Hospital Cost Model – A Case Study

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***Abstract*— Models are now tending to become a standard tool in health services management and research. Modeling in different forms has long been regarded as a cornerstone of health OR as an other field of application. This paper describes the development of a model of hospital inpatient costs. The model has three components: overhead, hotel and treatment costs. The size of each component is estimated using regression on historical hospital cost and activity data. It is argued that, for certain types of policy analysis, the model provides a better picture of hospital costs than do conventional accounting methods.**

Key words: Health-Care Services, Regression.

INTRODUCTION

During its thirty years history, the National Health Service (NHS) has experienced many changes. Despite a general improvement in the social and economic conditions of the country, the hopes of successive Governments in the 1950s and 1960s that the incidence of illness and thus the demand for health care would be reduced have proved unfounded; in fact, the pressure on the limited resources of the NHS are greater now than ever before. Although the length of stay of hospital inpatients has decreased steadily during the last twenty years [partly because of improved methods of treatment and partly because of changed attitudes to community care] demand still exceeds supply. It is therefore vital that when new policies and methods of treatment are being considered their costs are forecast as accurately as possible.

Although hospital cost accounts [1,2] provide detailed information about the breakdown of costs between inputs [doctors' pay, heating, catering, building maintenance etc] they provide very little information on which to construct the output – based measures which are needed for policy analysis [3, 4] [e.g. the costs of treating different types of patients, the marginal costs of treating an extra patient or the marginal costs of an additional day in hospital]. For planning purposes one would like to be able to identify the overhead, hotel and treatment components of hospital costs, so that marginal costs can be identified. Attempts have been made [5] to break costs into these components using accounting methods, but many categories of cost inputs cover two or even all three the components, making allocation rather arbitrary. For example, nursing time has to be divided between the hotel component of hospital care and the treatment component (not to mention the time spent in training, which should be regarded as an overhead).

Thus accounting methods encounter the dilemma of either [a] having to employ arbitrary, judgmental assumptions about the breakdown of each cost input, [5, 6] or [b] having to collect very detailed adhoc information in individual hospital on the allocation of each cost input to different types and stages of patient care [7-9]. The problem with the former approach is that the results obtained are likely to be as arbitrary as the assumptions made. The latter approach, though costly, is likely to give realistic and useful results for the individual hospitals studied but is much less likely to prove useful in policy analysis for the NHS as a whole since:

- The individual hospitals studied may not be sufficiently typical of hospitals in general and it may be prohibitively expensive to extend the data collection system to all hospitals.

- The data collection scheme is likely to be somewhat inflexible, i.e. difficult to adapt so that it can provide appropriate information for policy issues that were not considered when the system was designed.

In another variant of the accounting method, mentioned by Hurst [10], the average non-treatment costs of acute hospitals are assumed to be equal to the overall costs of convalescent hospitals and the excess costs of acute hospitals are assumed to be entirely due to their treatment costs. The main problem with this method is that it relies upon the untested assumption that the care given in convalescent hospitals equates to the non-treatment activities of acute hospitals.

An alternative approach has been employed by Hurst [10], Deeble [11], Feldstein [12], Gibbs [13] and Cullyer [14], namely to use regression models to estimate the size of the different cost components. This approach has the advantage of using only data that are available routinely from all hospitals in the NHS. Furthermore it has shown itself to be adaptable to application on a wide range of policy issues. The approach has been used by the Operational Research Service of the Department of Health and Social Security [DHSS] to aid the solution of a variety of planning problems. It is this work by the O.R. Service of DHSS which is reported in this paper.

DATA OF THE PROBLEM

The model, then, appears to yield consistent estimates, from which the appropriate cost breakdown can be calculated. By combining the coefficients shown in Table 1 for the 2006 full sample with sample mean values for the independent variables, the following breakdown of hospital costs was obtained:

Overheads 40%; Hotel 25%; Treatment 35%

With results of this type the model has been used in policy analysis to estimate the likely costs of options under consideration; some examples are described below.

TABLE 1: THE MODEL'S COEFFICIENTS: ESTIMATES FOR TWO YEARS AND FOR A SPLIT SAMPLE

	2005 Treatment Cost (Rs/case)	2006 Treatment Cost(Rs/case)		
		Sample	Set 1	Set 2
Rehabilitation Convalescent Preconvalescent Staff wards	16 (8)	2 (9)	17 (14)	13 (13)
General Medicine Infection diseases Chest diseases Dermatology Rheumatology Other specialist units Sexually transmitted diseases	135 (9)	147 (10)	181 (17)	129 (14)
Gynecology	69 (7)	74 (7)	67 (14)	94 (13)
Pediatrics Obstetrics Special Care baby units GP Maternity	89 (3)	103 (3)	106 (4)	96 (4)
General Surgery Ear, nose and throat Ophthalmology Dental surgery Orthodontics GP Dental	101 (4)	117 (50	117 (7)	111 (7)
Traumatic & orthopedic surgery Radiotherapy Plastic surgery Urology	182 (9)	180 (10)	180 (13)	183 (14)
Neurology Cardiology Neurosurgery Thoracic surgery	420 (24)	445 (26)	538 (38)	458 (54)
Geriatrics Units for the younger disabled	122 (27)	148 (28)	128 (39)	166 (50)
Gp other	58 (7)	53 (70)	61 (11)	52 (11)
Psychiatry children Mental handicap Mental illness Adolescent psychiatry units	243 (116)	214 (120)	57 (180)	202 (174)
Hotel cost (Rs/day) (standard error not calculated)	8.62	9.81	9.28	9.88
Overhead cost (Rs m^2 /year)	20.40 (1.01)	22.55 (1.26)	24.12 (1.88)	23.17 (1.81)
r value number of hospitals in the sample	0.90 1148	0.90 1177	0.91 587	0.89 590

* Standard errors are shown in brackets.

TABLE 2: THE EXTENT OF HOMOSCHEDASTICITY (2006 FIGURES)

Hospital size (available beds)	Standard error of residual	Number of hospitals
0-99	4.76	718
100-199	3.37	223
200-299	3.68	93
300-399	3.40	60
400-499	2.89	33
500-599	2.67	20
600-699	2.76	11
700+	2.76	19

TABLE 3: THE EXPLANATORY POWER OF VARIOUS SIMPLIFICATIONS OF THE MODEL (2006 FIGURES)

Simplification	r value
Full model	0.90
No overhead term	0.87
No overhead term and the same treatment cost for all specialties	0.80

THE MODEL

Detailed study of direct patient care [e.g. Babson [7]] has suggested that costs vary during a patient's stay as shown in Figure 1, yielding a cumulative cost as shown in Figure 2, i.e. there is a fixed component [or treatment cost] for each patient admitted and a variable component [or hotel cost] which depends upon the marginal cost of each extra day's stay beyond the minimum length of stay. Besides direct costs the hospital will incur overhead costs. It was therefore decided to construct a cost model with:

- **Overheads:** Defined as those costs which vary with the size of a hospital rather than it's throughout. They tend to include such items as heating, lighting, maintenance and administration. Early work used available beds as the size measure but since simply providing an extra bed is unlikely to affect overheads, more recent work has used the floor area of the hospital as a more appropriate measure.
- **Hotel Costs:** Defined as those costs which vary with the number of beds which are occupied in the hospital. They tend to include such items as laundry, catering and low dependency nursing.
- **Treatment Costs:** Defined as those costs which vary with the number of patients treated. They tend to include such items as doctors' time, high dependency nursing, X-ray and laboratory tests.

Since hotel and treatment costs may vary between different types of patient, it was decided to disaggregate the representation of patients according to the clinical specialty under which they are treated.

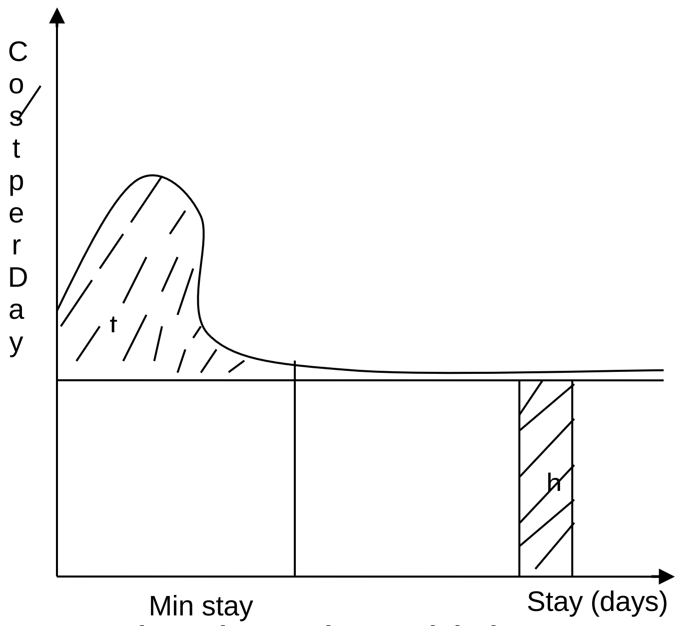

Fig 1. The cost incurred during a Patient's stay in Hospital

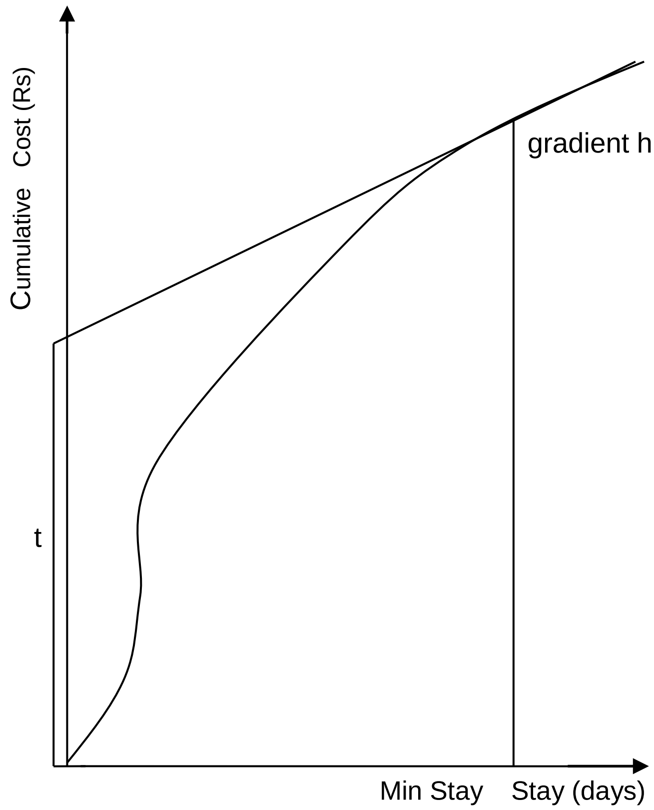

Fig 2: The Cumulative Cost incurred during a Patient's stay in Hospital

Thus the model can be expressed formally by

$$C_j = o_j A_j + \sum h_i B_{ij} + \sum t_i N_{ij} \qquad \ldots (1)$$

where

o = overhead cost per m^2 per annum

h_i = hotel cost per day for a patient in group i

t_i = treatment cost per case for patients in group i

These to be estimated -

C_j = total inpatient cost of hospital j per annum

A_j = floor area of hospital j [m^2]

B_{ij} = number of bed-days used by patients of group i in hospital j per annum

N_{ij} = number of patients of group i in hospital j per annum.

Obviously, hospitals are not going to satisfy this equation exactly. In practice, they will have differing overhead, hotel and treatment cost rates for a whole variety of reasons, only some of which can be quantified. For modeling purposes these differences will be viewed as random variations from the underlying cost model. Regression analysis can then be used to estimate the values of o, h_i and t_i.

However, the values of A_j, B_{ij} and N_{ij} will be strongly correlated; large hospitals will have a large floor area, and treat many patients in most specialty groups.

Equation [1] therefore has drawbacks from the point of view of regression analysis. This can be overcome by dividing through by the total number of patients [in which case the dependent variable becomes average cost per case], the number of occupied bed-days [in which case the dependent variable becomes average cost bed-day] or any other measure reflecting the scale of the hospital.

A further difficulty is that even after division by a scale factor, each B_{ij} will still be strongly correlated with the corresponding N_{ij}. [Bed-days are not used by a group unless patients are being treated in that group]. In order to remove this source of multicollinearity, one must assume either that hotel costs per day are the same for all patient groups or that treatment costs per case are the same. The former assumption was adopted since it seems more reasonable intuitively and previous work [15] has shown that it leads to an equation which fits hospital data more closely. Thus equation (1), after division by the total number of patients becomes:

$$CC_j = o\frac{A_j}{N_j} + hL_j + \sum t_i P_{ij} \qquad \ldots (2)$$

where

CC_j = average cost per case in hospital, j$(=\frac{C_j}{N_j})$

N_j = total number of cases in hospital, j$(=\sum N_{ij})$

L_j = average length of stay in hospital, j$(=\sum\frac{B_{ij}}{N_j})$

P_{ij} = proportion of cases in group i in hospital, j$(=\frac{N_{ij}}{N_j})$

h = average hotel cost per day (to be estimated).

Even in this equation there is likely to be collinearity between first two terms since length of stay, L_j, is one of the main determinants of a hospital's throughput, N_j. Accordingly an attractive alternative is to divide equation (1) by the number of occupied bed-days which yields:

$$CD_j = o\frac{A_j}{B_j} + h + \sum_i t_i \frac{N_{ij}}{B_j} \qquad \ldots (3)$$

where

CD_j = average cost per day in hospital j($=\frac{C_j}{B_j}$)

B_j = total number of occupied bed-days in hospital, j($=\sum B_{ij}$)

If the assumption which had to be made [i.e. uniform hotel costs per day] is invalid, then the treatment costs for any patient group with a higher than average hotel cost will be artificially inflated. Conversely, those for a low hotel cost group will be depressed. The method should still give a reasonable indication of the overall balance between hotel and treatment costs but may be somewhat misleading for particular patient groups.

When applied to data from 1150 non-psychiatric hospitals in India, a regression of the form of equation [3] yielded a high multiple correlation [r=0.90] and parameter estimates as shown in Table 1. Equations of the form [1] and [2] yielded higher r values [0.99 and 0.97 respectively] but because of the greater multicollinearity mentioned above, the standard errors of the coefficients were higher. Accordingly equations of the form [3] were used for the remainder of the analysis. There was some evidence [see Table 2] that the magnitude of the unexplained variability was larger for hospitals of less than 100 beds.

Various simplifications of the model were tested to assess the contribution of each component to the explanatory power of the model [see table 3]. The overhead term seems to be adding little to the explanatory power of the model but when it is not present the parameters are not so stable across subsets of the sample. Furthermore its presence is useful when examining certain policy issues. Further checks of the reliability of the model have been made by carrying out the analysis on more than one year's data and by splitting the sample randomly, performing the analysis on both halves. Reasonably stable values of the coefficients resulted.

RESULT AND ANALYSIS

One of the main policy issues facing health authorities is the closure of acute beds [i.e. hospital beds other than psychiatric and geriatric]. Over the past 25 years there has been a gradual but steady reduction in the number of acute beds. Despite this the hospital service has been able to increase the number of inpatients, mainly because of a relatively rapid reduction in average length of stay. If the downward trend in length of stay continues it would be possible to close more acute beds, and save money, without reducing the number of patients treated. If beds are not closed than the number of patients could increase and create an upward pressure on cost. In a hospital in which the average length of stay and the turnover interval – the average length of time between the departure of a patient from a bed and the receipt of a new patient to the same bed-are decreasing, the effects of various policy options can be examined. Under such circumstances there are two distinct policy options: [A] treat more patients with the same number of beds or [B] treat the same number of patients with fewer beds. There are, of course, intermediate options as well.

Suppose that planning is for a point in the near future at which both length of stay and turnover interval are expected to have declined by about 10% from their current values. Under option A, overhead and hotel costs will not change, but treatment costs will rise by about 10%. As treatment costs are about 35% of total running costs [from the results described above] the total running costs of the hospital will rise by about 3.5% i.e. total cost will increase by much less than the number of patients. The care in the hospital will need to become more intensive, i.e. the ratio of treatment to other resources will need to increase, because patients will remain in the hospital only during the more acute part of their illness. [The assumption here is that the extra patients admitted under this policy option would require the same level of treatment resources as the current average patient; this may well be an over-estimate since one might expect the marginal patient to be less seriously ill].

By similar arguments Option B leads to a reduction in total running costs of about 6.5%. An intermediate option [C] to reduce beds by that amount which does not change total running costs would require about a 3.5% reduction in beds, allowing almost a 6.5% increase in patients. Option B and C attract savings in non-treatment costs. The estimates of these savings derived above are theoretical maxima for a hospital that makes a perfect adjustment to its new throughput. In practice the amount of savings will depends on the way in which the number of beds is reduced. If whole wards or wings of the main building are closed the savings will be more substantial than merely removing beds in each ward because only then would one expect to observe a reduction in some of the administrative and support services.

It should be noted that the analysis described above is confined to hospital costs. It can be argued that for some types of patients a decrease in length of stay will only be achieved if extra post-discharge support is available from community health and/or social services.

REFERENCES

1. Health Service Costing Returns: *Department of health and social security.1997.*
2. Marion S. R. and Nikolaus B: *How many AEDs in which region? An economic decision model for the Austrian Red Cross,* European Journal of Operational Research, 2003, 150(1), 3-18.
3. Blake J.T. and Carter M.W: *Physician and hospital models under decreasing resource, Socio* - Economic Planning Sciences, 2000, 231-250.
4. Blake J.T. and Carter M.W*: A Goal- programming approach to resource allocation in acute- care hospitals,* European Journal of Operational Research, 2001, 222-238.
5. Luck G.M. et al.: *Patients, Hospitals and Operational Research,*

Tavistock, London, 1971, 77-82.

6. University College Hospital Computer Project Team: *Internal Report of Preliminary study.1969.*

7. Babson: *Disease Costing,* Manchester University Press. 1973.

8. Magee: *Hosp,* Hlth Serv, Rev. 1974, 70,422.

9. Harper D: *Hospital costing and clinician,* Department of health and social security, 1978, 15-22.

10. Hurst J.W: *Saving hospital expenditure by reducing in-patient stay,* Govt Economic Service, Occasional Papers, HMSO. 1977.

11. Deeble J: *An economic analysis of hospital costs,* Med.Care 3, 1965, 138-146.

12. Geldstein M: *Economic analysis for health service efficiency,* North Holland, Amsterdam, 1967.

13. Gibbs R.J: *Some consequences of the more intensive use of hospital bed, in elected papers on Operational Research in the health services,* Operational Research Society. 1976.

14. Cullyer A.J. et al.: *What account for the higher costs of teaching hospitals?* Soc.Economic. 1978, 12, 20-30.

15. Watt G.C: *Patient transfers-specialty costing,* Operational Research service (DHSS), 1976, Note 27/75.

16. Alois Geyer et al.: *Scenario tree generation and multi-asset financial Optimization problem,* Operations Research Letters, 2013, 41, 494-498.