are not efficient. Interestingly, it is worth to note that some port are efficient in model 2 and not in model 1, like Gioia Tauro, Salerno, Taranto and Catania.

The results also suggest that the most efficient ports usually all handle mixed cargoes with a general predominance of liquid and dry bulk.

Nevertheless, the paper has several limitations. First of all results should be analyzed on a time series due to the fact that the selected inputs and outputs may considerably change over time, in particular the investment cost and the cargo volume handled yearly. In fact, the investment cost varies considerably over a team period of 5 years and analyzing the data for a single year may not be as accurate as calculating the efficiency on a time span. Secondly, the study may gain some more value if an output model interpretation would be given and if a deeper IRS (increasing return to scale) DRS (decreasing return to scale) would be carried on.

Finally, the results may not be the most accurate as inputs and outputs were considered in aggregate whilst more reliable implications might be extracted when applying the same study at a terminal level.

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