The Production of Dialysis by For-Profit versus Not-For-Profit Freestanding Renal Dialysis Facilities

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Objective. A study was conducted to determine whether for-profit and not-for-profit freestanding renal dialysis facilities differ with respect to efficiency in the production of dialysis treatments.

Data Sources/Study Setting. National data on 1,224 Medicare-certified freestanding dialysis facilities were obtained from the Health Care Financing Administration's (HCFA) 1990 Independent Renal Dialysis Facility Cost Report. Data on Medicare patients receiving care at these facilities during 1990 were obtained from HCFA's End Stage Renal Disease (ESRD) Program Management and Medical Information System (PMMIS).

Study Design. Ordinary least squares regression (OLS) was used to estimate the association between monthly output of dialysis treatments in 1990 and (a) facility capital and labor inputs, (b) facility ownership characteristics, and (c) case-mix characteristics.

Data Collection/Extraction Methods. Facility and patient level data were extracted from the Facility Cost Report and the PMMIS databases, respectively. Patient level data were aggregated by facility and merged with facility level data.

Principal Findings. For-profit sole proprietorships, for-profit partnerships and for-profit corporations each produced significantly more dialysis treatments per month than not-for-profits, adjusting for quantities of resource inputs and case-mix characteristics.

Conclusion. For-profit facilities appear to be more efficient producers of dialysis treatments than not-for-profits. Further study should address whether other factors such as differences in severity of disease or in quality of care are responsible for these observations.

Keywords. For-profit medical care, renal dialysis, health economics, Medicare, end stage renal disease

The rise of the for-profit enterprise in health care has prompted debate over whether for-profit health care providers are more efficient than not-for-profits (Siafacu 1981; Held and Pauly 1983; Relman 1983; Sloan and Vraciu 1983); that is, whether they use fewer resources to produce a specific health care output. In this study we estimate the relationship between the profit status of freestanding renal dialysis facilities (defined as those not based at a hospital) and the production of renal dialysis treatments.

We elected to study freestanding renal dialysis facilities for several reasons. First, the increase in for-profit facilities providing dialysis to patients with end stage renal disease (ESRD), most of whom (92.5 percent) receive medical benefits through Medicare's ESRD program, has been rapid and extensive (Kolata 1980; Gardner 1981; Lowrie 1981; Gibson and McMullan 1984; Rettig and Levinsky 1991). In 1982, 37 percent of 71,108 dialysis patients enrolled in Medicare's ESRD program received dialysis at 438 freestanding for-profit facilities, compared to 51 percent of 154,230 patients who received care at 1170 freestanding for-profit facilities in 1991 (U.S. Renal Data System 1993). This increase occurred as the average rate of

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Dr. Powe's work has been supported, in part, by an award (KOlAG00561) from the National Institute on Aging.

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Medicare reimbursement for dialysis provided at freestanding dialysis facilities declined from $138 per dialysis session before 1983 to $125 after 1985 (Rettig and Levinsky 1991). Adjusting for inflation, the rate of decline in real dollars during this period has been even greater.

As shown in earlier research on efficiency in the ESRD program (Held and Pauly 1983), cost, amenity, and patient well-being are all likely to vary positively with reimbursement level. Therefore, there is concern that, in general, dialysis facilities will respond to declining reimbursement by reducing the resource inputs for dialysis treatment below levels necessary to maintain adequate quality of care, and that this response may be greater in facilities with a strong profit motive. However, proponents have suggested that for-profit facilities are more likely to respond by identifying ways of producing dialysis treatments of adequate quality with fewer resource inputs (Lowrie 1981).

Second, an important shortcoming of many previous comparisons of the efficiency of for-profit and not-for-profit hospitals or nursing homes is that it is necessary to adjust for the multi-output nature of these providers. In contrast to multi-output providers, most freestanding dialysis facilities produce only one type of output, namely, dialysis treatments, and such adjustments are unnecessary.

Third, when the types and quantities of inputs necessary to produce a specific type of output (e.g., a DRG-specific discharge) vary according to patient characteristics, it is important to adjust for variability in case mix to minimize the probability that observed differences in efficiency are actually due to unobserved differences in case mix. One advantage of comparing efficiency in dialysis facilities is that all patients have the same disease, chronic renal failure, although the types and quantities of inputs necessary to produce a dialysis treatment may vary according to patient case-mix characteristics, e.g., underlying cause of renal failure. Nationally representative ESRD provider and patient data are available to researchers through the Health Care Financing Administration's (HCFA) ESRD Program Management and Medical Information System (PMMIS) (U.S. Department of Health and Human Services 1990). Therefore, case-mix variables can be incorporated into analyses of efficiency in the production of dialysis treatments.

Finally, payment on a capitated basis, the method whereby HCFA reimburses for dialysis treatments, is likely to feature prominently in health care reform. Although not all medical services for ESRD patients are capitated (e.g., outpatient services other than dialysis), understanding providers' production of specific health services under capitated reimbursement, e.g., dialysis, provides insight into how different types of facilities might be expected to respond to health care reform.

METHODS

Study Design. This study entailed cross-sectional analysis of all Medicare certified freestanding renal dialysis facilities that produced dialysis services and submitted a Cost Report Form to HCFA in 1990.

Data Sources. The principal source of ESRD facility data was the Independent Renal Dialysis Facility Cost Report (Form HCFA-265-81). All Medicare-certified freestanding dialysis facilities are required by law (section 1833(e) of the Social Security Act and 42 CFR 405.5431 and 42 CFR 406.2133) to submit this report on an annual basis. The cost report contains information on the quantity of each type (modality) of dialysis treatment produced (outputs), the quantities and costs of labor and capital resources (inputs) consumed in the production of dialysis treatments, and information on the ownership characteristics of the facility. There is considerable financial incentive for facilities to submit a report, since those that fail to do so may become ineligible to receive HCFA reimbursement. The accuracy of the information in the report must be certified by the director of the dialysis facility, and HCFA monitors the content of the cost report by auditing selected facilities.

Data on the characteristics of Medicare ESRD patients receiving care at these dialysis facilities were obtained from HCFA's ESRD Program Management and Medical Information System (PMMIS) Enrollment file. Each quarter demographic and clinical data for newly enrolled patients are added to this file; the records of patients previously enrolled are updated.

Analysis File and Variable Construction. For those patients receiving dialysis treatments in 1990, records in the PMMIS Enrollment file were sorted by dialysis facility identification number. Then facility case-mix variables were constructed by summarizing patient level clinical and demographic data for each facility. Finally, data from the Cost Report file were merged, by facility identification number, with the facility level case-mix data.

The measure of output selected as the dependent variable in the multivariate analysis of production was total dialysis treatments per month, weighted by modality-specific cost (Feldstein 1968) to adjust for the fact that each treatment modality (outpatient maintenance hemodialysis, outpatient maintenance intermittent peritoneal dialysis, home maintenance hemodialysis, home maintenance intermittent peritoneal dialysis, home maintenance continuous ambulatory/continuous cycling peritoneal dialysis, hemodialysis training, intermittent peritoneal dialysis training, continuous ambulatory/continuous cycling peritoneal dialysis training) involves unique and distinguishable resource inputs (Dor, Held, and Pauly 1992).[1]

Independent variables in the model included labor and capital resource inputs used to produce dialysis treatments. Labor inputs were full-time equivalent (FTE) physicians, registered nurses, licensed practical nurses, aides, technicians, dieticians, and social workers. Capital inputs were the number of machines regularly used for dialysis and the number of available standby machines.

Facility ownership characteristics included type of ownership, specified as for-profit sole proprietorship, for-profit partnership, for-profit corporation, not-for-profit, or government-owned and other, and chain affiliation. The distinction between for-profit sole proprietorship and for-profit partnership was retained to provide an additional proximate indicator of facility size. A variable for geographic location of the facility was also included. Facility patient case-mix characteristics included average age, average duration of ESRD, percent male gender, percent black race, percent of patients receiving hemodialysis, percent with hypertension as an assigned cause of kidney failure, and percent with diabetes as an assigned cause. These case-mix characteristics were included as proximate indicators of severity of illness, which may be predictive of duration and complexity of dialysis. For instance, black race is associated with longer survival relative to white race; diabetes as an assigned cause of renal failure is associated with poor survival relative to other causes, such as hypertension.

FUNCTIONAL FORM FOR THE MULTIVARIATE ANALYSIS OF PRODUCTION

Ordinary least squares (OLS) regression was used to estimate adjusted associations between each of the independent variables and the output of weighted total dialysis treatments per month. We considered two alternative functional forms for the regression model: a linear form, and a transcendental form in which only the dependent variable was log transformed using the natural logarithm[2] (Goldman and Grossman 1983). The linear model with three alternative specifications–(a) labor and capital inputs (including squared and two-way interaction terms) only (Model A); (b) Model A plus facility ownership and geographic characteristics (Model B); and (c) Model B plus facility case-mix characteristics (without squared case-mix terms or two-way case-mix interaction terms–Model C)–was selected as the preferable functional form for describing the production of dialysis treatments.[3] All continuous independent variables were centered to eliminate collinearity with the intercept term.

RESULTS

FACILITIES AND THEIR CHARACTERISTICS

There were 1,272 facilities in the 1990 HCFA Independent Renal Dialysis Facility Cost Report File. Five (0.4 percent) facilities in the Cost Report File could not be matched with case-mix data from the PMMIS Enrollment File. In addition, inspection of the distributions of the resource input and dialysis output variables indicated the presence of large outliers in 43 (3.4 percent) records, which were inconsistent with other data within the record (e.g., 26 standby machines and 0 regular machines) and with other observations within the variable (e.g., 33,280 technicians). These outliers were apparently due to provider submission of inaccurate data or to coding errors. Records that could not be matched and those containing large outliers were removed from the data file prior to analysis.

Table 1 presents output, input, case-mix, ownership, and geographic characteristics of the remaining 1,224 (96.2 percent) freestanding renal dialysis facilities. The mean number of treatments per month was higher than the median (576) due to the fact that, while 90 percent (1,102/1,224 × 100) of the facilities produced less than 1,000 treatments per month, the maximum number of treatments was 4,019. Registered nurses and technicians were the most frequently utilized types of labor inputs while, on average, physicians were least utilized. The mean facility patient case-mix age was 57, reflecting the large number of elderly (>65) patients with ESRD. The mean percent of black patients was consistent with the fact that blacks are overrepresented in the ESRD population (compared to the percentage of blacks in the general population [12 percent]) due, in part, to the propensity of blacks with hypertension and diabetes to develop ESRD (Brancati, Whittle, Whelton, et al. 1992). The mean number of years of ESRD is quite short due to the poor prospects for long-term survival associated with chronic renal failure (Held, Pauly, and Diamond 1987). On average, 59 percent of patients had hypertension or diabetes as the assigned cause of renal failure. Finally, most freestanding dialysis facilities were for-profit and owned by corporations; very few were government-owned, reflecting the limited role that federal and state governments play in the actual delivery of dialysis treatments.

The mean weighted dialysis treatments per month was 686 among for-profit sole proprietorships ($n = 24$), 678 among for-profit partnerships ($n = 72$), 693 among for-profit corporations ($n = 979$), 800 among not-for-profits ($n = 130$), and 598 among government-owned and others ($n = 19$).

MULTIVARIATE ANALYSIS OF PRODUCTION

The results of a multivariate analysis of production, using the linear functional form and the three alternative specifications (models A–C) of this form, are presented in Table 2. As shown, in all three models labor inputs of RNs, LPNs, aides, and technicians were positively and significantly ($p < .001$) associated with output of dialysis treatments. Input of regular dialysis machines became significant ($p < .01$) in Model C, although the magnitude

Table 1: Characteristics of Freestanding Renal Dialysis Facilities

Variable	*Number of Facilities**	*Mean (%)*	*s.d.*
Output (per month)			
Dialysis treatments, weighted by cost (no.)		699.47	518.38
≤250	376		
251–500	273		
501–750	215		
751–1000	146		
1001–1250	92		
>1250	122		
Labor Input (no. FTE)			
Physicians		0.38	0.81
Registered nurses		4.06	3.70
Licensed practical nurses		1.73	2.23
Aides		1.65	3.27
Technicians		4.09	4.04
Social workers		0.57	0.52
Dieticians		0.41	0.39
Capital Input (no.)			
Machines regularly used for dialysis		14.31	7.22
Standby dialysis machines		1.96	1.59
Facility Patient Case-Mix Characteristics			
Mean age (years)		56.74	4.04
% male		47.36	8.60
% black		33.68	28.37
Mean duration of ESRD (years)		3.62	1.06
% patients on hemodialysis		91.19	14.00
% patients with hypertension as assigned cause of renal failure		30.04	13.08
% patients with diabetes as assigned cause of renal failure		29.05	10.80
Facility Ownership Type			
For-profit, sole proprietorship	24	(2.00)	
For-profit, partnership	72	(5.90)	
For-profit, corporation	979	(80.00)	
Not-for-profit	130	(10.60)	
Government-owned and others	19	(1.60)	
Member of a facility chain	677	(55.30)	
Facility Geographic Location (states)			
ME,NH,VT,MA,CT,RI	27	(2.21)	
NY,NJ	51	(4.17)	
PA,DE,MD,VA,WV	168	(13.73)	
KY,TN,NC,SC,GA,FL,MS,AL	407	(33.25)	
MN,WI,IL,IN,MI,OH	91	(7.43)	
NM,TX,OK,AR,LA	196	(16.01)	
IA,MO,NE,KS	48	(3.92)	

Continued

Table 1: Continued

Variable	Number of Facilities*	Mean (%)	s.d.
MT,WY,ND,SD,UT,CO	20	(1.63)	
CA,NV,AZ,HI	201	(16.42)	
AK,WA,OR,ID	15	(1.23)	

*N = 1,224 facilities included unless otherwise stated.

of the coefficient did not change appreciably among the three models. In both models (B and C) that contained ownership variables, for-profit sole proprietorships, for-profit partnerships, and for-profit corporations each produced significantly more dialysis treatments than not-for-profits (the reference category). Also, in both models facilities in the New York region produced significantly more treatments than facilities in the Seattle region (selected as the reference category). As shown in Model C, facilities with a greater percentage of blacks produced more treatments. Facilities with a greater percentage of patients on hemodialysis produced fewer treatments.

There were several statistically significant input interaction terms in Model C (Table 3). Those input interaction terms with estimated beta coefficients significantly greater than zero suggest that the two inputs are complements, whereas coefficients less than zero suggest the presence of input substitutes. Each model explained at least 86 percent of the variability in the dependent variable. Also, the F-statistic for each model was large and statistically significant.

A separate multivariate analysis using Model C, with hemodialysis treatments only as the dependent variable, produced similar results; compared to not-for-profits, for-profit sole proprietorships produced 104 more treatments, for-profit partnerships produced 102 more treatments, for-profit corporations produced 90 more treatments, and government and other facilities produced 110 more treatments.

DISCUSSION

The results of the multivariate analysis of production indicate that for-profit sole proprietorships, for-profit partnerships, and for-profit corporations each produce significantly more weighted dialysis treatments per month than not-for-profit facilities, adjusting for quantities of labor and capital resources used in production, other facility characteristics, and selected patient case-mix variables. The gains in productivity by these for-profit facilities are large. For example, as indicated by the magnitude of the estimated beta

Table 2: Results of a Multiple Linear Regression Analysis that Estimated Adjusted Associations between Weighted Total Dialysis Treatments per Month and Labor, Capital, Ownership, Geography, and Case-Mix Characteristics of the Dialysis Facility

Facility Characteristics Included in the Model	*Model A* Labor and Capital Inputs		*Model B* Labor and Capital Inputs (Ownership, Type, Geographic Location)		*Model C* Labor and Capital Inputs, Ownership Type, Geographic Location, Case-Mix Characteristics	
Variable name†	*Estimated Beta Coefficient*	*(S.E.)*	*Estimated Beta Coefficient*	*(S.E.)*	*Estimated Beta Coefficient*	*(S.E.)*
Capital Inputs (no.)						
Regular machines	4.52	(3.39)	5.66	(3.37)	9.87	(3.37)
Regular machines squared	0.23	(0.13)	0.18	(0.13)	0.05	(0.13)
Standby machines	7.66	(12.08)	6.36	(11.89)	13.95	(11.73)
Standby machines squared	−0.37	(1.27)	−0.16	(1.24)	−0.61	(1.22)
Labor Input (no. FTE)						
Physicians	−28.87	(21.42)	−40.97	(21.81)	−37.77	(21.46)
Physicians squared	14.79	(4.60)	17.68	(4.67)	17.65	(4.60)
Registered nurses	52.35	(5.71)	50.24	(5.78)	42.04	(5.85)
Registered nurses squared	0.26	(0.37)	−0.22	(0.37)	−0.07	(0.37)
Licensed practical nurses	40.83	(7.91)	46.90	(7.77)	43.43	(7.68)
Licensed practical nurses squared	−0.55	(0.62)	−0.67	(0.61)	−0.58	(0.60)
Aides	46.86	(7.06)	44.44	(6.95)	43.28	(6.83)
Aides squared	−0.73	(0.51)	−0.65	(0.50)	−0.74	(0.50)
Technicians	42.75	(5.59)	41.03	(5.56)	41.93	(5.46)
Technicians squared	−0.30	(0.37)	−0.20	(0.37)	−0.22	(0.36)
Social workers	−18.16	(55.26)	−11.41	(54.27)	−29.76	(53.33)
Social workers squared	7.66	(11.08)	7.42	(10.83)	7.91	(10.63)
Dieticians	109.10	(66.93)	70.11	(65.77)	54.12	(64.78)
Dieticians squared	−58.88	(45.38)	−17.24	(44.82)	−6.35	(44.00)
Facility Ownership Type						
For-profit, sole proprietorship			138.63**	(45.82)	146.03**	(45.13)
For-profit, partnership			114.48***	(30.17)	103.27***	(29.87)
For-profit, corporation			94.73***	(20.53)	91.60***	(20.29)
Government-owned and others			89.39	(53.42)	97.63	(52.65)
Not-for-profit			Reference		Reference	
Member of a chain‡			4.45	(12.83)	7.13	(12.75)

Continued

Table 2: Continued

	Model A		Model B		Model C	
Facility Characteristics Included in the Model	*Labor and Capital Inputs*		*Labor and Capital Inputs (Ownership, Type, Geographic Location)*		*Labor and Capital Inputs, Ownership Type, Geographic Location, Case-Mix Characteristics*	
Variable name†	*Estimated Beta Coefficient*	*(S.E.)*	*Estimated Beta Coefficient*	*(S.E.)*	*Estimated Beta Coefficient*	*(S.E.)*
Facility Geographic Location (states)						
ME,NH,VT,MA,CT,RI			128.47	(65.72)	121.89	(64.69)
NY,NJ			141.91	(61.43)	147.52	(60.76)
PA,DE,MD,VA,WV			−17.37	(55.34)	−39.08	(54.89)
KY,TN,NC,SC,GA,FL, MS,AL			−37.99	(54.33)	−61.75	(54.00)
MN,WI,IL,IN,MI,OH			37.43	(56.99)	28.73	(56.19)
NM,TX,OK,AR,LA			−41.73	(55.77)	−52.14	(55.11)
IA,MO,NE,KS			−16.95	(60.18)	−22.70	(59.35)
MT,WY,ND,SD,UT,CO			25.75	(70.92)	37.19	(69.78)
CA,NV,AZ,HI			9.96	(54.63)	4.53	(53.84)
AK,WA,OR,ID			Reference		Reference	
Facility Case-Mix Characteristics						
Mean age (years)					1.00	(1.63)
% male					−0.52	(0.66)
% black					0.57	(0.28)
Mean duration of ESRD (years)					6.00	(6.56)
% patients on hemodialysis					−2.99	(0.43)
% patients with hypertension as assigned cause of renal failure					0.51	(0.64)
% patients with diabetes as assigned cause of renal failure					−0.07	
Intercept Term	704.46	(6.22)	623.21	(53.74)	637.36	(53.38)
Model Degrees of Freedom (corrected)	54		68		75	
Error Degrees of Freedom	1169		1155		1148	
Adj. R^2	0.86		0.87		0.87	
F-*Value*	138.81***		117.97***		112.17***	

$^{**}p < .01$; $^{***}p < .001$.

†Each continuous variable has been centered to eliminate collinearity with the intercept term.

‡No affiliation with facility chain is the reference category.

Table 3: Statistically Significant Interactions among Inputs Included in the Linear Regression Model C

Interaction Term	*Beta Coefficient on Interaction Term in the Multivariate Model C*
Complements†	
Physician–Registered nurse	5.66**
Physician–Technician	6.85**
Physician–Dietician	49.05*
Registered nurse–Social worker	13.78*
Licensed practical nurse–Aide	3.98
Technician–Standby machine	6.06***
Dietician–Regular machine	8.86**
Substitutes†	
Physician–Social worker	−96.99***
Physician–Standby machine	−34.76***
Registered nurse–Aide	−2.52***
Registered nurse–Technician	−1.93***
Licensed practical nurse–Dietician	−26.83**
Technician–Dietician	−25.05***

†A positive number in a cell indicates a statistically significant complement. A negative number indicates a statistically significant substitute.

*$p < .05$; **$p < .01$; ***$p < .001$.

coefficient in Model C, ownership status is associated with 21 percent of the treatments in for-profit sole proprietorships, 15 percent in for-profit partnerships and 13 percent in for-profit corporations. The results suggest that for-profit facilities may be more efficient than not-for-profits because they produce more dialysis treatments with fixed levels of inputs.

In general, the positive and significant associations between labor and capital resource inputs and quantity of dialysis treatments produced are consistent with theoretical expectations. The fact that most of the squared capital and labor input terms were not significant suggests that, within the range of data available to this study, as quantities of inputs increase, output also increases linearly. Also, examination of estimated beta coefficients on resource input interaction terms from Model C suggests that several inputs are complements and several are substitutes.

This analysis is limited in several ways. First, the generalizability of the results may be limited because the analysis included only freestanding renal dialysis facilities and excluded hospital-based facilities. Clinical practice, or patients, may differ between freestanding and hospital-based facilities. For instance, Plough, Salem, Schwartz, et al. (1984) found that patients receiving care at hospital-based facilities were sicker than those in freestanding facilities. This finding was supported by Held, Pauly, and Diamond (1987). Further, the results may not be generalizable to health care providers as a whole. As discussed earlier, ESRD patients are unique: clinically, in the type of care they receive, and, in addition, because they are beneficiaries in the only public program that provides health insurance coverage based on the type of disease. However, the limited generalizability of this study is balanced by its strengths. For instance, while for-profits and not-for-profits may behave differently under different types of reimbursement, this analysis controls for that variability by examining care in a population with relatively homogeneous insurance benefits.

Second, a limited number of variables were available to adjust for severity of illness in the facility case-mix. This could affect conclusions regarding the relative efficiency of for-profits and not-for-profits. For instance, for-profit and not-for-profit facilities may differ in patient severity of illness (e.g., due to differential rates of referral for kidney transplant) and in other ways that are not captured in the analysis, with the result that observed differences attributed to relative efficiency may in fact be due to unobserved differences in severity of illness.

Third, dialysis treatments that are provided during admission to the hospital were not included in the measure of output. If patients in not-for-profit facilities spend more time in the hospital, then these not-for-profit facilities would appear to produce fewer dialysis treatments for a fixed level of capital and labor inputs than for-profits, as their patients would receive more dialysis sessions in the hospital.

Fourth, there may be variability in quality of care across providers that is associated with the level of resources expended in the production of dialysis. To the extent that this variability is systematic between for-profit and not-for-profit facilities, differences in this analysis that are attributed to differences in efficiency could really be due to differences in quality of care between for-profits and not-for-profits. For instance, Held, Levin, Bovbjerg, et al. (1991) found that patients treated with short-time dialysis are disproportionately treated in for-profit facilities, and that shorter duration of dialysis is associated with higher mortality and more intradialytic events.

Finally, no data on the quantity of supplies (dialyzers) were available. If there are systematic differences between for-profit and not-for-profit facilities in the quantity of supplies utilized in the production of dialysis, then these unobserved differences could be captured in the organizational coefficients in the multivariate model.

Within the limitations discussed above, it appears that for-profit freestanding dialysis facilities produce more dialysis treatments with fixed quantities of labor and capital inputs than not-for-profits. Therefore, for-profits may be more efficient providers of dialysis treatments. Although, based on these results, there is cause for cautious optimism that the presence of the for-profit enterprise in renal dialysis care may enhance efforts to contain the costs of providing care, it should be kept in mind that variability in case-mix, severity of illness, and quality of care among dialysis facilities may affect the results of this study. Therefore, before findings such as these can form the basis for policy decisions that encourage efficiency in the provision of dialysis, studies that include more comprehensive information on facility case-mix severity of illness and on quality of care within dialysis facilities should be performed.

NOTES

1. To adjust for the fact that quantity of home continuous ambulatory/continuous cycling peritoneal dialysis is reported in number of weeks, this quantity was first multiplied by 3 to obtain treatment equivalents (Dor, Held, and Pauly 1992). Although this approach, combined with weighting each type of treatment by cost, was designed to adjust for differences between methods of counting hemodialysis and peritoneal dialysis and differences in levels of inputs necessary to produce dialysis (e.g., staffing requirements), a separate analysis excluding peritoneal dialysis treatments was also performed to determine the effect of organizational status on the production of hemodialysis.
2. Initially, we also considered the Cobb-Douglas functional form and the translog functional form (Van Montford 1981). However, as Held and Pauly (1983) had previously observed, we found that in these dialysis facilities positive output was produced even in the absence of some inputs. We could have used either form by performing a Box-Cox transformation on the input variables. However, the Cobb-Douglas functional form is also somewhat restrictive in the constraints it imposes on empirical estimates (Held and Pauly 1983; Hellinger 1975).
3. Selection of the functional form was based on (a) examination of the adjusted associations between each of the continuous independent variables and output, using partial regression leverage plots (Rawlings 1988), (b) evaluation of consistency with the underlying assumptions of OLS regression, and (c) computation of the proportion of variance explained by the model. We compared the marginal product of each input and the efficiency gained by each type of for-profit facility in the linear model, to the corresponding measure in the transcendental model. We also performed a PE test (MacKinnon, White, and Davidson 1983) to determine whether each model explained a component of variability in output that was not explained by the other.

   Using a linear model, each of the adjusted associations between inputs and dialysis outputs was either linear or slightly curvilinear. Further, in the linear model the residuals were approximately normally, identically, and independently distributed, whereas in the transcendental function serial correlation in the residuals was present (although the Durbin-Watson test statistic was inconclusive)

(Rawlings 1988). In addition, the proportion of variance explained by the linear model was greater than that explained by the transcendental model. Comparison of the marginal products between the two functional forms indicated that the relative efficiencies as a function of profit status were robust and quite invariant to the selection of functional form. Finally, the results of the PE test were inconclusive in that each model explained a proportion of the variability in output that was not explained by the other.

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