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Military Hospitals Efficiency Evaluation: Application of Malmquist Productivity Index-Data Envelopment Analysis

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Abstract

The main purpose of this study is to look at the development of efficiency and productivity in the military hospital sector of Tehran province, by applying a nonparametric method. The study applied the nonparametric method to assess the efficiency of military hospitals service in Iran, Tehran, over the period 2013-2016. Utilizing non-parametric methodology, Data Envelopment Analysis (DEA) and Malmquist productivity index (MPI), individual hospital efficiency and productivity changes which took place within this period are estimated. The present study helps to understand the productivity and technological change and change in technical efficiency in this area, which is essential for policy making identifying improvement opportunities in resource allocation. The difference in productivity in this study is attributed to technological change rather than technical efficiency change. It was observed that military hospitals did not improve the efficiency with which they employed their inputs (i.e., staff and supplies) over the study period; moreover, the Malmquist Index Productivity increases and decreases interchangeably over the period. They did achieve gains and losses through the application of technologies. These results should be both informative and reassuring to military leaders and citizen alike. The most of past studies have been conducted in developed countries. But this paper provides a thorough study on the productivity growth of health care service in military hospitals in Iran using a non-parametric framework with Malmquist Productivity Index. Using panel data, this paper is the first study in Iran to use the Malmquist Productivity Index with Data Envelopment Analysis that provides new empirical evidence on the long-term trends in the efficiency of military hospitals in Iran.

Keywords: Data Envelopment Analysis (DEA), Military hospital performance, Malmquist Productivity index (MPI), Technological Efficiency.

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1. Introduction

As one of the most significant components of the healthcare industry, the hospital sector plays a crucial role to provide healthcare services. Hospitals are considered a critical tangible segment of the healthcare organization(1). In time, the efficiency of the healthcare system has become synonymous with health expenditures. Furthermore, for both the economies with a high development index and the economies with a medium development index, the increase in the efficiency of the expenses associated seems to be the only option that would allow public systems to overcome the pressure of the expenditures related to age and tax increase(2). Hospitals are usually considered as non-profit organizations assigned with the mission of meeting the healthcare needs of the general public(3). In recent years, due to rising healthcare costs and demands for higher quality, hospitals have invested in healthcare to reduce costs and errors, and improve the quality of healthcare(4). To identify useful healthcare productivity improvements, efficiency must be validly measured. On the other hand, if healthcare efficiency is incorrectly measured, then governmental policy makers and hospital managers may respond in ineffective and even counterproductive ways(5). Although hospitals may have become more efficient, it is also possible that quality of care was harmed as they had to conserve on staffing and other resources and used these resources more intensely to serve growing demand(6). It is essential for policy makers and decision makers to monitor and evaluate the hospital's performance by employing efficiency and productivity analysis. The mission of the military health systems is "to enhance the Health of personnel of the army and our nation's security by providing health support for the full range of military operations and sustaining the health of all those set rusted to our care. Differences between military

and civilian hospital are significant, military medical leaders face the problematic position of preparing military personnel for deployment, caring for wounded warriors returning from battle, and providing day-to-day medical care for active duty personnel, their family members, and retirees- all while being morally responsible to citizens and fiscally responsible to taxpayers. Military hospitals receive funding annually through congressional Appropriations. This added level of bureaucracy could alter the behavior of health care providers, although fundamentally, any effect should be similar to that of state and local hospitals that receive funding through governmental appropriations. In military hospitals, physicians are either employee who gets a salary for their services or contractors also paid directly from the facility's budget. The patient base of military hospitals is likely younger and healthier than the population served by civilian hospitals, and it is likely that the health needs of this patient base are different from a patient population. Military hospitals have a dual mission: it maintains medical readiness of personnel-including themselves-for war and it provides a "benefit" mission, caring for all its beneficiaries, including family members and retirees. Military hospitals care for a highly-valued segment of citizens- those who volunteer to defend our country and all citizens fund this care with taxes. If military hospitals provide similar care more efficiently, perhaps other healthcare providers can learn from military practices and procedures identified as efficiency-promoting. Alternatively, if military hospitals are not capable of providing high-quality health care efficiently, perhaps policymakers should consider pursuing other alternatives for providing healthcare to military beneficiaries(7). Politicians can use efficiency scores to re-appraise their payment policy(8). Economic pressure and the government's budget deficit have

placed increasing pressure on military hospitals in Iran to contain cost. Assessing the efficiency of healthcare systems is a complicated process, which often encounters methodological problems(2). Two main approaches have been employed by scholars to determine the efficiency and productivity of hospitals. Firstly, is the parametric one, i.e., Stochastic Frontier Analysis (SFA) and secondly the non-parametric one, i.e., Data Envelopment Analysis (DEA). Data envelopment analysis is a linear programming method for evaluating the relative efficiency of a set of decision-making units (DMU¹) by analyzing their weighted inputs and outputs. This method is flexible and allows the performance/efficiency of these DMUs to be interpreted based upon a set of selected performance metrics(9). First presented in 1978 and based on the paper of Farrell, the first DEA model is known in the literature as the CCR model, after its authors, Charnes, Cooper and Rhodes. Thus, by using linear programming and by applying nonparametric techniques of frontier estimation, the efficiency of a DMU can be measured by comparing it with an identified frontier of efficiency. The DEA model is input or output oriented. An output-oriented DEA model is channeled towards maximizing the outputs obtained by the DMUs while keeping the inputs constant, while the input-oriented models focus on minimizing the inputs used for processing the given amount of outputs. In practical evaluations, researchers will not only pay attention to static operational efficiencies of the evaluating unit in a certain period but also focus on dynamic operational efficiencies of the evaluated in different periods (10). However, the idea behind efficiency analysis is to use data

collected for firms to derive the best practice frontier what constitutes a best practice frontier can change over times. Therefore, it is essential to incorporate this aspect of the production process(11). In the present paper, the method applied for assessing the efficiency of military hospitals by Malmquist Productivity Index –Data Envelopment Analysis (MPI-DEA) for an input-oriented specification.

2. Literature review

Up to now, DEA has been applied to many areas such as banking, insurance, energy, and auditing. As shown in a recent survey of DEA application, health care is among the top-five industries(12). To our best knowledge, Sharman(1984) is the first to evaluate hospital efficiency using DEA even though Nunamaker (1983) publishes the first paper in health care focusing on nursing service efficiency(13). Several studies have reviewed the literature on the application of DEA in general; however, most of the earlier studies have focused on specific characteristics or types of the hospital rather than the evaluation efficiency in a period. This survey explicitly examines the changes in the productivity of army hospitals in 2013 and 2016. Information about efficiency change and technological change over time can be studied by using MPI-DEA(14). The MPI-DEA is a normative measure that is calculated using the ratio of distance functions at different input-output combinations for product comparison and is commonly used with DEA check trends in the productivity of the DMUs and to identify patterns of change(15). The MPI-DEA estimates total factor productivity (TFP) growth of a DMU (e.g., hospital). It reflects progress or regress in efficiency along with progress or regress of the

1. In this paper DMUs are military hospitals for which some inputs and outputs are selected.

frontier technology over time in the context of multiple inputs and multiple outputs. This character has made it particularly well suited to the analysis of hospital data. A review of literature and cross-references obtained from there revealed many researchers who have explicitly studied the MPI-DEA to measure efficiency and technical changes of hospital services Table 1 provides a summary of 10 of the newest studies conducted on the evaluation of performance of hospitals by MPI-DEA and includes the author(s), period, jurisdiction, and findings.

3. Methodology

The non-parametric approaches do not make any assumptions about the form of the production frontier. Instead, a ‘best-practice’ production frontier is built empirically from observed inputs and

outputs. It truly does envelop a data set as tightly as possible without any accommodation for statistical noise(16). In DEA, as a non-parametric method, the entities responsible for transforming inputs into outputs are referred to as ‘Decision-Making Units’ (DMU) which may represent any organizations such as hospitals as long as they perform the same or similar tasks.

The measurement of relative efficiency where there are multiple incommensurable inputs and outputs was developed by Farrell (1957), considered a pioneer in this field. His relative efficiency measure focused on the construction of a hypothetical efficient unit to play a role as a comparator for an inefficient unit. A measure for relative efficiency is,

$$\text{The efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}$$

Table 1. Previous studies on hospital productivity, efficiency, and technological change

Author(s)	Study period	jurisdiction	Main findings
Chowdhury et al. (2010)	2003-2006	Canada	they discovered that a large number of hospitals did not achieve significant progress regarding productivity.
Valdmanis et al. (2016)	2003-2007	Scottish	Each previous technical change variable had a negative effect on the later time technical change
Debela et al. (2017)	2007-2012	Ethiopia	Malmquist Total Factor Productivity(MTFP) of the hospital's decrees
Chen (2017)	2005-2012	Pennsylvania	They find that: (1)15.4% of hospitals are always efficient while 36.9% of hospitals are always inefficient for all years in 2005-2012
Guo et al.2017	2000-2013	Hong Kong	they found that the public hospital serving in a richer district has a relatively lower efficiency.
Li and He(2018)	2009-2014	China	There are pieces of evidence that both marketization and government subsidies can boost the treatment quality of the hospital's sector
Gimenez et al. (2018)	2009-2013	Colombian hospitals	The results demonstrated that adjusted production (service provision) and levels of quality and referrals to higher-level hospitals could be improved, on average, by 44 %.
Peixoto (2018)	2012, (12 months)	Brazil	Results show that the groups' formation represented divergences between both techniques applied.

It is normalized to from zero to one. Farrell's measure of efficiency requires a standard set of weights to be applied across all DMUs. The question of how we can obtain such an agreed standard set of weights presents the main criticism of this approach. This explicit definition of efficiency, that is, "overall efficiency" can be decomposed into "allocative" and "technical efficiency." Technical efficiency measures the extent to which a given combination of inputs produces as much output as feasible (Fig 1), whereas allocative efficiency measures the extent to which a DMU is minimizing the cost of providing the desired level of production(17).

Empirical measurement of inefficiency has been accomplished using two classes of methodologies: stochastic parametric regression-based methods and no stochastic nonparametric mathematical programming methods(17). In general, stochastic frontier analysis(SFA) measures technical or cost efficiency while DEA mainly estimates technical efficiency in particular, technical efficiency is a measure of how well a hospital produces output from a given amount of input or produces a given amount of the production with minimum quantities of input(18). DEA is ideally suited for the public sector,

not-for-profit environment, in which prices were suspect at best and missing at worst. Consequently, the majority of DEA models use only quantitative data and calculate the technical efficiency, even though with reliable information on both quantities and prices overall(economic) efficiency can be calculated and decomposed into its technical and allocative components, just as in the parametric(econometrics) approach. Monitoring performance over time is essential in health care organizations. The MPI-DEA is one of the most frequently used techniques(19) to calculates efficiency and provides an evaluation for productivity change over time(20). This index explains the difference in efficiency, or "catching up," and technological change(21).

The MPI-DEA is a method which provides an opportunity to compare the health care facility performance from one period to another. Such a tool was suggested first by Malmquist (1953), then developed as a productivity index by Caves, Christensen, and Diewert (1982), and then further developed by Fare, Grosskopf and Lowell (1994) as the Malmquist-DEA performance measure.

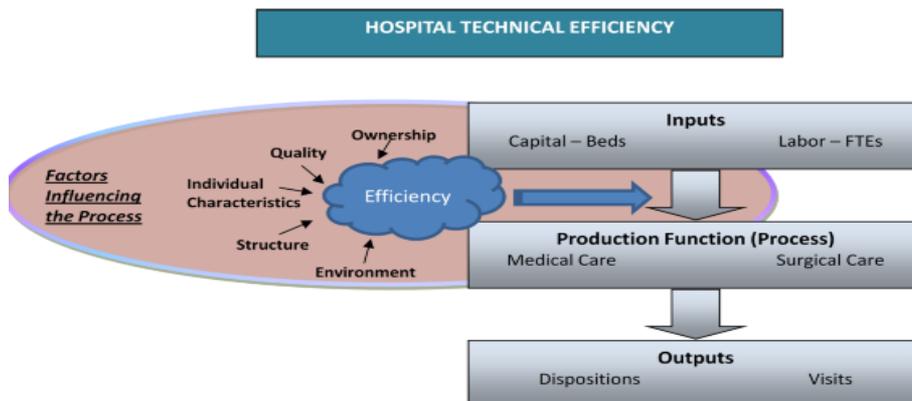


Figure 1. Conceptual Model of Hospital Technical Efficiency(7)

The advantage of applying The DEA-based Malmquist productivity index(MPI) indices when compared to others is that it does not necessitate prices while eliminating the need for assumptions about the structure of the technology(22).

To derive the Malmquist measure and its decomposition, we begin by representing hospital technology with the input the input requirement set, which includes all sets of inputs that can be used to obtain a specific set of outputs given the available technology. We begin by defining the technology as input quantities

$x = (x_1, \dots, x_N) \in N_+^N$ And outputs are given $y = (y_1, \dots, y_M) \in N_+^M$ The technology consisting of all feasible (x, y) is defined by:

$$T = \{x: z.M \geq y, z.K \leq x, z \in N_+^+\}$$

Where $z = (z_1, \dots, z_N)$ is a vector of non-negative weights that are applied to the observed input and output vectors ensuring a convex combination of the vectors that envelop the data, forming frontier. The lower bound of the input requirement set determines the best-practice frontier. Over time, hospital productivity can increase or decrease via changes in production technology (i.e., technical change). To gauge how hospitals' total factor productivity has changed over time, we calculate the input-oriented Malmquist Index of productivity change and its components. The DEA basic model, which assumes constant returns to scale everywhere, measures the Shepard(1970) input distance $D_i^t = (x_i^t, y_i^t)$ for a DMU $i(i=1,2,\dots,T)$, relative to the technology existing at the same period and it is always less than one. Computing the Malmquist index requires an additional input distance function to be defined: $D_i^{t+1} = (x_i^t, y_i^t)$ is the input distance function of the same DMU at time t , relative to technology at the period $t+1$. Using the variable returns to scale constraint would lead to biased findings. More formally, in a DEA setting

the input based Malmquist index ($M_i^{t,t+1}$) and its decompositions into efficiency and technological change indices between periods t and $t+1$, can be defined as (fare and et al., 1992, 1995):(23). The technological efficiency is the product of the Geometric mean of $TC_i^{t,t+1}$;

$$M_i^{t,t+1} = \frac{D_i^{t+1}(x_i^{t+1}, y_i^{t+1})}{D_i^t(x_i^t, y_i^t)} * \left[\frac{D_i^t(x_i^{t+1}, y_i^{t+1})}{D_i^{t+1}(x_i^{t+1}, y_i^{t+1})} * \frac{D_i^t(x_i^t, y_i^t)}{D_i^{t+1}(x_i^t, y_i^t)} \right]^{1/2} = EC_i^{t,t+1} * TC_i^{t,t+1}^{1/2};$$

$(i = 1, 2, \dots, n; t = 1, 2, \dots, T - 1)$

Where $EC_i^{t,t+1}$, and $TC_i^{t,t+1}$ represent the efficiency change and technological change, respectively(23). We define efficiency change as the movements towards the frontier whereas technological change measures the shift of the boundary. This definition is the consistent description of the decomposition of the Malmquist Productivity Index. Specifically, values of $(M_i^{t,t+1})$, $EC_i^{t,t+1}$ or $TC_i^{t,t+1}$ more than one indicate a positive change for a DMU $i(i = 1, 2, \dots, n)$ between period t and $t+1$. The MPE-DEA approach along with its decomposition into efficiency and technological change captures how firms, in our case, hospitals, converge practices with each other. Two phenomena might be detected. The first, coined as co-integration (the tracking of efficiency scores) demonstrates that the scores are moving in the same direction. The second is called convergence of technologies (the catching up of technology), and it indicates that the frontiers are moving closer together. Efficiency change identifies the DMUs' movements toward the frontier, whereas technological change measures the shift of the frontier(23).

3.1. Experimental Result

3.1.1. Data and Inputs and Outputs Variables

The difficulties involved in the measurement of the hospital performance due to the complex nature of both inputs and outputs require special attention to the specification of a model, (i.e. the definition of outputs and inputs and its functional relationship) while the use of non-parametric techniques allow us to avoid making assumption about the functional relationship (20).

Five military hospitals constituted the study (Table 4).

Before discussing the results of DEA Malmquist models, it would be useful to determine the input and output variables (Table 2), that in this survey we used the findings of Sadidi and et al., about most essential variables in military hospitals in Iran.

The descriptive Statistics-for one period (2014) of variables is presented in Table3. The data sets are sourced from published in annual reports of each hospital. The period selected is between 2013 and 2016. To investigate the evolution of efficiency, panel data of the hospital sector have been

used to design nonparametric frontier models MPI-DEA.

3.1.2. Empirical Results/Productivity changes over time

K ranges from 1 to L (the length of the periods in the data). Time interval=1 means (2013=2014), (2014=2015), (2015=2016) for the data set in Table 4 as evaluated by the Malmquist-I-C (input-oriented and constant returns-to-scale) model.

To measure the productivity, change of military hospitals over time, we calculate the Malmquist Productivity Index of the hospitals during 2013-2016. Estimates of MPI-DEA for each of the five military hospitals are presented in Table 4. The MPI is the product of the Efficiency Change (EC) and the Efficiency Frontier-Shift (EFS). This explanation of MPI could be interpreted as the geometric mean of efficiency change measured by period t and t+1 technology, respectively. $MPI > 1$ shows an improvement in the total factor productivity of DMU_0 from period t to t+1, while $MPI = 1$ and $MPI < 1$ shows stability and deterioration in total factor productivity, respectively(25).

Table 2. Selected variables (24)

Selected indicators							Latent variables				
1-Number of beds 2-No.Of surgeons' 3-No.Of specialized medical doctors 4- No. Of general medical doctors 5-No.Of professional nurse 6-squats 7-bed							Input variables				
1-No.of emergency visit 2-No.Of inpatients 3-No.Of outpatients 4-No.of surgeries							Output variables				

Table 3. Descriptive Statistics-tim period 2017

	prof Nurs	Non Prof Nurse	genericaldoc	special Doc	surgeions	squares	bed	outpatientet	inpatient	emergency visits	Surgeries
Max	337	192	210	46	26	112000	11	180801	102331	46137	13778
Min	38	17	20	2	0	9327	2	74902	2192	9515	1306
Average	177.33333	94.333333	69.666667	15.833333	11.333333	37604.333	6	147148.5	25818.667	22798.5	6105.3333
SD	95.015203	59.171127	64.798834	14.937834	10.370899	35433.405	2.8867513	37685.974	34587.972	12439.278	3822.7094

In Table 4 for all hospital's productivity changes differently. So the Malmquist index increases and decreases interchangeably. It indicates that these hospitals experience progress and regress in the total factor productivity at different points during 2013-2016.

As for the average MPI, two average MPIs is greater than unity, which indicates progress in the total factor productivity. Also, three are less than unity, which means regress in the total factor productivity (Fig 2).

If we focus on the quantitative change of the average MPI in 2013-2016, we find that the average MPI decreases in this

period (Fig 2). The average MPI for period 2015-2016 is smallest and less than unity (0.9121115). So it indicates regress in the total factor productivity in 2016. Moreover, the average MPI for period 2013-2014 is larger than unity. Thus it showed progress in the total factor productivity in 2014.

The statistics of the Malmquist index for each hospital are shown in Fig.3, which partly reflects each hospital's productivity change. Note that the year 2015 is the worst of the recession. The V-shape change of the average MPI partly demonstrates the situation of the military hospitals (Fig 3).

Table 4. Malmquist productivity index for military hospitals

Malmquist	2013=>2014	2014=>2015	2015=>2016	Average MPIs
Khanevade	1	0.9791083	0.9532539	0.9774541
Emamreza	1.0715528	0.2830497	0.9159189	0.7568405
Golestan	1.0581517	1.1670846	1.010267	1.0785011
Hajar	1	0.9195072	0.8415801	0.9203624
Bethat	0.9397799	1.4272764	0.8395374	1.0688646
Average	1.0138969	0.9552052	0.9121115	0.9604045
Max	1.0715528	1.4272764	1.010267	1.0785011
Min	0.9397799	0.2830497	0.8395374	0.7568405
SD	0.0528258	0.4246713	0.0734564	0.13138

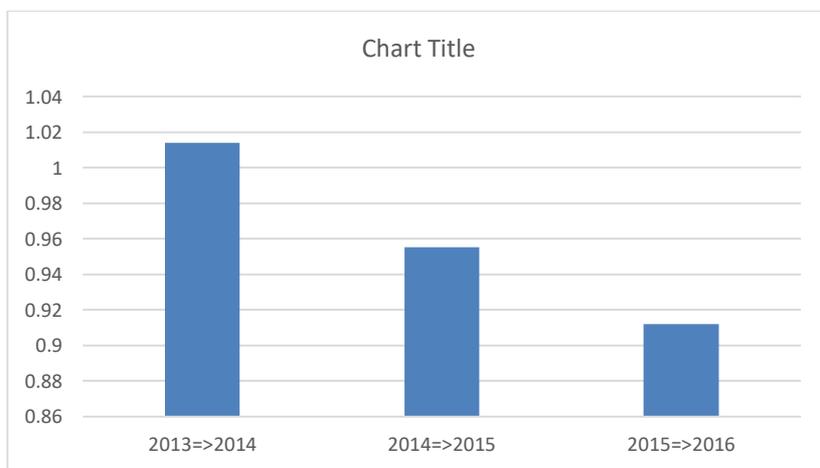


Figure 2. average efficiency of individual DMU's from 2013-2016

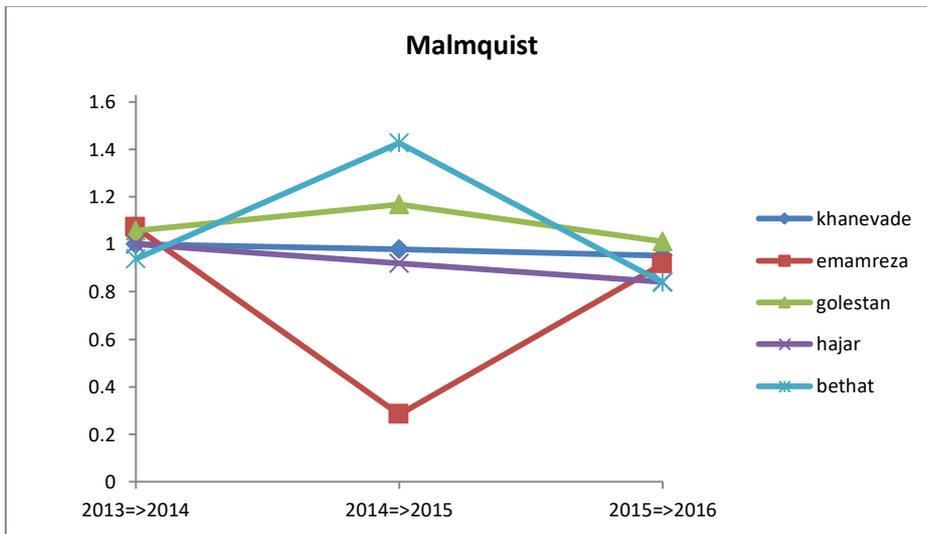


Figure 3 technological change

The minimal/maximal MPI is less (larger) than unity for all hospitals. Two DMU's minimal/maximal MPI is less/larger than 0.3/1.4, i.e., DMU Emamreza/Golestan. In comparison with the minimal/maximal MPI, the average MPI for each DMU is closer to each other. Moreover, all the DMUs' average MPI falls in the interval [0.2830497, 1.4272764].

Hospital of Emamreza has the smallest minimal MPI (0.2830497), which shows a massive change in productivity during 2014/2015.

4. Discussion

This paper analyzed the productivity growth of the five military Iranian hospitals. The fundamental question we ask in this paper is whether the military hospitals improved their productivity and efficiency over time in an environment where they were required to improve their services. Information about efficiency change and technological change over time can be studied by using a Malmquist productivity index. Using data from 2013 through 2016, we applied a Malmquist productivity index within the framework of DEA, to assess if the military hospitals

met this objective. The MPI –DEA allowed the determination of not only average productivity growth of the hospitals, but also the frontier growth (technological change) and the optimal resource utilization (technical efficiency change).

A Malmquist index value of greater than 1 indicates a productivity increase whereas an amount less than 1 points a productivity decline. A value of 1 indicates neither an increase nor a decrease in productivity (14).

The changes in hospital performance during the period were also quantified (temporal analysis), and are explained, in turn, as a result of the product of efficiency change (or catch up) and technological change.

The concept of efficiency change refers to whether hospitals are closer to or further away from observed best practices-which are determined by units(hospitals) lying on the frontier. The technological change, in contrast, refers to how these have moved over the period, i.e., to shifts of the border. Applying technological innovation is an essential way for enterprises to obtain a sustainable competitive advantage(26).

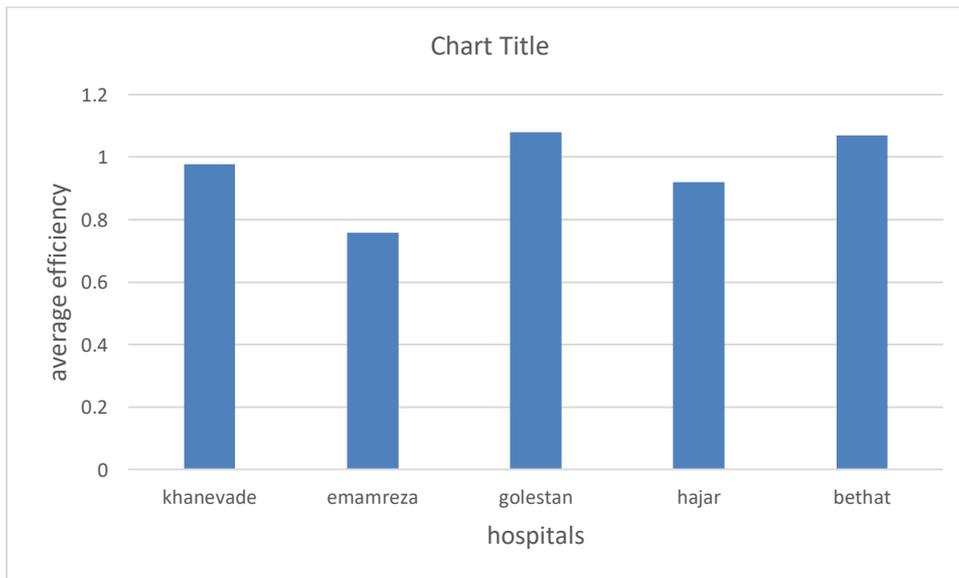
Comparing against individual hospitals, it is found that two of the hospitals experienced productivity progress (Figure 3). Hospital of Golestan claimed the most significant improvement in total factor productivity growth in the sample. On the other hand, the hospital of Emamreza experienced productivity retrogresses while hospital of Khanevade remained constant regarding productivity. This study shows that overall productivity and efficiency of military hospitals declined during the period 2013-2016.

Military hospitals operate under a government run and not a price-driven competitive market; these hospitals are required to produce services efficiently or else, because of the fixed budget, they cannot provide as much care(23).

Military hospitals could not adopt

different strategies to navigate through economic downturns. For example, military hospitals could not downsize operation, layoff some staffs, offer fewer services, expand geographic areas to reach more well-insured patients. One source to variation over time can relate to the fact that hospitals become more efficient or that there is some technological innovation that makes it possible to, overall, use less inputs to produce a given amount of output.

In this research, we don't observe the variation in scale efficiency, so the problem of the scale efficiency is related to the capability of entrepreneur and the capability of overcoming the decrease of returns-to-scale by the Optimization of organizational structure(e.g., distribution of decision-making power, performance assessment, and promotion methods(10).



Moreover, this first empirical contribution to Iranians military hospitals performance opens new paths for future research. Future work includes sensitivity analysis should be performed to determine which factors have the most impact.

Conflicts of interest: the authors declare no conflict of interest.

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