Review of Industrial Organization **13:** 447–466, 1998.

Market Structure and Hospital Efficiency: Evaluating Potential Effects of Deregulation in a National Health Service *

EULÀLIA DALMAU-MATARRODONA and JAUME PUIG-JUNOY
Universitat Pompeu Fabra, Department of Economics, Trias Fargas 25-27, Edifici Jaume I, 08005 Barcelona, Spain

Abstract. In this article we examine the potential effect of market structure on hospital technical efficiency as a measure of performance controlled by ownership and regulation. This study is relevant to provide an evaluation of the potential effects of recommended and initiated deregulation policies in order to promote market reforms in the context of a European National Health Service. Our goal was reached through three main empirical stages. Firstly, using patient origin data from hospitals in the region of Catalonia in 1990, we estimated geographic hospital markets through the Elzinga–Hogarty approach, based on patient flows. Then we measured the market level of concentration using the Herfindahl–Hirschman index. Secondly, technical and scale efficiency scores for each hospital was obtained specifying a Data Envelopment Analysis. According to the data nearly two-thirds of the hospitals operate under the production frontier with an average efficiency score of 0.841. Finally, the determinants of the efficiency scores were investigated using a censored regression model. Special attention was paid to test the hypothesis that there is an efficiency improvement in more competitive markets. The results suggest that the number of competitors in the market contributes positively to technical efficiency and there is some evidence that the differences in efficiency scores are attributed to several environmental factors such as ownership, market structure and regulation effects.

Key words: Geographic markets, market concentration, technical efficiency, data envelopment analysis, censored regression model.

I. Introduction

Deregulating policy measures promoting market reforms in health care markets are common in all health care systems of developed countries (Abel Smith and Mossialos, 1994). A coincidental point in health care reforms of National Health Services (NHS) lies in the introduction of competition among producers of health services, specially among hospitals, by splitting financing, contracting and producing functions. Competition may be achieved by the introduction of quasi-markets or internal markets (Maynard, 1991) even in a publicly financed health care system, with publicly and/or privately owned producers. In all cases the degree of market

* This paper is part of a research supported by the *Comisión Interministerial para la Ciencia y la Tecnología del Ministerio de Educación y Ciencia* under contract SEC94-0192.

competition appears as a fundamental tool in the most part of health care reforms (OECD, 1996).

The Spanish health care system is no an exception to the prevailing proposed reforms. Interest in the determination of hospital markets in Spain derives from the government's intention to reform the health care sector creating internal markets to control costs and improve efficiency. This proposition contains some elements for encouraging competitiveness. Spanish public health care system has a universal coverage, with 78 percent of public financing and 67 percent of public production. Catalonia is a region of six million inhabitants in the Spanish State. The health care system in Catalonia presents some specificities relevant in the context of this paper. First, it is characterised by a mixture of private (for-profit and nonprofit) and public hospitals. Second, it has developed an innovative contracting policy and payment system since 1982 in contrast to the predominance of public producers and cost reimbursement policy in the rest of the country. Third, it is the region of the country that first announced and applied advanced deregulating policy measures in the health care system.

In order to assess the expected effects of proposed policies it is very important to detect the potential effects of changes in market structure on hospital technical efficiency. In this paper we develop an initial evaluation of the effects of *observed present* market structure on hospital technical efficiency in all Catalan acute care hospitals. Current evidence may bring forward observations on outcomes from projected policies. Studies of hospital markets generally assume that the market area coincides with an existing geographical or geopolitical entity. In contrast to this assumption our empirical analysis is based on patient origin data to measure geographic hospital market. The market level of concentration was estimated using the Herfindahl-Hirschman index. This paper contributes to the existing literature on performance and hospital market structure by defining a two-stage approach. First, a Data Envelopment Analysis (DEA), is applied to the measurement of the best practice frontier and technical inefficiency scores. Then, we apply a censored regression model to find out the importance of environmental variables, specially the role played by the calculated Herfindahl-Hirschmnan index and the number of competitors in the local market, explaining differences in performance measures. We use efficiency scores to test the hypothesis that there is less inefficiency in more competitive markets.

The paper is organized as follows. Section II critically describes preceding literature on measuring geographical markets and their influence on hospital inefficiency. Method and the main results concerning market area definition and concentration are presented in Section III. Section IV proposes an application of DEA analysis to acute care hospitals, and an econometric model to analyse the factors explaining inefficiency scores. Special attention is paid to the role of market concentration while controlling other relevant factors. Concluding remarks, are presented in the final section.

II. Recent Empirical Evidence

1. Measuring Hospital Markets

Underlying any market definition is an effort to identify the constraint on providers. With the proliferation of merger activity among acute care hospitals in the U.S. in recent years, an appropriate determination of the relevant product market and the relevant geographic market has become a focal point in antitrust litigation.

The relevant product market consists of those services and products that enable sellers to exercise their monopoly power and that prevent buyers from switching to substitutes provided by others. Defining the product market for hospital health care is difficult because it is essentially unique to each consumer, as each patient needs treatment specifically tailored to his/her illness. The Department of Justice (DOJ) and the Federal Trade Commission (FTC) have argued that the product market should be defined as "general acute care hospital care". This definition could oversimplify the reality: hospitals do not compete for generic acute care patients. Two general acute care hospitals can compete essentially along their whole product line or they may hold local monopolies in specialized services from which they derive a substantial proportion of their patients (Zwanziger et al., 1994; Blackstone and Fuhr, 1992[1]). Although this definition has failed in part, it is still the prevailing view (Magleby, 1996).

Two general approaches have been widely proposed and used for defining the relevant geographic market for a specific product or service. One definition is based on *movements of products' prices* in different geographical areas, and the other is based on *movements of actual physical quantities* of the product between different areas. The problem of using prices to detect markets in health care has led economists to devise measures based on the second approach.[2]

Because our primary interest in market definition derives from its use in the calculation of market shares that are in turn used for evaluating the degree of competition among providers, we have based our hospital market definition on the *Elzinga–Hogarty Criterion*. This shipment-based technique involves measurement of product flows into and out of an area, to detect a market area. Elzinga and Hogarty

[1] Some analysis adress the question if outpatient and inpatient care are close enough substitutes to be in the same market. Blackstone and Fuhr (1992) showed that the geographic market is different depending on the level of care, being the smallest market associated with primary care and the widest market with tertiary care. Primary category are very basic hospital services, such obstetrics, general surgery, and general medicine. Secondary services require more specialized equipment and/or personnel, such as magnetic resonance imagers or intensive care units. Tertiary services are highly specialized, generaly provided by a teaching hospital on a regional basis. Competition for rural patients exists between urban and rural hospitals. Rural consumers, who must travel to obtain specialized care, may have more alternatives, especially for secondary and tertiary care, than urban consumers.

[2] Simple ad hoc measures used are government-defined geographical boundaries, such as cities (Dranove et al., 1992, 1993) or metropolitan areas (Noether, 1988). Other market boundaries are health planning areas, health service areas, 5 or 15 mile radii around a hospital (Robinson and Luft, 1985), and the area contained within 30 minutes (i.e., a vehicle travel time to the hospital; Propper, 1996).

(1973, 1978) defined a Geographic Market as one in which there is relatively small outflow of goods to other areas (i.e., little goes out from inside = LOFI) and relatively small inflows (i.e., little comes in from outside = LIFO[3]) from elsewhere. The logic behind this approach is simple: If producers export significant amounts elsewhere, they will have difficulty raising prices without attempting their external markets. Thus, those external markets must be included. Similarly, if imports are substantial, an increase of prices will result in a substitution towards more imports. Therefore, the geographic markets supplying the imports must be included. The boundaries of a market are to be judged by a *weak* or *strong* definition. The weak definition identifies a market as a geographical area where both imports and exports must be less than 25 percent of product flows.[4]

This shipment's approach has been criticized in several studies (Noether, 1988; Werden, 1989; Dranove et al., 1992; Nguyen and Derrick, 1994; Zwanziger et al., 1994). In the main, these studies argued that in the hospital industry, except for rural and isolated small urban areas, tends to be a substantial number of patients who would move across any reasonable boundary, so that the markets defined overstate the true size of the market. On the other hand, patient data underestimate the market size if an anticompetitive price increase makes shipment from greater profitable distance, which provokes patients to travel long distance. In contrast, if some firms in the defined market area were operating at full capacity, they could not increase output in response to an anticompetitive price increase of some other firms in the same market area.

We recognize that no market definition is likely to be accurate for all markets. The argument using patient origin data in our analysis is partially pragmatic and partially theoretical. First, this kind of data is generally available. The theoretical argument stems from the observation that patient origin data are very stable. This stability is a reflection of a referral and admission patterns. In our scenario where the patients are beneficiaries of publicly financed insurance and they usually do not decide which hospital to use (unless the patient self-referral to emergency room), hospitals account for a relatively fixed proportion of patients from a given area. We do not want to measure the potential for competition among hospitals (the number of rival firms that could enter an industry) but to provide a snapshot of the hospital's current competitors.

---

[3] The LOFI component of the definition reflects conditions on the sellers' side of the market and the LIFO component reflects conditions on the buyers' side of the market (Crane and Welch, 1991): Let z_1 = Sales of Firms in a Defined Area to Buyers in that Same Area. Let z_2 = Total Sales of Firms in the Defined Area. Let z_3 = Total Purchases by Buyers in the Defined Area. Then the criteria are: LOFI = z_1/z_2 and LIFO = z_1/z_3.

[4] The application of these criteria to the hospitals implies that, for example, to satisfy the 75 criterion, hospitals must provide at least 75 percent of their services to patients residing in the market, and patients residing in the market must receive no more than 25 percent of their care from hospitals located in other areas (Morrisey et al., 1988; Melnick and Zwanziger, 1988; Ferguson and Palmer, 1994). The strong definition requires the same evaluations, but at 10 percent level.

A significant dimension of competition among hospitals is the market structure, a characterization of the intensity of competition among hospitals within a market area. It seems reasonable to assume that providers facing different degrees of competition in the market will have different incentives to alter their behaviour.[5] The *Herfindahl–Hirschman Index (HHI)* is a useful measure of market structure. The definition of this index is the sum of squares of the market shares, expressed as a percentage, held by each firm in an industry. The HHI reflects the number of competitors in the market and the level of concentration in the market (market share), factors that the economic theory would suggest are the critical determinants of a market's competitiveness.

$$\text{HHI} = S_1^2 + S_2^2 + \cdots + S_n^2 = \sum_{i=1}^{n} S_i^2.$$

Where S_i is the market share of the firm i, and n is the number of firms in the industry. The maximum value is 10,000 (i.e., 100^2 in a pure monopoly) and the minimum approach to zero[6] (in an atomistic market). This index gives greater weight to the larger firm(s) than to the smaller firm(s), and at an increasing rate, and embodies two aspects of the distribution of S_i, in an industry: 1) The variation or dispersion in S_i, and 2) The number of firms.[7] This index is used for antitrust purposes. Consistent with the 1984 Horizontal Merger Guidelines designed by DOJ and the FTC, the 1992 merger guidelines recognized two critical concentration levels, in the evaluation of horizontal mergers (DOJ and FTC, 1993). The HHI spectrum was divided in three regions: "unconcentrated" (post-merger HHI $<$ 1,000); "moderately concentrated" (1,000 $<$ post-merger HHI$<$1,800); and "highly concentrated" (post-merger HHI $>$ 1,800).[8] HHI has been used in most

[5] If the market is defined too broadly so that the hospitals that are not trully competing are included, measures of market concentration will err on the low side. In contrast if the market is defined too narrowly, excluding meaningful competitors, concentration ratios will err on the high side (Scherer and Ross, 1990).

[6] This index is measured as a percentage ranging betwen zero and 100, rather than 0 to 1. Of course the sum of the market shares (not squared) over all (n) firms in the market is the unity or (100%):

$$\sum_{i}^{n} S_i = 1.$$

[7] HHI is related (directly) to a specific measure of variability (the coefficient of variation V) and (inversely) to the number of firms in the industry (n) by the following formula:

$$\text{HHI} = \frac{V^2 + 1}{n}.$$

For the derivation of this relationship among HHI, V, and n, see Miller et al. (1982, pp. 615–617).

[8] See Bazzoli et al. (1995) for an excellent review.

hospital market studies as a structural proxy of monopoly power. An economic criticism on the HHI concept argues that such an index itself says little about competitive behaviour. It is possible that some industries with few firms may compete vigorously, whereas others with many firms may not. Another factor is the fact that almost all hospital geographic markets start out with an HHI over 1,800,[9] therefore most hospital markets are considered to be highly concentrated, because most communities have only few hospitals, and patients generally do not consider hospitals outside their communities to be acceptable alternatives for most procedures. As well, it has been criticized because its behaviour depends on using a homogeneous definition of a product.

2. Performance and Marked Structure

In several economic sectors a number of studies concluding evidence of a positive relation between competition and both technical and allocative productive efficiency. Contrasting with this, in the hospital industry a large number of papers have documented a positive relation between costs per admission or per patient-day and more competitive markets (Hersch, 1984; Robinson and Luft, 1985). Nevertheless, only few of these papers addressed explicitly the relation between technical efficiency and competition.[10] A positive relation of competition with higher average cost or cost inefficiency does not imply necessarily technical inefficiency: It might be either a case of exclusively allocative or price inefficiency, or both technical and allocative inefficiency in different unknown proportions. Three studies addressed explicitly the effect of competition on technical inefficiency, being the most relevant measure of performance for public hospitals, by explaining differences in DEA scores. Register and Bruning (1987) did not find any relation between DEA scores and market concentration. Chirikos and Sear's (1994) results showed that inefficiency scores are higher in markets with more vigorous inter-hospital competition, the relation being more intense in highly competitive markets, and Hadley et al. (1996), using efficiency scores from a multiproduct frontier cost function, found that hospitals in highly competitive markets were affected significantly by interhospital competition.

Recent empirical evidence presents some limitations that deserve attention. First, measures of concentration such as the Herfindahl–Hirschman index are often calculated for administrative regions and not for real local market areas. Second, studies that do not try enough to identify the sources of slack, are slightly useful for the appropriate design of policies to improve performance. But there are also those studies that consider market structure as the only explanatory factor: it is impossible

[9] The lowest possible HHI value in a given market will occur when all firms have an identical market share, a highly unusual circumstance. For a market with six firms the lowest HHI value is 1,667, for market with four firms it is 2,500 (Magleby 1996).

[10] Recent empirical research, estimating econometrically a frontier cost function, found weak evidence to sustain that competition from other hospitals is related to inefficiency (Eakin, 1991; Zuckerman et al., 1994).

to sort out the market structure matter from the ownership and regulation matters. And third, empirical evidence refers almost exclusively to the North American health care system, that might not be adequate for the European systems and with a quasi non-existent NHS evidence.

About the relation between hospital performance and local market structure, this paper adds to the preceding literature in three aspects. Firstly, it does not restrict attention to larger or urban hospitals since all acute care hospitals are considered and a Herfindahl–Hirschman index of concentration is calculated for every hospital using patient origin data. Secondly, it encompasses the analysis of a wider range of environmental variables apart from market concentration as factors explaining efficiency, and it also considers some control variables for efficiency scores. Ratios partially measuring inefficiency are ruled out as factors explaining efficiency (i.e., occupancy rate, length of stay, etc.). And thirdly, it focuses explicitly on the effects on technical efficiency (not on average production/cost function), partitioned into scale and pure technical efficiency, and not on cost efficiency that is not always an adequate basis to compare performance of public, nonprofit and private hospitals.

III. Identifying Markets and Measuring Concentration

1. Data and Method

In this article we examine the hospital market structure in the Spanish Health Care System using specific data from Catalonia in 1990. The process of measuring competition has involved two different parts: defining the relevant market and identifying the competitors within each market.

In our analysis we use "general acute care hospital services" as a product market definition. Geographic market delineation for hospital care has been based on patient origin data, using hospital and patient flows reported in the "1990 Catalonia Acute Hospital Discharges".[11] The boundaries of a market have been judged, using the *Elzinga-Hogarty Criterion*, by weak definition (25% level) to avoid overstate the size of the market. Once the product and geographic markets are defined, we compute an overall index of competition for each market using the *Herfindahl–Hirschman Index (HHI)*. Two variables are used for calculating the HHI index: 1) A measure of the output (the number of discharges produced in each market); and 2) A measure of capacity (the number of beds in each market). The number of observations (discharges) used to calculate the markets were $N = 31{,}094$ from 96 hospitals. These included 25 public hospitals, 5 nonprofit private and 46 profit private hospitals, representing the 5.41% of the total discharges during 1990.[12]

To examine if the hospital product was too broadly defined, we measured the proportion of flows from one market to another originated by the more severe

[11] Sample of the total acute hospital discharges, collected by the Catalan Health Service in 1990.

[12] The total number of beds were 18,893 with mean 196.8 and 203.1 as a standard deviation. The average length of stay was 8.56 days and the number of beds per 1,000 inhabitants was 3.117. Finally the total number of discharges were 574,730 with mean 5,986.7 and 5,895.2 as a standard deviation.

and complex cases, suggesting that more severe or complex cases may be treated outside of the market of residence, because their treatment was not available. To test the differences in case complexity between markets, we define a "complex case" as a case having a case mix weight value above one. With the information about diagnoses[13] and length of stay we approximated for each diagnosis the case mix weight, using the proportion between all hospitals' average length of stay for diagnosis j and the general average length of stay. Case mix weight was computed for every hospital and market from individual patient data. Obviously this weight index does not capture intra-diagnostic severity of illness.

2. Results

The geographic markets were created beginning with the smallest geographic area (the municipality) and then proceeding sequentially outwards. We identified 23 markets, twelve of which may be considered as small markets (covering less than 100,000 inhabitants) (Figure 1). The distribution of hospital market areas across the region, falls into three groups: 1) no competing areas with eight markets identified and 3.76% of the population; 2) a few competing areas having 1–5 neighbours, with thirteen markets identified and 32.61% of the population; and 3) many competing areas, with two markets identified, with 10 or more neighbours and covering more than half of the total population. Table I describes individual characteristics of identified geographic markets and Table II examines the number of markets that satisfy the Elzinga–Hogarty approach.

Administrative areas, as "districts", have been used in the literature as geographic hospital markets. Our results show that they represent a misspecification of geographic markets. Thirteen "districts" have been identified with a single-hospital. However, markets do not restrict to the geographical boundaries of these districts. Only five out of the thirteen single-hospital districts (38.5%) were a market themselves.

A priori the results of the market 23 suggest that the market area may be too large (Table I). If so, we would tend to overstate the true level of concentration. The reason could be explained if there were a difference in case complexity between this market and the others, so the assumption of the appropriateness of the product definition in this market could fail. To explore these considerations, primary, secondary and tertiary categories[14] were used to examine the area's pattern of services in order to compare each market. Only in the market 23 we identified four hospitals providing tertiary services, so a priori these hospitals may be included in a national market for these services. But primary, secondary and tertiary categories are somewhat ambiguous, and far from homogeneous. For example, transplants are clearly in the tertiary category, and normal deliveries, general medicine, and general surgery

[13] The diagnostic procedures had been grouped according to the International Classification of Diseases, 9th Clinical Modification (ICD-9CM).

[14] See Note 1.

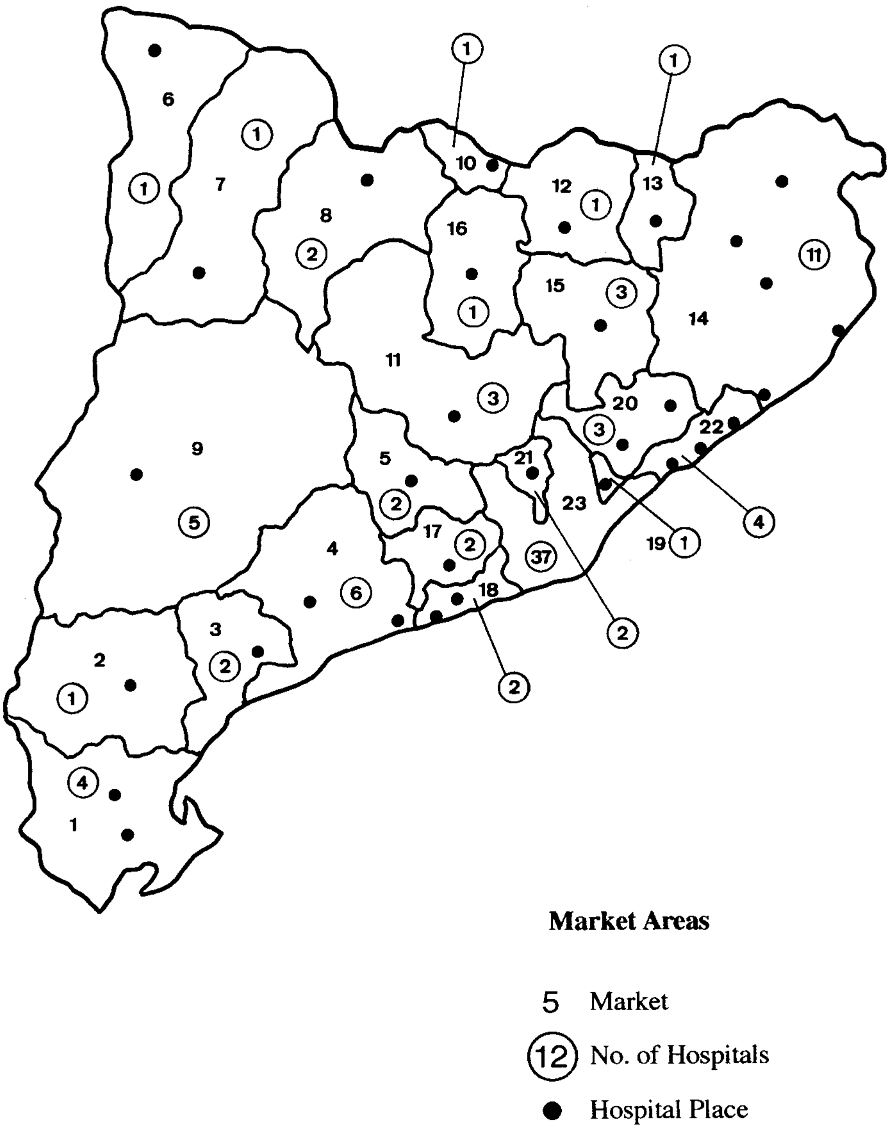

Figure 1. Catalonia market areas.

in the primary category. The four hospitals, classified as a hospital that provides tertiary services, have the vast majority of their patients in the former two services, so these hospitals can compete with the other hospitals within the same market, because the product provided is similar.

As discussed above, a measure of complexity was created to see differences in case complexity among markets. Calculated case mix weights for all treated cases, the results showed no significant statistical difference between patients residing

Table I. Market area description

Market No.	No. of complete districts in market	No. of hospitals	No. of beds per 1,000 inhabitants	% of population covered	HHIB[a]	HHID[b]
10	0	1	7.45	0.16	10,000	10,000
6	2	1	2.98	0.17	10,000	10,000
7	1	1	2.32	0.28	10,000	10,000
13	0	1	4.60	0.38	10,000	10,000
12	1	1	2.72	0.45	10,000	10,000
16	1	1	3.20	0.64	10,000	10,000
2	1	1	2.32	0.66	10,000	10,000
19	0	1	2.61	1.02	10,000	10,000
17	1	2	1.73	1.21	6,652	6,979
3	0	2	2.78	1.91	7,426	6,901
8	1	2	4.32	0.36	5,067	6,117
21	0	2	4.14	3.60	5,611	5,661
18	1	2	5.50	1.30	5,896	5,499
20	0	3	2.32	3.31	4,562	5,289
5	1	2	3.89	1.38	5,000	5,192
15	1	3	3.51	1.95	3,868	4,819
1	2	4	5.54	1.99	3,905	4,470
4	3	6	2.99	4.24	2,988	3,593
11	2	3	4.35	2.69	3,475	3,430
9	5	5	3.00	4.81	3,190	3,274
22	0	4	2.41	3.86	2,728	3,159
14	1	11	2.92	7.38	1,671	2,140
23	2	37	2.99	56.25	531	459

[a] HHIB: The Herfindahl–Hirschman Index using Beds as a unit of analysis.
[b] HHID: The Herfindahl–Hirschman Index using Discharges as a unit of analysis.

outside the market but treated within the market, and patients inside the market but treated in other markets. Then, this index does not indicate important differences in the proxied complexity of patient flows between markets. These facts reinforce the appropriateness of output definition (acute care) adopted in this study (exports and imports are not different products from the cases remaining in the market).

The results concerning market concentration in Table II show that the estimates of HHI are not very sensitive to whether using beds (HHIB) or discharges (HHID) as a unit of market share measurement. Mean HHI in these markets, using discharges as a unit of analysis (HHID), was 6,390 with 2,906 as standard deviation. Only one out of the 23 hospital markets had an HHID below 1,000, the level considered by the DOJ as "unconcentrated".

Although the results apparently speak for a concentrated market, it is actually a two-tiered system. From the policy point of view, this study shows that the

Table II. Markets by number of hospital firms

Markets with	1 Hosp.	2 Hosp.	3 Hosp.	4 Hosp.	5–10 Hosp.	11 Hosp.	11+ Hosp.
No. of Markets	8	6	3	2	2	1	1
% of population covered	3.76	9.76	7.95	5.85	9.05	7.38	56.25
Mean of population	28,494	98,585	160,726	177,307	274,381	447,532	3,404,016
Mean HHIB[a]	10,000	5,942	3,968	3,317	3,089	1,671	531
% of markets with Herfindahl > 1,800[c]	100	100	100	100	100	0.0	0.0
Mean HHID[b]	10,000	5,038	4,513	3,815	3,434	2,140	459
% of markets with Herfindahl > 1,800	100	100	100	100	100	100	0.0

[a] HHIB: The Herfindahl–Hirschman Index using Beds as a unit of analysis.
[b] HHID: The Herfindahl-Hirschman Index using Discharges as a unit of analysis.
[c] Herfindahl > 1,800; Market "Highly Concentrated". Source: 1992 Horizontal Merger Guidelines (DOJ and FTC).

hospital sector in Catalonia is structured in two sub-sectors. One is shaped by twenty-two small hospital markets performing with a high level of concentration, eight of them with only one hospital (geographic monopolies) and six with only two hospitals, and the other one is composed by one market with 37 hospitals, 3.4 million inhabitants, and characterized by a high degree of competition. Expected effects on performance of incentives from promoting competition policies will probably have doubtful effects on the first sub-sector, or at least, very different effects in comparison to the second sub-sector.

IV. Efficiency and Market Structure

1. Efficiency Definition and Measurement

The efficiency concept used is that of technical efficiency. Technical efficiency might be characterized as either (i) the feasible increase in outputs for a given set of inputs or (ii) the feasible reduction of inputs for a given set of outputs when waste is eliminated. Production processes that have multiple inputs and outputs can be compared from the point of view of efficiency by defining efficiency as the ratio between the weighted sum of outputs and the weighted sum of inputs. In this section we develop the concept of efficiency used in this article, as a measure of performance. As well, a nonparametric and deterministic methodology of measurement is outlined.

Efficiency Definition. A hospital is said to be technically efficient if an increase in an output requires a decrease in at least one other output, or an increase in at least one input. Alternatively, a reduction in any input must require an increase in at least one other input or a decrease in at least one output.

To characterize the production technology relative to which efficiency is measured, each hospital uses variable inputs $x = (x_1, \ldots, x_N) \in \mathbb{R}_+^N$, to produce variable outputs $y = (y_1, \ldots, y_M) \in \mathbb{R}_+^M$. Inputs are transformed in outputs using a technology that can be described by the graph: $GR = \{(x, y) : x \text{ can produce } y\}$. Corresponding to the graph there is a family of input sets:[15] $L(y) = \{x : (x, y) \in GR\}$, $y \in \mathbb{R}_+^M$. Input sets contain their isoquants: $I_{\text{Isoq}}\ L(y) = \{x : x \in L(y), \theta x \notin L(y), \theta \in (0, 1)\}$, $y \in \mathbb{R}_+^M$, which in turn contain their efficient subsets: Eff $L(y) = \{x : x \in L(y), x' \notin L(y), x' \leq x\}$, $y \in \mathbb{R}_+^M$.

Then, a radial measure of the technical efficiency (Debreu, 1951; Farrell, 1957) of input vector x in the production of output vector y is given by: $TE_I\ (x, y) = \min\ \{\theta : \theta x \in L(y)\}$, where $\theta = 1$ indicates radial technical efficiency and $\theta < 1$ shows the degree of radial technical inefficiency.

Efficiency Measurement. Empirical measurement of inefficiency ranges over two main alternative methodologies: From stochastic parametric regression-based methods to nonstochastic nonparametric mathematical programming methods.[16] The method choice lies in the management of the tradeoff between functional form rigidity and determinism. DEA has been proved specially valuable in cases like hospitals, in many institutional settings where nonmarketed multi-output is considered and correct weighting of outputs cannot be defined.

Let's assume the hospital under evaluation as having data (x^0, y^0), and consider the problem, where $x^i \in \mathbb{R}_+^N$ and $y^i \in \mathbb{R}_+^M$, and $i = 1 \ldots I$; Where I is the number of hospitals in the sample:

$$
\begin{aligned}
&\min_{\mu, v}\ v^T x^0 / \mu^T y^0 \\
\text{subject to}\quad & v^T x_i / \mu^T y^i \geq 1 \qquad i = 1, \ldots, 0, \ldots, I \\
& \mu, v \geq 0
\end{aligned}
$$

The minimization problem seeks for a set of nonnegative weights (v, μ) which, when applied to the inputs and outputs of the hospital under evaluation, minimizes the ratio of weighted input to weighted output, subject to the normalizing constraint that no hospital in the sample, including the hospital under evaluation, has a ratio

[15] Input sets satisfy the properties of convexity and strong disposability of inputs.

[16] Parametric methodology obtains efficiency measures, computed in terms of the distance that lies between the observation and the estimated function. Then, scores may differ according to the functional specification chosen. Data Envelopment Analysis (DEA), the most useful family of linear programming models, in contrast, assumes no measurement error or random fluctuations in input-output measures, being a completely deterministic method.The advantage of this technique is that it does not impose any specific functional form on the underlying production function.

less than unity when weights of the hospital under evaluation are applied. In order to provide a linear programming representation of the radial efficiency measure given previously, this nonlinear ratio model can be converted to the following linear programming multiplier problem:

$$\begin{aligned} &\max_{u,v} u^T y^0 \\ \text{subject to } &v^T x^0 = 1 \\ &u^T Y - v^T X \leq 0 \\ &u, v \geq 0 \end{aligned}$$

where X is an $(N \times I)$ input matrix with columns X^i, and Y is an $(M \times I)$ output matrix with columns y^i. And the dual of the preceding programming multiplier problem is the input-oriented linear programming envelopment (*input-oriented CCR DEA model*):

$$\begin{aligned} &\mathrm{TE}_I(x^0, y^0) = \min_{\theta,\lambda} \theta \\ \text{subject to } &\theta x^0 - X\lambda \geq 0 \\ &-y^0 + Y\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned}$$

where λ is an $(I \times 1)$ intensity vector.

The input orientation model describes the minimum amount of inputs required to achieve the given output level. The technology implied by the constraints of the preceding envelopment problem is:

$$C(y) = \{x : x \geq X\lambda, y \leq Y\lambda, \lambda \geq 0\}, \quad x \in \mathbb{R}_+^N.$$

Then this problem provides a linear programming representation of the radial efficiency measure given in Debreu and Farrell's definition. The optimal value of θ provides a technical efficiency measure of the hospital under evaluation. Input-oriented radial efficiency requires $u^T y^0 = \theta = 1$. A hospital is judged to be technically inefficient if at optimum $\theta < 1$, and technically efficient if at optimum θ = 1. The input-oriented CCR model incorporates the assumption of constant returns to scale in production. Banker, Charnes and Cooper (1984) (BCC) generalized the CCR formulation to allow variable returns to scale (*input-oriented BCC DEA model*). CCR and BBC models differ only in that the latter includes *convexity* constraint $(e^T\lambda = 1)$.[17] The input-oriented CCR DEA model (constant returns to scale) measures overall technical efficiency (OTE). The input-oriented BCC DEA model (variable returns to scale) measures exclusively pure technical efficiency (PTE). Then, following Banker et al (1984), the ratio between the two measures of efficiency in CCR and BCC DEA models is a measure of scale efficiency (SE).

[17] Where e^T is an $(I \times 1)$ row vector of ones.

2. Efficiency Scores

We applied Data Envelopment Analysis to calculate overall and pure technical efficiency, identifying 94 Catalan acute care hospitals as a production unit (decision making unit), in 1990.[18]

Variables to represent inputs and outputs were selected among those that had been used primarily in the DEA hospital efficiency literature. Output is defined in this paper as health services or intermediate outputs (*throughputs*). We define a wide set of eight output variables: Case-mix adjusted discharged patients (Y_1); In-patient days in acute and subacute care medicine services, except intensive care units (medicine, surgical, obstetrical, gynaecological and paediatric services) (Y_2); In-patient days in intensive care units, including intensive neonate and burnt units (Y_3); In-patient days in long-term (psychiatric, long stay, and tuberculous services) and other services (Y_4); Surgical interventions (Y_5); Hospital day care services (Y_6); Ambulatory visits (Y_7); Resident physicians (Y_8). Selected output variables represent the multi-output dimension of hospital production: inpatient activities (admissions and in patient days), outpatient hospital services (visits and day care), and teaching activities (residents). On the input side, four variables representing resource consumption are defined: Full-time equivalent (FTE) physicians, including residents (X_1); FTE nurses and equivalents (X_2); FTE other non-sanitary personnel (X_3); In-patient beds (X_4). The first three inputs are labour inputs and the last one is a proxy for net capital assets, as suggested by Grosskopf and Valdmanis (1987). Descriptive statistics for input and output variables appear in Table III. Table IV summarize the average overall, pure and scale efficiency scores from calculating DEA models.

Results from DEA models show an average technical inefficiency of 10.1%. That is to say, hospitals use in average 10.1% more inputs than necessary if all of them were operating on the efficiency frontier. Overall efficiency scores range from 0.545 to 1. Pure technical inefficiency scores show a lower level of inefficiency, being the average 6.1%. Average scale inefficiency is 4.3%.

All hospitals on the frontier show no possible proportional reduction in inputs, given output level, and no slack for any input. That is, boundary hospitals are efficient boundary hospitals. For overall technical efficiency the percentage of hospitals operating on the frontier is 36.3. The average efficiency score for nonfrontier hospitals is 0.841, implying that non-efficient hospitals use on average roughly 18.9 per cent more inputs per unit of output than efficient hospitals. According to pure technical efficiency criterion, 50 of the hospitals operate efficiently, with an average efficiency score of 0.871 for nonfrontier hospitals. The efficiency ranking of the hospitals is reasonably stable with respect to the two versions of DEA. Distribution of scores is summarized in Table V.

[18] Source: “Estadística de Establecimientos Sanitarios con Régimen de Internado, 1990”. Two hospitals included in the preceding analysis of market structure were dropped out because of non data availability or erroneous information.

Table III. Descriptive statistics of input, output, explanatory and control variables (n = 94)

	Mean	Std.	Min.	Max.
Inputs				
X_1	79.6	132.6	3.5	721
X_2	230.6	335.7	6.6	1765.5
X_3	132.2	175.2	0.3	951.5
X_4	200	203.6	14	949
Outputs				
Y_1	6210.4	6346	224.4	32268.5
Y_2	49868.7	57925.1	1133	285308
Y_3	1597.9	3864	0	22512
Y_4	6075.1	13991	0	95449
Y_5	3761.4	3431.7	61	15050
Y_6	1190.9	4315.1	0	32021
Y_7	49993.5	71379.5	0	520591
Y_8	10	31.5	0	163
Explanatory Variables				
Z_1	0.26	0.44	0	1
Z_2	0.47	0.5	0	1
Z_3	3139.3	2917.8	459	10000
Z_4	16.3	16.2	0	36
Z_5	0.552	0.415	0	98.4
Control Variables				
W_1	22.8	18.4	0	86.2
W_2	0.05	0.23	0	1
W_3	0.925	0.102	0.106	99.9
W_4	200.2	203.6	14	949
W_5	81075.5	178047.1	196	900601

Table IV. DEA efficiency scores

Efficiency definition	Mean	Std.	Min.	Max.
Overall Technical Efficiency (OTE)	0.989	0.126	0.545	1.000
Pure Technical Efficiency (PTE)	0.939	0.093	0.570	1.000
Scale Efficiency (SE)	0.957	0.093	0.545	1.000

3. Censored Regression of Efficiency Scores

What causes a hospital to produce using more than the minimum quantity of inputs for a specific vector of outputs? In order to determine the influence of environmental variables on efficiency a two-stage approach is adopted.

Let $z^i \in \mathbb{R}_+; i = 1, \ldots, I$; be a discrete or continuous environmental variable which reflect causes or explanatory variables of inefficiency. Let $w^i \in \mathbb{R}_+; i =$

Table V. Distribution of DEA scores

Score value	OTE[a]		PTE[b]		SE[c]	
	Number	%	Number	%	Number	%
0.500–0.599	5	5.3	2	2.1	2	2.1
0.600–0.699	3	3.2	–	–	3	3.2
0.700–0.799	12	12.8	6	6.4	1	1.0
0.800–0.899	14	14.9	15	16.0	3	3.2
0.900–0.999	26	27.6	21	22.3	49	52.2
1.000	34	36.2	50	53.2	36	38.2

[a] Overall Technical Efficiency.
[b] Pure Technical Efficiency.
[c] Scale Efficiency.

$1, \ldots, I$; be a discrete or continuous proxy variable for input or output characteristics omitted or imperfectly measured in DEA model (control variables for the input-output specification). In the first stage, inefficiencies are calculated using a DEA model in which the environmental variables are ignored and selected input and output variables are used. In the second stage we define a model that includes both types of variables to estimate the effects on efficiency. The general form of the regression model is:

$$\theta^i = f(z^i) + f(w^i) + e^i; \quad i = 1, \ldots, I$$

DEA scores (θ^i) can be understood as presenting a censored normal distribution, that is to say, the values of the dependent variable in the regression model above a threshold are measured by a concentration of observations at a single value. A censored Tobit[19] model is proposed to explain the score differences, taking the following form:

$$\begin{array}{ll} \theta^i = \text{actual score} & \text{if score} < 1 \\ \theta^i = 1 & \text{otherwise.} \end{array}$$

Tobit regression in a two-stage approach context used as cross-check, to obtain validation of DEA results, constitutes an example of the complementary capabilities of DEA and stochastic regressions. Censored regression model is used to detect if measures of inefficiency are related to factors that one might expect to be sources of inefficiency.

Factors explaining the performance of hospitals, measured by productive efficiency, may be conceptualized in three categories: ownership, market structure and regulation. Ownership is considered, by classifying hospitals in three types, a dummy variable: Nonprofit hospitals (Z_1); for-profit hospitals (Z_2) and public hospitals. Market structure or competition is proxied by two variables: the

[19] Tobit model avoids asymptotically biased estimates from ordinary least squares (Greene, 1993).

Herfindahl–Hirschman index (Z_3), and the number of competitors in the local market (Z_4). The Herfindahl–Hirschman index is specifically used for testing the hypothesis that there is more efficiency in less concentrated markets. The presence of regulation influences specially hospital behaviour through the payment system and patient flow directive regulation. The proportion of hospital revenues received from the NHS (Z_5) may be a proxy measure of the relative importance of regulation in hospital activities. These monetary flows are influenced by NHS payment system corresponding to patients subject to NHS directive regulated flows.

Control variables to test the influence of input or output characteristics omitted or imperfectly measured in DEA model on efficiency are designed to reflect differences in severity of treated cases, teaching status and differences in outcome quality. There is no direct measure available on severity of illness. In this situation, severity is proxied by the number of surgical interventions with more than one hour of length per admitted patient. Outcome quality, the direct measure of which is not available, is proxied by the proportion of discharged patients with a recovered health status. Additionally, efficiency scores are controlled for the potential influence of hospital dimension (scale economies) by including the number of beds and square beds as a differentiated type of control variables. Since overall technical efficiency scores assume that the efficient frontier exhibits constant returns to scale, hospital size is probably an explaining factor. According to the preceding arguments, control variables are empirically defined as: More than one hour surgical interventions per one hundred patients (W_1); Teaching status (W_2); Proportion of recovered discharged patients (W_3); Number of beds (W_4); Number of square beds (W_5).

Tobit estimation,[20] for DEA efficiency scores, are presented in Table VI. Econometric results indicate that only the number of competitors in the local market presents a significant contribution when explaining differences in overall and pure technical efficiency scores. In both cases, the number of competitors raises significantly the efficiency level. Hospitals operating as local monopolies, those with very few local competitors, are less efficient than hospitals operating in a more competitive environment. As results indicate, what influences efficiency is the number of competitors rather than the level of concentration (market share). Other factors apart from market structure do not show any relevance in explaining observed levels of overall and pure technical efficiency. Then, ownership does not make any difference in efficiency levels.

Scale inefficiency appears very related to the hospital size, as expected, and probably to decreasing returns to scale in larger hospitals. As results indicate, efficiency increases as hospital size increases but in a decreasing way. The variable acting as a proxy of severity of illness (W_1) appears contributing positively to scale efficiency. W_1 may also be acting as a proxy for specialization.

[20] Tobit results have been checked, as in Kooreman (1994), by re-estimating the model using rank indices of the scores as the dependent variable. Results remained unchanged in terms of sign and significance.

Table VI. Factors explaining DEA efficiency scores[a]

Explanatory variables	Overall technical efficiency		Pure technical efficiency		Scale efficiency	
	Coefficient	t-stat.	Coefficient	t-stat.	Coefficient	t-stat.
Intercept	−121.67	−1.09	−78.0025	−0.94	−122.18	−1.61
	(19.85)[b]		23.27		(13.73)	
Z_1	0.065	0.012	1.34	0.24	−1.16	−0.29
	(5.53)		(5.55)		(3.87)	
Z_2	−7.13	−1.33	−3.27	−0.60	−5.67	−1.50
	(5.35)		(5.44)		(3.76)	
Z_3	0.00058	0.51	0.000034	0.03	0.00042	0.54
	(0.0011)		(0.0011)		(0.00078)	
Z_4	0.39	2.01*	0.41	2.03*	0.19	1.40
	(0.19)		(0.20)		(0.13)	
Z_5	−0.0099	−0.16	−0.08	−1.40	0.03	0.75
	(0.061)		(0.062)		(0.043)	
W_1	0.079	0.72	−0.16	−1.43	0.19	2.45*
	(0.10)		(0.11)		(0.079)	
W_2	19.90	1.09	65.0	0.00073	16.92	1.26
	(18.23)		(87888)		(13.41)	
W_3	0.043	0.23	−0.139	−0.62	0.09	0.71
	(0.18)		(0.22)		(0.12)	
W_4	0.049	1.36	−0.07	−1.26	0.049	1.92
	(0.36)		(0.061)		(0.025)	
W_5	−0.000063	−1.35	0.00019	1.61	−0.000069	−2.10*
	(0.46)		(0.00012)		(0.000033)	
SIGMA	15.87	10.19*	14.84	8.52*	10.90	10.25*
Log-l	−276.704		−206.315		−244.676	
Log-l ratio[c]	18.118		26.238		22.572	

[a] Total observations: n = 94. * Indicates significance at 5% level. [b] Standard errors in parentheses. [c] Log likelihood ratio test: Tests the joint significance of the independent variables. The likelihood ratio is computed as $-2\log(L_0/L_a)$, where L_0 is the value of the likelihood funtion if all coefficients except the intercept are zero, and La is the value of likelihood for the full model. The log-likelihood ratio test has a Chi square distribution, where the degrees of freedom are the number of restrictions imposed under the null hypothesis.

V. Conclusions

In this paper hospital markets in a European NHS are defined and measured using observed flow of patient data. Regulated competition possibilities may be limited by market dimension and concentration level. Our results suggest a two-tiered market structure with 22 small hospital markets where producers operate as if they were in geographical monopolies, and only one big market with a low level of concentration.

Technical efficiency of hospital production has been analysed by means of Data Envelopment Analysis. Results from DEA model suggest an average technical inefficiency of 10.1% with 36.3% hospitals operating on the *best-practice* production frontier. An stochastic censored regression of efficiency scores has proved the positive influence of market structure on the level of efficiency attained by every producer. The presence of competitors in the local market, independently of their market share, improves technical efficiency. Hospital mergers justified by expected improvements in scale efficiency may have a negative counterpart on technical efficiency by eliminating potential competitors.

Market definition in this study may be limited in several ways. First, using a shipment approach to define local markets (Elzinga–Hogarty criteria), potential competitors might not be identified by the patient flows. Second, directive regulation of flows may also contribute to misidentify all potential competitors. And third, competition to attract patients is obscured by the fact that price competition is nowadays only possible in a very limited segment of the market.

Problems of DEA frontier estimation are related to the existence of omitted outputs or inputs not measured; and to the assumption of no measurement error or random fluctuations in output. Although these problems have been managed in this paper through the two-stage approach, this research might be extended in several ways. Input and output variables might be improved, specially output measures that take into account quality dimension of health. It is essential that the relationship between quality and input volume would be accounted in the measurement of inefficiency. The method employed in this paper might be used when estimating allocative and cost efficiency rather than only limiting attention to technical efficiency. Additional work on DEA measurement of hospital efficiency should address specially two main problems. First, DEA ignores that the observations may be subject to random fluctuations. Deterministic scores should be converted into stochastic ones, which may probably be obtained by the availability of complete panel data or by the use of a chance constrained DEA model. Finally, although we focus on hospital efficiency, we do not pay attention to find out if patients receive an appropriate amount of care.

References

Abel-Smith, B., and E. Mossialos (1994) ‘Cost Containment in Health Care Reform: A Study of the European Union’, *Health Policy*, **28**, 89–132.

Banker, R. D., A. Charnes, and W. W. Cooper (1984) ‘Some Models for Estimating Technical and Scale Efficiencies in Data Envelopment Analysis’, *Management Science*, **30**, 9.

Bazzoli, G. J., D. Marx, R. J. Arnould, and Larry M. Manheim (1995) ‘Federal Antitrust Merger Enforcement Standards: A Good Fit for the Hospital Industry’, *Journal of Health Politics, Policy and Law*, **20**(1), 137–169.

Blackstone, E. A., and J. P. Fuhr (1992) ‘An Antitrust Analysis of Non-Profit Hospital Mergers’, *Review of Industrial Organization*, **8**, 473–490.

Chirikos, T. N., and A. M. Sear (1994) ‘Technical Efficiency and the Competitive Behavior of Hospitals’, *Socio-Economic Planning and Science*, **28**(4), 219–227.

Crane, S. E., and Patrick J. Welch (1991) 'The Problem of Geographic Market Definition: Geographic Proximity vs. Economic Significance', *Atlantic Economic Journal*, **19**(2), 12–20.

Debreu, G. (1951) 'The Coefficient of Resource Utilization', *Econometrica*, **19**(3), 273–292.

DOJ and FTC (1993) 'Horizontal Merger Guidelines', *Review of Industrial Organization*, **8**, 231–256.

Dranove, D., Mark Shanley, and Carol Simon (1992) 'Is Hospital Competition Wasteful?', *RAND Journal of Economics*, **23**(2), 247–262.

Dranove, D., M. Shanley, and William D. White (1993) 'Price and Concentration in Hospital Markets: The Switch from Patient-Driven to Payer-Driven Competition', *Journal of Law and Economics*, **36**, 179–204.

Eakin, B. K. (1991) 'Allocative Inefficiency in the Production of Hospital Services', *Southern Economic Journal*, **58**, 240–248.

Elzinga, K. G., and Thomas F. Hogarty (1973) 'The Problem of Geographic Market Delineation in Antimerger Suits', *The Antitrust Bulletin*, **18**(1), Spring.

Elzinga, K. G., and Thomas F. Hogarty (1978) 'The Problem of Geographic Market Delineation Revisited: The Case of Coal', *The Antitrust Bulletin*, **23**(1), Spring.

Farrell, M. J. (1957) 'The Measurement of Productive Efficiency', *Journal of the Royal Statistical Society*, Series A, General, 120, Part 3, pp. 253–81.

Ferguson, B., and Stephen Palmer (1994) 'Markets and the NHSM Guidelines Costs and Prices in the NHS Internal Market', *Working Paper #120*, Centre for Health Economics, University of York.

Greene, W. H. (1993) *Econometric Analysis*, 2nd. ed. New York: Macmillan.

Hadley, J., S. Zuckerman, and L. I. Iezzoni (1996) 'Financial Pressure and Competition: Changes in Hospital Efficiency and Cost-Shifting Behavior', *Medical Care*, **34**(3), 205–219.

Hersch, P. (1984) 'Competition and the Performance of Hospital Markets', *Review of Industrial Organization*, Win, 324–341.

Kooreman, P. (1994) 'Nursing Home Care in the Netherlands: A Nonparametric Efficiency Analysis', *Journal of Health Economics*, **13**, 301–316.

Magleby, J. E. (1996) 'Hospital Mergers and Antitrust Policy: Arguments Against a Modification of Current Antitrust Law', *The Antitrust Butlletin*, Spring, pp. 137–201.

Maynard, A. (1991) 'Developing the Health Care Market', *The Economic Journal*, **101**, 1277–1286.

Melnick, G. A., and Jack Zwanziger (1988) 'Hospital Behavior under Competition and Cost-Containment Policies: The California Experience, 1980–1985', *JAMA*, **260**, 2669–2675.

Miller, R. A. (1982) 'The Herfindahl–Hirschman Index as a Market Structure Variable: An Exposition for Antitrust Practitioners', *The Antitrust Bulletin*, Fall.

Morrisey, M. A., F. A. Sloan, and J. Valvona (1988) 'Defining Geographic Markets for Hospital Care', *Law and Contemporary Problems*, **51**(2), 165–194.

Nguyen, X. N., and Frederick W. Derrick (1994) 'Hospital Markets and Competition: Implications for Antitrust Policy', *Health Care Management Review*, **19**(1), 34–43.

Noether, M. (1988) 'Competition Among Hospitals', *Journal of Health Economics*, **7**, 259–275.

OECD (1996) 'La réforme des systèmes de sauté. La volanté de changement', *Études de Politique de Santé*, 8. Paris.

Propper, C. (1996) 'Market Structure and Prices: The Responses of Hospitals in the U.K. National Health Service to Competition', *Journal of Public Economics*, **61**, 307–335.

Register, C. A., and E. R. Bruning (1987) 'Profit Incentives and Technical Efficiency in the Production of Hospital Care', *Southern Economic Journal*, **53**, 899–914.

Robinson, J. C., and Harold S. Luft (1985) 'The Impact of Hospital Market Structure on Patient Volume, Average Length of Stay, and the Cost of Care', *Journal of Health Economics*, **4**, 333–356.

Scherer, F. M., and David Ross (1990) *Industrial Market Structure and Economic Performance*. 3rd ed., Boston. Hougthon Mifflin.

Werden, G. J. (1989) 'The Limited Relevance of Patient Migration Data in Market Delineation for Hospital Merger Cases', *Journal of Health Economics*, **8**, 363–376.

Zuckerman, S., J. Hadley, and L. Iezzoni (1994) 'Measuring Hospital Efficiency with Frontier Cost Functions', *Journal of Health Economics*, **13**, 255–280.

Zwanziger, J., G. A. Melnick, and K. M. Eyre (1994) 'Hospitals and Antitrust: Defining Markets, Setting Standards', *Journal of Health Politics, Policy and Law*, **19**(2).