Research Institute of Agricultural Economics
Committee on Agricultural Economics, Hungarian Academy of Sciences

STUDIES IN AGRICULTURAL ECONOMICS No. 113

Budapest
2011

Studies in Agricultural Economics No. 113

The Studies in Agricultural Economics is a scientific journal published by the Hungarian Academy of Sciences and the Research Institute of Agricultural Economics, Budapest. Papers of agricultural economics interpreted in a broad sense covering all fields of the subject including econometric, policy, marketing, financial, social, rural development and environmental aspects as well are published, subsequent to peer review and approval by the Editorial Board.

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HU ISSN 1418 2106

Studies in Agricultural Economics No. 113 p. 97-104. (2011)

Parametric farm performance and efficiency methodology: Stochastic Frontier Analysis

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Abstract

There is a continuously growing literature on the agricultural transformation in Central and Eastern European countries (see some surveys in *Brooks and Nash* 2002; *Rozelle and Swinnen* 2004). The research has focused on various aspects of transition, including land reform, farm restructuring, price and trade liberalisation, but even though Farm Accountancy Data Network (FADN) data are now available for some years, there are only a few studies (e.g. *Bakucs et al.* 2010, *Fogarasi and Latruffe,* 2007, *Baráth et al.,* 2009) focusing on Hungarian farm performance. The objective of this paper is to shed light on some methodological issues that are needed to study Hungarian farm performance. Here we consider one aspect of farm performance, namely technical efficiency. This measure refers to whether farmers are capable of using existing technology to its full potential by producing the most possible from a given set of production factor quantities.

Keywords

farm technical efficiency, Stochastic Frontier Analysis, methodology

Stochastic Frontier Analysis (SFA)

Technical efficiency can be measured using parametric or non-parametric approaches. The latter (e.g. Data Envelopment Analysis, DEA) have however severe shortcomings such as the sensitivity of the results to outliers and the potential bias in the results due to the exclusion of potentially more efficient firms. To circumvent this problem, researchers have resorted to various methods such as the bootstrapping technique (e.g. *Brümmer*, 2001). Another drawback of the non-parametric methods is that they do not account for random noise. Within the parametric approaches, the Stochastic Frontier Analysis (SFA) is commonly used. *Aigner at al.* [1977] and *Meeusen and Van den Broeck* [1977] have simultaneously yet independently developed the use of SFA in efficiency analysis.

The main idea is to decompose the error term of the production function into two components, one pure random term (v_i) accounting for measurement errors and effects which cannot be influenced by the firm such as weather, trade issues and access to materials, and a non-negative one, measuring the technical inefficiency, i.e. the systematic departures from the frontier (u_i):

$$Y_i = f(x_i)\exp(v_i - u_i) \tag{1}$$

or, equivalently:

$$\ln(Y)_i = \beta x_i + (v_i - u_i) \tag{2}$$

where Y_i is the output of the i^{th} firm, x_i a (k+1) vector of inputs used in the production, *f(·)* the production function, u_i and v_i the error terms explained above, and finally, β a (k+1) column vector of parameters to be estimated. The output orientated technical efficiency, (TE) is actually the ratio between the observed output of firm *i* to the frontier, i.e. the maximum possible output using the same input mix x_i (*Battese*, 1992, Figure 1).

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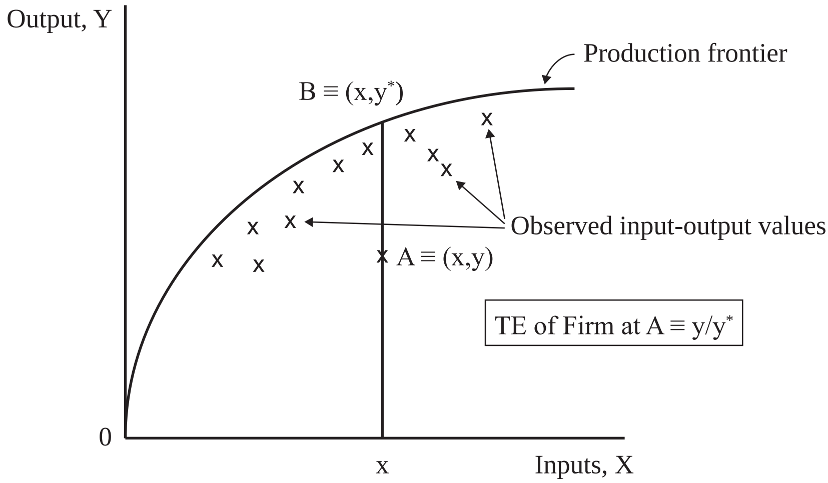

Figure 1: Technical efficiency of farms

Source: Battese (1992), p. 187

Arithmetically, technical efficiency is equivalent to:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{\exp(x_i\boldsymbol{\beta} + v_i - u_i)}{\exp(x_i\boldsymbol{\beta} + v_i)} = \exp(-u_i), 0 \leq TE_i \leq 1 \tag{3}$$

Contrary to the non-parametric DEA approach, where all production technical efficiency score are located on, or below the frontier, in SFA they are allowed to be above the frontier if the random error *v* is larger than the non-negative *u* (Figure 2).

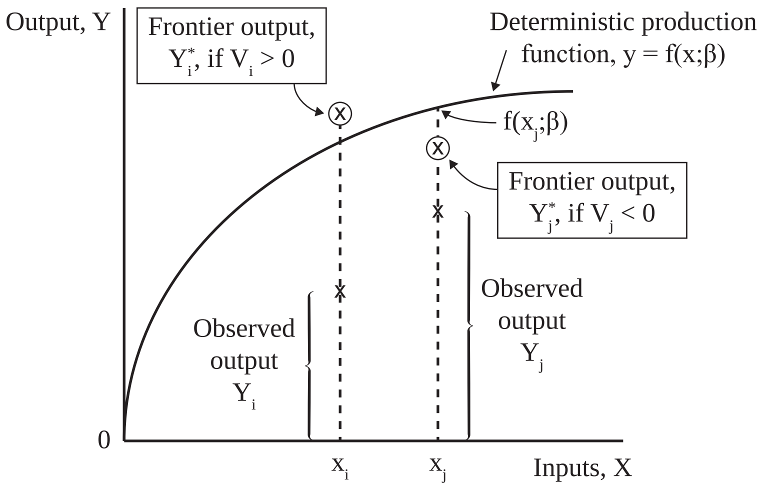

Figure 2: Stochastic frontier model

Source: Battese (1992), p. 191.

Applying SFA methods requires distributional and functional form assumptions. Firstly, because only the $w_i = v_i - u_i$ error term can be observed, one needs to have specific assumptions about the distribution of the composing error terms. The random term v_i is usually assumed to be identically and independently distributed drawn from the normal distribution, $N(0,\sigma_v^2)$, independent of u_i. There are a number of possible assumptions regarding the distribution of the non-negative error term u_i associated with technical inefficiency. However most often it is considered to be identically distributed as a half normal random variable, $N^+(0,\sigma_u^2)$ or a normal variable truncated from below zero, $N^+(\mu,\sigma_u^2)$.

Secondly, being a parametric approach, it is necessary to specify the underlying functional form of the Data Generating Process, DGP[2]. There are a number of possible functional form specifications available, however most studies employ either Cobb-Douglas (CD):

$$f(x_i) = e^{\beta_0}\prod_{k=1}^{K} x_{ik}^{\beta_k} \tag{4}$$

or TRANSLOG (TL) specification:

$$\ln f(x_i) = \sum_{k=1}^{K}\beta_k \ln x_{ik} + \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{K}\beta_{kj}\ln x_{ik}\ln x_{jk} \tag{5}$$

Because the two models are nested, it is possible to test the correct functional form by a Likelihood Ratio, LR test. The TL is the more flexible functional form, whilst the CD restricts the elasticities of substitution to 1, thus being more restricted but easier to estimate and interpret. The model could be estimated either with Corrected Ordinary Least Squares (COLS) or Maximum Likelihood (ML). With the availability of computer software, the estimation by ML became less computationally demanding and the ML estimator was found to be significantly better than COLS.

Extensions of the basic SFA model

Incorporating time effects

With panel data, TE can be chosen to be time invariant, or to vary systematically with time. To incorporate time effects, *Battese and Coelli* [1992] define the non-negative error term as an exponential function of time:

$$u_{it} = \exp[(-\eta(t-T))]u_i \tag{6}$$

where t is the actual period, T the final period and η a parameter to be estimated. TE either increases ($\eta > 0$), decreases ($\eta < 0$) or it is constant over time, i.e. invariant ($\eta = 0$). LR tests can be applied to test the inclusion of time in the model.

Determinants of technical inefficiency scores

Since TE is allowed to vary, the question arises, what determines the changes of TE scores? Early studies applied a two-stage estimation procedure, firstly determining the inefficiency scores and then, in a second stage, regressing TE scores upon a number of firm specific variables assumed to explain changes in inefficiency scores. Some authors however showed that conflicting assumptions are needed for the two different estimation stages. In the first stage, the error term representing inefficiency effects is assumed to be independently and identically distributed whilst in the second stage they are assumed to be function of firm specific variables explaining inefficiency, i.e. they are not independently distributed (*Curtiss*, 2002). *Battese and Coelli* [1995] proposed a one stage procedure where firm specific variables are used to explain the predicted inefficiencies within the

[2] Within the econometric literature there are a number of possible interpretations of the DGP. Here we refer to the true, but unknown model generating the data that is approximated by a 'best available' functional form.

SFA model. The explanatory variables are related to the firm specific mean μ of the non-negative error term u_i:

$$\mu_i = \sum_j \delta_j z_{ij} \tag{7}$$

where μ_i is the i^{th} firm-specific mean of the non-negative error term; δ_j are parameters to be estimated, and z_{ij} are i^{th} firm-specific explanatory variables.

The heteroscedastic SFA model

Using cross-section or panel data may often lead to heteroscedasticity in the residuals. With heteroscedastic residuals, OLS estimates remain unbiased but no longer efficient. In frontier models, however, the consequences of heteroscedasticity are much more severe as the frontier changes when the dispersion increases. *Caudill et al.* [1995] introduced a model which incorporates heteroscedasticity into the estimation. That is done by modelling the relationship between the variables responsible for heteroscedasticity and the distribution parameter σ_u:

$$\sigma_{ui} = \exp\left(\sum_j x_{ij}\rho_j\right) \tag{8}$$

where x_{ij} are the j^{th} input of the i^{th} farm, assumed to be responsible for heteroscedasticity, and ρ_j a parameter to be estimated.

Within the SFA approach it is possible to test whether any form of stochastic frontier production function is required or the OLS estimation is appropriate using a LR test. Using the parameterisation of *Battese and Cora* [1977], we define γ, the share of deviation from the frontier that is due to inefficiency:

$$\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2} \tag{9}$$

where σ_v^2 is the variance of the v and σ_u^2 the variance of the u error term.

It should be noted, however, that the test statistic has a 'mixed' chi square distribution, with critical values tabulated in *Kodde and Palm* [1996].

Some applications of SFA methods

Most efficiency and productivity studies focused on three main groups of issues when explaining the sources of inefficiency: farm owner/manager characteristics, farm type and size, and finally the effect of various subsidies. Here we focus on the literature applying the SFA methodology and studying the latter two issues.

The impact of optimal farm size and structure upon the technical efficiency of farms

The optimal farm structure as well as the optimal farm size has long been in the focus of agricultural economics debates. The issues seem to be even more controversial in transitional newly acceded European Union (EU) economies where (in most cases) political-social and economic changes in the early 1990s were followed by the dismantling of socialist agricultural farm structures (de-collectivisation and the breaking up of socialist state agricultural enterprises) and the emergence of various new, mostly family farm based structures. *Gorton and Davidova* [2004] reviewed the efficiency studies focusing on Central and Eastern European Countries (CEEC). Of the studies employing the SFA methodology, *Curtiss* [2002] found that, on average, in the Czech Republic wheat and rapeseed farms larger than 150 ha perform better, then smaller ones, or farms specialised on other field crops. *Munroe* [2001] found that in Poland, farms smaller than 15 ha are less efficient, whilst for Slovakia, *Morisson* [2000] analysed seven commodities and concluded that there is a positive relationship between the scale of production and efficiency scores. In addition, *Curtiss* [2002] found evidence of higher technical efficiency of individual farming in sugar beet production, but lower in wheat production, compared to corporate farming. *Latruffe et al.* [2004] reinforced Munroe's results for Poland and found that for both crop and livestock farms the size-efficiency relationship is positive, meaning large farms are more efficient. More recently, *Alvarez and Arias* [2004] using data from a group of 196 dairy farms in Northern Spain found a significant positive relationship between technical efficiency and size.

The impact of agricultural subsidies upon the technical efficiency of farms

As it has often been shown in agriculture, public support reduces farmers' effort, implying greater waste of resources and thus further distance from the efficient frontier. This may be even more appropriate when considering decoupled payments since these government transfers are not linked to output. Thus if income supports are mainly through decoupled transfers, higher production does not imply bigger premia. This in turn may reduce incentives to produce close to the possible frontier resulting in increased inefficiencies (*Serra et al.,* 2008).

Serra et al. [2006] elaborated a theoretical framework that allows for both output and input price uncertainty and incorporates risk attitudes of economic agents. The theoretical framework and empirical analysis revealed that in a non-risk neutral scenario decoupling will cause farms with decreasing absolute risk aversion, DARA (increasing absolute risk aversion, IARA) to increase (decrease) input use if the input is risk increasing. If, however, the input is risk decreasing then the impacts of decoupled government transfers are inconclusive. *Bakucs et al.* [2010] investigated the determinants of the technical efficiency of Hungarian farms using Hungarian FADN data for the 2001-2005 period, the crucial phase of adjustment and first years of membership of the EU. The results showed that accession to the EU has reversed the pre-accession trend of decreasing efficiency. Increased competitiveness, opening of new market opportunities or access to better inputs may be reasons for this. The investigation of the determinants of technical efficiency has made it possible to characterise the most efficient farms in Hungary over the period studied: these were companies located in the favourable region of Western Hungary, with a non specialised and labour intensive production system. This, along with the large production elasticity of labour (0.319), suggests labour scarcity in Hungarian agriculture 10-15 years after the transition. The direct effect of agricultural support policies on farm production and efficiency was also investigated in the paper. Accession to the EU was found to only slightly enhance technological change and production, contrary to what was expected from accession, but to improve farms' efficiency. However, the other side of the coin about EU membership is that public subsidies received by farmers in the frame of the Common Agricultural Policy (CAP) have a negative influence on their technical efficiency. This effect was found here to be even stronger in periods where subsidies were higher (2005 c.f. 2004).

Latruffe et al. [2008], using non-parametric methods, investigated the relationship between CAP direct payments and managerial efficiency of French crop and beef farms, and found significantly negative correlationfor crop farms and a significantly positive one for beef farms. They concluded that the type of payments also matter, since Less Favoured Area and area-based payments decrease crop farms' efficiency, whilst agri-environmental and headage payments increase beef farms' efficiency scores.

Serra et al. [2008] revisited the issue of the relationship between technical efficiency and decoupling. Using an additive SFA approach as opposed to the Stochastic Frontier Production Function used in *Serra et al.* [2006], they have shown that since technical inefficiencies are positively related to output variability and negatively to production mean, a decoupling process affecting the input use will also have an impact upon technical inefficiencies. Using empirical farm level data from Kansas the paper found that an increase in decoupled transfers will induce an increase (decrease) in DARA (IARA)[3] farms' technical inefficiency if the given input is risk decreasing. With risk increasing inputs, however, the effect of decoupling upon technical inefficiencies can be either positive or negative, somehow contradicting previous studies that mostly concluded that government transfers are farm inefficiency increasing.

Software packages

There are a large number of computer software packages appropriate for estimating the technical efficiency of farms. Most often the LIMDEP (www.limdep.hu), NLOGIT (www.limdep.com), STATA (www.stata.com), and TSP commercial software packages or programs written in Ox, SAS, Gauss program languages are used for SFA estimations. There are however some freely downloadable programs that are appropriate for SFA analysis. *Coelli* [1996] developed the program Frontier (www.uq.edu.au/economics/cepa) and Mark Steel of the Warwick University has the WinBUGS software for SFA estimations available at the http://www2.warwick.ac.uk/fac/sci/statistics/staff/academic/steel/steel_homepage/software.

Acknowledgements

Zoltán Bakucs gratefully acknowledges financial support from the 'János Bolyai' scholarship of the Hungarian Academy of Sciences.

[3] Decreasing Absolute Risk Aversion and Increasing Absolute Risk Aversion respectively.

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