The Irish Accounting Review (2002), Vol. 9, No. 2, 1–21

A PRICE EFFICIENCY ANALYSIS OF POSSIBILITIES FOR ADJUSTMENTS IN STAFFING IN NORTHERN IRELAND'S ACUTE HOSPITALS

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ABSTRACT

This paper illustrates how cost efficiency measures, based on labour prices, can provide comparative information for managers who are concerned with hospital staffing issues in an environment of budgetary constraints. Using data on acute hospital services and associated labour inputs within Northern Ireland, and employing Data Envelopment Analysis (DEA) techniques, we estimate cost efficiency (based on labour prices) for each hospital. Where there is found to be evidence of cost inefficiency, relative to best practice within the region, we show that managers can identify whether this is due to allocative inefficiency, in other words the wrong mix of labour prices, or to technical inefficiency, that is paying labour prices that are proportionately higher than elsewhere in the hospital sector. Furthermore, we suggest that hospital managers can use measures of the relative over- or under-pricing of the individual labour inputs as a guide in planning a more appropriate skill mix or grade mix within each of the main categories of labour.

INTRODUCTION

The provision of services within acute hospitals in Northern Ireland represents a substantial share of resources secured for health programmes. Two main factors have made it imperative to examine issues of cost and efficiency in the use of these resources. Firstly, the system has come under extreme pressure in an environment where there is limited new finance available and patients are faced with lengthy waiting times for consultations and surgery. Secondly, the difficulties within the acute sector have been accentuated by a concurrent shortage of community care provision that has resulted in delays in discharging some patients, and has led to demands for a redistribution of resources within the health system. Labour costs account for almost 70 per cent of the total revenue budget of the acute hospitals, with the provision of nursing staff constituting the largest component. Consequently, any initiative to improve the (cost) efficient use of resources within the hospitals must focus upon staff-related expenditures, namely by addressing issues of the skills and costs of different kinds of labour.

The focus of this study has been on the possibilities for substitution both within each labour category, and between labour categories. The model envisages that hospital managers, having made a decision on the quantity of, for example, nursing staff to employ, are then faced with the decision as to the grade mix within the hospital. Proponents of the reform of skill mix in the National Health Service (NHS) argue that there are opportunities for cost efficiency gains by substituting lower skilled (and less expensive) staff for higher skilled (and more expensive) staff. However, Richardson and Maynard (1995, p.3) comment that 'policy makers ought not to consider solely the unit costs of labour, but use these in combination with outcomes and data on time taken per task to identify the optimal skill mix'. In theory, our model could be easily extended to incorporate some degree of capital–labour substitution, but in practice the researcher would have to proceed with caution, given the recognised complementary relationship between capital and labour inputs in the NHS (Mayston, 1990). Moreover, from a management accounting perspective, the separation of certain capital and revenue expenditures in hospital budgets, and the 'lumpy' nature of investment, may make such a total cost minimisation exercise meaningless.

A key initiative within the public sector over the last five years has been the drive to introduce rigorous approaches for comparing performance across similar providers. Generally this has required individual units to measure performance on specified aspects of service provision, with a view to identifying where practice is poor relative to performance across the particular sector. Such initiatives have been especially prevalent throughout all parts of the NHS, with the aim of supporting the dual objectives of improving economic efficiency in the use of resources, and securing health care services of an assured clinical quality (Department of Health, 1997). Currently, the vast majority of decision-making in the hospital sector proceeds on the basis of various cost accounting analyses, with these analyses taking the following two key assumptions for granted: (1) that similar type hospitals feature in relative comparisons, and (2) that minimum acceptable standards of quality of care are not being compromised by cost-based decisions. Accounting cost analyses thus play a vital role in resource allocation in the hospital sector. This has lead to two developments: (a) improvements in cost accounting procedures in hospital systems, and (b) the exploration of how other methodologies can complement cost-based decisions. Clearly, since Data Envelopment Analysis (DEA) uses available cost accounting data to attempt to provide cost efficiency evaluations of hospital performance relative to best practice benchmarks, it is highly relevant to (b) above.

The chief contribution of this paper is to demonstrate how the technique of DEA can contribute to a manager's understanding of a hospital's cost performance in relation to the average wage rates paid for different types of labour, given practice elsewhere in the sector. In addition, we demonstrate how the technique can indicate the direction of grade mix adjustment (or substitution of lower skilled for higher skilled staff) required within the different labour categories if (wage) cost efficiency is to be enhanced. Moreover, while cost accounting procedures have uncovered significant differences in the average costs of labour and other inputs across hospitals, DEA studies have so far ignored this source of inefficiency. Our paper therefore provides an innovative, indicative, empirical illustration of how this methodology can complement cost accounting analyses. The DEA literature includes applications to measuring performance within the public sector (Jesson, Mayston and Smith, 1987), and DEA techniques have been used for examining technical efficiency in the hospital sector by Hollingsworth and Parkin (1995), Rosenman, Siddharthan and Ahern (1997), and Kerr, Glass, McCallion and McKillop (1999). In addition, Hollingsworth, Dawson and Maniadakis (1999) provide a comprehensive review of the application of DEA to measuring efficiency performance within health care services. More recently, an application of DEA has appeared in the accountancy literature (Worthington and Hurley, 2002).

The next section of the paper describes DEA methodology and input price efficiency measures, while the third section details the key issues that have to be addressed in applying this model to the hospital sector. Using this technique, we estimate overall cost efficiency relative to average wage rates of the different types of labour for hospitals in Northern Ireland, and present the results in the fourth section. The fifth section demonstrates how the results of the analysis can be used to guide managers in planning adjustments in staffing, namely the substitution of lower grade staff for higher grade staff within each broad category of labour. Before concluding, we discuss in section six the possible limitations of our analysis in light of the relationship between skill and the quality of health care.

METHODOLOGY

We begin our study by examining cost efficiency relative to labour prices, in other words unit wage costs, for each individual hospital across the sector of interest. Employing the technique of DEA, (overall) cost efficiency is estimated using an approach based on the input price efficiency model of Färe, Grosskopf and Lovell (1994). This technique constructs empirical production frontiers formed from best-observed practice among units within the sample. It is these efficiency frontiers which then provide the benchmark against which the performance of an individual unit – in this study, a hospital – is measured. Those hospitals that are found to be operating on (and determining) this frontier are termed efficient, while those not operating on the frontier are termed relatively inefficient.

The input price efficiency model of Färe et al. (1994) departs from the usual assumption that input prices are taken as given and the choice variables are input quantities. Rather, it is assumed in this model that within each individual unit there is flexibility over input prices while input quantities must be regarded as fixed. In our study, we have adapted this model to a scenario in which the hospital manager cannot make changes to the patient–staff ratios, but does have a degree of flexibility over the average price paid for each type of labour within the context of a given (total cost) staffing budget. Applied to the acute hospital sector, this type of analysis provides information on whether there exists the possibility for a manager to make changes in the average prices paid for labour within the hospital in a bid to improve cost efficiency, and yet maintain the same level of service provision. Thus, relative to best practice, the analysis may indicate that a hospital has some scope for substituting lower grade staff for higher grade staff in a certain labour category.

To proceed, we have calculated cost efficiency relative to (staff) input prices using the measure of overall input price efficiency developed by Färe et al. (1994). Färe et al. demonstrate how to compute overall input price efficiency (which is the ratio of minimum staffing cost to observed staffing cost) for each individual unit. Minimum staffing cost for each hospital is found by minimising over (cost-normalised or cost-deflated) input prices. (Further details are provided in the appendix.) This gives an estimate of the minimum staffing cost at which the observed outputs of the hospital could have been produced, given labour usage by that hospital, and given the rates paid for each type of labour elsewhere within the sector under consideration. Where the estimated (potential) minimum cost is less than the observed cost of a hospital, this is interpreted as evidence of overall cost inefficiency. In this situation, it is possible for the hospital to provide the same services at lower cost by changing the prices it pays for staffing resources. Therefore, as will be illustrated later, managers and policy-makers within the health sector can obtain an estimate of comparative cost efficiency for an individual hospital, given current rates paid for staff across the set of hospitals under consideration.

Evidence of cost inefficiency within a hospital indicates that the input prices are non-optimal, given practice elsewhere in the sector and given usage of labour inputs and the provision of services by that particular hospital. This may be due to a combination of two factors. Firstly, the average wage rates paid for the different types of labour may be proportionately too high, given practice elsewhere within the sector (termed input price technical inefficiency by Färe et al. (1994)). Secondly, given the numbers of the different types of labour employed within a particular hospital, there may be the opportunity to reduce overall costs by changing the relative prices of staff (termed input price allocative inefficiency by Färe et al.).

In order to estimate input price technical efficiency for each hospital, we solve a linear programming problem that finds the greatest proportional reduction in (cost-deflated) input prices at which the hospital can achieve its observed output given a (minimum cost) target budget. The finding of a potential reduction in observed (cost-deflated) input prices indicates that the hospital could potentially achieve its observed output with the (minimum cost) target budget by paying proportionately lower input prices. In other words, relative to best practice within the sample of hospitals, the given hospital is paying average labour prices that are proportionately too high (or technically inefficient).

Since overall cost inefficiency is due to some combination of technical and allocative input price inefficiency, an estimate of the latter type of inefficiency can be obtained from our estimates of overall cost and technical inefficiency. Färe et al. (1994) show that the input price allocative efficiency measure is given by the ratio of the overall input price efficiency to input price technical efficiency measure. A finding of input price allocative inefficiency indicates that, compared to best practice, the hospital is paying the wrong relative prices for types of staff given its observed mix of staff quantities.

Clearly, where there is allocative inefficiency, it is important for managers to be able to identify its causes. Such insight can be gained by assessing whether there is relative over- or under-pricing of each type of labour employed. The measure that we have used in this paper is the ratio of the technically-efficient price (given the observed input price mix) to the cost-minimising price (given the optimal input price mix) of the labour input, where both are obtained as a by-product of the DEA. Where the ratio of these prices is less than one this indicates relative under-pricing of the particular input. Conversely, a ratio greater than one provides evidence that the input in question is relatively over-priced.

THE DATA

This study applies the methodology described above to comparing efficiency across acute hospitals within Northern Ireland. However, in order to specify an operational model, we have had to address three key issues, at least two of which will be common to any application of DEA techniques for comparison of performance within the hospital sector.

The first issue confronting the practitioner is that of comparing hospitals that typically provide a diverse range of services from a complexity of input factors. Moreover, one must be alert to the fact that the results of a DEA analysis are potentially sensitive to data misspecification, particularly where the sample is small (Smith, 1997). In view of this, we have taken care to include all the main services of the acute hospitals and those inputs that account for the greater part of hospital revenue expenditure. However, before proceeding with a DEA study, one must also ensure that the total number of inputs and outputs of the model is not too large relative to the size of the available data set (Nunamaker, 1985). To enable meaningful analysis, some aggregation is necessary, and so consequently we decided to model each hospital as an independent unit producing five outputs and using four labour inputs.

The second issue relates to the possibility of significant year-to-year variation in efficiency for each hospital, rendering simple comparisons of annual performance misleading. For example, Parkin and Hollingsworth (1997) found that the measured efficiency of Scottish hospitals varied considerably from one year to another. It must be acknowledged that, to an extent, the demand for health care is uncertain (Friedman and Pauly, 1981), and health care planners must allocate human resources to particular services on the basis of projections. Consequently, given employment contracts and the attendant wage commitments, and considering the limited catchment area for a particular hospital, then any significant local variations in demand (from that anticipated over the year) will influence measured efficiency. To limit potential bias from this source, it is preferable to average annual performance over a period of consecutive years.

The third issue relates to the very small number of acute hospitals within the Northern Ireland region that were suitable for comparison. These numbered, once specialist units were omitted, just 22 over the period of our study, 1990–92. Taking the latter two issues into consideration, it was decided that an appropriate action would be to create a three-year data set by pooling the annual observations of each hospital (see Lovell, 1993) from 1990 to 1992. By designing a data set comprised of three years of observations on each of the hospitals, we have in total 66 observations. This means, for example, that the performance of a hospital is compared relative to that of all hospitals of the set in each year from 1990 to 1992. Such a data set permits us to track the performance of each hospital over the three-year period or, alternatively, to measure the average efficiency of each over the period.

Within our model, the main services provided by each hospital are classified into five categories: 'Surgical'; 'Medical'; 'Obstetrics and Gynaecology'; 'Accident and Emergency'; 'Outpatients'. 'Surgical' measures total surgical inpatients during a year. 'Medical' and 'Obstetrics and Gynaecology' are similarly measured. 'Accident and Emergency' is the total number of visits to a unit over a year, and 'Outpatients' measures total visits to outpatient clinics over the year. The four inputs are nursing staff, medical staff, administrative staff and ancillary staff. For each category of hospital staff we take the number of total employees, measured as full-time equivalents. The average price or unit wage cost of each of these labour inputs was then found by dividing the total wage bill by the total number of full-time equivalents.

Before leaving the discussion of our data, it is important to raise the issue of hospital case mix, as this will inevitably influence the appropriate staffing grade mix and costs within each hospital. Unfortunately, reliable data on case mix were not available for NI hospitals over the period of this study. Recognising this deficiency, we sought to develop a sample in which the majority of hospitals can be argued to provide broadly similar services – for example, we have taken care to exclude specialist units and long-stay hospitals. If adequate case mix data were available for NI hospitals this information could be easily incorporated into the modelling format, and the data envelopment analysis would then yield much richer empirical insights into hospital efficiency. Nevertheless, we believe our sample to be valid because we are using a group of hospitals similar to that being compared by the government in NI under the recent cost benchmarking initiative.

DISCUSSION OF RESULTS

Table 1 presents the labour cost efficiency results, as averaged over the three-year period, for each of the 22 hospitals of our data set, with values less than unity indicating cost inefficiency. For those hospitals that are found to exhibit cost inefficiency, performance is variable and estimates of efficiency range from a value of 0.468 for hospital (1) to 0.997 for hospital (14). This suggests that management could have reduced costs within hospital (1) by over 50 per cent (whilst maintaining the same level of services) through changing the average prices paid for staff without making changes to the numbers of each type of staff employed within the hospital. As will be discussed later, this would involve grade mix adjustment within a given category of staff.

Table 1: Hospital Efficiency over the Three-year Period, 1990–92

Hospital	Labour Cost Efficiency	Labour Price Technical Efficiency	Labour Price Allocative Efficiency
1	0.468	0.616	0.759
2	0.485	0.593	0.819
3	0.579	0.607	0.954
4	0.560	0.613	0.916
5	0.606	0.766	0.792
6	0.571	0.723	0.791
7	0.957	1.000	0.957
8	0.673	0.862	0.782
9	0.956	0.992	0.963
10	0.614	0.666	0.927
11	0.820	0.880	0.933
12	0.642	0.806	0.798
13	0.974	0.994	0.979
14	0.997	1.000	0.997
15	0.568	0.644	0.889
16	0.628	0.918	0.686
17	0.722	0.786	0.926
18	0.906	1.000	0.906
19	0.700	0.764	0.916
20	1.000	1.000	1.000
21	0.942	1.000	0.942
22	0.549	0.847	0.651

Nevertheless, our analysis has generally found much less scope for cost reduction within this group of hospitals, with the average labour cost efficiency score for the group of 66 observations estimated to be 0.700. This indicates that, on average, there was potential for a maximum reduction of 30 per cent in staff-related expenditures in each hospital over the period of this study. It is worth noting, however, that within a third of the hospitals, we found that there was opportunity for cost reductions of less than 10 per cent.

As outlined in the methodology section, labour cost inefficiency, as defined in this paper, is potentially due to a combination of both labour price technical inefficiency and labour price allocative inefficiency. **Table 1** above presents the efficiency scores for these constituent parts for each of the 22 hospitals.

The estimates of labour price technical inefficiency range from 0.593 for hospital (2) up to 0.994 for hospital (13), with a mean score for the group of 0.808. This means that, on average, there was a loss of almost 20 per cent in performance on costs, because the wage rates paid to all categories of staff were proportionately higher than in the efficient hospitals of the set.

For those hospitals found to be operating off the best-practice frontier, the scores for labour price allocative efficiency range from 0.651 for hospital (22) up to 0.997 for hospital (14). We found the mean score for the group to be 0.871. This can be interpreted as a measure of the average loss to hospital efficiency performance caused by paying the wrong relative labour prices, given the chosen combination of nursing, medical, administrative and ancillary staff, and best practice elsewhere in the region.

With the ongoing debate over the appropriate scale of operations within the acute sector (Ferguson, Posnett and Sheldon, 1997), it is interesting to examine cost efficiency performance by hospital size. The evidence suggests that cost inefficiency related to labour pricing was more pronounced within the larger hospitals of the region, with the average score estimated to be 0.536 for hospitals (1) to (5) inclusive (see **Table 2**). By comparison, the remaining hospitals of the group achieved superior performance with an average cost efficiency score of 0.756.

As **Table 2** summarises, the larger hospitals achieved relatively poor outcomes on technical efficiency with an average score of 0.635, as compared with 0.843 and 0.865 for the medium-sized and small hospitals respectively. In addition, as regards allocative efficiency, performance is to some degree poorer within the larger hospitals with a mean score of 0.844, as compared with 0.898 for the medium-sized hospitals and 0.874 for the small hospitals. From this information, one can discern that the relatively poor performance by the larger hospitals on labour cost efficiency is largely the result of technical inefficiency, or paying average rates for labour that were in excess of those paid by efficient hospitals elsewhere in the region. However, perhaps this result is not surprising given that, as discussed in the previous section, we have not been able to adjust for case mix, and clearly the larger hospitals may well be employing more skilled and therefore more expensive staff in order to manage more complex cases.

Table 2: Hospital Size and Efficiency Performance

Hospital Size	Labour Cost Efficiency	Labour Price Technical Efficiency	Labour Price Allocative Efficiency
Large (1–5 inc.)	0.536	0.635	0.844
Medium (6–15 inc.)	0.756	0.843	0.898
Small (16–22 inc.)	0.756	0.865	0.874

ADJUSTMENTS IN STAFFING/LABOUR SUBSTITUTION

Within the NHS in the Northern Ireland region, hospital managers face fixed bands of pay for each particular grade within medical, nursing, administrative and ancillary staff. In this respect, hospital managers must be regarded as price-takers. However, there exists a degree of choice over the grade mix within each broad category of staff. If it can be assumed, for example, that a higher grade mix within the nursing staff of the hospital is associated with payment of a higher average wage rate for nursing services, then the hospital manager may be described indirectly as a price-maker. In this respect, choice over the grade mix or skills mix within a category of staff confers a degree of flexibility for management over the unit wage costs of staffing, particularly over the longer term. It should be remembered, however, that the NI hospitals recruit mainly from local labour markets. Therefore, the lowest average price at which they can obtain each type of staff will depend not only on the NHS pay scales agreed by unions and government, but also on conditions of supply within the local labour market.

In view of this interpretation, evidence of labour price technical inefficiency within a hospital in our study means that the particular hospital is employing too high an average grade mix across the four main staff groupings. Likewise, the existence of labour price allocative inefficiency implies that there exists the opportunity to make cost savings by changing the relative skills mix across the staffing groups. For example, this may be achieved by employing medical staff of a lower grade and nursing staff of a higher grade. Such analysis for management recognises the flexibility that can be afforded when management considers not simply whether nurses and doctors can be substituted for one another, for example, but how skills and associated tasks can be redistributed across the team.

Table 3 further illustrates the possibilities for making changes in staffing in the eight hospitals of our sample with the poorest performance on allocative efficiency. For each of the four labour inputs, we have calculated the ratio of the technically-efficient price (given the observed labour price mix) to the cost-minimising price (given the optimal labour price mix). A ratio greater than one indicates that the optimal price of the input is lower than the technically-efficient price. This suggests relative over-pricing of this input. Conversely, a ratio of less than one indicates that the optimal price of the input is in fact higher than the technically-efficient price, thus suggesting relative under-pricing of this input. This input-pricing information provides management with a general guide to staffing and grade mix strategies, relative to best practice in the sample of hospitals.

Table 3: Ratio of Technically-Efficient Price to Cost-minimising Price for each Type of Labour

Hospital	Input Price Allocative Efficiency	Medical	Nursing	Administrative	Ancillary
22	0.651	1.031	1.910	0.700	1.155
16	0.686	1.198	1.701	0.670	1.509
1	0.759	0.984	1.434	1.306	2.091
8	0.782	1.055	1.711	0.812	0.807
6	0.791	1.030	1.350	1.792	0.770
5	0.792	1.052	1.512	1.093	0.776
12	0.798	1.172	1.562	0.798	0.846
2	0.819	1.041	1.082	3.183	2.661

Table 1 shows approximately 15 per cent technical inefficiency in hospital (22), meaning that (relative to best practice) average wage rates could be reduced by 15 per cent without a loss of service provision. However, when we consider **Table 3** it is clear that the optimal average wage rate for nursing staff involves a further reduction of almost 50 per cent (as shown by the value 1.910). At the same time, the optimal

average wage rate to pay for administrative staff would be just over 40 per cent higher than the technically-efficient price (as shown by the value 0.700). This indicates to managers that it would be efficient to make changes in staffing, such that the hospital employs nursing staff of a lower grade on average, and administrative staff of a higher average grade, as compared with present practice.

If we consider hospital (2), **Table 3** indicates that the ratio for each staff type is greater than one. This suggests a degree of allocative inefficiency in terms of the average prices or unit costs of all staffing types as compared to practice in efficient hospitals within the region. Therefore, there were opportunities to make cost savings by altering the grade mix within all categories of staff. However, the results on allocative inefficiency suggest that a drive towards greater efficiency would require making relatively larger adjustments in terms of lowering the average grade of both administrative and ancillary staff employed within the hospital and thus reducing the unit wage cost of these categories of staff. By contrast, relatively smaller adjustments would have been possible with nursing and medical staff within that particular hospital.

Of the eight hospitals of our sample where allocative inefficiency is most prevalent, it is almost consistently the case that our research indicated the possibility of making relatively large adjustments in the grade mix of nursing staff. The results suggest that cost efficiency will be enhanced by replacing some higher grade nurses with lower grade staff. It is likely, however, that lesser skilled staff may require more supervision by senior nursing and medical staff while carrying out certain tasks. In addition, lower grade staff with less experience may take longer to complete tasks. Consequently, an improvement in cost efficiency performance is not guaranteed by simply replacing higher cost staff by lower cost staff (Richardson and Maynard, 1995). Therefore, it would be interesting, but outside of the scope of this paper, to investigate how nursing staff were organised in efficient hospitals of the sample so as to make such improvements possible. While DEA analysis assists the manager in identifying comparative inefficiencies related to the unit costs of staff and the information obtained points to the direction of grade adjustment necessary at the macro level of staffing, questions of how staff are effectively organised and supervised are not addressed by this methodology.

THE QUALITY OF HEALTH CARE

In any comparison of hospital performance, it is desirable that the method should take into account both the quantity and quality of the health care provided. In respect of our own study, omitting to take account of the quality of care raises the possibility that some of the hospitals classed as cost efficient may have sacrificed the quality of care provided by deploying less expensive but lower skilled staff. This is a particular concern here when one considers the evidence of Carr-hill, Dixon, Griffiths, Higgins, McCaughan, Rice and Wright (1995) from a study looking at the link between nursing skill and the quality of health care provided. Using grade as a proxy for skill, their study found (p. 63) that 'both grades and skill mix have an effect on the quality of care, in that the higher the grades (and skills) of the nurses who provide care, the higher the quality of care'. Moreover, the research indicated that costs increase with the quality of nursing care.

However, as encountered in earlier studies of hospital performance (Söderlund, Csaba, Gray, Milne and Raftery, 1997), adequate adjustment for output quality is an exceedingly complex matter. For example, Thanassoulis, Boussofiane and Dyson (1998) have noted that there are two distinct aspects to the quality of health care, namely, the medical outcome (or clinical quality), and the associated manner of delivery (or service quality). Both raise complex measurement problems as detailed further in McCallion, Glass, Jackson, Kerr and McKillop (2000) and to date there is no reliable measure of quality for NI hospitals.

Nevertheless, even if one had reliable information on the quality of health care within each hospital, there still remains the difficult decision of how to incorporate quality appropriately in a DEA model. Moreover, how should we value quantity versus quality (in particular service quality) in the event of any trade-off between the two when there is excess demand for health care within the region?

In the absence of reliable data on the quality of hospital care for the period of our study, we have been able to include only output quantity variables in our model. It should be noted, however, that all else being equal, those hospitals that are able to produce more output are also more effective in reducing waiting times. Waiting time is an important aspect of service quality and, moreover, is often correlated with the quality of the clinical outcome, not least because the period of poor health and suffering is reduced for the patient. (We could introduce waiting time as an output variable in the DEA model, but unfortunately for the period of our study there is no suitable data available at the hospital level). Despite the difficulties as outlined above, it is obvious that the issue of quality is important and should be examined explicitly at some point in a DEA study. Therefore, in this study we have conducted an ex post check on quality, and to do so we have relied on auditor evaluations of whether the (clinical) quality of care has maintained a satisfactory standard in each hospital. The report of the Northern Ireland Audit Office (1993) found no evidence that quality had been regularly compromised in any part of the acute hospital sector.

However, the end objective of any efficiency comparison is often to find efficient units and emulate their performance. This necessitates follow-up case studies of the management of a hospital and the organisation of staff, and it is at this stage that the analyst can incorporate an investigation of the issue of the quality of care. Such an approach may be more fruitful than attempting to take account of quality within the DEA model. This is because the DEA model requires a standardised, quantitative measure of the quality of care and to date there is no satisfactory statistic measuring clinical outcome quality available. For a discussion of the exceeding complexity of constructing such an adequate measure, see McCallion et al. (2000). However, it may well be feasible for the analyst to collect qualitative data (for example, through patient surveys or observations of staff organisation at the ward level) that can provide richer evidence of the quality of care in certain settings. To illustrate, the study by Carr-hill et al. (1995) indicates that the organisation and supervision of staff is key to minimising any drop in the quality of care provided in the situation where less skilled nursing staff were substituted for more skilled staff. They found that while lower grade staff may be associated with lower quality care, the difference is lessened if these members of staff are working alongside more senior staff. Therefore, the evidence of such working patterns in an efficient hospital may well indicate to the analyst that the quality of care is not being compromised.

CONCLUSION

As illustrated by this study, the DEA methodology can be adapted for assessing cost efficiency performance relative to prices or average wages costs within the hospital sector. Since the price efficiency model of Färe et al. (1994) takes account of outputs as well as input quantities and prices, it then indicates where factor substitution can be cost efficient. Furthermore, because the analysis is relative to best practice within the hospitals of the given sample, it can provide an assessment of comparative performance as desired by current policy. It should be noted, however, that the chief contribution of DEA analysis in this area is as a tool to identify better performers and indicate where staffing practice may be cost-inefficient within a region. Therefore, more micro-based studies of labour organisation within the efficient hospitals are needed to ascertain how staffing can be successfully adjusted without compromising the quality of outcomes.

ACKNOWLEDGEMENT

The authors wish to thank Bruce Hollingsworth and other participants at the UK Health Economists' Study Group Conference (July 2000) for helpful comments on an earlier version of the paper. The authors are also indebted to the Northern Ireland Department of Health and Social Services, Strategy and Intelligence Group, Analytical Support Branch, for providing data.

APPENDIX

In this appendix, we outline how the Färe et al. (1994) price efficiency analysis can be utilised to obtain measures of cost efficiency relative to input prices. The analysis permits the identification of shadow input prices so that any difference between shadow and observed input prices can be used as a measure of input price allocative efficiency.

Measuring cost efficiency relative to input prices

As a first step, note that the performance of hospitals can be measured with respect to their relative cost efficiency by utilising DEA. The standard procedure involves choosing the optimal input *quantities* that minimise the hospital's input expenditure while still permitting it to produce its observed output vector at its observed input prices. Let us assume that we observe $j = 1,\ldots,J$ hospitals each using $n = 1,\ldots,N$ inputs x_{jn} to produce $m = 1,\ldots,M$ outputs y_{jm} and paying input prices w_{jn}. The cost minimising linear programme for hospital j is thus

$$C^j = \min_{z,x} \Sigma^N_{n=1} w_{jn} x_n$$

$$\text{subject to} \quad \Sigma^J_{j=1} z_j y_{jm} \geq y_{jm} \quad m = 1,\ldots,M$$

$$\Sigma^J_{j=1} z_j x_{jn} \leq x_n \quad n = 1,\ldots,N$$

$$z_j \geq 0 \quad j = 1,\ldots,J \tag{A.1}$$

where z_j denotes the intensity variables from activity analysis. The solution of (A.1) yields the minimum cost C^j and the optimal input quantities x^*_n. The overall cost efficiency of hospital j is then measured as the ratio of minimum to observed cost $C^j/\Sigma^N_{n=1} w_{jn}x_{jn}$.

In measuring hospital j's performance relative to input price sets we are concerned with finding the cost-normalised or cost-deflated input (shadow) *prices* which minimise its cost while still enabling it to achieve its observed output vector given its observed input (quantity) vector. Thus, if hospital j's observed input prices are deflated by minimum cost C^j obtained from (A.1), to give $\hat{w}_{jn} = w_{jn}/C^j$, the desired shadow input prices can be obtained from the following minimisation problem (for hospital j):

$$DC^j = \min_{z,\hat{w}} \sum^N_{n=1} \hat{w}_n x_{jn}$$

$$\text{subject to} \quad \Sigma^J_{j=1} z_j (1/y_{jm}) \geq 1/y_{jm} \quad m = 1,\ldots,M$$

$$\Sigma^J_{j=1} z_j \hat{w}_{jn} \leq \hat{w}_n \quad n = 1,\ldots,N$$

$$z_j \geq 0 \quad j = 1,\ldots,J \tag{A.2}$$

with this dual or shadow cost function yielding minimum cost DC^j and the optimal shadow input prices $\hat{w}^*_n$. Overall cost efficiency with respect to input prices is then measured as the ratio of minimum to observed cost $DC^j/\Sigma^N_{n=1} \hat{w}_{jn}x_{jn}$. Where this ratio is less than one, and thus denoting cost inefficiency, then hospital j is spending more on inputs than is required by best practice to produce its observed output vector, given its observed input (quantity) vector. This excess expenditure is due to paying input prices that are proportionately too high (denoted technical input price inefficiency) and/or the relative observed input prices being inconsistent with the given input quantity mix (denoted allocative input price inefficiency).

The Farrell-type input price measure of technical efficiency for hospital j is computed via

$$DF^j = \min_{\lambda,z} \lambda$$

$$\text{subject to} \quad \Sigma^J_{j=1} z_j(1/y_{jm}) \geq 1/y_{jm} \quad m = 1,\ldots,M$$

$$\Sigma^J_{j=1} z_j \hat{w}_{jn} \leq \lambda \hat{w}_{jn} \quad n = 1,\ldots,N$$

$$z_j \geq 0 \quad j = 1,\ldots,J \qquad \text{(A.3)}$$

where a minimising value of λ (denoted λ^*) less than one denotes technical input price inefficiency (indicating that hospital j's $\hat{w}_{jn}$ are proportionately too high to enable it to achieve its observed output vector given the input expenditure budget C^j). The input price measure of allocative efficiency can then be obtained residually as the ratio of overall cost efficiency to technical efficiency (with both of the latter being defined with respect to input prices as above).

To gain insight into the over- or under-pricing of input n for hospital j, we can compare the technically-efficient cost-deflated price of input n (given the cost-deflated *observed* input price mix used in (A.3) above) with the shadow cost minimising price of input n (given the *optimal* shadow input price mix yielded by (A.2) above). For hospital j, the technically-efficient cost-deflated price of input n is given by $\lambda^*\hat{w}_{jn}$ where λ^* is the minimising value of λ yielded by (A.3) and $\hat{w}_{jn}$ is the cost-deflated observed input price. The shadow cost minimising price of input n is $\hat{w}^*_{jn}$ as given by (A.2). The resulting ratio $\beta = \lambda^*\hat{w}_{jn}/\hat{w}^*_{jn}$ indicates whether the input is being over-priced ($\beta>1$) or under-priced ($\beta<1$) relative to cost-efficient (best practice) input pricing ($\beta=1$) for this input.

It is important to note that a finding of $\beta<1$ (or $\beta>1$) essentially provides information about input pricing *mix* after technical input price inefficiency has been removed. The input price measure of technical efficiency informs an inefficient hospital that it is paying proportionately too much for *all* its inputs relative to best practice. For the same hospital, a finding of $\beta<1$ for input n indicates that the input pricing *mix* should move in favour of this input so as to achieve overall cost-efficient performance. Also note that the above discussion measures input price efficiency relative to a constant returns to scale, strong disposability price technology (defined in terms of cost-deflated input prices instead of input quantities as in (A.1) above). As indicated by Färe et al. (1994), other technologies can be applied.

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