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Estimating production function: a tool for Hospital Resource Management

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Background: The necessity of correct management of costs in hospitals as an economic agent and their significance as the largest and most cost-consuming operational units of health system emphasize the importance of applying managerial tools and methods.
Objectives: This study was conducted to estimate the production function of all hospitals affiliated with the Social Security Organization (SSO).
Patients and Methods: This was a cross-sectional study conducted on 64 hospitals affiliated with SSO during 2007-2009. The Cobb-Douglas model was applied, estimating the above hospitals production functions. The numbers of physicians, nurses, other staff and active beds were considered as inputs and the numbers of outpatients and inpatients were mentioned as the study outputs. Log form of production function, EViews 5 and SPSS, were used.
Results: The production function of the studied hospitals showed that all the production factor indexes except for other staff had significant positive relationships with the number of inpatients as our output; meanwhile, the most and the least marginal production rates were related to active beds and other staff, respectively. Other findings showed a decreasing return to scale (DRS) in these hospitals. Moreover, during the whole study period, the highest average of surplus belonged to other staff.
Conclusions: According to the present results, it seems that these hospitals have to revise their human resource management policies to be able to apply this valuable input in an optimum manner. Furthermore, using appropriate economical tools may help them to recognize their surplus factors and in this way improve their productivity and efficiency.

Keywords: Hospital; Resource; Cost

1. Background

Hospitals play a crucial role in the economics of health and treatment, as they are the main organizations providing health service and are the largest and most expensive operational units in health system (1). While hospitals in developing countries use roughly 50% to 80% of the health sectors resources, almost 80% of these resources is spent on hospitals whose outputs are less than half their potential capacities (2). In recent years, a rising trend can be observed in the cost of hospitals in many countries (3), in a way that on average, around 60% of the total expenditure of health sectors is related to hospitals (4). Moreover, in developing countries, the surge in treatment cost in relation to revenue, the economic crises and governments' low budgets has made hospitals face high pressures regarding controlling and reducing the expenses (5). Conversely, in developed countries, the expenditures of state hospitals do not go beyond 40% of the health system total budget, emphasizing the importance of paying more attention to the economics of hospitals in developing countries (6). Despite spending large budgets, there is still a huge gap between the available and the required resources in hospitals of Iran and other developing countries in general. Such a limitation in the resources is more often than not met with a soaring trend in the demand for products and health services, rendering it practically impossible to gain perspective as to fully meeting the needs of consumers in the hospital sector (7). Moreover, the inadequacies in the economic infrastructure and its vulnerability when it comes to facing the flux in the market are expected to be compounded in the future. This is while the low utilization in such countries entails no benefit from investment and the workforce and threatens the interest in future investments in this sector (1). Production function is a systematic method presenting the relationship among the various amounts of an input that can be employed in the usage of an output. In other words, production function, which is obtained using different values of a variable input, indicates an organization's amount of production or service. Not to be forgotten is the fact that rather than controlling their level of production, state hospitals react to the demands for medical care. In other words, many state hospitals provide service not with the aim of maximizing the profit; they rather organize their services in accordance with the market demand for medical services. Accordingly, it is not unlikely that in comparison with the hospitals of the private sector, the level of production (the number of outpatients, inpatients, surgery and active beds) in such hospitals be different (8). Because in any case, hospitals, apart from their kind of ownership, earn money from their production and medical services (outpatient or inpatient service, surgery, daily bed occupation and etc.) and such activities are dependent upon rare resources. Estimating their short-term production function is possible through five suppositions: first, a hospital produces a coherent and unified product; second, in any hospital there are two coherent inputs: nursing hours and the availability of a mixed capital (a combination of different kinds of properties like medical equipment and hospital environment); third, given the stability of at least one production input in the short run, the amount of capital is supposed as stable; fourth, hospitals, as economic establishments, are driven to creating jobs; and finally, hospitals possess full information as to the market demand for their product (9). Via these five suppositions, it will be possible to estimate the production function of hospitals, through which it becomes clear how different inputs combine so as to create a product (10). Furthermore, managers consider the input elasticity in their short-term decisions as to meeting the rise in service demand. Production function of a hospital indicates a technical relationship between input and output, with the aim of acquiring the maximum output through combining various inputs (11). Given the necessity of a proper cost management system in hospitals as economic establishments, which account for around 2% of the gross national production (GNP) in Iran and in line with the necessity of employing the available facilities and resources and the fact that the motivation behind using scientific and practical economic methods in assessing the performance of hospitals, such as estimating production function, is nothing but to improve their efficiency and utilization, applying managerial and economical tools is inevitable.

2. Objectives

This study undertook the estimation of the production function in the hospitals affiliated with social security organization (SSO).

3. Patients and Methods

This was a cross-sectional study conducted on 64 hospitals affiliated with SSO from 2007 to 2009 to estimate their production function. To collect data from the hospitals, some forms were designed, completed and evenly collected by researchers according to the information provided by the research and statistic center in SSO regarding all the hospitals under its protection (N = 64) over the course of three years. These forms comprised of tables including 64 rows with the names of the social security hospitals, four columns representing the inputs (the number of doctors, nurses, staff and active beds) and four columns specifying the outputs (the number of inpatients, outpatients, surgeries, and daily bed occupations). To estimate the hospitals production function, different forms of function can be used such as constant elasticity substitution of production function and log form of production function and Cobb-Douglas function. The first two functions have limitations, among which one can mention the fact that the variables are considered in general terms, leading to loss of a lot of information regarding the combination of work force skills. Moreover, the flexible log form of production function creates multi-collinearity between various input square levels. To avoid such drawbacks, Cobb-Douglas function was employed in the present study (12). One of the advantages of this function is that its coefficients indicate production elasticity in relation to the inputs, showing to what extent a 1% change in the production factors increases the outputs. Production factors elasticity is a function coefficient in the Cobb-Douglas linear logarithm production function and the simplicity with analyzing the results is one of the other advantages of this function. In fact, such a function allows for a facile determination of the kind of output in scales, the efficiency of production factors, elasticity among inputs, and production elasticity. Cobb-Douglas function is also useful and easy to perform when it comes to experimental econometrics analysis (13). This function is even more in the limelight, thanks to its presenting the possibility of replacement among the factors in the course of production and its proper functional form. To estimate the production function, the numbers of doctors, nurses, other hospital staff and active beds were defined as input, while the numbers of outpatients and inpatients were considered as output. The acquired production function in this study was estimated based on the following equation:

$$Lny_{it} = \alpha^{*} + \beta_1 LnP + \beta_2 LnN + \beta_3 LnB + \beta_4 LnO + U_{it}$$

P, N, B, and O indicate the number of doctors, nurses, active beds, and staff, respectively. Moreover Lny_{it} shows the amount of production, which in this study is the number of inpatients and outpatients. α^{*} is the constant part and U_{it}, which has a normal distribution with a zero mean and constant variance, represents the uncontrollable factors in estimating the efficiency. Therefore, to obtain the coefficients, Cobb-Douglas linear logarithm production function and EViews 5 were employed.

4. Results

In Cobb-Douglas production function, the estimated coefficients indicate the production elasticity in relation to the inputs, meaning that it shows to what extent a 1% change in each production factor increases the outputs. Table 1 shows the results obtained after the usage of the number of inpatients, doctors, nurses, other staff and the occupied beds related to the hospitals under study and estimating the production function in the process. According to the data presented in Table 1, all the coefficients of production factors are meaningful except for the "other staff" input, which has an inverse relationship with the number of inpatients. This study showed that

99% of all the changes in the number of inpatients is described and explicated through the variable regression of "the number of inpatients" variable on explanatory variables. As can be seen, the production elasticity is negative in comparison with the "other staff" input, indicating that production has taken place in the third zone (production noneconomic zone). In other words, compared with other inputs, "other staff" was higher. Table 2 indicates the descriptive statistics of the studied variables obtained via E Views 5 program, which also determined the hospitals production function and production factors elasticity. In the aforementioned table, the mean of variables was used to obtain the average production of each production factor. The average production of each production factor is defined as the ratio of production level to the input level. In this study, the number of inpatient reception was considered as the product; to obtain the average production of each production factor, the mean number of the inpatient reception of the hospitals under study was divided by the mean number of each production factor in the same market. The results are as follows:

$AP_P = \bar{Y}/\bar{P} = 11390/42 \approx 271$
$AP_N = \bar{Y}/\bar{N} = 11390/117 \approx 97$
$AP_B = \bar{Y}/\bar{B} = 11390/126 \approx 90$
$AP_O = \bar{Y}/\bar{O} = 11390/212 \approx 54$

Production factors elasticity indicate the extent to which a 1% change in each production function increases the hospital output. The sum of production factors elasticity (function coefficient) indicates the ratio of output to scale in health system. When more than one, function coefficient demonstrates the ratio of output to a rising scale, when equal to one, it shows the ratio of output to a constant scale, and when less than one, it indicates the ratio of output to a falling scale. If the elasticity of each production factor gets multiplied by its mean production, the result will be the final production of that factor, which indicates how much the output changes with a unit increase in the input. Therefore, in this study, the final production of each production factor equals:

$MP_B = E_{Y,B} \times AP_B = 0.52 \times 90 \approx 47$
$MP_P + E_{Y,P} \times AP_P = 0.05 \times 271 \approx 14$
$MP_N + E_{Y,N} \times APN = 0.04 \times 97 \approx 4$
$MP_O = E_{Y,O} \times AP_O = - 0.04 \times 54 \approx -2$

As can be noticed, the highest and the lowest amounts of final production belong to "active bed" and "other staff", respectively. Table 3 shows production factors elasticity. The findings of this study indicated that after summing, the elasticity function coefficient is less than one, showing the decrease return to scale.

$$\varepsilon = E_{Y,P} + E_{Y,N} + E_{Y,PP} = 0.05 + 0.04 + 0.52 + 0.04 = 0.65$$

Table 4 indicates the amount of surplus in the inputs. The surplus data demonstrates the potential economies of scale in inputs without any reduction in the amount of the inputs. Based on such data, in all the three years of study, the highest surplus means belonged to the "other staff" input (10 units) of Shahid Beheshti (Shiraz), Shahid Lavasani (Tehran) and Imam Reza (Orumie) Hospitals, respectively. After that come the "nurse" and "doctor" inputs with means of 6 and 2 units, respectively. The lowest surplus mean belonged to the "bed" input (0.6 units). Moreover, during the three years of study, 36% of the hospitals did not demonstrate any surplus in any of the inputs, while 19% indicated a surplus in at least one of the inputs.

Table 1. Fixed Effects Production Function

Explanatory Variables	Fixed Effects
Fixed amount, C	2.86 (102.97)
LnP	0.05 (3.58)
LnN	0.04 (2.45)
LnB	0.52 (36.7)
LnO	0.04 (-7.6)
$\bar{R}^2$	0.99
Number of observations	192
"F", parameter (test of regression)	257368
Durbin Watson	2.71

Table 2. Explanatory Variables

	Indicator				
	Bed (B)	**Nurse (N)**	**Physician (P)**	**Other Personnel (O)**	**Inpatient (Y)**
Average	126	117	42	212	11390
Mean	112	100	37	188	10373
Maximum	438	408	163	631	29169
Minimum	20	15	11	56	2018
Standard deviation	85	79	25	111	6229
Number of observations [a]	192	192	192	192	192

[a] During three times observation of hospitals.

Table 3. Elasticity of Input

Parameter	$E_{Y,N}$	$E_{Y,B}$	$E_{Y,P}$	$E_{Y,O}$
Elasticity	0.04	0.52	0.05	0.04

Table 4. Input Surplus of Social Security Hospitals in Iran 2007-9 [a, b]

		Year											
		2007				2008				2009			
		P	N	O	B	P	N	O	B	P	N	O	B
1	17th Shahrivar Abadan	0	0	0	0	0	0	0	0	0	0	0	0
2	17th Shahrivar Mahshahr	0	26.70	52.12	0	0	8.82	15.52	0	0	10.30	17.55	-
3	29th Bahman Tabriz	0	0	0	0	0	0	0	0	0	0	0	0
4	Atieh Hamedan	0	0	0	0	0	0	0	0	0	4.33	30.31	0
5	Ayatollah Kashani Tehran	0	0	0	0	15.89	0	41.63	0	0	0	29.66	8.43
6	Ayatollah Kashani Kerman	0	0	0	0	9.43	50.68	87.83	0	0	0	0	0
7	Aras Pars Abad	0	0	0	0	0	0	0	0	0	0	0	0
8	Ershad Karaj	0	0	0	0	0	0	0	0	0	0	0	0
9	Alborz Karaj	0	0	0	0	0	0	0	0	0	0	0	0
10	Imam Hossein Zanjan	0	0	0	0	0	0	0	0	0	0	0	0
11	Imam Khomeini	0	0	0	0	0	0	0	0	0	0	0	0
12	Imam Reza Urmia	0	0	0	0	0	0	0	0	15.79	15.2	40.36	0
13	Imam Ali Shahrekord	0	0	98.96	10.98	0	0	0	0	0	9.88	0	1.96
14	Imam Ali Zarand	0	17.73	27.09	0	0	14.97	25.02	0	0	22.21	19.96	0
15	Amirolmomenin Ahvaz	34.45	0	30.83	10.34	0	0	0	0	0	0	0	0
16	Omid Abhar	0	0.92	3.38	0	0	0	0	0	5.76	8.48	2.27	0
17	Bojnord	0	0	0	0	0	0	0	0	0	0	0	0
18	Behbahan	0	6.13	30.80	0	0	0	0	0	0	0	0	0
19	Booali Neka	0	0	0	0	0	0	0	0	0	0	0	0
20	Birjand	0	0	0	0	0	0	0	0	0	0	0	0
21	Takestan	0	0	18.11	0.65	0	0	55.92	0	0	0	29.91	0
22	Torbat Heidar	0	0	0	0	0	0	0	0	0	0	0	0
23	Jorjani Gorgoan	0	0	0	0	11.78	22.73	17.86	0	14.94	52.51	29.86	0
24	Hazrat Fateme Najafabad	0	1.69	17.91	0	0	0	27.04	0	6.44	3.46	31.09	0
25	Hazrat Masoume Kermanshah	0	0	0	0	0	0	0	0	0	22.91	32.34	0
26	Hekmat Sari	0	0	0	0	0	0	0	0	0	0	0	0
27	KhatamolanbiaGonbad	0	0	0	0	5.43	3.95	0	0	0	50.69	34.33	0
28	Khoramabad	29.25	0	75.56	0	6.67	0	54.99	0	14.31	7.52	4.25	0
29	Khalijfars Bandar Abbass	0	0	21.87	0	0	0	32.61	0	0	0	0	0

30	Dr. Gharazi Esfahan	0	0	0	0	0	0	0	0	0	0	0	0
31	Dr. Shariati Esfahan	0	0	0	0	0	0	0	0	0	0	0	0
32	Dr. Gharazi Sirjan	-	5.41	16.36	0	0	0	0	0	0	8.39	0	0
33	Ghazvin Razi	0	0	0	0	2.57	-	37.66	0	0	0	20.3	10.4
34	Chaloos Razi	0	0	0	0	0	0	0	0	0	0	0	6.63
35	Rasht Rasoul	0	0	0	0	0	0	0	0	0	0	0	0
36	Zahedan	0	0	0	0	1.55	0	18.69	0	0	0	0	0
37	Ardabil	11.99	0	0	7.9	0.27	0	7.73	0	4.57	6.58	0	8.44
38	Saghez	5.85	17.87	27.7	0	0	0	-	0	0.72	0	0	0
39	Booshehr Salman	4.43	19.45	8.82	0	0	32.98	36.78	0	9.82	42.43	11.51	0
40	Sanandaj	0	5.73	33.2	4.29	0	5.73	2.14	0	0	5.02	10.22	0
41	Shazand	0	0	0	0	0	0	0	0	0	4.36	6.19	19.92
42	Kashan	0	54.52	24.42	0	0	0	0	0	0	0	0	0
43	Shafa Babol	0	3.69	0	0	0	0	0	0	0.58	0.71	0	0
44	Shafa Seman	0	1.22	6.93	0	0	4.97	7.08	0	0	0	0	0.86
45	Shohada Kermanshah	0	0	32.56	2.52	0	0	0	0	0	0	0	0
46	15th Khordad Varamin	0	0	0	0	21.72	-	82.58	0	0	0	0	0
47	Kargar Yazd	0	0	0	0	0	0	0	0	0	0	0	0
48	Shahriar Karaj	0	11.14	27.04	0	0	14.17	57.7	0	0	23.55	3.74	0
49	Beheshti Shiraz	0	-	68.79	-	6.4	30.51	64.52	0	0	42.54	19.08	0
50	Chamran Saveh	0	0	0	0	0	0	10.97	0	0	0	0	0
51	Fayaz Tehran	0	0	0	0	0	0	0	0	0	0	0	0
52	Labbafi Tehran	0	0	0	0	0	0	0	0	0	0	0	0
53	Moayedi Tehran	0	7.2	0	0	0	0	0	0	0	0	0	0.27
54	Lavasani Tehran	0	0	0	0	13.74	16.22	10.88	0	0	0	0	0
55	Alinasab Tabriz	0	0	0	0	0	0	0	0	18.45	19.82	50.87	0
56	Gharazi Malayer	0	0	0	0	0	0	0	0	0	0	0	0
57	Gharazi Malayer 1	0	0	4.75	0.53	21.97	17.3	-	11.5	0	0	0	0
58	Kosar Boroujerd	0	0	0	0	0	0	0	0	0	0	0	0
59	Tehran Maryam	0	0	0	0	0	0	0	0	0	0	0	0
60	Borazjan Mehr	0	0	6.5	0.75	0	0	0	0	0	0	0	0
61	Narges Doroud	0	0	0	0	0	0	0	0	0	0	0	0
62	Hedayat Tehran	0	4.5	32.91	0	0	3.15	39.14	-	26.53	13.1	13.55	0
63	Hashtgerd	0	0	0	0	0	0	0	0	0	0	0	0
64	Vali Asr Ghaemshar	0	0	0	0	0	0	0	0	0	0	0	0
Mean		1.34	5.26	10.41	0.59	1.83	5.80	13	0.18	1.84	5.84	6.83	0.84

[a] Abbreviations: B, bed; N, nurse; P, physician; O, other personnel; Y, inpatient.
[b] absolute zero: there is no surplus.

5. Discussion

The results of the production function in the present study indicated the meaningfulness of all production factors coefficients except for the "other staff" factor which was not located within the economic and logical zone (production second zone), meaning that with increase in the "other staff" variable, the input production of the hospital (which is the number of inpatients in this study) decreases.

Accordingly, through expanding the production and choosing proper production capacity, the studied hospitals can reduce the costs of production units in the long run. As it is demonstrated by the results of the production function estimate, the number of beds had the highest effect (maximum coefficient) on the production level, with doctor and nurse coming next; therefore, to increase production, hospitals should improve these inputs respectively. This result was in line with the findings of Reza Pour et al. who reported as negative, the "doctor" input production elasticity in hospitals affiliated with Ghazvin Medical University, indicating that with the rise in the number of doctors, the hospital production fell (14). According to the estimated production function, the production factors elasticity used in this study were 0.52, 0.05, 0.047 and 0.044 for "bed", "doctor", "other staff" and "nurse" inputs, respectively, meaning that, compared with other inputs, a 1% change in the "bed" input had the maximum effect on the hospital output. In other words, a 1% increase in the number of beds will increase the number of inpatients (as the hospital production) by 0.52. The same point was emphasized by Honson who reported the positive effect of active bed and its 54% production elasticity in the public section of Sri-Lanka health system in 2000 (15). Most of the researches conducted in this regard have proven the doctors' influence on production process as positive (16, 17) and it seems that such a result is more in line with the present findings. Hadian et al. study results were somehow different from that of the present study, declaring the order of inputs as effective in production function, in which the production elasticity for the "nurse" input was higher than other production factors, where with a 1% increase in the number of nurses, 3.4% change was observed in the production. "Other staff" and "bed" occupied the second and third positions, respectively. The reason for such a discrepancy in the findings might be the substantial difference between educational and academic hospitals and noneducational hospitals. The findings of this study indicated that in 2007 and 2008, 26 hospitals had a 41% decreasing return to scale, while in 2009 a 4% decrease was observed, meaning that in 2009 there were fewer inefficient hospitals active in counterproductive scales. To reach an efficient scale and obtain a constant-return to scale, such hospitals have to reduce their own production capacity and better exploit the production factors. The number of hospitals with a rising output return to scale in 2007, 2008 and 2009 were 19 (30%), 12 (19%) and 15 (23%), respectively. This reveals the fact that on average, 24% of social security hospitals (based on the average efficiency during the three years) had to increase their production capacity to obtain scale efficiency. In 2007, 19 (30%) hospitals had a constant output return to scale. This number reached 26 (41%) in 2008 and 2009, meaning that there was an 11% rise in the number of hospitals active on an efficient scale. Moreover, the results showed that output return to scale in social security hospitals is on the course of improving. In the same light, Hadian et al. reported an increasing output return to scale in the hospitals under his study. His results were in line with those of the two studies conducted on Iranian academic hospitals (12, 14). Comparing these results, it can be concluded that social security hospitals have a better condition than academic hospitals in terms of output return to scale. Nevertheless, there is still much to be done about achieving a constant output, so that alongside maintaining the efficiency of hospitals, the important concept of justice can be met (while metropolitan hospitals with an excess of scale benefit from a surplus of workforce, hospitals in less privileged areas are facing with a lack of such workforce) and natural exclusion, which is a characteristic of hospitals with an excessive scale, be prevented. The findings showed that in all the three years, the highest mean surplus belonged to the "personnel" input; therefore, it seems that in social security hospitals, the efficiency can surge through a 10% reduction in the "personnel" input. In a parallel way, the results of the estimated production function indicated a negative elasticity for this production factor, showing that it belongs to the third (noneconomic) zone of production, which demonstrated a negative final production and a falling total production. As a result, the producer should not increase the inputs to the extent that they fall in the third zone of production, as in such a zone, even if the inputs are free, their employment leads to a reduction in the production, hence it is not economic. Based on what has already been said, it seems that the managers and authorities of social security hospitals have to reduce their number of personnel so as to fall in the second (economic) zone of production. In line with the discussion, in 2000, Junoy considered the amount of input saving of the hospitals in Spain as 7%, 14%, and 8.4% reduction in the number of doctors, nurses and "other personnel", while no surplus was reported for the hospital beds (18). Additionally, in 2004, Harrison estimated the workforce surplus as 18% in the US and concluded that ameliorating the efficiency of hospitals depends on redistributing workforce among hospitals based on the facilities and regional needs, training them, and creating stimulants to improve the skill levels of key specialists (19). Given the present findings and the fact that 60-80% of hospital costs is related to the workforce, managers have to reconsider their policies in terms of hiring workforce so as to be able to fully benefit from this input and avoid spending huge amounts of money. The surplus of workforce might stand in the way of the harmony among different sectors and disrupt the team work; such imbalance can affect other activities of the hospitals in a negative way and prevent them from attaining their goal. Therefore, it seems that with respect to the resource limitations in the health sector and the aforementioned problems, the authorities, via employing proper economic tools, should identify the surplus factors in hospitals and improve their performance in the process. The surplus of workforce and bed can also be used in less privileged and needier hospitals.

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Authors' Contributions

Kimia Pourmohammadi: data collection, data analysis. Nahid Hatam: thesis supervisor. Peivand Bastani: making the manuscript draft and technical consults. Farhad Lotfi: data analysis.

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