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Measuring health production performance in the OECD

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This paper contributes to the estimation of the best practice frontier in health production in the OECD countries at the aggregate level, in the tradition of the concept of health production function originally developed by Grossman. Estimates of technical efficiency for the OECD countries, decomposed into their components of pure technical efficiency and scale efficiency, using a nonparametric method (Data Envelopment Analysis) are presented. In a two-stage approach, differences in efficiency scores are attributed to environmental factors using a stochastic censored regression model.

I. INTRODUCTION

The purpose of this paper is to present an empirical investigation into the technical efficiency of health production as a measure of its relative performance. The efficient health production function is derived from all observations in the OECD countries since 1960. The *best practice* production function is constructed from the observed inputs and outputs by linear programming techniques. The resulting frontier is a best practice frontier representing minimal input use in OECD countries, given output levels.

In contrast to the previous work on health production functions, the methodology of performance measurement used in this paper allows us: (a) to analyse the best practice frontier in the input-output transformation and to measure deviations from best-practice pattern of consumption resources rather than obtaining only an average production function; (b) to apply extended versions of Data Envelopment Analysis (DEA) to a health production function; and (c) to apply stochastic models of regression, in a two stage approach, to ascertain the influence of environmental variables on health performance.

Examining health as the final output of health services and related inputs permits us to determine the most efficient way of allocating resources to increase health. Because increased expenses on health care are expected to improve health performance, it is important to derive empirical estimates of this relationship.

Empirical studies of health production functions have been conducted at two levels of aggregation: studies using macrodata (average values at the county, state, or national level), and microanalysis using individuals as the unit unit of measurement. Our focus in this paper is on aggregate data analysis. Most prior studies of health production functions at the aggregate level assume that the estimated relationships are technically efficient (see, for example, Auster *et al.*, 1969; Wolfe, 1986; Corman *et al.*, 1987; Hadley, 1988). This is a serious limitation, as these studies only provide a measure of the *average* pattern of health production. In contrast, in this paper deviation from best practice pattern of resource consumption is measured by a version of linear programming known as DEA.

II. THEORETICAL FRAMEWORK

Grossman's (1972) model of demand for health is useful for conceptualizing the health production function. The net investment in health stock of an individual j is equivalent to the gross investment carried out minus stock depreciation experience during the period observed, in accordance with the following identity: $H_{t+1j} - H_{t,j} = I_{t,j} - \delta_{t,j}H_{t,j}$ where $H_{t,j}$ is health stock at the beginning of the period t, $I_{t,j}$ is gross investment on health during the period t, and $\delta_{t,j}$ is rate of depreciation during the period t.

From this identity, and following Grossman's model (1972), the gross health production function during the period t can be expressed as: $I_{t,j} = I_{t,j}(M_{t,j}, TH_{t,j}; E_{t,j})$ where $M_{t,j}$ is consumption of health services, $TH_{t,j}$ is time devoted to produce health, and $E_{t,j}$ is stock of human capital.

Grossman assumes that a shift in human capital changes the efficiency of the production process. In other words,

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individuals with a greater stock of human capital may be able to transform inputs into health more efficiently.

From past equations and replacing the value of I_t, the following expression of the health production function during the period t for the individual j can be written as:

$$(1 - \delta_{t,j})H_{t,j} = I_{t,j}(M_{t,j}, TH_{t,j}; E_{t,j})$$

According to Grossman's model, the rate of depreciation is positively correlated with age. In other words, in order to maintain a given level of health, older individuals require a larger gross investment than younger individuals. The empirical specification of the model commonly uses a function in which depreciation depends on a set of environmental variables as well as age (Cropper, 1981).

If absolute depreciation of the health stock depends on age as environmental variables, the health production function is transformed into the following expression:

$$H_{t+1j} - H_{t,j} = I_{t,j}(M_{t,j}, TH_{t,j}, t_j, X_{t,j}; E_{t,j})$$

where t_j is age of the individual, and $X_{t,j}$ is life style of the individual during the period t.

III. METHOD AND DATA

This paper uses a variant of a linear programming technique known as Data Envelopment Analysis (DEA) to analyse relative health production performance. DEA is a methodology for constructing a best practice frontier which tightly envelops observed data on producers' inputs and outputs, and then evaluates the relative performance of producers in terms of their proximity to the best practice frontier (see Charnes *et al.*, 1994, for a recent survey). An increasing number of researchers apply DEA to hospital efficiency analysis, but to the best of our knowledge, no attempt to apply this technique to health production at country level has been attempted until now.

We consider each national health care system as a production unit or decision making unit (DMU) which uses different combinations of inputs per person to produce a health output for a representative individual of that country.

Although DEA was originally developed for use in microeconomic environments to measure the performance of individual firms or public sector entities, the technique is ideally suited to the macro level of performance analysis. When output does not have a single dimension and services are not exchanged in markets (and thus have no prices), DEA is an appropriate analytical method for evaluating relative performance.

In our study, countries are compared on the basis of their relative technical efficiency. A DMU is said to be technically efficient in the health production process if an increase in an output requires a decrease in at least one other output, or an increase in at least one input. Technical efficiency scores computed are those corresponding to the input-oriented CCR ratio model (Charnel, Cooper and Rhodes, 1978) and the input-oriented BCC model (Banker, Charnes and Cooper, 1984). The CCR ratio model yields an objective evaluation of overall technical efficiency. The BCC model makes a distinction between technical and scale inefficiencies by estimating pure technical efficiency at the given scale of operation, and identifying whether increasing, decreasing, or constant returns to scale possibilities are present.

The variables chosen as the measure of the output (health stock) are the variation of male (Y_1) and female (Y_2) life expectancy at birth. Five variables are considered as inputs into the health production process. The number of physicians (X_1) and the number of nonphysician personnel (X_2) employed in the health sector per 1000 inhabitants, together with the number of hospital beds per inhabitant (X_3), represent health care consumption. Tobacco (X_4) and alcohol (X_5) consumption per capita are life style proxies.[1] In addition, the proportion of individuals under 65 (X_6) is used as a proxy for age, and is considered as a nondiscretionary variable (Banker and Morey, 1986).

The source of our data is the OECD Health Data File. The data include all OECD countries excluding Turkey.[2] The time periods considered are the decades of the 1960s, 1970s, and 1980s. When the necessary data are not available, individual countries are eliminated from the analysis of a particular decade.[3]

Some discrimination among efficient countries may be necessary in order to ensure that relative efficiency is not simply a consequence of an unbearable weighting structure given the absolute weight flexibility of the method. The cross-efficiency matrix, which shows the relative efficiency of country j with the DEA weights optimal for another country i, may reveal that country j only appears efficient when we ignore with its weighting structure all but very small subsets of its inputs and outputs. Our analyses of the data have shown that it is possible for the country which has the highest number of physicians per capita and/or the lowest value of male life expectancy to operate on the production frontier (and it does not appear in the peer group of any other inefficient country). In this case the DEA score may be the result of an optimal weighting structure with very low values for these variables. In order to avoid these situations, we introduce the following constraints into each DEA model $\nu_{X1} > \nu_{X2}$, $0.25 < u_{Y1}/u_{Y2} < 4$, and $0.25 < u_{Y3}/u_{Y4} < 4$.

[1] For use in DEA models, these variables are defined as a constant minus observed level of the variable. The constant is set equal to the highest value for all countries during the three decades.

[2] Turkey is excluded due to the fact that it is an outlier in terms of most socioeconomic variables. DEA analysis is very sensitive to the presence of outliers.

[3] The DEA models estimated exclude Austria, Luxembourg, New Zealand, Norway, Spain and the United Kingdom in the 1960s ; Luxembourg, Spain and the United Kingdom in the 1970s ; and Luxembourg and Spain in the 1980s.

The interpretation of the constraints is that the weight assigned to physicians must not be in any case lower than that of non-physician personnel, and that the weight of male life expectancy (or increase in male life expectancy) must not be greater or lower than four times female life expectancy (or increase in female life expectancy).

IV. THE EFFICIENCY SCORES

Table 1 summarizes the average overall, pure and scale efficiency scores from calculating the different DEA efficiency scores. Results from constrained DEA model show an average overall technical efficiency of 0.594 in the 1960s, 0.678 in the 1970s and 0.720 in the 1980s. Pure technical efficiency scores show a lower level of relative inefficiency, with values of 0.947, 0.912 and 0.916 in each decade, respectively.

Table 2 summarizes individual efficiency scores for the 1980s. According to the constrained DEA model, in this decade six out of the 21 countries considered (28%) are operating on the frontier: Austria, Greece, Italy, Japan, Portugal, and United Kingdom. The average overall efficiency score for nonfrontier countries is 0.61, with a range between 0.17 and 0.97. In other words, nonefficient countries use, on average, approximately 39% more inputs per unit of health stock than efficient countries. The most inefficient countries are northern countries such as Denmark, Finland, Sweden and Norway. Inefficiency is associated primarily with nonincreasing returns to scale: ten of the 15 overall inefficient countries display decreasing returns to scale.

Considering the various DEA specifications and those countries for which we have data for all three decades under consideration, the most efficient producers of health appear to be Portugal, Japan, Greece, United States, Italy and Canada. These countries differ greatly in the structure and financing of health care, as well as in their general level of economic development. On the other hand, our study suggests that the most inefficient producers of health are Sweden, Denmark, Iceland, Germany and Finland. Efficiency scores for each country and decade are available from the author, along with detailed input specifications.

The United States appear, not unsurprisingly, as one of the most *technically* efficient producers of health. Efficiency scores of the United States are greater than those of countries with a considerably lower level of per capita health spending. Cost (or price) efficiency is the result of both technical and allocative efficiency. The results of our study suggest that the problems of inefficiency in the American and other health care systems may spring from allocative efficiency rather than technical efficiency. This conclusion would be consistent with Pauly's (1993) finding that the number of health care workers per 1000 inhabitants is lower in the United States than in Northern Europe. Then, in this case allocative inefficiency appears as a more important problem than technical inefficiency.

Table 1. *Average DEA efficiency scores*

DEA model	OTE	PTE	SE
Period 1961–70			
Unconstrained model	0.645	0.948	0.670
	(0.325)	(0.084)	(0.315)
Constrained model	0.594	0.947	0.670
	(0.322)	(0.086)	(0.313)
Period 1977–80			
Unconstrained model	0.691	0.913	0.743
	(0.255)	(0.105)	(0.232)
Constrained model	0.678	0.912	0.731
	(0.251)	(0.105)	(0.232)
Period 1981–90			
Unconstrained model	0.732	0.921	0.791
	(0.259)	(0.114)	(0.247)
Constrained model	0.720	0.916	0.782
	(0.263)	(0.122)	(0.249)

Note: Numbers in parenthesis indicate standard deviation.

Table 2. *Efficiency scores for the period 1981–90*

Country	Model 2-II(c)	
	OTE	PTE
Australia	0.75940	0.78524
Austria	1.00000	1.00000
Belgium	0.80717	0.89007
Canada	0.61255	0.90786
Denmark	0.16759	1.00000
Finland	0.34850	0.59972
France	0.72512	0.72987
Germany	0.83711	1.00000
Greece	1.00000	1.00000
Iceland	0.53266	0.68524
Ireland	0.97157	1.00000
Italy	1.00000	1.00000
Japan	1.00000	1.00000
Netherlands	0.51489	0.95189
New Zealand	0.58907	0.82124
Norway	0.28088	0.86466
Portugal	1.00000	1.00000
Sweden	0.43753	1.00000
Switzerland	0.74958	1.00000
United Kingdom	1.00000	1.00000
United States	0.78318	1.00000

V. AN ECONOMETRIC ANALYSIS OF EFFICIENCY SCORES

In order to determine the influence of environmental variables on efficiency, we use a two-stage approach. In the first stage we calculate inefficiencies using a DEA model in which the environmental variables are ignored and selected input and output variables are used. In the second stage variation in calculated efficiencies is attributed to variation in operating environments by means of a regression model.

DEA scores (θ^i) can be conceptualized as presenting a censored normal distribution, in which the values of the dependent variable in the regression model above a threshold are measured by a concentration of observations at a single value. Here a censored Tobit model is proposed as applied in recent literature in order to avoid asymptotically biased estimates from ordinary least squares (Greene, 1993). In this case, the censoring takes the following form: θ^i = actual score if score < 1, and $\theta^i = 1$, otherwise

The factors which affect the overall and pure technical efficiency of a health system are many, and obviously it is not possible to model the system completely. Keeping in mind that our analysis is necessarily partial, we now explore three explanatory hypothesis regarding the level of technical efficiency of individual countries during the 1980s:

1. Human capital (Z_1) increases the technical efficiency of the health production function (Grossman, 1972, p. 244).
2. Private financing of health care services (Z_2) contributes to a greater technical efficiency in the health production (Oxley and McFarlan, 1994).
3. Health care systems in which general practitioners act as gatekeepers (Z_3) who control access to specialized services (dummy variable) produce health services (and health) more efficiently than systems without gatekeepers (Oxley and McFarlan, 1994).

Human capital (Z_1) is represented by the average years of schooling of the total population over age 25 (data from Barro and Lee, 1993). Z_2 is the proportion of health care expenditure privately financed. Z_3 is a dummy variable which takes a value of 1 in those countries in which general practitioners act as gatekeepers to more specialized services. In addition, we define two dummy variables which measure temporal effects: T_1 for the 1970s, and T_2 for the 1980s.

Tobit regression results for DEA efficiency scores in the three decades analysed as dependent variables are presented in Table 3. Two of the explanatory variables, Z_1 and Z_2, are significantly correlated with overall (and also pure) technical efficiency DEA scores. In contrast, Z_3, (primary care physicians acting as gatekeepers) does not have a statistically significant influence on efficiency, although its sign is consistently positive.

Our empirical findings suggest human capital, measured as the average number of years of schooling of the total population over 25, is significantly and negatively related to efficiency, both overall and pure. This result is counter-intuitive, and requires some clarification. In the first place, the estimation in this paper refers only to the average representative individual of each country, and does not reflect within-country variations. More specifically, our results do not exclude the possibility that within a given country, the relationship between education and efficiency of health production is positive. Secondly, human capital may be acting as a proxy for permanent income. To the extent that higher incomes lead to increased levels of health care consumption, and efficiency declines with greater consumption, we may observe a negative relationship between human capital and health production efficiency.

Table 3. *Factors explaining overall technical efficiency DEA scores*

Variables	Unconstrained model	Constrained model
Intercept	1.6151	1.6377
	(8.102)	(9.288)
Human capital	−0.0937	−0.0814
	(13.152)	(11.881)
Private financing	0.0173	0.0163
	(20.985)	(21.373)
Gatekeepers	0.1279	0.1299
	(1.997)	(2.233)
Seventies	0.3657	0.3309
	(9.539)	(9.121)
Eighties	0.5329	0.5222
	(15.187)	(16.256)
log likelihood	−15.335	−14.582
sigma	0.2755	0.2688

Note: Chi square values in parenthesis

According to our findings, technical inefficiency in health production decreases with an increase in the proportion of health expenditures financed privately. This relationship holds for both overall and pure technical efficiency, although the latter to a lesser degree. Our results suggest that free care does not improve the technical efficiency of the care.

The group of least efficient countries is not characterized by either a low human capital level or by having a small proportion of health services financed by the public sector. An important part of the variation in health production efficiency remains unexplained, suggesting that other variables not included in our analysis are important.

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