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Greek health system efficiency and productivity: A window DEA and Malmquist method measurement

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C H R O N I C L E

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A B S T R A C T

To calculate the change in the values of efficiency and productivity of public hospitals in Greece during the period 2015 to 2019. The calculation of the efficiency values includes the technical, pure and scale efficiency using the window-DEA method and the productivity change using the Malmquist index. The source of the data used to calculate the change in the efficiency of Greek public hospitals is the statistical databases of the Greek Ministry of Health that have resulted from the collection of data through Information Systems in combination with data provided by the Greek Statistical Authority (ELSTAT). The design of the study was based on the realization of a Window DEA study and the calculation of the Malmquist index with its components. The study was designed to measure the change in efficiency and productivity but over a relatively long period of time. The data were obtained from the databases of both financial and operational data of Greek Public Hospitals held by the Greek Ministry of Health and located on the Ministry's website. Also, additional data were requested and obtained from ELSTAT. The data were examined and those which were appropriate for the conduct of the study were selected. The technical efficiency of Greek hospitals follows a slightly upward trend with ups and downs. Their pure efficiency follows a steady course with ups and downs. Scale efficiency is on an upward course. Productivity exhibits an overall negligible change. The research's fluctuation of the inputs and outputs determines the change in the values of efficiency and, in combination with technological change, of productivity. During the period under study, the best placement of Greek hospitals on the scale is achieved in terms of their size. Hospital management cannot achieve better utilization of resources. A parallel increase of some of the inputs and outputs prevents increase in the values of technical and pure efficiency. The change in efficiency constrains the change in productivity.

1. Introduction

The work of economists Debrew and Koopmans in the 1950s to assess efficiency formed the basis for the development of the Data Envelopment Analysis (DEA) method by Farell (Coelli, 1996). Farell (1957) found the inability to find the actual production function and distinguished overall efficiency into technical efficiency and allocation efficiency. Farell explained efficiency with an inputs (X) and outputs (Y) chart. Using an equal production curve, he indicated Technical Efficiency (TE), Allocative Efficiency (AE) and Overall Efficiency (OE). Figure 1 shows the graph of theoretical interpretation of efficiencies (Farell, 1957). The DEA does not require any production function to be found between inputs and outputs and is often used to measure the efficiency of public institutions (Ray, 2004). Thanassoulis (2001) points out that the DEA

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method uses the inputs and outputs of a system which converts the inputs consumed by the system into produced outputs through a process of conversion that occurs within the system.

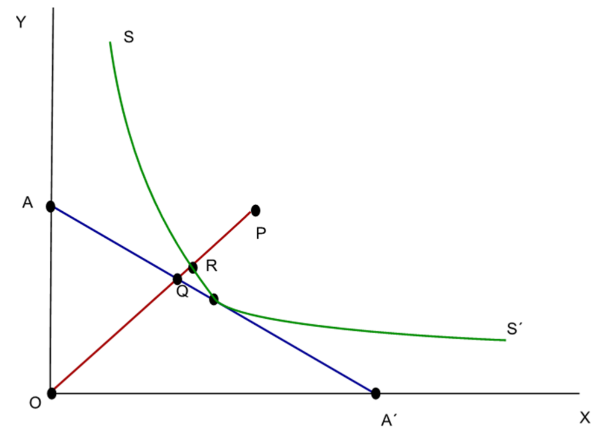

Fig. 1. Graph of theoretical interpretation of efficiencies (Source: Farell, 1957)

The DEA does not require any production function to be found between inputs and outputs and is often used to measure the efficiency of public institutions (Ray, 2004). Thanassoulis (2001) points out that the DEA method uses the inputs and outputs of a system which converts the inputs consumed by the system into produced outputs through a process of conversion that occurs within the system. The selection of Scheel data (2000) and the avoidance of unwanted data leading to unwanted outcomes (Koopmans, 1951), are two important elements to take into account in the DEA study. Hoang and Coelli (2011) developed a method to shift unwanted outputs to inputs and subsequently to apply DEA in order to derive objective results. Seiford & Zhu (2002) developed alternative techniques in order to avoid unwanted results and to avoid defects in shifting unwanted outputs to inputs. The rationality of the solutions is imperative to DEA in order to avoid irrational solutions that may be provided by DEA in an efficiency study. For this reason, limiting the weights of each input or output is desirable in the DEA efficiency studies. This limitation is achieved by introducing weighting factors, which determine the weight (importance) of the inputs or outputs of the study compared to the rest of the inputs and outputs and do not leave room for irrational solutions (Allen, Athanassopoulos, Dyson & Thanassoulis, 1997; Thanassoulis, Dyson & Foster, 1987). According to Pedraja-Chaparro, Salinas-Jimenez & Smith (1997) weights play a fundamental role in determining the measured performance of a unit.

Efficiency values are related to each other by a basic relationship, which according to Kaitelidou et al. (2016) is:

$$[\text{Technical Efficiency}] = [\text{Pure Efficiency}] \times [\text{Scale Efficiency}]$$

where according to Isik & Hassan (2002), Kumar & Gulati, (2008) and Lee (2009) the descriptors are:

- Technical Efficiency (TE) is the production capacity of the unit based on the specific resources it uses in combination with size adequacy.
- Pure (Technical) Efficiency (PTE) is the performance of the management activity.
- Scale Efficiency (SE) is the efficiency that depends on the size-based placement of the unit within the scale.

Fragkiadakis et al. (2016) distinguish efficiency into two categories, depending on the type of inputs used:

- Operational efficiency, which results from inputs related to operating elements (number of personnel, operating characteristics)
- Economic efficiency, which results from inputs related to economic data (expenses)

According to this distinction, the efficiency values calculated are further distinguished into the above. To measure efficiency with the DEA method, various models which study efficiency in order to achieve the most objective results have been developed.

Such models are:

- The CCR model
- The BCC model
- The window-DEA model
- The Malmquist Index
- The Bootstrap DEA model

The CCR model, developed by Charnes et al. (1978), accepts steady return to scale, i.e., that an increase in inputs corresponds to a proportional increase in outputs, which is not the case in the production process. This assumption tightens the results by setting very few units within the production limit. The CCR model is mainly used for the calculation of Technical Efficiency (TE).

The BCC model, developed by Banker et al. (1984), accepts the variable return to scale, i.e. that an increase in inputs corresponds to a non-proportional increase in outputs. With this assumption, it calculates the production limit more widely than the previous model. The BCC model is currently used to determine Pure Technical Efficiency (PTE), which then leads to Allocative Efficiency (AE). The window-DEA model was originally developed by Yue (1992) and complemented by Charnes et al. (1994) and Charnes et al. (2013). The window-DEA model addresses the disadvantage of classic DEA models, which cannot measure reliable results over extended periods of time in which technological change is evolving. For this reason, this method groups the sub-periods of the extended period and calculates the efficiency values more reliably. The Malmquist index was introduced by Economist Malmquist (Egilmez & McAvoy, 2013). The Malmquist Index (MPI) is used together with the window-DEA model to measure efficiency over extended periods of time (Fare et al., 1994). According to Hulten (2001), it shows the production of a time period using inputs from another period and thus calculates efficiency over extended periods of time. The Bootstrap-DEA model (Assaf & Matawie, 2010) can efficiently measure the relative performance of many decision-making units with similar purposes and objectives (Kounetas & Papathanasopoulos, 2013). The purpose of using the bootstrapping approach is to obtain corrected efficiency estimates and confidence intervals of DEA performance scores and also to overcome the problem of DEA performance scores correlation and to produce consistent conclusions for their explanation. Measuring efficiency is an important issue for each type of organisation, and is used in the health sector, as it allows their performance to be compared to that of their competitors and develops a corresponding policy to improve performance. The DEA method has proven to be an effective and flexible tool for measuring the efficiency of health care and its use has spread around the world as a non-parametric method that allows the comparison of health care units, using multiple inputs such as doctors, hospitals, nurses, beds, in order to produce multiple outputs (Kounetas & Papathanasopoulos, 2013; Xenos et al., 2017).

2. Literature review

The selection of inputs and outputs used in efficiency studies is known, based on the number of DEA studies performed (Aletras et al., 2007). In a systematic review and classification of performance studies of hospitals using DEA, O'Neill, Rauner, Heidenberger & Kraus (2008) provide relevant techniques for measuring efficiency but also refer extensively to inputs and outputs of hospital efficiency studies based on hospital operation. The most common inputs and outputs applied in health performance studies, according to the reviewed literature, are shown in Table 1.

Table 1
Selection of some routine input-output in health efficiency studies (Farantos & Koutsoukis, 2022)

		Inputs		Outputs	
Researchers	**Year**	**Beds**	**Financial data**	**Hospitalisation days**	**Number of Patients (Various Categories)**
Lee, Chun & Lee	2008	√			√
Kirigia et al.	2008	√	√		√
Caballer-Tarazona et al.	2010	√			
Pham	2010	√		√	
Chang, Hsiao & Chang	2011	√		√	
Kreng & Yang	2011		√		
Hu, Qi & Yang	2012	√	√	√	
Dimas, Goula, &Soulis	2012	√	√		√
Varabyova & Schreyögg	2013	√			
Audibert et al.	2013	√			√
Kirigia & Asbu	2013	√	√		√
Asandului, Roman & Fatulescu	2014		√		
Jehu-Appiah et al.	2014	√	√	√	
Kawaguchi, Tone, & Tsutsui	2014				√
Du et al.	2014	√	√		√
Narcı et al.	2015	√			√
Alonso, Clifton & Díaz-Fuentes	2015	√			√
Narcı et al.	2015	√			√
Van Ineveld et al.	2016			√	√

Source: Farantos & Koutsoukis (2022)

The orientation towards inputs or outputs gives priority to the reduction of inputs or the increase of outputs respectively. Some studies emphasise on input orientation, which is the most common for public structures, while some emphasise on output orientation arguing that management has more difficulty controlling outputs (Cheng et al., 2016; Thanassoulis, 2001). Exogenous or non-discretionary inputs and outputs, are those that do not depend directly on the control of the unit, but depend on exogenous factors for the most part (such as the health system or the influence of the external environment health system). However, these affect the efficiency of hospitals and should be taken into account when measuring efficiency. These variables should be addressed in a DEA study (Cordero, Pedraja, & Santín. 2009; Estelle, Johnson & Ruggiero, 2010; Yakob, Yusop, Radam & Ismail, 2014). In the study on the efficiency of Greek NHS clinics, Katharaki (2008) mentions the combination of inputs and outputs in the context of a policy mix, which can be measured and then used to improve the efficiency of Greek hospitals. She highlights the importance of each productive factor used and the results produced in shaping the efficiency of Greek hospitals. In their study of Greek hospitals Fragkiadakis, Doumpos, Zopounidis & Germain, (2016) use beds as input variables taking into account the logarithm of the number of beds and its square to introduce the effect of the size and clinical capacity of hospitals. This is because the use of the square variable allows the modelling of non-linear variable results. The table provides useful information on the selection of inputs and outputs used in health efficiency studies for Greek hospitals, in order to non-bindingly proceed in the selection of inputs and outputs we use in our research.

Table 2
Selection of certain common inputs-outputs in efficiency studies of Greek health units (Authors, 2021)

		Inputs		Outputs	
Researchers	**Year**	**Beds**	**Financial data**	**Hospitalisation days**	**Number of patients**
Athanassopoulos et al.	1999		√	√	
Kontodimopoulos et al.	2006	√		√	
Aletras et al.	2007	√			√
Katharaki	2008	√	√	√	√
Tsekouras et al.	2010	√		√	
Halkos & Tzeremes	2011	√		√	
Polyzos	2012	√	√		√
Dimas et al.	2012	√	√	√	
Mitropoulos et al.	2013		√		√
Mitropoulos et al.	2013				√
Balamatsis & Chondrocoukis	2014	√	√		√
Mitropoulos et al.	2015	√	√		√
Kaitelidou et al.	2016	√	√		√
Oikonomou et al.	2016				√
Fragkiadakis et al.	2016	√	√		√
√enos et al.	2017	√	√		√
Trakakis et al.	2021				√

From this table, the most common inputs and outputs of the DEA efficiency studies, which are often used in Greek hospitals, are confirmed to be selected in this study. The window-DEA method allows dynamic evaluation of decision-making units over time (Pulina et al., 2010). Window-DEA uses a moving average approach, which allows a comparison of a decision-making unit with its own performance in other years, but also with the performance of the other units (Bosetti et al., 2003). This is achieved with the help of "windows", each of which includes a length of years, within which the comparison is made. The length of each window is calculated based on methodological guidelines (Cooper et al., 2007). Fig. 2 shows an example of a three-year window selection for an efficiency study which has been carried out (Muhammad et al., 2018).

Window 1	2005	2006	2007								
Window 2		2006	2007	2008							
Window 3			2007	2008	2009						
Window 4				2008	2009	2010					
Window 5					2009	2010	2011				
Window 6						2010	2011	2012			
Window 7							2011	2012	2013		
Window 8								2012	2013	2014	
Window 9									2013	2014	2015

Fig. 2. Windows for the three-year window-DEA application (Muhammad, Ra & Farooq, 2018)

The main advantage of the approach with this method is the successful treatment of small samples of data and the examination of trends in efficiency change in different time periods (Ohe & Peypoch, 2016). The method serves to assess technical efficiency in individual regions, allowing quantification of regional disparities, but also allows comparison of results from year to year (Miszczynska, & Miszczyński, 2021). Window DEA has been widely used in the study of changing hospital efficiency. Studies that have used the method include:

- Kazley & Ozcan (2009) used window-DEA to assess the impact of the use of medical records on changing hospital efficiency.
- Polyzos, Niavis & Pnevmatikos (2012) studied the impact of local Greek policies on the efficiency of hospitals with window-DEA.
- Miszczynska & Miszczyński (2021) used a window-DEA to measure the efficiency of the Polish public health sector with a 2-year window for a period of 5 years.
- Mirmozaffari & Alinezhad (2017) compare 12 local cardiological hospitals with the window-DEA method for 6 years using two-stage DEA.
- Stefko, Gavurova & Kocisova (2018) studied the change in efficiency for a period of 7 years in Slovak hospitals.

The work of the economist Malmquist was used by Caves et al. (1982) in order to analyse production, by calculating the ratio between the distance and productivity function, which he called the Malmquist Productivity Index (MPI). The MPI can take a value greater, equal or less than one, depending on whether productivity increases, is maintained equal to or decreases (for output orientation, whereas for input orientation the opposite is true) (De Castro Lobo, Ozcan, da Silva, Lins & Fiszman, 2010). This indicator emphasises technological change due to new technologies, information systems and production systems occurring in the production process between two time points (Ozcan & Luke, 2011). The indicator can be broken down into two components, one for changing technical efficiency and one for technological change. So the MPI-based efficiency equation is:

$$[\text{Malmquist Index}] = [\text{Change in Technical Efficiency}] \times [\text{Technological Change}]$$

$$\text{MPI} = \text{EC} \times \text{TC}$$

The Graphic interpretation of the MPI is shown in Fig. 3. The input-output observations for a particular unit at two different times are shown by P1 and P2. Technological progress over a period of time shifts the efficient VRS border 1 to the VRS border 2 position. The TOPS point for period 2 is shown as P2tops. While the decision making unit shifts from P1 to P2 and falls within the old efficient VRS frontier 1, it falls outside the new efficient VRS border 2 resulting from the technological change that has occurred in the meantime.

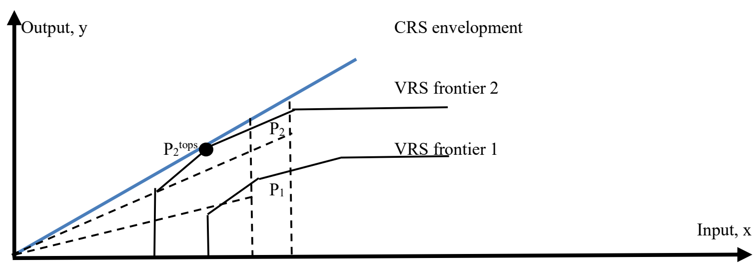

Fig. 3. Graphic explanation of Malmquist Productivity Index (Førsund et al., 2015)

According to Egilmez and McAvoy (2013), two models of the Malmquist index are used depending on the type of input or output orientation:

- The FLGR model, when the constant return to scale is used (Färe, Grosskopf, Lindgren & Roos, 1992).
- The FGNL&FLGR model, when variable return to scale is used (Fare, Grosskopf, Norris & Zhang, 1994).

3. Research method

The research material consists of data on inputs and outputs from public hospitals, most commonly used in DEA studies. The extensive literature review revealed the inputs and outputs most commonly used in DEA studies. These data were obtained from the databases of the Greek Ministry of Health which include the data as recorded by the Information Systems of the Ministry of Health. 126 public hospitals of the Greek National Health System from all the Health Regions of the Greek MoH participated in the study. The methods chosen for processing the data were window-DEA and the Malmquist index. These methods were chosen following a literature review which revealed the advantages of these methods in this particular case. The free software program Hoger Scheel was used to process the data. The orientation of the study was chosen as the input orientation. The orientation of the study was chosen following a literature review. The selection of the study's inputs and outputs is shown in Table 3.

Table 3
Inputs and outputs used in research (Authors, 2021)

Input/output	**Name**	**Description**	**Exogenous**
Input Code			
I1	Total purchases	Total amount of purchases of Greek hospitals	NO
I2	Number of beds	Number of beds in hospitals	NO
Output Code			
O1.	Patients Examined	Number of patients examined in outpatient clinics	YES
O2	Number of hospitalised persons	Number of patients discharged	YES
O3	Hospitalisation days	The sum of the days on which any short or permanent hospitalisation took place	NO

The software used in the study is the free EMS software, owned by Hoger Scheel. This software includes the ability to calculate efficiency values based on BCC, CCR and window-DEA models. The software provides the ability to handle exogenous variables. Then, with the help of the software, the values of the technical, the pure and the scale efficiency were calculated for the period studied. The results of the calculation were presented with a table and diagram. The software calculated the Malmquist index for the change in productivity and its components during the period under study. An analysis of descriptive statistics was included in the study. The results were discussed with emphasis on the impact of the change in the inputs and outputs of the investigation on the change in the values of efficiency and the productivity index and its components. Important conclusions were drawn from the analysis on the change in efficiency and productivity during the study period.

4. Results and discussion

4.1 DEA results

The calculation of efficiency values is performed with Hoger Scheel's EMS software. We want to limit the burdens in order to avoid their absolute freedom and finding ineffective solutions (Allen et al., 1997). Thus, the finding of a solution with weights of a significant input/output smaller than those of a less significant one, or of zero input/output significance, is avoided.

Weight limitations are as follows:

- P1>2*P2. It expresses the relative weight of the expenditure variable compared to the bed variable, which is difficult to change as shown by the DEA studies and retains inputs.
- 2Q1<Q2. It expresses the relative weight of hospitalised patients compared to the examined patients, due to the increased importance and the use of more extensive resources by hospitals for the category of hospitalised patients.
- Q2<Q3. It expresses the weight of the hospitalisation days compared to the examined patients, which is also an exogenously determined input.

In this case, the weight table is formed as follows:

$$W = \begin{bmatrix} 1 & -2 & 0 & 0 & 0 & 0 \\ 0 & 0 & -2 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix}$$

The technical efficiency (TE) of hospitals is measured in principle. The orientation of this study is that of input orientation. The number of Window-DEA periods is 5 while the span of each window is 3 years. Similar methodology (with different periods and span) has been applied by Pulina et al. (2010) and Jia and Yuan, (2017). Technical efficiency shall be calculated from the yearly averages for each year of the study period. Then, using the VRS model, pure efficiency values are calculated over the years of the period considered. The calculation is conducted using the window-DEA method in a similar way as before. The windows are calculated and the units are separated for the years to which the calculated efficiencies of each unit refer to and the pure efficiency is calculated for each year of the study. The change in the technical, pure and efficiency scale of Greek general public hospitals per year for the period studied is shown in Table 4 and a supervisory change thereof in Fig. 4.

Table 4
Change in technical, clean and efficient scale of Greek hospitals during the study period

	2015	2016	2017	2018	2019
TE	0.7542	0.8812	0.7719	0.9294	0.8246
PTE	0.8735	0.9600	0.8301	0.9460	0.8628
SE	0.8634	0.9178	0.9299	0.9824	0.9557

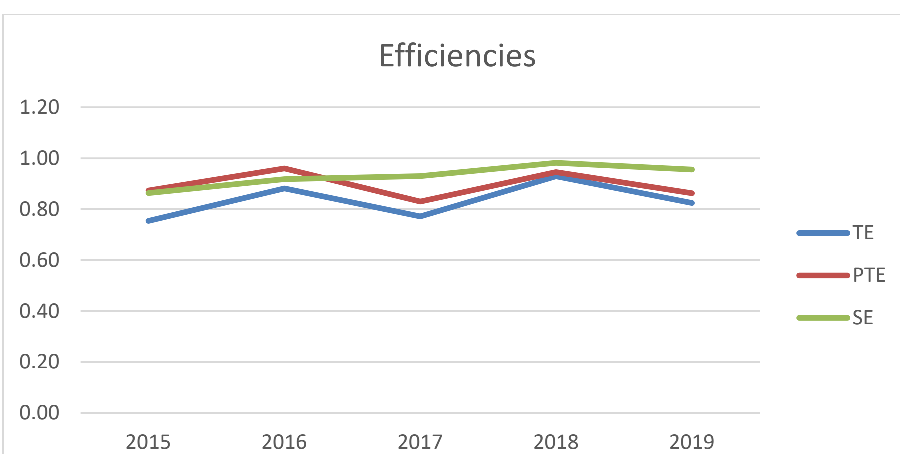

Fig. 4. Graphical representation of the change in the values of the efficiency of Greek Hospitals during the period under study

The study of the diagram shown in the picture shows the following:

1) Regarding the change in technical efficiency:
   - Technical efficiency increases considerably in the second year of the study period (88.12%) compared to the first year of the study period (75.42%).
   - Then, technical efficiency declines in the third year of the study (77.19%).
   - Subsequently, in 2018, technical efficiency increases to its highest value during this period (92.94%).
   - Finally, technical efficiency declines again in the last year of the study (82.46%).

There is a slight upward trend in technical efficiency in the middle of this period, with a temporary lag in 2017. It seems that technical efficiency follows an upward trend with ups and downs.

2) Regarding the change in pure efficiency:
   - pure efficiency increases considerably in the second year of the period studied (96%) compared to the first year of the period (87.35%).
   - Then, pure efficiency declines in the third year of the study (83.01%).
   - Subsequently, in 2018, pure efficiency increases to its highest value during this period (94.60%).
   - Finally, pure efficiency declines again in the last year of the study (86.28%).

The value of pure efficiency does not increase overall during this period. There is stability, with a temporary decline in 2017. It seems that pure efficiency follows a stability with ups and downs, while its change resembles that of technical efficiency.

3) Regarding the change in scale efficiency:

Scale efficiency follows a steady upward trend during the first four years of the period under study (2015-2018). In its last year alone (2019), scale efficiency shows a slight decrease. In general, scale efficiency follows an increasing trend.
Table 5 shows the results of the Malmquist index for the period studied and the components of the change in technical efficiency and production technology for the periods considered in this study.

Table 5
Malmquist Index and components during the study period

Window	Years	Malmquist - TFP Index	Efficiency change (TEC)	Technology change	Pure efficiency change (PEC)	Scale efficiency change (sec)
Period 1	2015-16	**0.940**	1.168	0.804	1.099	1.063
Period 2	2016-17	**1.044**	0.876	1.192	0.865	1.013
Period 3	2017-18	**0.938**	1.204	0.779	1.140	1.056
Period 4	2018-19	**1.104**	0.887	1.245	0.912	0.973
Average	2015-19	**1.007**	1.034	1.013	1.004	1.026

For the five-year period 2015 to 2019, the Malmquist index is estimated at 1.007%. This result indicates an almost complete stability of the productivity value over the whole period, taking into account technological change. The Malmquist index assumes negative values (positive change in productivity given technological change as well) in the periods 2015-16 and 2017-18. On the contrary, the index assumes positive values during the periods 2016-17 and 2018-19. The values of the components that compose the Malmquist index for the period studied are also given. It is also noteworthy that production technology is fluctuating, affecting the formation of the Malmquist index. Production technology increases in the first and third sub-periods (decrease of the relevant indicator) and decreases in the second and fourth sub-periods of the study. The Descriptive Statistics for the years of the study were then studied. Statistics selected are averages (avg.), standard deviation (STDEV) and Coefficient Variation (CV).

Table 4
Descriptive statistics (averages and coefficients of variation) for all input/outputs

		Inputs		Outputs		
Year	**Component**	**Purchases**	**Beds**	**Examined persons**	**Hospitalised persons**	**Hospitalisation days**
2015	Avg	1,709,209,871	33001	11,935,404	2,047,024	8,397,485
2016	Avg	1,900,755,219	33335	12,184,736	2,350,798	8,346,921
2017	Avg	1,995,350,198	33416	12,701,744	2,421,070	8,335,312
2018	Avg	2,072,526,095	33057	12,229,323	2,525,419	8,439,621
2019	Avg	2,312,873,217	33717	13,119,515	2,537,750	8,351,876

STDEV	198,777,507	259	422,904	178,538	38,927
CV	0.10	0.01	0.03	0.08	0.00

From the average of the inputs we observe that the total purchases are constantly increasing while the number of beds remains almost stable. From the outputs we observe an increase, with a fluctuation, in the number of patients examined while for hospitalized patients a constant increase is observed. Finally, there is a fluctuation in the hospitalization days. From the change in STDEV we observe very small deviations from the values of the number of beds and the hospitalization days. From the change of the Coefficient Variation, which is below the absolute value of 0.10 in all cases, we conclude a small dispersion of the results and a great reliability of the results.

Table 5
Percentage change in study inputs and outputs

Year	Purchases	Beds	Examined persons	Hospitalised persons	Hospitalisation days
2015	1.00	1.00	1.00	1.00	1.00
2016	1.11	1,01	1.02	1.15	0.99
2017	1.17	1,01	1.06	1.18	0.99
2018	1.21	1.00	1.02	1,23	1,01
2019	1,35	1.02	1.10	1.24	0.99

From this table, we observe that regarding inputs the purchases show a large percentage increase, while the beds remain relatively stable. Regarding outputs, we observe a medium and high increase in the examined and hospitalized persons, while stability in hospitalization days is observed. From the comparison of inputs and outputs, it appears that the beds remain stable, while those examined and hospitalized increase (the increase of whom probably indicates a shift to public hospitals). This reflects an attempt by health policy to make better use of available resources by achieving higher occupancy rates. On the output side, the decrease in hospitalization days, combined with the increase of patients and those examined, indicates an effort of faster treatment in combination with the new health technology that allows for shorter hospitalization.

4.2 Discussion

The study showed the change in efficiency values over the period 2015-2019. In terms of technical efficiency, stability was observed over the whole period with a marked variation in the intervening years. This shows that the combination of the hospitals' productivity capacity on the basis of the specific resources used and the size adequacy in order to implement scale economies does not change over the whole period, there is only an intermediate variation. Pure efficiency presents a similar picture, that of overall stability with intermediate fluctuation. Therefore, the result quotient to the resources spent is overall stable. The performance of management performance, expressed by pure efficiency, cannot be increased during the study period. On the contrary, scale efficiency follows an upward trend (with a slight exception in the last year). Therefore, this demonstrates that the administrations have chosen the optimal sizes for the units and that hospitals have been placed in a more appropriate way on the scale.

The Malmquist Index provides a clear picture of the change in productivity over the period studied. It appears that productivity remains completely stable over the period as a whole. We can see fluctuations in productivity in the middle of the period and a last big decrease in the last sub-period is the one that keeps it stable. Therefore, the rate of development of hospital services is zero and this is also related to the fluctuation in production technology. The question of the use of the average length of hospitalization in hospitals was addressed during the investigation. Thomas et al. (1997) found that length of stay can be considered a sign of poor quality of care. Kooreman (1994) points out that patients with longer stays may represent more serious cases that require greater hospitalization. We chose not to use the average length of hospitalization, because for the most part it depends on the two other possible outputs of the research, namely the hospitalization days and the number of discharged patients. Therefore, such use would run the risk of introducing into the study a variable dependent on other variables. It was also found that the average duration of hospitalization is not reported in the majority of the reviewed studies. The interpretation of the results can be conducted by studying the variability of inputs and outputs. The strong growth in markets is certainly having a negative impact on changes in efficiency values, while bed stability is holding them back. Regarding outputs, the increase in hospitalized patients and the smaller increase in the examined patients has a positive effect on the change in the efficiency values, while the stability of the hospitalization days holds this change back.

5. Conclusion

The study of the change in efficiency values with the Window-DEA method and of productivity with the Malmquist index, reveals the changes in these values and the causes of these changes during the study period. Technical efficiency is on a very slight rise, pure efficiency is stable and intermediate changes take place with ups and downs. Scale efficiency is on the rise. Management performance fails to increase efficiency, and hospitals are better placed in terms of size scale. The non-achievement of the increase in the values of technical efficiency and pure efficiency is explained by the variation of the study's inputs and outputs. One of the inputs (markets) increases significantly over the period considered, a fact which attempts to reduce and ultimately restrain efficiency values. The values of two outputs, hospitalised persons and to a lesser extent examined persons, increase and tend to increase efficiency. The effect of these changes is to contain efficiency values. The intermediate change in inputs and outputs depending on the extent to which it occurs in the year of the study period for the units participating in the study is the one that determines the yearly changes in efficiency values. While productivity initially tends to increase, it ultimately remains almost stable over the period and this is due to the combination of efficiency change and technological change. It seems that health policy is not geared towards increasing efficiency, because both inputs and outputs show an increase in their values, but it does not manage to increase productivity. This change in outputs in relation to inputs appears to be geared towards increasing the provision of services and increasing the size of the public health system, rather than increasing efficiency. The detailed interpretation of the effect of health policies on change in efficiency over the period studied is up to other studies.

References

Aletras, V., Kontodimopoulos, N., Zagouldoudis, A., & Niakas, D. (2007). The short-term effect on technical and scale efficiency of establishing regional health systems and general management in Greek NHS hospitals. *Health Policy. 83*(2-3), 236-45.

Allen, R., Athanassopoulos, A., Dyson, R. G., & Thanassoulis, E. (1997). Weights restrictions and value judgements in data envelopment analysis: evolution, development and future directions. *Annals of operations research*, *73*, 13-34.

Assaf, A. & Matawie, K. M. (2010) Improving the accuracy of DEA efficiency analysis: a bootstrap application to the health care foodservice industry. *Applied Economics, 42*(27), 3547-3558.

Athanassopoulos, A. D., Gounaris, C., & Sissouras, A. (1999). A descriptive assessment of the production and cost efficiency of general hospitals in Greece. *Health Care Management Science*, *2*(2), 97-106.

Balamatsis, G., & Chondrocoukis, G. (2010). *Measuring the Efficiency of Greek Public Hospitals Compared to Private Hospitals Listed on the Athens Stock Exchange Using Data Envelopment Analysis (DEA)*. Christchurch, New Zealand, 11-23.

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science*, *30*(9), 1078-1092.

Bosetti, V., Cassinelli, M., & Lanza, A., 2003. *Using data envelopment analysis to evaluate environmentally conscious tourism management. In: International Conference on Tourism and Sustainable Development*, CRENoS Cagliari, Sassari University and World Bank, September 19–20, Chia, Sardinia.

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). Multilateral comparisons of output, input, and productivity using superlative index numbers. The economic journal, 92(365), 73-86.

Charnes, A., Cooper W. W., & Rhodes. E. (1978). Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research 2*(6), 429–444.

Charnes, A., Cooper, W. W., Lewin, A. Y., & Seiford, L. M. (Eds.). (2013). *Data envelopment analysis: Theory, methodology, and applications*. Springer Science & Business Media.

Charnes, A., Cooper, W. W. & Seiford, L. M. (1994). *Extension to DEA Models.* In A. Charnes, W. W. Cooper, A. Y. Lewin & L. M. Seiford (eds.). Data Envelopment Analysis: Theory, Methodology and Applications. Kluwer Academic Publishers.

Cheng, Z., Cai, M., Tao, H., He, Z., Lin, X., Lin, H., & Zuo, Y. (2016). Efficiency and productivity measurement of rural township hospitals in China: a bootstrapping data envelopment analysis. *BMJ open, 6*(11), e011911.

Coelli, T., J. (1996). *A guide to DEAP version 2.1: A Data Envelopment Analysis (Computer) Program, CEPA Working Papers,* Armidale: University of New England.

Cooper, W. W., Seiford, L. M., & Tone, K. (2007). *Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software* (Vol. 2). New York: Springer.

Cordero, J. M., Pedraja, F., & Santín, D. (2009). Alternative approaches to include exogenous variables in DEA measures: A comparison using Monte Carlo. *Computers & Operations Research, 36*(10), 2699-2706.

De Castro Lobo, M. S., Ozcan, Y. A., da Silva, A. C., Lins, M. P. E., & Fiszman, R. (2010). Financing reform and productivity change in Brazilian teaching hospitals: Malmquist approach. *Central European Journal of Operations Research, 18*(2), 141-152.

Dimas, G., Goula, A., & Soulis, S. (2012). Productive performance and its components in Greek public hospitals. *Operational Research*, *12*(1), 15-27.

Du, J., Wang, J., Chen, Y., Chou, S. Y., & Zhu, J. (2014). Incorporating health outcomes in Pennsylvania hospital efficiency: an additive super-efficiency DEA approach. *Annals of Operations Research*, *221*(1), 161-172.

Egilmez, G., & McAvoy, D. (2013). Benchmarking road safety of US states: A DEA-based Malmquist productivity index approach. *Accident Analysis & Prevention*, *53*, 55-64.

Färe, R., Grosskopf, S., Lindgren, B., & Roos, P. (1992). Productivity changes in Swedish pharmacies 1980-1989: A non-parametric Malmquist approach. *Journal of Productivity Analysis, 3*, 85-101.

Fare, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review 84*(1), 66–83.

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General)*, *120*(3), 253-281.

Førsund, F. R., Edvardsen, D. F., & Kittelsen, S. A. (2015). Productivity of tax offices in Norway. *Journal of Productivity Analysis, 43*(3), 269-279.

Fragkiadakis, G., Doumpos, M., Zopounidis, C., & Germain, C. (2016). Operational and economic efficiency analysis of public hospitals in Greece. *Annals of Operations Research*, *247*(2), 787-806.

Halkos, G. E., & Tzeremes, N. G. (2011). A conditional nonparametric analysis for measuring the efficiency of regional public healthcare delivery: An application to Greek prefectures. *Health policy, 103*(1), 73-82.

Hoang, V. N., & Coelli, T. (2011). Measurement of agricultural total factor productivity growth incorporating environmental factors: a nutrients balance approach. *Journal of Environmental Economics and Management*, *62*(3), 462-474.

Isik, I., & Hassan, M. K. (2002). Technical, scale and allocative efficiencies of Turkish banking industry. *Journal of Banking & Finance, 26*(4), 719-766.

Kaitelidou, D., Katharaki, M., Kalogeropoulou, M., Economou, C., Siskou, O., Souliotis, K., ... & Liaropoulos, L. (2016). The impact of economic crisis to hospital sector and the efficiency of Greek public hospitals. *EJBSS, 4*, 111-25.

Katharaki, M. (2008). Approaching the management of hospital units with an operation research technique: The case of 32 Greek obstetric and gynaecology public units. *Health Policy, 85*(1), 19-31.

Kazley, A. S., & Ozcan, Y. A. (2009). Electronic medical record use and efficiency: A DEA and windows analysis of hospitals. *Socio-Economic Planning Sciences, 43*(3), 209-216.

Kontodimopoulos, N., Nanos, P., & Niakas, D. (2006). Balancing efficiency of health services and equity of access in remote areas in Greece. *Health policy*, *76*(1), 49-57.

Kooreman, P. (1994). Nursing home care in The Netherlands: a nonparametric efficiency analysis. *Journal of health economics, 13*(3), 301-316.

Kumar, S., & Gulati, R. (2008). An examination of technical, pure technical, and scale efficiencies in Indian public sector banks using data envelopment analysis. *Eurasian Journal of Business and Economics, 1*(2), 33-69.

Lee, C. C. (2009). Analysis of overall technical efficiency, pure technical efficiency and scale efficiency in the medium-sized audit firms. *Expert Systems with Applications, 36*(8), 11156-11171.

Mirmozaffari, M., & Alinezhad, A. (2017, October). *Window analysis using two-stage DEA in heart hospitals.* In 10th International Conference on Innovations in Science, Engineering, Computers and Technology (ISECT-2017) (pp. 44-51).

Miszczynska, K., & Miszczyński, P. M. (2021). Measuring the efficiency of the healthcare sector in Poland–a window-DEA evaluation. *International Journal of Productivity and Performance Management 70*(3), https://doi.org/10.1108/IJPPM-06-2020-0276.

Mitropoulos, P., Mitropoulos, I., & Giannikos, I. (2013). Combining DEA with location analysis for the effective consolidation of services in the health sector. *Computers & Operations Research, 40*(9), 2241-2250.

Mitropoulos, P., Mitropoulos, I., & Sissouras, A. (2013). Managing for efficiency in health care: the case of Greek public hospitals. *The European Journal of Health Economics*, *14*(6), 929-938.

Mitropoulos, P., Talias, M. A., & Mitropoulos, I. (2015). Combining stochastic DEA with Bayesian analysis to obtain statistical properties of the efficiency scores: An application to Greek public hospitals. *European Journal of Operational Research, 243*(1), 302-311.

Muhammad, A., Rao, T., & Farooq, Q. (2018). DEA Window Analysis with slack-based measure of Efficiency in Indian Cement Industry. *Statistics, Optimization & Information Computing, 6*(2), 292-302.

Ohe, Y., & Peypoch, N. (2016). Efficiency analysis of Japanese Ryokans: A window DEA approach. *Tourism Economics, 22*(6), 1261-1273.

Oikonomou, N., Tountas, Y., Mariolis, A., Souliotis, K., Athanasakis, K., & Kyriopoulos, J. (2016). Measuring the efficiency of the Greek rural primary health care using a restricted DEA model; the case of southern and western Greece. *Health care management science, 19*(4), 313-325.

O' Neill, L. & Rauner, M., Heidenberger, K. & Kraus, M. (2008). A cross-national comparison and taxonomy of DEA-based hospital efficiency studies, *Socio-Economic Planning Sciences 42*(3), 158-189.

Ozcan, Y. A., & Luke, R. D. (2011). Health care delivery restructuring and productivity change: assessing the Veterans Integrated Service Networks (VISNs) using the Malmquist approach. *Medical Care Research and Review, 68*(1_suppl), 20S-35S.

Pedraja-Chaparro, F., Salinas-Jimenez, J., & Smith, P. (1997). On the role of weight restrictions in data envelopment analysis. *Journal of Productivity Analysis, 8*(2), 215-230.

Polyzos, N. (2012). A three-year Performance Evaluation of the NHS Hospitals in Greece. *Hippokratia, 16*(4), 350-55.

Polyzos, S., Niavis, S., & Pnevmatikos, T. (2012). Longitudinal evaluation of Greek regional policies using window data envelopment analysis. *MIBES Transactions, 6*(1), 53-65.

Pulina, M., Detotto, C., & Paba, A. (2010). An investigation into the relationship between size and efficiency of the Italian hospitality sector: a window DEA approach. *European journal of operational research, 204*(3), 613-620.

Ray, S. (2004). *Data Envelopment Analysis*. Cambridge: Cambridge University Press.

Scheel, H. (2000). *EMS: Efficiency Measurement System.* User's Manual, Version 1.3, 2.

Seiford, L. M., & Zhu, J. (2002). Modeling undesirable factors in efficiency evaluation. *European journal of operational research*, *142*(1), 16-20.

Stefko, R., Gavurova, B., & Kocisova, K. (2018). Healthcare efficiency assessment using DEA analysis in the Slovak Republic. *Health economics review, 8*(1), 1-12.

Thanassoulis, E. (2001). *Introduction to the Theory and Application of Data Envelopment Analysis, A foundation text with integrated software.* Massachusetts: Kluwer Academic publishers, 19-23.

Thanassoulis, E., Dyson, R. G., & Foster, M. J. (1987). Relative efficiency assessments using data envelopment analysis: an application to data on rates departments. *Journal of the Operational Research Society*, *38*(5), 397-411.

Thomas, J. W., Guire, K. E., & Horvat, G. G. (1997). Is patient length of stay related to quality of care?. *Journal of Healthcare Management, 42*(4), 489.

Trakakis, A., Nektarios, M., Tziaferi, S., & Prezerakos, P. (2021). Total productivity change of Health Centers in Greece in 2016–2018: a Malmquist index data envelopment analysis application for the primary health system of Greece. *Cost Effectiveness and Resource Allocation, 19*(1), 1-11.

Tsekouras, K., Papathanassopoulos, F., Kounetas, K., & Pappous, G. (2010). Does the adoption of new technology boost productive efficiency in the public sector? The case of ICUs system. *International Journal of Production Economics, 128*(1), 427-433.

Xenos, P., Yfantopoulos, J., Nektarios, M., Polyzos, N., Tinios, P., & Constantopoulos, A. (2017). Efficiency and productivity assessment of public hospitals in Greece during the crisis period 2009–2012. *Cost Effectiveness and Resource Allocation, 15*(1), 1-12.

Yakob, R., Yusop, Z., Radam, A., & Ismail, N. (2014). Two-stage DEA method in identifying the exogenous factors of insurers' risk and investment management efficiency. *Sains Malaysiana, 43*(9), 1439-1450.

Yue, P. (1992). Data envelopment analysis and commercial bank performance: a primer with applications to Missouri banks. *IC² Institute Articles*.