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Measuring the Performance of Neonatal Care Units in Scotland

Kamal Field[1] and Ali Emrouznejad[2]

Policy makers continue to debate whether or not to increase the share of health care expenditures in United Kingdom. On the other hand, the pressure of operating within tight budgets and the advances in technology are forcing more locally based hospitals to close. One that could be used by policy makers as a benchmark is the measure of relative performance of hospitals. Many researchers have examined the source of inefficiency in health sectors (see, for example, Harris et al. Oper. Res. Soc. *57:801–811, 2000, Ozcan et al.,* Med. Case *30:781–784, 1992; Ozcan et al.,* J. Med. Syst. *20(3)141–150, 1996; and Grosskopf and Valdmanis,* J. Health. Econ. *6:89–107, 1987 but there is no evidence of measuring performance of neonatal care units of Scottish hospitals in the DEA literature. The purpose of this paper is to measure both technical and scale efficiency using data envelopment analysis in a selection of 22 neonatal care units in Scotland. The analysis suggests that major inefficiency likely exists in health care production in United Kingdom. There is potential for improving productivity by 20%.*

KEY WORDS: data envelopment analysis; hospital efficiency; health case policy; neonatal care unit; health sector performance.

INTRODUCTION

The efficiency of health services is one of the most important issues in the current political and economic debate. It has been claimed that considerable savings can be achieved by improving hospitals' efficiency. The last Conservative government in the United Kingdom introduced a reform to the NHS in 1991, where the government proposed the idea of self-governing hospitals. By this, the government intended to create a mechanism for minimizing the cost of activities by encouraging competition among hospitals to win contracts. District and GP budget holders, as purchasing agents, can exploit cost variations between hospitals to maximize health care for

[1]Dr. Kamal Field, Lloyds TSB, London, United Kingdom.
[2]Statistics and Operational Research Group, Coventry University, Priory Street, Coventry, United Kingdom.
[3]To whom correspondence should be addressed; e-mail: a.emrouz@coventry.ac.uk.

their population. It is anticipated that there will be an incentive for providers to cut costs and improve efficiency.[1] The reform was inspired by the argument that there are variations in performance among individual hospitals, for example, wide variations in unit cost, length of stay, and rate of drug prescription. The pressure of operating within tight budgets and the advances in technology are forcing more locally based hospitals to close. It was proposed by the Labour government to merge 32 trusts on April 1, 1999, in the first step, but a survey by *the Independent* has identified more than 80 acute hospitals affected by planned closures or transfer of services (*The Independent*, March 11, 1998).

This study is aiming to measure the relative performance of unit trusts and the authors believe that this study could give an insight to policy makers for further decision of closing or merging hospitals. Technically, the principal problem associated with measuring the efficiency of hospitals is that they produce nonhomogeneous multiple outputs. Hospitals have different specialities and engage in diverse treatments; this poses a challenging problem in measuring their efficiency. To reduce the impact of the heterogeneity among hospitals, the analysis here is based on one particular speciality: neonatal care units. Even at this level of analysis, the authors are not claiming full homogeneity of the services provided by these units. To control fully for diversity across units, data on patients by their diagnoses would be required, but such detailed information is not available in a useful format. Notwithstanding this problem, a number of authors have attempted to analyze efficiency in hospitals, particularly in the U.S.A. and in other European countries.[2–5] The aim of this paper is to give hospital managers (in Scotland) an insight into relative efficiency, by showing the position of each unit relative to the others. Such information should lead to constructive inquiries for improvements in position of inefficient units.

The remainder of this paper is organized as follows. Section 2 briefly reviews the aspects of modelling relative efficiency. Section 3 describes the data and DEA model for measuring efficiency of neonatal care units. This follows with presentations of the results and discussions, including sensitivity analysis, in section 4. Section 5 concludes the paper with some general comments.

RELATIVE EFFICIENCY

To study the efficiency of an organization, knowledge of the organization's objectives and the resources that are required to achieve these objectives need to be identified. A common methodology to analyze productive efficiency is to employ Data Envelopment Analysis (DEA), whereby a best-practice technology is constructed using observations on inputs and outputs, and the performance of other organizations is measured relative to the constructed best practice.[6] To illustrate this methodology, consider three organizations A, B, and C in Fig. 1.Each organization produces one unit of output using different combinations of two inputs X_1 and X_2. The units with the lowest level of inputs are located on the efficient isoquent (MM' in Fig. 1). Therefore, units B and C are efficient organizations. Under the assumptions of constant returns to scale, relative technical efficiency for an organization such as A is defined by the ratio TE = OD/OA.[7]

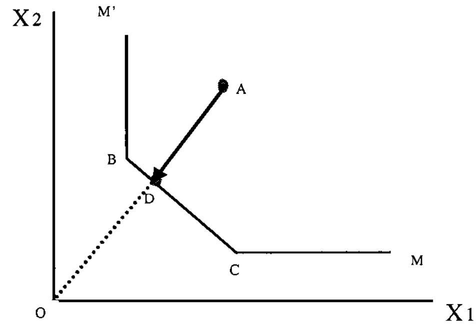

Fig. 1. The input-oriented DEA.

The studies that have made use of Farrell's definition[7] of productive efficiency can be classified into parametric and nonparametric approaches according to their specification and estimation of the efficiency technology.[8,9] In the parametric approach, a production function is constructed by a specific functional form and then parameters must be estimated according to observed inputs and outputs. In the nonparametric approach, a frontier technology is constructed as a piecewise linear technology,[10,11] For example, if the organizations A, B, and C in Fig. 1 use different combinations of two inputs X_1 and X_2 to produce one unit of output, then the best-practice technology can be constructed by the following linear programming problem:[12]

Minimize θ_i

St.

$$Q_A Z_A + Q_B Z_B + Q_C Z_C \geq Q_i$$
$$X_{1A} Z_A + X_{1B} Z_B + X_{1C} Z_C \leq X_{1i}\theta_i$$
$$X_{2A} Z_A + X_{2B} Z_B + X_{2C} Z_C \leq X_{2i}\theta_i$$
$$Z_A, Z_B, Z_C, \geq 0.$$

The above three constraints are output and input constraints. The first is the output constraint, which restricts the feasible production to processes that yields outputs higher than or equal to observed outputs. The second and third are inputs constraints, restricting the feasible solution to an efficient area. In Fig. 1, the efficient production possibility is MM' (of which A and B and their convex combinations form part of it). Basically, this method constructs an efficient isoquant for all inputs combinations, which provides the benchmark for the efficiency analysis (For further details of Data Envelopment Analysis see Ref. 13).

Färe *et al.*[14] argued that by relaxing the assumptions of constant returns to scale it is possible to disaggregate overall technical efficiency (OTE) into pure technical efficiency (PTE), congestion efficiency (CE), and scale efficiency (SE). Such deconstruction will help give a detailed picture of the way in which productive efficiency can be increased (See Grosskopf et al., 1995). According to Fare's decomposition, OTE is given by :

$$\text{OTE} = \text{PTE} \times \text{CE} \times \text{SE}$$

DATA AND EMPIRICAL ANALYSIS

The relative efficiency of 22 neonatal care units is analyzed here by using data taken from the *Cost Book of the National Health Services* for 1993/94.[16] A statistical summary of the basic characteristics of these units is provided in Table I.

The table shows the number of staff cot-days, occupied cot-days, and the number of nursing and medical staff assigned (whole time equivalent per 100 cots). According to this table average staff cot-days is 7337 while average occupied cot-days is 3874. The number of medical staff and nurses vary, with the average of 3.2 medical staff and 34.5 nurses in each unit.

The contribution of a hospital treatment to a patient's health is hard to quantify. In absence of such a measure, sociologists consider the number of successful treatments but ignore the cases terminated by death. Epidemiologists consider the number of cases dealt with (this approach implicitly assumes that cases are homogeneous, and therefore does not distinguish between cases of different severity), while economists have proposed the number of case-mix.[18]

The economists' measure is relatively more reliable since patients are grouped according to a specific classification, such as diagnostic-related group (DRG). However, such an approach remains insensitive to the fact that resources and the severity of cases within each diagnostic group may vary substantially. To facilitate measuring efficiency of neonatal care units we have to consider various variables from the number of cots available, number of staff, and number of cots occupied. The advantage

Table I. Statistics of Scottish Neonatal Care Units

Hospital	Staff cot-days	Number of medical staff per 100 cots	Number of nurses per 100 cots	Occupied cot-days
1. Ninewells	8760	8	44	5339
2. Royal Alexandra Hospital	5490	1	22	2483
3. Southern General, Glasgow	8739	7	38	2915
4. Raigmore, Inverness	7300	2	19	3393
5. Eastern General, Edinburgh	5111	1	21	2978
6. St. John's at Howden	5110	2	21	2493
7. Borders General	2952	2	13	1662
8. Vale of Leven, Alexandria	4144	2	17	1111
9. Law, Carluke	3650	1	15	1535
10. Perth Royal Infirmary	3651	0	15	2055
11. Falkirk Royal Infirmary	4392	3	19	1388
12. Stirling Royal Infirmary	5489	1	30	2731
13. Royal Maternity, Glasgow	12589	5	93	8255
14. Queen Mother's, Yorkhill	11680	1	45	7189
15. Aberdeen Maternity	14600	6	86	8649
16. Simpson Memorial, Edinburgh	14600	8	85	10031
17. Rankin Memorial	2920	0	11	1399
18. Forth Park, Kirkcaldy	8970	1	23	4112
19. Rutherglen Maternity	6205	5	20	2140
20. Bellshill Hospital	12410	7	55	5749
21. Cresswell Maternity, Dumfries	2440	1	18	2078
22. Ayrshire Central	10220	6	49	5535
Average	7337.4	3.2	34.5	3873.6
SD	3900.2	2.7	25.1	2639.6

Source: *The Cost Book for the National Health Service in Scotland*, 1993/94.

of using DEA is that we can deal with several inputs/outputs simultaneously, while the above proposed measures consider a simple ratio analysis.[19–21]

Thus we measure, using DEA, the performance of each unit, where neonatal care units attempt to minimize their number of medical staff and nurses per occupied cot-days. As a proxy of input cost to the hospital we also included the number of cots available to the model.

RESULTS AND DISCUSSIONS

Table II shows the various measures of economic efficiency, where performance of each unit is measured with respect to best-practice technology.

For relatively efficient units, the score of overall efficiency is equal to 1 and for less efficient units the score is less than 1. Accordingly, units 4, 10, 14, 18, and 21 are relatively efficient units. To get further insight into efficiency of other units, the index of overall technical efficiency (OTE) is deconstructed into (a) pure technical inefficiency (due to lack of staff motivation and skill); (b) congestion inefficiency (due to the use of congested technology or excessive resources); and (c) scale inefficiency (due to operating at nonoptimal scale). Each of these indices will be equal to 1 for the efficient units and be less than 1 for less-efficient units. Table II also shows that the average score of overall efficiency is 0.80, indicating that there is a potential for improving productivity by 20%. The average scores for pure technical efficiency, congestion efficiency, and scale inefficiency are 0.91, 0.93, and 0.94, respectively. These figures indicate that there is greater potential for increasing efficiency by improving

Table II. Economic Efficiency of Neonatal Care Units

Hospital	Overall efficiency	Pure technical efficiency	Congestion efficiency	Scale efficiency	Type of return scale
1. Ninewells	0.88	1.00	0.91	0.97	DRS
2. Royal Alexandra Hospital	0.72	0.76	1.00	0.95	IRS
3. Southern General, Glasgow	0.51	1.00	0.52	0.99	DRS
4. Raigmore, Inverness	1.00	1.00	1.00	1.00	CRS
5. Eastern General, Edinburgh	0.92	0.98	1.00	0.94	IRS
6. St. John's at Howden	0.77	0.83	0.98	0.95	IRS
7. Borders General	0.86	1.00	1.00	0.86	IRS
8. Vale of Leven, Alexandria	0.42	0.47	0.99	0.91	IRS
9. Law, Carluke	0.66	0.75	1.00	0.89	IRS
10. Perth Royal Infirmary	1.00	1.00	1.00	1.00	CRS
11. Falkirk Royal Infirmary	0.49	0.56	0.93	0.94	IRS
12. Stirling Royal Infirmary	0.72	0.80	0.91	0.99	DRS
13. Royal Maternity, Glasgow	0.78	1.00	0.98	0.79	DRS
14. Queen Mother's, Yorkhill	1.00	1.00	1.00	1.00	CRS
15. Aberdeen Maternity	0.79	1.00	0.94	0.84	DRS
16. Simpson Memorial, Edinburgh	0.92	1.00	1.00	0.92	DRS
17. Rankin Memorial	0.93	1.00	1.00	0.93	IRS
18. Forth Park, Kirkcaldy	1.00	1.00	1.00	1.00	CRS
19. Rutherglen Maternity	0.64	1.00	0.66	0.96	IRS
20. Bellshill Hospital	0.71	1.00	0.73	0.97	DRS
21. Cresswell Maternity, Dumfries	1.00	1.00	1.00	1.00	CRS
22. Ayrshire Central	0.80	0.87	0.95	0.97	DRS
Average	0.80	0.91	0.93	0.94	

Table III. Super Efficiency, DEA Model of Anderson and Peterson (1993)

Hospital	Super efficiency score
4. Raigmore, Inverness	1.0036
18. Forth Park, Kirkcaldy	1.0836
14. Queen Mother's, Yorkhill	1.1138
10. Perth Royal Infirmary	1.1748
21. Cresswell Maternity, Dumfries	1.2794

staff motivations and skill. The table also reveals that there are eight units operating with decreasing returns, nine with increasing returns and five with constant returns to scale.

While the technique outlined above is capable to quantify and identify relative efficiency, this type of measurement of efficiency is highly sensitive to "outliers" in the data, which may arise from observations being contaminated by measurement errors, or may merely be observations with low probability of being observed. Outliers of the second type are not a problem, but the former type may severely bias the efficiency scores. When outliers due to data errors lie on the computed production surface, the efficiency scores of other units are also affected, as efficiency is measured in a relative sense. To account for outliers, we have carried out a sensitivity analysis by omitting one of the efficient units each time and running DEA again. To decide which efficient units must be omitted from the model first, we need a further analysis to rank the efficient units according to their performance. For this purpose the efficient units 4, 10, 14, 18, and 21 are ranked using the procedure described by Anderson and Peterson.[18] This ranking method assigns scores greater than 1 to each efficient unit, frequently called super efficiency. According to Table III unit 21 is the most efficient unit, then units 10, 14, 18, and 4.

Earlier we discussed that outlier can affect on the efficiency scores since DEA measures the efficiency of each inefficient unit by comparing it with a convex combination of efficient units. DEA can also identify which efficient units are peers to nonefficient units. Table IV illustrates the peers to each non-efficient unit.

As can be seen in this table, unit 18 is not peer to any other unit. This means that excluding this unit would not affect on the efficiency score at all. Unit 21, the most efficient unit, is a peer to units 1–3, 5–8, 10–12, 15, 16, 20, and 22. Therefore, excluding this unit from the model will affect the efficiency score of all above units since unit 21 is part of the outlier for the above units. Similarly, excluding units 10, 14, and 4 from the DEA model may affect the scores of other units according to the peers in Table IV.

Once an efficient unit is excluded from the model the outliers will change; therefore the efficiency scores of some of non-efficient units will be changed.

As a part of sensitivity analysis and to compensate for the effect of outlier we used the same DEA model and excluded unit 18 since it has no effect on the efficiency scores (remember, according to Table IV this unit is not peer to any other unit), and then excluded the most efficient unit from the model at each time. Therefore, first we measure the efficiency of 20 units (excluding units 18 and 21), then we measure the efficiency in a model with 19 units (excluding unit 10 also), 18 units (excluding unit 14

Table IV. Table of Peers

Inefficient units	Efficient units				
	4. Raigmore, Inverness	10. Perth Royal Infirmary	14. Queen Mother's, Yorkhill	18. Forth Park, Kirkcaldy	21. Cresswell Maternity, Dumfries
1. Ninewells			√		√
2. Royal Alexandra Hospital			√		√
3. Southern General, Glasgow			√		√
5. Eastern General, Edinburgh			√		√
6. St. John's at Howden			√		√
7. Borders General			√		√
8. Vale of Leven, Alexandria			√		√
9. Law, Carluke			√		√
11. Falkirk Royal Infirmary			√		√
12. Stirling Royal Infirmary		√	√		√
13. Royal Maternity, Glasgow		√			√
15. Aberdeen Maternity			√		√
16. Simpson Memorial, Edinburgh			√		√
17. Rankin Memorial		√			
19. Rutherglen Maternity	√		√		
20. Bellshill Hospital			√		√
22. Ayrshire Central			√		√

also), and 17 units (excluding unit 4 also). The results shown in Table V indicate that overall ranks of the inefficient units are more or less identical to the rank obtained before eliminating efficient units. This proves that the inefficiency of units are due to their operational factors rather than to their being very sensitive to outliers.

Table V. Sensitivity Analysis of DEA

Hospitals	Exclude 18 and 21	Exclude 10, 18, and 21	Exclude 14, 18, 10, and 21	Exclude 4, 14, 18, 10, and 21
1. Ninewells	0.93	0.93	0.95	0.95
2. Royal Alexandra Hospital	0.73	0.73	0.79	0.8
3. Southern General, Glasgow	0.53	0.53	0.56	0.56
4. Raigmore, Inverness	1	1	1	
5. Eastern General, Edinburgh	0.93	0.93	1	1
6. St. John's at Howden	0.78	0.78	0.84	0.84
7. Borders General	0.89	0.89	0.94	0.94
8. Vale of Leven, Alexandria	0.43	0.43	0.46	0.46
9. Law, Carluke	0.67	0.67	0.72	0.72
10. Perth Royal Infirmary	1			
11. Falkirk Royal Infirmary	0.5	0.5	0.53	0.53
12. Stirling Royal Infirmary	0.79	0.79	0.86	0.86
13. Royal Maternity, Glasgow	0.99	0.99	1	1
14. Queen Mother's, Yorkhill	1	1		
15. Aberdeen Maternity	0.89	0.89	0.91	0.91
16. Simpson Memorial, Edinburgh	1	1	1	1
17. Rankin Memorial	0.93	1	1	1
18. Forth Park, Kirkcaldy				
19. Rutherglen Maternity	0.64	0.64	0.67	0.75
20. Bellshill Hospital	0.73	0.73	0.77	0.77
21. Cresswell Maternity, Dumfries				
22. Ayrshire Central	0.83	0.83	0.87	0.87

Table VI. Some Aspects of Neonatal Care Units of Scottish Hospitals by Efficiency Groups

Efficiency groups	Cost per occupied bed-day £000	Occupancy rate	Number of cots	Direct cost per cot £000	Number of neonatal Care units
OTE = 1	0.19	0.59	18	44	5
OTE = (0.80–0.99)	0.23	0.58	20	48	6
OTE = (0.60–0.79)	0.26	0.49	22	46	8
OTE = (0.50–0.69)	0.32	0.33	23	39	1
OTE < 0.49	0.92	0.29	12	41	2

To gain further insight into the characteristics of the efficient units, Table VI, compares some of their economic aspects. The table classifies the units according to their overall technical efficiency (OTE) score as follows: Group 1, where OTE = 1, Group 2, where OTE = 0.80–0.99, Group 3, where OTE = 0.60–0.79, Group 4, where OTE = 0.50–0.69, and Group 5, where = OTE < 0.49. For Group 1 (the fully efficient units), the average number of cots is 18 and occupancy rate (the ratio of number of occupied cot-days to total number of cot-days during the year) is 0.59. These characteristics should be regarded as a model for the less efficient units.

CONCLUSIONS

This paper is an attempt to advance our understanding of efficient resource allocation in Scottish hospitals. Resources are limited and seeking efficiency is both a managerial and a moral obligation; without efficacy we will inevitably deny health care to some patients. To reduce heterogeneity in hospitals' activities, a sample of 22 neonatal care units has been subject to efficiency analysis. A mathematical programming technique was used to construct a frontier production surface and to identify the best-practice units. Our findings show that there are a number of neonatal care units that are operating inefficiently. The average score for OTE is 0.80, indicating that there is potential for increasing performance of neonatal care units by 20%. Increasing staff skill and motivation, improving the mix of factors of production, and adjusting the size of the units to an optimal level could improve productivity by up to 9, 7, and 6%, respectively. Highly efficient units have the following characteristics: number of cots 18–20, cost per occupied cot-day (£190–£230), annual cost per cot (£44000–£48000) and an occupancy rate of 0.58–0.59 cots. Units that are based in large general and major maternity hospitals tend to be the most efficient. The main sources of efficiency in these units are employment of highly skilled staff and a competitive and demanding environment. Occupancy rates and the ratio of number of doctors to nurses are statistically significant in explaining cost variation; but the Scottish data did not support the claim that large teaching hospitals are more expensive to run. It is important to note that using economic measures alone to judge the efficiency of health care units could be misleading; these units are aiming to provide high quality health care for their patients and should therefore not simply be concerned with quantitative results. Hospitals usually aim to ensure provision of care for the population they serve; as such it is unfair to judge a health care unit as inefficient if it is not working at full capacity. One way to facilitate quality would be to equip hospitals with sufficient resources that are necessary to meet unexpected demand. To develop a more balanced measure for efficiency, a cot-occupancy range could be utilized, such that the constructed 'best-practice' would be restricted to satisfy this range. Such developments could lead to a more balanced judgement of the efficiency of health care units. In addition to quality of services, future research should address staff's and patient's concerns and incorporate information on patients' diagnoses.

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