J. OF PUBLIC BUDGETING, ACCOUNTING & FINANCIAL MANAGEMENT, 11(1), 19-27 SPRING 1999

A REVIEW OF STATISTICAL TECHNIQUES IN MEASURING EFFICIENCY

Catherine Craycraft*

ABSTRACT. In the world of corporate downsizing and government cutbacks, the ability to measure an entity's efficiency is increasing in importance. Researchers have used many statistical techniques to measure efficiency and the factors that influence it. This paper is a review of the statistical techniques used in previous research and an analysis of the strengths and weaknesses of each statistical method.

INTRODUCTION

Efficiency has become a common theme in the 1990s, as budget and program cutting becomes the norm. This emphasis on efficiency makes appropriate measures necessary. Measuring efficiency is especially important for nonprofit organizations because, in many cases, outputs are difficult to measure and the lack of a net income figure makes performance hard to measure. Specifically, in the hospital industry, measuring efficiency is imperative since the government reimburses hospitals a fixed rate designed to compensate hospitals for "efficient" treatment. Corporations are increasingly channeling patients to hospitals they identify as "efficient." The rapid increase in hospital costs has put pressure on hospitals to improve efficiency. Major cost savings may be achieved if better measures allow inefficiencies to be identified and reduced. As more and more emphasis is placed on hospital efficiency, better measures are necessary.

* *Catherine Craycraft, Ph.D., is Associate Professor, Department of Accounting, University of New Hampshire Her teaching and research interests are in not-for-profit and financial accounting.*

Measuring efficiency is difficult, and inaccurate measures of efficiency may lead to poor decisions. If efficiency is improperly measured, it may lead to a misallocation of resources among and within hospitals. If hospitals are considered inefficient and are truly efficient, resources may be inappropriately allocated away from these hospitals. This potential for misallocation is especially important for hospitals since it could have a major impact on the quality of healthcare provided. Since quality of care is difficult to measure, hospitals that provide a higher quality service may be regarded as inefficient and thereby not receive the funding they should. The same may be true for departments within a hospital. As more decisions are based on efficiency, the ability to measure it accurately increases in importance. This paper is a non-technical review of the statistical techniques used in the literature to measure efficiency. Understanding the assumptions and limitations of these techniques is critical for rigorous research and the subsequent policy decisions which can be generated. This paper looks at appropriate usage of various statistical techniques rather than factors associated with efficiency.

RATIO AND REGRESSION ANALYSIS

Before 1980, most studies of efficiency used either a form of regression or ratio analysis. Ratio analysis examines the relationship between a single input and a single output. Ratios can provide pertinent information for a hospital, especially when compared to national averages published in the Monitrend reports of the American Hospital Association. A ratio such as "Cost per Patient Day" can be compared to other hospitals to determine if the hospital is out of line with the norm. Ratio analysis is beneficial in determining extremely good or bad aspects of a hospital's operations. Ratios, especially when tracked over time, can pinpoint changes in a hospital's operations. For example, a hospital can calculate the ratio "Cost per Full Time Equivalent" which measures the cost per unit of staff. If this ratio is higher than other comparable hospitals, the hospital could have a problem with payroll such as excessive overtime or over-qualified staffing. In addition, by tracking the ratio over time, the hospital can examine reasons for increases or decreases in costs. There are two major limitations with ratio analysis when used to measure efficiency. First, it is difficult with ratio analysis to incorporate multiple factors which is a problem since efficiency is multidimensional. Secondly, ratio analysis does not indicate how much variance from the industry mean is considered inefficient or even if the mean itself is efficient. A hospital can compare its ratios to the national average but the national average probably is not efficient. Also, determining how much variance from the norm is attributable to inefficient operations is an arbitrary decision (Sherman, 1984). Ratio analysis is very useful in pinpointing specific areas of a hospital's operations that may vary enough from the norm to warrant further investigation or to track expenses over time but is usually not appropriate in measuring a hospital's overall efficiency.

Regression analysis overcomes the difficulties of comparing single inputs to single outputs by estimating the average relationship between multiple inputs and outputs. Examples of how regression analysis can be used include estimating marginal costs per patient, efficient rates of substitutions, fixed versus variable costs, and whether economies of scale exist (Sherman, 1984). For example, regression analysis can be used to examine whether it is more efficient to build one large hospital or two smaller ones (Vitaliano, 1987). Regression analysis has also been used to examine characteristics that impact a hospital's costs. For example, Felstein's (1968) seminal study used regression analysis to determine that case-mix has an impact on hospital costs. Dowling (1974) also used regression analysis to determine that teaching status influences costs. Regression analysis is very useful in examining characteristics that impact costs but is not very useful in determining an individual hospital's inefficiencies because measures of efficiency are developed by comparing firms to the sample mean.

FRONTIER ANALYSIS

Frontier Analysis uses multiple inputs (e.g. materials and labor) and outputs (e.g. inpatient care, outpatient care, teaching and research) from a sample of hospitals to develop an efficiency frontier and evaluate the efficiency of a Decision Making Unit (DMU) relative to all other DMUs in the sample. DMUs that are on the frontier are considered efficient while units below the frontier are considered less efficient with the distance from the frontier interpreted as the inefficiency. Frontier analysis evaluates how efficient a DMU is in either 1) producing the maximum level of outputs from a given level of inputs or 2) using the minimum level of inputs for a given level of outputs relative to all other firms in the sample. Frontier analysis compares an individual hospital to the "best practice set" of the sample rather than to the sample mean.

Frontier analysis allows different units of measure to be used for inputs and outputs (e.g. payroll expenses and patient days) and even among inputs or outputs (e.g. payroll expenses and number of physicians). This flexibility in data definition is very helpful especially when data availability is limited, which is often the case in the public sector. For example, doctors' services can be used as an input into the analysis rather than doctors' costs which often are unavailable. Also, multiple inputs and outputs can be used without assigning relative weights. The flexibility of frontier analysis allows for different types of hospitals in different environments with different objectives and technologies to be compared (Grosskopf and Valdmanis, 1987).

Frontier analysis has been used to examine many important issues in the hospital industry. Frontier analysis has been used to examine the relative performance of public and nonprofit hospitals in California (Grosskopf and Valdmanis, 1987), whether there is a relationship between efficiency and profitability (Zuckerman, Hadley and Iezzoni, 1994), whether there is a difference in the efficiencies of urban and rural hospitals (Hadley and Zuckerman, 1991), and to determine cost standards for variance analysis and management control (Banker, Das and Datar, 1989). Frontier analysis can determine the sources and amounts of inefficiency and indicate the amount of input reduction or output increases necessary for efficiency (Sherman, 1984). In addition, marginal rates of substitution of inputs, marginal productivities, and returns to scale for both aggregate and specific production possibility sets can be estimated (Banker, Conrad and Datar, 1986). DMUs used in frontier analysis do not have to be individual hospitals but can be departments or resources within a hospital. For example, Bradford and Craycraft (1996) used frontier analysis to examine the efficient mix of capital and labor for hospitals under the Prospective Payment System. Frontier analysis has provided many opportunities to examine hospital efficiency and various aspects of hospital performance.

To determine a frontier, there are two statistical methods to choose from: Data Envelopment Analysis (DEA) and Stochastic Frontier Estimation (SFE). DEA is a linear programming technique that estimates a deterministic frontier based on data from the sample[1]. SFE is a parametric technique that uses a multiproduct cost function to determine hospital-specific inefficiencies[2]. When choosing between these two statistical techniques, there is a tradeoff between structure and flexibility. The more structure that is imposed, the better the estimates derived from the statistical technique <u>assuming the structure imposed is correct</u>. SFE is more structured than DEA which allows for a more detailed analysis of the data. DEA has the benefit of not imposing a structural form but has its own limitations when interpreting the data. SFE is based on statistical assumptions that allow the frontier to be <u>estimated</u> from the data. DEA, by using linear programming <u>derives</u> the frontier instead of estimating it. The fact that the frontier is estimated using SFE makes hypothesis testing possible (Schmidt and Lovell, 1979). Researchers should be well aware of the benefits and limitations of the two techniques as discussed below.

DEA uses linear programming to derive the frontier estimation. Its major benefit is that no assumptions of functional form are necessary. This benefit, however, comes at a cost. The major shortcoming of DEA is that because it is derived, it is sensitive to the sample. DEA can not determine whether all hospitals in the sample are inefficient but rather the inefficiencies of an individual hospital when compared to others in the sample (Sherman, 1984). More importantly, DEA is sensitive to variable selection, model specification, and data errors. Sampling error and measurement error are a problem since no underlying distribution of the error term is assumed. The frontier may be "warped if the data are contaminated by statistical noise" (Bauer, 1990: 39). Omission of critical variables in the model has significant effects on the results (Seiford and Thrall, 1990). However, increasing the number of variables decreases the ability of the model to discriminate between DMU's. The reliance on the sample to derive the frontier makes DEA extremely sensitive to outliers. Large, carefully selected samples must be used to mitigate some of these problems. Researchers should be aware of their existence and control for them as much as possible.

The major benefit of stochastic frontiers is it allows for a more detailed breakdown of the inefficiency measure. With DEA, all deviation from the frontier is assumed to be inefficiency on the part of the hospital. Stochastic frontiers allow the deviation from the frontier to be broken down into 1) technical inefficiency, 2) allocative inefficiency, and 3) statistical and sampling errors and random shocks (Wagstaff, 1989). This breakdown allows a more thorough analysis of why a hospital is operating off the frontier. Technical inefficiency is when more output could be produced given the same level of inputs used. This is what most people think of as inefficient behavior. In addition, SFE measures allocative inefficiencies which are inefficiencies caused by not using the optimal mix of inputs (Zuckerman, Hadley and Iezzoni, 1994). SFE also measures the portion of the deviation from the frontier that has causes other than firm behavior. The cost frontier may be influenced by problems with sample selection or variable selection or elements beyond the firm's control which are called random shocks(3). That SFE controls for all of these difficulties is a major benefit of SFE.

As with all statistical techniques, there are assumptions and limitations with SFE. SFE is more structured than DEA. SFE is based on assumptions of the underlying functional form of technology and also the distribution of the error term. The error term is divided into two parts. The first part measures statistical noise, sampling errors, and random shocks and is assumed to be normally distributed. The second part of the error term captures the two measures of inefficiency and is assumed to have a one-sided distribution. This distribution can take a variety of forms; for example, half normal or exponential (Aigner, Lovell and Schmidt, 1977), truncated normal (Stevenson, 1980) or a Gamma distribution (Greene, 1990). However, determining which structure to impose on the data is not an easy task. "The appropriate structure to impose can be determined only by a careful consideration of the data and the characteristics of the industry under study." (Bauer, 1990: 41) The effect of using an inappropriate structure on the results is unclear (Wagstaff, 1989). If an incorrect functional form is assumed, incorrect inferences could be the result. More research needs to be done on the appropriateness of different assumptions with SFE and the effect of using an incorrect structure on the results.

Schmidt and Sickles (1984) attempt to overcome the assumptions necessary in SFE by using panel data. While overcoming the need to impose a functional form on the data, the use of panel data necessitates the questionable assumption that inefficiencies remains constant over time.

SFE allows better estimates of an individual hospital's efficiency measure and the sources of the inefficiency (whether technical or allocative). SFE also allows for the statistical and sampling errors common in empirical research. However, the lack of knowledge of the correct functional form to use or the effects of using an inappropriate function form makes interpreting the results difficult.

CONCLUSION

Most current studies use frontier analysis to examine efficiency in the public sector, particularly in hospitals. Ratio and regression analysis are beneficial when examining other issues, but most researchers agree that frontier analysis provides better overall measures of efficiency. When choosing between the two methods of frontier analysis, the question of which method to use becomes more complex. The sensitivity of DEA to outliers, the inability to test hypotheses, and the assumption of no measurement error or statistical noise has led many researchers to use SFE. SFE has many advantages over DEA but at an unknown cost. One solution to the dilemma is for researchers to use both methods of frontier analysis. However, Wagstaff (1989) compares the results obtained using DEA, stochastic frontiers, and stochastic frontiers with panel data and found the results differ significantly with the statistical method chosen. These results are quite disturbing. The inconsistency of the results among statistical techniques makes it imperative that more research be done in determining the appropriateness of the different methods. Caution should be used by researchers and government officials in interpreting results and making policy decisions until a better understanding of the costs and benefits of DEA and SFE has been achieved.

ACKNOWLEDGEMENTS

The author would like to thank Stanley Sedo for his helpful comments.

NOTES

1. For a detailed explanation of the DEA model, see Charnes, Cooper and Rhodes (1978), and Banker (1984).

2. See Zuckerman, Hadley and Iezzoni (1994), Schmidt and Lovell (1979); and Aigner, Lovell and Schmidt (1977) for details of Stochastic Frontier Estimation.

3. An example of a random shock for the hospital industry would be an epidemic.

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