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Türkiye'de Tıbbi Görüntüleme Cihazlarının Verimliliğini Etkileyen Faktörlerin Değerlendirilmesi: İki Aşamalı Veri Zarflama Analizi

Evaluation of the Factors That Affect the Efficiency of Diagnostic Imaging Technologies in Turkey: A Two-Stage Data Envelopment Analysis

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Öz

Giriş ve Amaç: Sağlık sektörü hem emek hem de teknoloji yoğun bir sektör olarak görülmektedir. Özellikle teknolojik gelişmelere bağlı olarak sağlık harcamalarında büyük artışlar yaşanmaktadır. Sağlık harcamaları üzerinde baskı oluşturan teknolojik cihazlar tüm dünyayı etkilerken, teknoloji yönetimlerini küresel bir endişe ve uzun vadeli bir sorun haline getiriyor. Bu çalışma, Türkiye'de 81 il arasında tıbbi cihaz kullanım etkinliğini karşılaştırmayı amaçlamaktadır. Bu çalışmanın temel amacı, tıbbi cihaz kullanımı açısından verimli ve verimsiz illeri yansıtarak ulusal bir çerçeve belirlemek ve buna göre çeşitli önerilerde bulunmaktır.
Gereç ve Yöntemler: Çalışma iki aşamalı analizden oluşmaktadır. İlk olarak Veri Zarflama Analizi (DEA) ve ardından Sıradan En Küçük Kareler (OLS) analizi yapılmıştır. DEA ile tıbbi cihaz kullanımında verimli ve verimsiz iller belirlenirken, illerin verimliliğini etkileyen faktörler OLS ile belirlenmiştir.
Bulgular: Toplam 81 ilden 22'si verimli, 59'u verimsiz bulunmuştur. Regresyon modeline göre büyükşehir olma durumu, üniversite mezun oranı ve kişi başına düşen gayri safi yurtiçi hasıla değişkenlerinin verimlilik skoru üzerinde istatistiksel olarak anlamlı bir etkisi bulunamazken ($p>0.05$); hekim sayısı ve yaşlı bağımlılık oranının verimlilik skoru üzerinde istatistiksel olarak anlamlı bir etkiye sahip olduğu görülmüştür ($p\leq0.05$).
Sonuç: Bu çalışmadan elde edilen sonuçların sağlık politikası yapıcılarına ve planlayıcılarına yol gösterici bilgiler sağlayacağı düşünülmektedir.

Anahtar Kelimeler: Bilgisayarlı tomografi, Manyetik rezonans görüntüleme, Tıbbi görüntüleme cihazları, Türk Sağlık Sistemi, Verimlilik.

Abstract

Objective: The healthcare sector is observed to be both labor and technology concentrated. Particularly based on the technological developments, there is a major increase in health expenditures. Technological devices, which make pressure on health expenditures, affect the whole world while making technology management become a global concern and a long-term problem. This study aims to compare the efficiency of medical device use among 81

provinces in Turkey. The main objective of this study is to determine a national framework by reflecting the efficient and inefficient provinces in terms of medical device use and to make various recommendations accordingly.
Materials and Methods: The study is comprised of a two-stage analysis. Firstly, the Data Envelopment Analysis (DEA) and then the Ordinary Least Squares (OLS) were utilized respectively. The efficient and inefficient provinces regarding medical device use were identified through DEA while the factors affecting the efficiency of provinces through OLS.
Results: 22 provinces were found as efficient and 59 as inefficient among 81 provinces in total. According to the regression model, there is not any statistically significant effect of the variables such as metropolitan, rate of university graduates, gross domestic product per capita on the efficiency score ($p>0.05$); the number of physicians and old-age dependency rate has a statistically significant effect on the efficiency score ($p\leq0.05$).
Conclusion: This study is considered to provide guiding information to health policy makers and planners through its results.

Keywords: Computed tomography, Diagnostic imaging technology, Efficiency, Magnetic resonance imaging, Turkish health system.

1. Introduction

In the previous years, there were very limited facilities for the provision of effective healthcare services for patients. However, the efficiency of healthcare services is recently improved with the development of various health technologies such as effective diagnosis devices (i.e., radiography, computerized tomography), effective medication (i.e., antibiotics), and other interventions [1]. The use of health technologies is crucial in the prevention, diagnosis, and treatment of disease as well as the rehabilitation of patients [2]. While *health technologies* are defined as the implementation of organized knowledge and skills in the way of developed devices, vaccines, medications, procedures, and systems [3]; the *medical device* is defined as an object, device, apparatus or machine used to identify, measure, correct or modify the nature and structure of the body for the purposes of prevention, diagnosis, treatment of disease or some other health purposes, and that cannot provide their main functions through pharmacological, immunological or metabolic effects when used on human [1]. Recently, there is rapid development in health technologies. Altman and Blendon [4] considered the development of health technologies as the offender behind the increase in health expenditures and noted that since there is an interest in media towards developing health technologies (i.e. CT) and the public perception of health technology is changing, the health expenditures show a tendency to increase.

The rapidly increasing healthcare services costs had become a significant matter in question in many countries in the 1980s and early 1990s. Such costs impose a threat particularly in the United States of America to providing better quality services to wider population groups. The aging of the population and associated chronic diseases and the occurrence of disabilities can be listed among the reasons for the increase in costs. Additionally, the use of more resources in healthcare services in addition to the momentum of technological developments and the correlation between technology and resource consumption are also given as reasons too [5]. Since it is not possible to restrict general expenditures for healthcare services and to balance existing resources and technological developments, health policies with regard to the assessment of health technology should be established accordingly. The new and multi-disciplinary domain called health technology assessment provides help to policy makers regarding the medical, economic, social, and ethical effects arising in the use and generalization of health technologies [1]. Technological developments, changing disease patterns, aging and demands of healthcare services users cause increases in health expenditures. Such factors that make pressure on health expenditures affect the whole world while making technology management a global concern and long-term problem [1].

Considering the rapid increase in health expenditures, one of the factors affecting such expenditures is the investment in and use of medical devices. Therefore, the efficiency and effectiveness of medical devices used in the healthcare system become subject matter. A number of individuals and institutions show an effort to promote much rational use of limited resources through the assessment of health technology [1]. Additionally, there is an increasing interest in assessing the efficiency of health technologies and medical devices and presenting the research results to decision makers for rational decision making. The comparative efficiency research are a significant effort to prevent increasing health expenditures and improve the health results of the population, yet it is observed that the efficiency comparison of medical devices is not that cared about and there is not sufficient number of research in that field. The comparative efficiency research on medical devices and interest regarding the prioritisation of the results of such research would encourage the demand for up-to-date data, and hence it would be possible to obtain better research results [6]. Within this framework, this study aims to compare the medical device efficiency in 81 provinces in Turkey.

2. Materials and Methods

This study aims to compare the medical device efficiency in 81 provinces in Turkey, which would reflect the provinces with medical device efficiency and inefficiency, and to determine national framework and to make recommendations accordingly (Table 1). The study is comprised of two stages where firstly Data Envelopment Analysis (DEA) and then Ordinary Least Squares (OLS) regression are utilized The input variables in DEA are MRG device, BT device, USG device, Doppler USG device and Echo devices per 100,000 people in the provinces while the output variables are the number of imaging with MRG device per 1000 examinations, the number of imaging with BT device per 1000 examinations, the number of imaging with USG device per 1000 examinations, the number of imaging with Doppler USG device per 1000 examinations and the number of imaging with Echo device per 1000 examinations.

Table 1. Distribution of variables (81 provinces in Turkey)

Variables	Mean	Sd.
Input Variables		
Number of MRG Device (per 100,000 people)	0.46	0.24
Number of BT Device (per 100,000 people)	0.81	0.34
Number of USG Device (per 100,000 people)	3.96	1.69
Number of Doppler USG Device (per 100,000 people)	3.85	2.04
Number of Echo Device (per 100,000 people)	1.63	0.61
Output Variables		
Number of Imaging with MRG Device per 1000 Examinations	22.49	6.06
Number of Imaging with BT Device per 1000 Examinations	31.14	7.57
Number of Imaging with USG Device per 1000 Examinations	60.16	27.27
Number of Imaging with Doppler USG Device per 1000 Examinations	27.28	17.63
Number of Imaging with Echo Device per 1000 Examinations	15.48	4.34
Independent Variables		
Rate of University Graduates 15 Years and Older (%)	12.94	2.52
Gross Domestic Product per capita ($)	9101.64	3381.80
Number of physicians (per 100,000 people)	57.00	12.80
Old age dependency rate (65+ years)	14.55	4.97
Number of metropolitans	Number	%
	30	0.37

Following the DEA analysis, OLS regression model is created with independent variables as rate of university graduates (%), GDP per capita (PPP, $), number of physicians per 100,000 persons, old age dependency rate (population rate over the age of 65) and metropolitan status of the province, and dependent variable as the efficiency score generated with DEA (Table 2).

The following section provides information about DEA and OLS regression, both of which are the main methods of study.

DEA is a non-parametric mathematical analysis based on linear programming where decision-making units (DMU) found as efficient as a result of analysis get a value of 1 and inefficient DMUs get a value of less than 1. DEA was firstly developed by Charnes et.al [7] who were influenced by Farrell [8], under constant returns-to-scale (CRS). Pursuant to this model, it is considered that where a decision-making unit proportionately increases its inputs, the level of increase in its outputs would be the same. Afterward, Banker et.al [9] developed the variable returns-to-scale (VRS) model showing that the increase in outputs might be more than the increase in the inputs (i.e., increasing returns to scale) or less than the increase in the inputs (decreasing returns to scale). CRS model shows *total efficiency* with pure technical efficiency due to administrative performance together with the scale efficiency due to the size of related DMU. On the other hand, VRS model shows pure technical efficiency without the size component, i.e., scale efficiency.

The efficiency scores are affected by which methods are adopted in DEA as either CRS or VRS. Another factor affecting the efficiency scores of DMUs is whether DEA is input or o8utput oriented. Pursuant to such orientation, the criteria to be considered efficient or inefficient are as follows [10]:

a) Where it is possible to increase output for a decision-making unit without increasing any input and decreasing any output, then that decision-making unit is not efficient (output-oriented).

b) Where it is possible to decrease an input for a decision-making unit without increasing any input and decreasing any output, then that decision-making unit is not efficient (Input-oriented).

Table 2. Efficiency Scores by Provinces

Provinces	CRS	Provinces	CRS
Adana	1,00	Kahramanmaraş	1,00
Adıyaman	0,68	Karabük	0,54
Afyonkarahisar	0,94	Karaman	0,79
Ağrı	0,91	Kars	0,57
Aksaray	1,00	Kastamonu	0,97
Amasya	1,00	Kayseri	1,00
Ankara	0,60	Kilis	0,72
Antalya	1,00	Kırıkkale	0,79
Ardahan	0,60	Kırklareli	0,72
Artvin	0,49	Kırşehir	0,59
Aydın	0,68	Kocaeli	1,00
Balıkesir	0,60	Konya	0,79
Bartın	0,96	Kütahya	0,89
Batman	0,99	Malatya	1,00
Bayburt	1,00	Manisa	0,86
Bilecik	0,65	Mardin	1,00
Bingöl	0,89	Mersin	0,92
Bitlis	0,96	Muğla	0,78
Bolu	0,43	Muş	0,99
Burdur	0,43	Nevşehir	0,68
Bursa	0,96	Niğde	0,93
Çanakkale	0,73	Ordu	0,61
Çankırı	1,00	Osmaniye	1,00
Çorum	0,68	Rize	1,00
Denizli	1,00	Sakarya	0,75
Diyarbakır	1,00	Samsun	0,68
Düzce	1,00	Şanlıurfa	1,00
Edirne	0,82	Siirt	0,44
Elazığ	1,00	Sinop	0,69
Erzincan	0,68	Şırnak	0,70
Erzurum	0,44	Sivas	0,79
Eskişehir	0,83	Tekirdağ	0,95
Gaziantep	1,00	Tokat	0,96
Giresun	0,70	Trabzon	0,70
Gümüşhane	0,97	Tunceli	0,48
Hakkari	1,00	Uşak	1,00
Hatay	0,81	Van	0,93
Iğdır	1,00	Yalova	0,85
Isparta	0,99	Yozgat	0,32
İstanbul	1,00	Zonguldak	0,66
İzmir	0,65	**Average Efficiency Score**	**0,82**

CRS with the input-oriented model is selected for this study. The reason for having this study as input-oriented is that DEA studies conducted in the domain of healthcare services are mainly input-oriented since the managerial control in healthcare services is on the inputs rather than outputs [11-13].

The reason for choosing CRS model in this study is the aim of comparing the provinces compared based on technology use in healthcare services, in consideration of pure technical efficiencies arising from managerial performance together with their sizes.

The mathematical presentation of input-oriented CRS model under DEA is given as follows [7]:

$$Maximize\ \Theta_o = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$

$$subject\ to\ \ \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$$

$$u_r, v_i \geq 0$$

j *refers to DMUs compared with each other* $(1,2,\ldots\ldots,n)$;

u_r *and* v_i *refer to the weights applied to the outputs and inputs, respectively*;

y_{rj} *and* x_{ij} *refer to the selected outputs and inputs, respectively*;

Θ_o *refers to the efficiency scores of DMUs.*

For this study, OLS is utilized as the second-stage analysis with the aim of reflecting the factors that influence DEA, which is the health technology use efficiencies of provinces. Under the OLS regression, it is required that the independent variable should not bear any measurement error while dependent variables should have a constant analytic effect. This situation, which is known as the constant variance assumption is crucial with regard to the reliability of OLS regression [14]. In the OLS regression technique, it is also crucial that residuals show normal distribution without any multicollinearity and autocorrelation problems. The test conducted showed that the model established within the scope of this study does not have related problems. Such results are given under the results section.

3. Results and Discussion

3.1.Results

Table 1 shows the mean and standard deviation values of input and outputs used in DEA and of independent variables used in regression analysis.

Pursuant to Table 1, the average number of MRG devices per 100,000 people is 0.46 (±0.24), 0.81 (±0.34) for BT devices, 3.96 (±1.69) for USG devices, 3.85 (±2.09) for Doppler USG device and 1.63 (±0.61) for Echo device. Considering the output variables, the average number of imaging per 1000 examinations with MRG device is 22.49 (±6.06), 31.14 (±7.57) with BT device, 60.16 (±27.27) with USG device, 27.28 (±17.63) with Doppler USG device, and 15.48 (±4.34) with Echo device. Finally, the independent variables indicate that the average rate of university graduates is 12.94%; the average gross domestic product per capita is 9101.62; the average number of physicians per 100,000 people is 57 and the average rate of old-age dependency is 14.55. Where the number of 81 provinces evaluated in terms of metropolitan status, 37% of provinces were found as metropolitan. Table 2 presents the results of the CRS analysis that was conducted to reflect the medical device efficiency of provinces. Pursuant to the analysis, the provinces found as efficient are given in dark color on the table. Therefore, 22 of provinces were found as efficient and 59 as inefficient among 81 provinces in total. The efficient provinces are Adana, Aksaray, Amasya, Bayburt, Çankırı, Denizli, Diyarbakır, Düzce, Elâzığ, Gaziantep, Hakkâri, Iğdır, İstanbul, Kahramanmaraş, Kayseri, Kocaeli, Malatya, Mardin, Osmaniye, Şanlıurfa, Rize and Uşak. Additionally, the mean efficiency score for 81 provinces is generated within the scope of analysis while the mean rate for general efficiency is 0.82. The general inefficiency rate for 59 provinces is 0.75. Finally, the province with the lowest inefficiency rate is found in Yozgat with 0.32.

Table 3 represents the correlation coefficients between independent variables used in the regression analysis conducted within the scope of research.

Table 3. Correlation Coefficient Between Independent Variables

Variables	**Status of Metropolitan**	**Rate of University Graduates for 15 Years and Above (%)**	**Gross Domestic Product per Capita ($)**	**Number of physician (per 100,000 people)**	**Old-age Dependency Rate (+65)**
Status of Metropolitan	1				
Rate of University Graduates for 15 Years and Above (%)	0.259*	1			
Gross Domestic Product per Capita ($)	0.272*	0.702**	1		
Number of physicians (per 100,000 people)	-0.119	0.448**	0.356**	1	
Old-age Dependency Rate (+65)	-0.352**	0.316**	0.281*	0.465**	1

*p<0.05; **p<0.01

Pursuant to the relevant correlation coefficients, the correlation coefficients between the variables are found as between -0.119 and 0.702. Hence, the highest correlation efficiency (r=0.702) was generated between the rate of university graduates and gross domestic product per capita, yet such a correlation coefficient is within the acceptable limits. Therefore, it is concluded that the correlation coefficients are not high; hence all variables used in the research are eligible for analysis. Before the test results regarding the sufficiency of the model established under the study. Therefore, Jargue-Bera test is used to analyze whether residuals show normal distribution and the result indicated that they have normal distribution (p=0.61).

Breusch-Godfrey Test (Prob. Chi-Square=0.60) was conducted to reflect that there is not any autocorrelation between the residuals. The residuals were also evaluated whether they have any heteroscedasticity problem and the results showed that they do not have such problem. Finally, the model pattern is evaluated with Ramsey Reset Test and the result indicated that the model pattern is established correctly (p=0.11).

Table 4 shows the results of OLS regression on the five variables considered to affect the medical device efficiency of provinces.

Table 4. OLS Regression Analysis Results on the Factors Affecting the Efficiency Scores

Variable	Coefficient	Standard Error	t-Statistic	Prob.	Collinearity Statistics VIF
Constant	1.317	0.089	1.472	0.00	-
Status of Metropolitan	-0.075	0.041	-0.894	0.37	1.337
Rate of University Graduates for 15 Years and Above (%)	-0.006	0.000	-0.784	0.44	1.277
Gross Domestic Product per Capita ($)	0.082	0.000	1.654	0.10	1.436
Number of physicians (per 100,000 people)	0.362	0.002	5.241	0.00	1.318
Old-age Dependency Rate (+65)	0.009	0.004	1.972	0.05	1.453
S.E. of regression	0.15	R-squared (R^2)			0.37
Sum squared residue	1.75	Adjusted R-squared			0.33
Log likelihood	40.37	Mean dependent var.			0.82
F-statistic	8.89	S.D. dependent var.			0.19
Prob.(F-statistic)	0.00	Durbin-Watson (d)			2.09

Therefore, the established model is observed as significant in general (F=8.89; p<0.001). Additionally, Durbin-Watson coefficient showing whether there is auto-correlation in the model is found as 2.09, which reflects no autocorrelation between the variables. Where Durbin-Watson (d) value and R^2 value are compared; the model can be considered as having no spurious regression with $d>R^2$. In consideration of the coefficient of determination (R^2), the five variables under the model explain 37% of medical device efficiencies in provinces.

According to the regression model, there is not any statistically significant effect of the variables as the status of metropolitan, rate of university graduates and gross domestic product per capita on the efficiency score (p>0.05); the number of physicians and old-age dependency rate has statistically significant effect on the efficiency score (p≤0.05). Based on the Beta coefficients (0.362), the effect of number of physicians has higher effect on the efficiency score than other variables under the model.

Considering the in-depth analysis regarding the effects of independent variables found as significant under the model, the variables of number of physicians and old-age dependency rate have positive effects on the efficiency. Hence, the efficiency score of provinces increases in direct proportion to the number of physicians and old-age dependency rate.

3.2.Discussion

Recently, it is a known fact that the major developments particularly in the medical devices used for imaging purposes (e.g., MRG and BT) provided significant benefits in the diagnosis and treatment of diseases [15, 16]. The use of such technologies in the provision of healthcare services increased through their advantages as they do not require any interference from the patient and the results can be generated together with advanced health technologies (e.g., PACS) [17-23]. However, other than the benefits of medical devices, they are also deemed responsible for most of the increase in the cost incurred in healthcare services [24-27]. This brings up the issue of whether the existing medical devices are used efficiently, and what other health policies might be developed to improve efficiency.

Within such perspective, this study aims to identify the efficiency levels of medical devices (MRG, BT, USG, Doppler USG, Echo) in Turkey as one of the countries with average level of advanced medical devices yet with the high level of use [28], and to present the factors affecting the efficiency. The result of the analysis conducted for such purpose, only 22 provinces were found as efficient while 59 are inefficient among 81 provinces. The efficiency score is found as 0.82 in general and 0.75 for the inefficient provinces. Such inefficiency can be explained by the fact that majority of inefficient provinces are in rural regions and people living in rural areas tend to use such services less than people in the urban regions [29-31]. The study by Cinaroglu and Baser [32] conducted to analyze the distribution of medical devices in public hospitals of Turkey showed that the provinces are grouped as urban and rural, and regarding the number of devices, there is a difference against the provinces in the rural regions. Also, Songur and Top [33] found that there were inequities in medical devices according to regions in Turkey. The study by Ozcan and Legg [34] regarding the efficiencies of radiology clinics in America reflected that the units providing advanced radiology services have an efficiency level of 0.615 in general while such value is 0.418 for inefficient units. According to the study by Keshtkaran et.al [35] on the efficiencies of radiology units in the public hospitals of Iran, the general efficiency level is 0.880.

Within the scope of the study, out of the independent variables used to identify the efficiency levels of medical devices, the number of physicians (per 100,000 people) and old-age dependency rate (+65) have significant effect ($p<0.05$) while the status of metropolitan, number of graduates aged 15 and above, and gross domestic product per capita have not any significant effect ($p>0.05$). Among the variables of number of physicians and old-age dependency, the number of physicians have higher effect on the efficiency level ($\beta=0.362$) and both number of physicians and old-age dependency rate have positive effect on the efficiency level; in other words, the efficiency level increases as the rates of number of physicians and old-age dependency increase. Since the number of imaging per examination is used as output variable under the study, the increase in efficiency levels has a direct proportion with the increase in medical device use.

The effect caused by the increase in the number of physicians on the efficiency level can be explained by the wide use of medical devices with imaging purpose by physicians in the diagnosis and treatment of diseases due to giving faster results and consequently contributing to earlier diagnosis as well as being a barrier before wrong diagnosis [26, 36-41]. Moreover, the such circumstance can also be explained by the fact that in Turkey there must be a justification on the discharge report and examination result documentation for the reimbursement of medical devices used for imaging purposes, and the use of such medical devices must be invoiced together with the report of radiology specialist doctor. Regarding the old-age dependency rate (65+), which is another factor affecting the efficiency of medical devices, the literature indicates that the use of medical devices used for imaging purposes increase with the aging of population, and elderly individuals tend to use such services at a relatively higher level [19, 22, 42-45]. Pursuant to the study of Hu [46] conducted to identify the factors affecting the efficiency and use of medical devices used for imaging purposes, the age of the patient was found as an important factor respectively.

4. Conclusion

Finally, this study identified the efficiency levels of medical devices used in Turkey and analyzed the factors affecting efficiency. Within this perspective, the number of medical devices was used as an input variable and number of imaging per examination as output variable to identify the efficiency levels, and the majority of provinces (about 73%) were found as inefficient in using medical devices. Therefore, the study recommends the review of health policies in the assignment of medical devices and improvement of regulating activities that increase efficiency. In consideration with the factors affecting efficiency, the number of physicians and old-age dependency rate was found as the variables that positively affect efficiency. Such variables can be considered as increasing the use of medical devices since the numbers of imaging per examination were used as output variables. At this point, it is important to ensure the unnecessary use of medical devices. It should be also considered that the results generated through this study might be different when the study is repeated with different input, output and independent variables. The variables regarding the radiology personnel and costs, which might affect the efficiency of medical devices, could not be used under this study due to the data constraints, which can be considered as the limitation on this research. Therefore, it is recommended to take into consideration such variables in future studies for efficiency calculations with other variables that might affect the efficiency of medical devices. However, this study becomes more important since the rate of medical device use in Turkey is higher than other countries with similar development level, and the number of studies concerning the efficiency of medical devices in Turkey is very few in number. This study is considered to provide guiding information to health policy makers and planners through its results.

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