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A multiple-output multiple-input model of the hospital industry in North Carolina

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I. INTRODUCTION

The multiproduct nature of the hospital industry has been a source of frustration for economists. However, the development of the neoclassical joint cost function and the complementary development of the flexible functional forms have facilitated analysis of the cost-production structure of such firms. The present study reports the results of estimating a translog joint cost function consisting of three outputs (non-Medicare, Medicare, and child inpatient days) and four inputs (general services, nursing services, ancillary services, and capital). The results indicate: (a) hospital cost functions exhibit constant returns to scale; (b) nursing and ancillary services are complementary to capital, while general services and capital are substitutes; (c) the marginal cost of child inpatient days is substantially greater than the marginal cost for the other types of inpatient days; and (d) that the cost-minimizing input mix is not independent of the output mix.

II. COST MINIMIZATION AND THE HOSPITAL INDUSTRY[1]

Application of the translog joint cost function to the not-for-profit hospital industry requires that we assume they minimize costs. This assumption of cost minimization is reasonable in view of the pressures on hospital administrators.

Within the hospital, three principal factors determine cost: the nature of the demand for hospital services, the nature of factor markets, and the impact of third party reimbursement policies. With regard to the nature of the demand for hospital services, we view it as exogenous to the principal decisions of the hospital administrator; physicians in our view operate as independent, demand-creating entities.[2]

[1]Extensive reviews of the health economic literature have been done by Klarman (1965), Lave (1966), Mann and Yett (1968), Hefty (1969), Davis (1972) and Feldstein (1974).
[2]See, for example, Arrow (1963) and Smallwood and Smith (1975).

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The administrator must provide,[3] on demand, quantities of services sought by the staff at quality standards consistent with the long-run policy set by the board of trustees. Thus, given policy and the various constraints, the administrator is responsible for hiring factor inputs which are combined with physician services to provide the necessary treatments in an efficient manner. Since physician services are provided at zero cost[4] to the hospital or firm, it is the hiring and composition of the factor inputs that generate the costs for the hospital. With regard to factor markets *per se*, we assume that they are competitive and free from monopsonistic pressures.

The major force which creates cost-minimization pressures comes from the parties reimbursing hospitals. Over 85% of all hospital costs billed to individuals in the US are paid through the third party insurers—either private insurance companies, federal programmes such as Medicare and Medicaid, or state and local welfare agencies.[5] Over a long period of time the agencies have developed reimbursement policies based on 'reasonable costs'[6] incurred for the delivery of care. Reasonable costs are calculated by requiring hospitals to report in detail their costs on at least an annual basis and by on-site inspection and audits of records.

These agencies set reimbursement rates for each hospital based on cost reports and comparisons with other hospitals, and thus exercise substantial power over the hospital. If costs are not in line with the agencies' criteria, they (the agencies) have the authority to lower reimbursement rates or to cancel the agreements altogether.[7] Such actions would lower or cut off the major source of revenue to the hospital. Therefore, in the absence of collusion, incentives exist for the administrator to deliver services at minimum cost.

In our view, given the policy of the board of trustees, the hospital administrator must meet an exogenously generated demand for services. Demand is exogenous to the decisions of the hospital because the physician operating independently orders a particular mix of services for patients. Also, because there are alternative hospitals, private medical practices and other medical care providers, it is reasonable to assume competitive behaviour in the factor markets.[8]

[3]Harris (1977) develops a model where the internal decision structure of the hospital is composed of two separate units: the administration and the medical staff. The model described above has many similar characteristics except that the role of the administrator is emphasized. See Newhouse (1970), Lee (1971), Davis (1972), Pauly and Redish (1973) and Dusansky and Kahman (1974) for a sample of other decision structures.

[4]Baron (1974), p. 36 has argued that the 'costs' of physician services are non-zero and are composed of various types of capital expenditures such as CAT scanners and intensive care units. This may be the case. However, from the administrator's perspective these costs are still exogenous.

[5]For details see Blue Cross Reports number 13 (1975).

[6]For a discussion of reasonable costs see North Carolina Medical Assistance Program (1968).

[7]See Hospital Administrative Services (1968).

[8]For an alternative view to the assumption of competitive factor markets see Davis (1972), p. 9.

III. THE TRANSLOG JOINT COST FUNCTION

Many previous empirical studies of the hospital industry have assumed cost-minimizing behaviour but have employed functions which place severe restrictions on the structure of production.[9] Through the use of a neoclassical joint cost function and the flexible functional form,[10] it is possible to estimate a more general form of the cost function than, say, Cobb–Douglas and to test empirically parametric restrictions such as separability and homogeneity.

To estimate hospital cost relationships, we use the transcendental logarithmic function. Following Brown *et al.* (1979) the joint cost function is defined as:

$$\ln C = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln Y_i + \sum_{i=1}^{m} \beta_i \ln W_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \delta_{ij} \ln Y_i \ln Y_j + \frac{1}{2} \sum_{i=1}^{m} \sum_{j=1}^{m} \gamma_{ij} \ln W_i \ln W_j + \sum_{i=1}^{n} \sum_{j=1}^{m} \rho_{ij} \ln Y_i \ln W_j \quad (1)$$

Where Y_i is the output indexed by $i = 1, \ldots, n$; $Y_i \neq 0$

W_i is the input prices indexed by $i = 1, \ldots, m$

and $\delta_{ij} = \delta_{ji}$, $\gamma_{ij} = \gamma_{ji}$.

Since cost functions are linearly homogeneous in input prices, the following restrictions on Equation 1 are implied:[11]

$$\sum_{i=1}^{m} \beta_i = \sum_{j=1}^{m} \rho_{ij} = 0 \text{ for all values of } i, \quad \text{and} \quad \sum_{j=1}^{m} \gamma_{ij} = 0 \text{ for all values of } i. \quad (2)$$

Two types of restrictions on the structure of hospital production will be tested: separability, and homogeneity of degree one. Separability between outputs and inputs implies that the cost minimizing input mix is independent of the output mix.[12] In the present context, the following restrictions, which we will test statistically, on the translog form are sufficient to ensure separability:

$$\rho_{ij} = 0 \text{ for all values of } i \text{ and } j \quad (3)$$

Homogeneity of degree one in outputs implies that a proportional increase in all outputs results in an equal proportional increase in total cost. The restrictions required to impose

[9]See Feldstein (1974) for a discussion of this literature.

[10]No attempt will be made here to fully develop either the theory of the neo-classical cost function or the various restrictions placed on the translog function. For the former see: McFadden (1966, 1970); Lau (1969); Diewert (1974); and Berndt and Christensen (1973b). For the latter see: Berndt and Christensen (1973a); Christensen *et al.* (1973); Christensen and Greene (1976); Brown *et al.* (1975); and Caves and Christensen (1976).

[11]See Lau (1969) for detailed analysis and Berndt and Christensen (1973a) for complete definitions.

[12]See Burgess (1976) and Lau (1969) for a complete discussion.

homogeneity (or constant returns to scale) on the translog cost function are:

$$\sum_{i=1}^{m} \alpha_i = 1 \tag{4}$$

$$\sum_{i=1}^{m} \delta_{ij} = 0 \qquad j = 1, \ldots m.$$

$$\sum_{i=1}^{m} \rho_{ij} = 0 \qquad j = 1, \ldots m.$$

The translog function contains a large number of parameters even for a relatively small number of inputs and outputs. As a result estimation of Equation 1 via ordinary least squares is likely to result in imprecise parameter estimates due to multicollinearity. Fortunately, an estimation procedure to alleviate this problem exists.[13] Shephard's Lemma is employed to derive m factor share equations (of which $m - 1$ are indepedent) in the following form:[14]

$$\frac{\partial \ln C_s}{\partial \ln P_i} = \frac{P_i X_i}{C_s} = M_i \beta_i + \sum_{j=1}^{m} \gamma_{ij} \ln P_j + \sum_{j=1}^{n} \rho_{ij} \ln Y_j \text{ for all values of } i. \tag{5}$$

These relationships increase the amount of information about the production structure without increasing the number of parameters. Specifying classical disturbances, Equations 4 and 5 now comprise a multivariate system. These disturbances may be interpreted as random errors in achieving the cost minimizing bundle for each hospital. Thus the disturbances are assumed to be correlated within each hospital because errors involving one input will affect the cost shares of other inputs and total costs. With such a specification the system can be iteratively estimated by the Zellner (1962)[15] procedure. This is the procedure which was adopted to obtain the results to which we now turn.

IV. EMPIRICAL RESULTS FOR THE NORTH CAROLINA HOSPITAL INDUSTRY

The data used in this study are based on the audited Medicare cost reports submitted by 114 North Carolina hospitals to North Carolina Blue Cross–Blue Shield which were available under the Freedom of Information Act for fiscal year 1978, and a similar set of reports submitted to the Duke Endowment which was provided to the authors.[16] Extensive cross-

[13]See Brown *et al.* (1975).

[14]Shephard's Lemma assumes price-taking behaviour in factor markets. Thus its use is justified by the model developed earlier.

[15]Because the factor shares sum to one, the disturbances will sum identically to zero, resulting in a singular covariance matrix. Dropping one equation in the estimation procedure and calculating the omitted coefficents from those remaining is the standard solution to this problem.

[16]See North Carolina Blue Cross (1978).

checking between the two data sources was necessary to ensure that the variables properly reflected the behaviour to be modelled. Restricting the sample to one state was desirable because it ensures a single institutional and regulatory environment. Costs are reported in some detail in these reports and to facilitate estimation the price of factor inputs was aggregated into four major service inputs:[17] (a) nursing; (b) ancillary service (including operating room labour costs and anesthesiology, laboratory, and X-ray wages); (c) administration and general service (including dietrary, housekeeping, etc.); and (d) Capital.

The definition of output has been a constant problem in estimating cost functions for the hospital industry.[18] Because of our interest in the impact of different age group's utilization of hospital services, we partition total inpatient days into three categories; child inpatient days, non-Medicare inpatient days, and Medicare inpatient days. Besides stratifying output by age group, distinguishing Medicare and non-Medicare inpatient days facilitates an analysis of two groups whose costs are financed by different methods.

Table 1 reports the estimated results for the unrestricted translog form as well as three restricted forms: homogeneous of degree one; separable; and homogeneous and separable. To test the various restrictions, the hypothesis test based on the *F*-criterion was used.[19] The results of these hypothesis tests are reported on Table 2. The results indicate that constant returns to scale cannot be rejected at the 1% level, while all the other restrictive forms cannot be accepted at this level.

Based on the results in Table 1, we conclude that the constant returns to scale model is the most adequate representation of the production structure for the sample hospitals, and that the cost-minimizing input mix is not independent of the output mix. It should be noted that this result is consistent with a large body of past research on scale economies in hospitals (see Feldstein 1974). Thus, the constant returns to scale model will be used to analyse various characteristics of the hospitals' production structure.

Marginal costs for each output are defined as:

$$\frac{\partial C}{\partial Y_i} = \left(\alpha_j + \sum_{j=1}^{m} \ln Y_j + \sum_{j=1}^{m} \rho_{ij} \ln W_j\right) \cdot \frac{\hat{C}}{Y_i} \tag{6}$$

where: $\hat{C}$ = fitted total costs.

Columns 4, 5, and 6 of Table 3 report the mean marginal costs for each output for various hospital sizes. Note that the marginal cost of a child inpatient day is substantially higher than the marginal cost for the other two groups. This difference probably reflects the unique

[17]Outputs (Y_i) and input prices (P_i) are defined as: Y_1; child Days (Age < 14): Y_2; Adult Days (14 ≤ Age < 85): Y_3; Medicare Days (as defined in Medicare cost reports): P_1; price per unit hour of nursing service: P_2; price per unit hour of ancillary service (as defined in Medicare cost reports): P_3; price per unit hour of general service (as defined in Medicare cost reports): P_4; price of capital (assumed to be constant for each hospital. The cost share for capital was calculated as the sum of depreciation and interest charges). Prices were calculated as average costs including fringe benefits.

[18]For example, in a study of New York hospitals, Cowing and Holtmann (1980) use the total number of inpatient days and number of emergency room visits to measure hospital outputs. We prefer instead to disaggregate total inpatient days into its components.

[19]This test was suggested by Zellner (1962).

Table 1. *Parameter estimates for translog joint cost function with various restrictions*[a]

Parameter	Unrestricted	Linear homogeneous	Separable	Linear homogeneous separable
α_0	8.2648	6.6680	7.7089	−1.2570
	(0.9240)	(0.5161)	(1.0132)	(0.3248)
α_1	0.3217	0.4598	0.2013	0.0334
	(0.1552)	(0.0933)	(0.1735)	(0.0715)
α_2	0.3461	0.6667	−0.5240	0.2855
	(0.3228)	(0.1825)	(0.3534)	(0.1318)
α_3	−0.1204	−0.1264	0.1822	0.6811
	(0.3678)	(0.1357)	(0.4143)	(0.0778)
β_1	−0.2940	−0.2459	0.2798	0.5896
	(0.0634)	(0.0513)	(0.0383)	(0.0345)
β_2	0.1648	0.0630	0.0243	0.0708
	(0.0784)	(0.0742)	(0.0581)	(0.0580)
β_3	1.0508	0.8240	0.7720	0.5532
	(0.0970)	(0.0909)	(0.0844)	(0.0837)
[b]β_4	0.0784	0.3589	−0.0761	−0.2136
	(0.1399)	(0.1281)	(0.1094)	(0.1075)
δ_{11}	0.0185	0.0531	0.0506	0.0284
	(0.0241)	(0.0238)	(0.0278)	(0.0275)
δ_{12}	−0.0064	0.0332	−0.0459	0.0795
	(0.0515)	(0.0441)	(0.0596)	(0.0497)
δ_{13}	−0.0058	−0.0863	−0.0050	−0.1079
	(0.0490)	(0.0272)	(0.0569)	(0.0296)
δ_{22}	0.2513	0.4592	0.3018	0.5254
	(0.1406)	(0.1071)	(0.1626)	(0.1184)
δ_{23}	−0.1402	−0.4924	−0.1757	−0.6049
	(0.1347)	(0.0755)	(0.1562)	(0.0827)
δ_{33}	0.2177	0.5787	0.1900	0.7128
	(0.1446)	(0.0589)	(0.1676)	(0.0641)
γ_{11}	0.1311	0.0155	−0.0028	−0.0250
	(0.0078)	(0.0029)	(0.0027)	(0.0024)
γ_{12}	−0.0471	−0.0039	0.0068	0.0009
	(0.0073)	(0.0036)	(0.0029)	(0.0029)
γ_{13}	−0.0637	0.0379	−0.0075	0.0066
	(0.0100)	(0.0042)	(0.0036)	(0.0035)
[b]γ_{14}	−0.0223	0.0495	0.0035	0.0175
	(0.0146)	(0.0062)	(0.0054)	(0.0051)
γ_{22}	0.2182	0.2411	0.2424	0.2388
	(0.0152)	(0.0142)	(0.0134)	(0.0134)
γ_{23}	−0.1124	−0.1382	−0.1625	−0.1503
	(0.0147)	(0.0127)	(0.0117)	(0.0117)
γ_{24}	−0.0587	0.0990	−0.0867	0.1360
	(0.0224)	(0.0194)	(0.0180)	(0.0180)
γ_{33}	0.1010	0.0266	0.0820	0.0710
	(0.0226)	(0.0197)	(0.0187)	(0.0187)
[b]γ_{34}	0.0751	0.0737	0.0880	0.0727
	(0.1026)	(0.0238)	(0.0223)	(0.0223)
[b]γ_{44}	0.0006	−0.0242	−0.0048	−0.2262
	(0.1060)	(0.0313)	(0.0292)	(0.0291)

Table 1. *Continued*

Parameter	Unrestricted	Linear homogeneous	Separable	Linear homogeneous separable
ρ_{11}	−0.0220	−0.0249		
	(0.0046)	(0.0044)		
ρ_{12}	−0.0039	−0.0045		
	(0.0061)	(0.0057)		
ρ_{13}	0.0288	0.0343		
	(0.0069)	(0.0066)		
[b]ρ_{14}	−0.0003	−0.0049		
	(0.0103)	(0.0098)		
ρ_{21}	−0.0704	−0.0092		
	(0.0111)	(0.0092)		
ρ_{22}	0.0291	0.0418		
	(0.0141)	(0.0066)		
ρ_{23}	0.0076	−0.0760		
	(0.0161)	(0.0089)		
ρ_{24}	0.0337	0.0434		
	(0.2411)	(0.0171)		
ρ_{31}	−0.0305	0.0341		
	(0.0100)	(0.0071)		
ρ_{32}	0.0380	−0.0373		
	(0.0131)	(0.0052)		
ρ_{33}	0.0054	−0.0168		
	(0.0149)	(0.0060)		
ρ_{34}	−0.0129	0.0200		
	(0.0222)	(0.0107)		

[a]Standard Errors in Parentheses. [b]Coefficient and standard error are derived.

Table 2. *Test statistics for restricted models*[a]

Model	Number of restrictions	Test statistic	Critical level of $F(q, \infty)$ at 0.01 significance level
Homogeneous of degree one	7	0.01	2.64
Separable	9	9.81	2.41
Homogeneous of degree one and separate	13	15.26	2.18

[a]See Caves and Christensen (1976) for details of the calculation.
These results are means for 89 hospitals which satisfied the necessary and sufficient conditions for cost minimization, i.e. ($\sigma_{ii} \leq 0$ and the Hessian of the cost function being negative semi-definite).

Table 3. *Calculated averages of marginal cost for alternative hospital sizes*

Category	Number	Average beds	Occupancy rate %	Marginal cost of child	Marginal cost of adult	Marginal cost of medicare	Average revenue
Less than 50	14	29.07	61.15	208.32	94.73	85.33	148.62
50–99	34	72.12	71.9	212.54	102.12	70.39	129.29
100–149	19	123.11	73.0	184.51	83.07	60.23	114.95
150–199	16	164.50	77.4	209.27	99.46	54.24	117.41
200–249	2	203.00	81.7	201.57	101.53	60.29	118.81
250–299	6	272.83	88.12	172.96	116.95	73.04	120.24
300–349	6	319.33	81.30	170.73	88.74	43.67	131.51
350–399	5	382.40	89.00	186.62	100.10	44.14	139.60
400–449[a]	4	424.50	85.79	171.93	154.99	87.05	149.31
500–549	2	532.00	88.37	165.12	103.99	41.85	194.12
550–599	1	565.00	86.96	162.50	125.19	41.45	106.37
559–	5	725.60	87.13	253.50	84.67	81.31	203.33

[a]No hospital in the sample was in the 450–499 Bed Range.

Table 4.

Estimated elasticities of substitution						Estimated own-price demand elasticities			
Nursing-ancillary	Nursing-general	Nursing-capital	Ancillary-general	Ancillary-capital	General-capital	Nursing	Ancillary	General	Capital
0.95	1.48	−0.87	−0.07	−3.86	5.44	−0.71	−0.01	−0.56	−0.08

services that are available to infants and children, i.e., nurseries, special care nurseries, and children's wards and also the unusually high expenses of neo-natal care.

Also of interest is the finding that the mean marginal cost values for a Medicare inpatient day is consistently lower than the marginal cost for a non-Medicare patient day. Examination of detailed data indicates that Medicare patients tend to use less expensive inputs than their non-Medicare counterparts. Less than half (47.1%) of all non-Medicare days are in this category. Since the other service categories (in particular the various surgery groups and OB-GYN) are more expensive on average than medicine, part of the difference in marginal cost is the result of the difference in the distribution of cases.

Further, the average length of stay for the Medicare group is, upon examination, always higher than the non-Medicare group in every diagnostic classification. While the cost of 'treatment' *per se* (i.e., the cost of performing an operation, etc.) does not vary greatly among age groups, the longer average length of stay due to the longer recuperation period for the elderly, makes the marginal cost per day lower for the elderly because it 'spreads out' the treatment costs over a longer period of time. Medicare patients also utilize Medicine services for a longer period of time than do other groups, thus reflecting the substitution of hospital residency, which is covered by Medicare.

Table 4 displays the final estimates for partial elasticities of substitution and the own price demand elasticities.[20] Recall that the partial elasticities of substitution for the translog are defined as:

$$\sigma_{ij} = \frac{\gamma_{ij} + \hat{M}_i\hat{M}_j}{\hat{M}_i\hat{M}_j}\; i \neq j$$
$$\sigma_{ii} = \frac{\gamma_{ii} + \hat{M}_i(\hat{M}_{i-1})}{\hat{M}_i^2} \,. \tag{7}$$

The parameter estimates in Table 4 indicate that nursing services are fairly substitutable for both ancillary and general services, but are complementary with capital services. Ancillary services are also complementary with capital and with general services (but the size of this effect is very small). Capital and general labour services are strong substitutes for each other. These results for capital and general labour services are quite intuitive. The expansion of the capital stock toward more sophisticated technologies increases the demand for highly skilled technicians to operate and maintain them. Also larger hospitals in terms of numbers of beds need more nurses to serve the additional patients. Since the general service category includes maintenance, housekeeping, dietary, etc., an increase in capital can be expected to substitute for the 'non-technical' categories.

Finally, the own price elasticities of the various inputs show a greater price sensitivity for general and nursing services than do the other two categories. This result is also intuitive. General services and nursing services are more easily substituted for the other inputs and thus can be expected to have a larger own price elasticity.

[20]See Uzawa (1962) for derivations.

V. SUMMARY AND CONCLUSIONS

The empirical results reported here offer one explanation for the observed rapid increase in hospital costs. The complementary nature of nurses, technicians, and other specialized labour with capital suggests that introducing new forms of capital-intensive technologies has increased the demand for these highly skilled (highly paid) groups of labour and disproportionately increased costs.

These results indicate that the use of a multiple-output, multiple-input model of hospitals can provide valuable insights into aggregate hospital cost behaviour. With such recent proposals as certificate of need legislation, and other forms of cost controls as well as the increasing pressure for some form of national health insurance, the hospital sector is in a state of substantial transition and such models permit a more realistic appraisal of such policies than heretofore has been available.

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