National Textile Center
FY 2004 New Project Proposal

Project No.

S04-PH*07

Competency: Management Systems

Maximizing Production Efficiency via Stochastic Frontier Analysis

Project Team:
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Objective:
The textile industry is under attack. In order to be competitive, our industry must target appropriate niches, keep pushing the technological boundaries and throughout all, eliminate losses due to inefficiency. Our team will employ an emerging analytical technique, Stochastic Frontier Analysis (SFA), to identify inefficiencies in production, estimate the magnitude of these inefficiencies, and identify the determinants of the inefficiencies in order to eliminate them.

Relevance to NTC Mission:
While expanding upon the latest econometric techniques, our work will enhance the competitiveness of the US textile industry by providing an algorithm that can inform management decisions and provide a useful benchmarking tool. Our results will identify areas in which firms can improve their efficiency with regard to minimizing costs of production, optimal input allocation, as well as output mix. These firms will be in a better competitive position with respect to foreign firms that may enjoy lower labor costs or less apparent advantages such as government subsidies

State of the Art:
SFA originated in 1977 as a methodology used evaluation of plants' relative efficiency. SFA is a powerful and effective new methodology for organizing and analyzing data, identifying the best practice frontiers and inefficiency sources, and providing improved performance. While the methodology of SFA in fact goes beyond that, it is clearly recognized as a fruitful method of analysis to solve real world problems. Specifically, SFA is used in benchmarking studies, the evaluation of value chain efficiency, and the identification of best practice to provide new managerial implications.

Conventional economic theory assumes that producers are successful optimizers; that is, producers minimize the costs of manufacturing, given the state of technology and the prices of inputs they face. However, while producers may attempt to optimize, they do not always succeed. The recent econometric advances of Stochastic Frontier Analysis allow us to re-examine the theory of producer behavior, to allow for the possibility of less-than-optimal choices. The need to infuse greater reality to economic models is moot without the new econometric techniques with which to apply the theories. Now, rather than simply estimate production, cost and profit functions from the data at hand, we can recast the analysis towards the identification of the frontiers of the data using Stochastic Frontier Analysis (Kumbhakar and Lovell, 2000).

SFA is attributed originally to two papers in 1977: Meeusen and van den Broeck (MB) in June, and Aigner, Lovell, and Schmidt (ALS) a month later, and then a third SFA paper by Battese and Corra (BC) in the same year. These three original SFA models shared the composed error structure in the context of a production frontier. The model can be expressed as

$$y = f(x;\beta) \cdot \exp\{v-u\}$$

where y is a scalar output, x is a vector of inputs, and β is a vector of technology parameters. The econometric innovation lies in the disaggregation of the error term into two components, the standard random component and efficiency losses. Thus, the first error component $\nu \sim N(0,\sigma_\nu^2)$ is intended to capture the effects of statistical noise, and the second error component $u \geq 0$ is intended to measure the effects of technical inefficiency. Producers operate on or beneath their stochastic production frontier given by $f(x;\beta) \cdot \exp\{\nu\}$ according to whether $u = 0$ or $u > 0$, respectively.

The modeling of the efficiency parameter differs in the three papers: MB use an exponential distribution of u, BC assume a half-normal distribution of u, while ALS consider both approaches. Parameters to be estimated include β, σ_ν^2 and a variance parameter σ_u^2 associated with u. Either distributional assumption on u implies that the distribution of the composed error ($\nu - u$) is negatively skewed, and statistical efficiency requires that the model be estimated by maximum likelihood. After estimation, an estimate of mean technical inefficiency in the sample is provided by $E(-u) = E(\nu - u) = -(2/\pi)^{1/2}\sigma_u$ in the normal-half normal case and by $E(-u) = E(\nu - u) = -\sigma_u$ in the normal-exponential case. (Kumbhakar and Lovell, 2000).

Cornwell, Schmidt, and Sickles (CSS) (1990) and Kumbhakar (1990) were the first to propose a stochastic frontier *panel data* model with time-varying technical efficiency. Lee and Schmidt proposed an alternative formulation in 1993 for which Ahn, Lee and Schmidt (1994) proposed a generalized method of moments approach for its estimation. If independence and distributional assumptions are tenable, it is also possible to use maximum likelihood techniques to estimate time varying technical efficiency model. While theses techniques are innovative and esoteric, they have been proven in the academic arena and present a useful and new approach to the analysis of efficiency.

Previous NTC funding has been allocated for research on productivity, S01-PH13, *Optimal Investment Strategies for Enhancing Productivity* with S. Christoffersen as Principal Investigator. That work was founded on the recent work of Grilliches (1996), in the tradition established by the pioneering work of Abramovitz (1956). A spin off from that grant, S03-PH02 entitled *Strategies for Improving the Competitiveness of the US. Textile and Apparel Industries: A Production-Cost Approach,* lead by Anusua Datta focuses on cost functions. The current proposal builds upon the databases and knowledge acquired under the first proposal and extends the methodology by shifting the focus from estimating functions to establishing efficiency frontiers and measuring inefficiencies as distances from the frontiers (SFA).

Approach:

There are three types or components of efficiency that we can measure/estimate/discuss. *Technical efficiency* refers to the case where the minimal amount of inputs is used, given the available technology, to produce a given output, resulting in minimal expenses. *Allocative efficiency,* also referred to as *Cost efficiency,* refers to the proper choice of the mix of inputs given their relative prices (assumed fixed). If the minimal amounts of inputs are employed but they are not allocated appropriately given their prices, this misallocation leads to a failure to minimize expenditures. The third type of efficiency is referred to as *Scale Efficiency* or *Profit efficiency*. Even if producers attain technical and allocative efficiency, they may not be producing the most efficient combination of goods. Scale efficiency entails an optimal allocation of output in order to maximize profit, given the output prices in the market (Kumbhakar and Lovell, 2000).

Our first investigation will be technical efficiency. We will use panel data, that is, repeated observations over time of a cross-section of textile industry sectors. The panel data production frontier models allow technical efficiency (TE) to vary across sectors and through time for each sector. We assume that output y is a function of inputs, x, and technology parameters, β, such that

$$y_{it} = f(x_{it};\beta) \cdot \exp v_{it} \cdot \mathrm{TE}_{it}$$

where i stands for the i^{th} production sector at time t, and $\exp v_{it}$ incorporates sector-specific random shocks. TE is the ratio of the observed output to the maximum feasible output in a stochastic environment:

$$\mathrm{TE}_{it} = y_{it} / f(x_{it};\beta) \cdot \exp v_{it}$$

where $TE_{it} = \exp\{-u_{it}\}$. Efficiency is indicated by $TE_{it} = 1$ thus we require that $TE_{it} \leq 1$, and $u_{it} \geq 0$.

Next, assuming that $f(x_{it};\beta)$ takes the log-linear Cobb-Douglas form, with n inputs,, the stochastic production frontier model becomes:

$$\ln y_{it} = \beta_{0t} + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it}.$$

Where $u_{it} \geq 0$ guarantees that $y_{it} \leq f(x_{nit};\beta)$. This is a linear regression model with a nonpositive disturbance term. The objective is to obtain estimates of the parameter vector β_n, which describes the structure of the production frontier, and also to obtain estimates of the u_{it}, which can be used to obtain estimates of technical efficiency for each sector by means of $TE_{it}=\exp\{-u_{it}\}$.

Further specification of the model include the Fixed Effects Model and Random Effects Model, the two main analyses made possible by the use of panel data. As referenced in the State of the Art section, the CCS and Kumbacher model expand the stochastic frontier model, specifically to the following:

$$\begin{aligned} \ln y_{it} &= \beta_{0t} + \sum \beta_n \ln x_{nit} + v_{it} - u_{it} \\ &= \beta_{it} + \sum \beta_n \ln x_{nti} + v_{it} \end{aligned}$$

where β_{0t} is the production frontier intercept common to all producers in period t, $\beta_{it}=\beta_{0t} - u_{it}$ is the intercept for producer i in period t, all other parameters are as previously defined. This leaves a very large number of parameters to estimate. Various statistical methods are proposed by CSS (1990), Kumbacher (1990), Lee and Schmidt (1993), Kumbacher and Hjalmarsson (1993), amongst others. Little is to be gained by reproducing these lengthy econometric specifications here as they are not readily summarized and would lose veracity and comprehension. Once parameter values are calculated, the technical efficiency of each producing sector can be calculated from the slacks in the functional constraints.

A time indicator can be included among the regressors, enabling one to disentangle the effect *of technological change* from *technological efficiency change*. This has been accomplished by Coelli and Battese (1992), and is a promising direction in which to extend this work. Future directions will also include the measurement of Allocative efficiency as well as Scale efficiency, again applying the innovative econometric technique of Stochastic Frontier Analysis to the robust data available in our panel dataset for the textile industry.

This Year's Goal:
Data collection should not be too grand a task; we have identified the relevant data sources and simply will need to update the latest available information. Our main task in the first year will be to conduct the Stochastic Frontier Analysis to identify production inefficiencies. Understanding the magnitude of the inefficiencies is the next stage. This ought to be accomplished within the first year. Once technical efficiency is studied, we will extend the analysis to allocative and scale efficiency. The determinants of the inefficiencies may be the most difficult aspect to quantify and would reasonably take the following two years to fully research.

Outreach to Industry:
At first the analyses will be conducted on a sectoral basis. The analysis can be replicated using firm level data, however only for publicly traded firms at this point, providing valuable benchmarking information for those firms.

The results will also be of interest to academic audiences and could be presented at the North American Productivity Workshop, the International Applied Business Research Conference, the Eastern Economics Association, and possibly the American Economic Association. Due to the interest in Stochastic Frontier Analysis, we can reasonably expect to be published in highly respected economics and business journals.

New Resources Required:
Software: Frontier analysis £495 as of 2002, now about $900.

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