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MEASURING PRODUCTIVE EFFICIENCY OF FARMERS: TECHNIQUES AND APPLICATION

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ABSTRACT

In developing countries such as Iran, where many factors of production are in short supply, inefficient use of resources is particularly undesirable. Analysis of efficiency can help farmers to identify the possibilities for increasing output as well as conserving resource use. The objective of this study was to investigate the technical efficiencies for a sample of wheat farms situated in the Ferydan region, Isfahan province. A stochastic frontier production function model was estimated. Parameters of the stochastic frontier production function and the parameters associated with determinants of technical inefficiencies were simultaneously estimated for the sample farmers. Results of this study demonstrated that the production of wheat can be increased by 33% at the current levels of resource use if the technical efficiency gap among farmers is suitably narrowed. Factors affecting the estimated level of technical inefficiency of production of wheat farmers included levels of education and farming experiences.

KEY WORDS: **Technical efficiency, Stochastic frontier production function, Single step model.**

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دانشیار بخـش اقتصادکشـاورزی دانشـکده کشـاورزی دانشـگاه شـیراز، شـیراز، جمهـوری اسلامی ایران.

چکیده

در کشورهای درحال توسعه مانند ایران، که بسیاری از عوامل تولید محدود است، استفاده ناکارا از منابع بویژه نامطلوب می‌باشد. تحلیل کارایی می‌تواند به زارعان در شناخت امکـان افزایـش محصول و صرفه‌جویی در مصرف نهاده‌های تولید یاری دهد. هدف این مطالعه، تعیین کارایی فنـی نمونه‌ای از گندمکاران منطقه فریدن در استان اصفهان بود. تابع تولید مرزی تصادفی برآورد گردید. پارامترهای تابع تصادفی و عوامل مؤثر بر عدم‌کارایی گندم کاران عضو نمونه مورد مطالعه به طـور همزمان تخمین زده شد. نتایج حاصل از این مطالعــه نشـان داد کـه، در صـورت کـاهش فاصلـه بیـن کارایی زارعان مورد مطالعه، تولید گندم را می‌توان حدود ۳۳ درصـد افزایـش داد. عوامـل مؤثـر بـر میزان کارایی فنی، شامل سطح سواد و میزان تجربه زارع بود.

INTRODUCTION

Productive efficiency has received considerable attention in economic literature in recent years (5, 11). It can help farmers to identify the possibilities for increasing output while conserving resource use. So, the role of increased efficiency may be viewed as a variable complement to any set of policies to stimulate domestic production and/or to promote resource conservation (14). If a farmer happens to operate efficiently, implying doing the 'best' within the existing constraints, then the only feasible way that output of agricultural products could be increased is with better quality resources or technologies. However, if farmers are not using their resources efficiently, it may be desirable to reallocate resources to improve economic efficiency (27).

Many studies, particularly in less developed countries (LDC's), have demonstrated the possibilities of increasing output and thereby farmers' total net revenue through better use of available resources or by moving closer to the current technology frontier (4, 9, 14, 17, 18, 24,). In a developing country such as Iran, where many factors of production are in short supply, inefficient use of resources is particularly undesirable. The government is naturally concerned with growth in agricultural production and encouraging research to evolve improved agricultural technology However, the process has been slow. So, it seems reasonable to stress the importance of increasing the level of agricultural production by increasing farmers' levels of productive efficiency, at farm level, with the existing technology. This effort, in the short run, would be more cost-effective than introducing new technologies. So, in order to formulate appropriate policies for reducing the level of technical inefficiency, it is important to estimate its level at the farm-level, and also identify the sources of such inefficiency. Such information is important for formulating appropriate policies for reducing the level of productive inefficiency.

Productive efficiency is the degree to which producers can achieve the goal of producing a given level of output at the lowest cost (12). It may be divided into two components, namely, technical and allocative efficiencies. A farm is technically efficient if it produces the maximum obtainable level of output from a certain amount of inputs, given the current technical state of the arts. Allocative efficiency refers to the proper choice of input combinations or mixture of outputs for a given set of relative prices.

A farm is said to be economically (or productively) efficient if it maximizes profit by operating on the frontier of the technically efficient production function and chooses an input combination corresponding to the points of tangency between the isoquant and isocost lines. In the context of two variable inputs producing a single product under certainty, the tangency condition means that the farm has equated the ratio of the marginal product of an input to the unit price of the input for all input variables. Differences in levels of economic efficiency among farms which face the same biological and environmental constraints may be attributed to differences in their degree of technical and/or allocative efficiency (14).

However, the concept of economic efficiency is by no means unambiguous and its usefulness as a measure of economic performance has been questioned. Pasour (23) argued that efficiency measures, derived by assuming profit maximization, are not appropriate standards to measure the performance of economic agents operating under conditions of imperfect information whose objective functions involve elements other than profit. To avoid the conceptual difficulties surrounding the above argument, this paper will focus on technical rather than allocative efficiency.

Farrell (12) in 1957 defined productive efficiency (later called economic efficiency) as the ability of a production organization to produce a well-specified output at minimum cost. He introduced a technique with which the efficiency of a production activity could be divided into technical and allocative efficiencies. Following the work of Farrell (12), various methods have been developed to measure the technical component of economic efficiency (11). The essence of the frontier models is to estimate a frontier rather than an average production function (11, 13). Frontier approaches, basically, may be classified into two categories as either deterministic or stochastic frontier models. Limitations of the various techniques for estimating deterministic frontiers have been noted by many authors (13, 27). So, in the present study the stochastic frontier function is used to measure farm level technical efficiency.

The stochastic frontier model was independently proposed by Aigner *et al.* (3) and Meeusen and van den Broeck (21). In this model the fact that a firm's output may be affected by exogenous variables, such as climate, is considered (13). The error term in this model is composed of two parts: a symmetrically distributed component for statistical noise and a one-sided error component which captures the effect of inefficiency. The first component represents factors not under the firm's control while the second part of the error term represents things under the control of the firm.

Many authors have proposed extensions of the original specification of the stochastic frontier production function. A thorough review of frontier production functions and their relationship to efficiency measurement has been provided by Forsund *et al.* (13) and Coelli (11). Stochastic frontier production functions are used in a large number of studies to estimate the technical efficiency of production activities (see 5, for applications of stochastic frontier in agricultural economics).

The objective of the present study was to investigate the technical efficiencies for a sample of wheat farms in the Ferydan region, Isfahan province. The single step stochastic frontier production function model was used to simultaneously investigate the parameters of stochastic frontier as well as the determinants of technical efficiency of the sample farms.

This paper provides a brief review of the Farrell technique as well as the Stochastic frontier approach. This is followed by the econometric model of the study. In the final section, empirical results and discussion are presented.

The pioneering work of Farrell (12) focused attention on the concept of productive efficiency and the consequences of its recognition for the modeling of production processes. He suggested two forms of productive or economic efficiency, viz., technical and allocative or price efficiency.

Fig. 1 clarifies the concept of economic efficiency and its components for the firms which use two inputs of X_1 and X_2 that yield a particular level of Y. The curve Y_A is the technically efficient unit isoquant (EUI) derived for a group of firms and shows the various combinations of least amounts of inputs to produce a unit of output. That is, frontier technology can be shown through the unit isoquant (13). Thus, technical efficiency can be measured in a relative sense as a deviation from the 'best' performance in a representative group.

Firms at P and Q produce the same level of output using different amount of inputs. For the firm at P, Farrell defined degree of technical efficiency (TE) as OQ/OP. The point Q is technically efficient in the sense that at Q, the output is produced with only OQ/OP as much as of each factor as the firm at P.

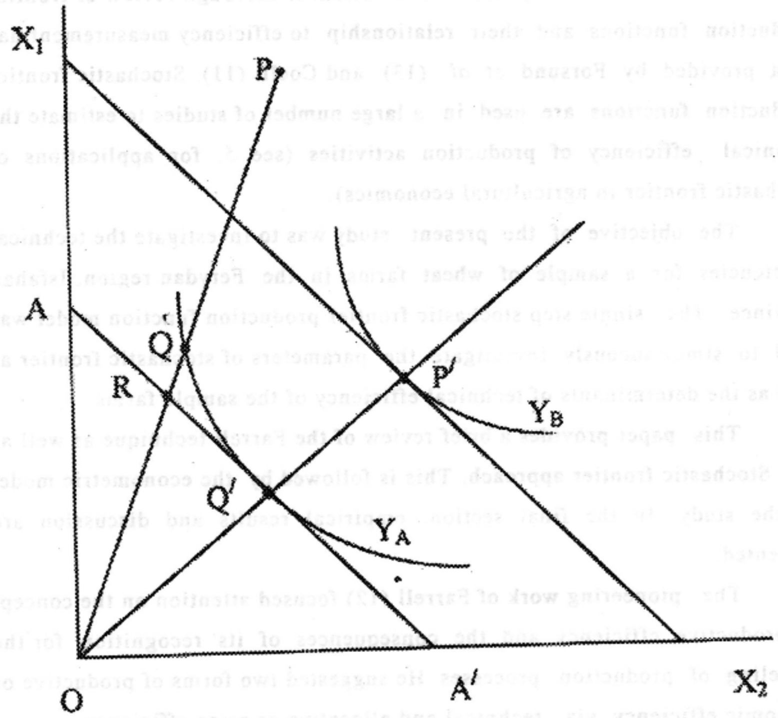

Fig 1. Farrell's efficiency measures.

By considering the relative prices of the inputs as depicted by the slope of the isocost line AA′, indicating the minimum cost of producing one unit of output, the concept of allocative efficiency can be introduced. Its slope reflects the factor price ratio. So that the cost minimizing point is Q′. Since the cost at R is equal to the cost at Q′, the degree of allocative efficiency could be shown as OR/OQ, while 1-OR/OQ indicates the allocative inefficiency (13).

A firm operating at Q is technically efficient, but allocatively inefficient. Firms operating at P are technically inefficient, and may be allocatively inefficient as well. Only the firm operating at Q' is both technically and allocatively efficient. Defining economic efficiency as the product of technical and allocative efficiency, only firm Q' is economically efficient. Further, Farrell (12) shows that the overall efficiency index of the firm P is the product of the technical and allocative efficiencies, i.e., OQ/OP * OR/OQ = OR/OP.

Stochastic frontier production function was first proposed by Aigner *et al.* (3) and Meeusen and van den Broeck (21), based on the composed error term, to study the technical efficiency. The model may be expressed as:

$$Y_i = f(x_i; \beta) \exp(\varepsilon), \qquad i=1, \ldots, N$$

where Y_i is the observed level of production of the i-th firm, x_i is a row vector of inputs, β is a vector of unknown parameters, $f(x_i; \beta)$ is a suitable function and ε is the stochastic error term composed of two independent type of disturbances

$$\varepsilon = (V_i - U_i),$$

where V_i is symmetrically distributed, as $N(0, \sigma^2_V)$, and assumed to represent uncontrolled random variation in output due to factors such as weather, diseases and measurement error. It is independent of U_i which is a non-negative random variable which captures the effect of technical inefficiency relative to the stochastic frontier. The variance of the normal distribution that is truncated as zero to get the distribution of U_i is $\sigma^2_S = \sigma^2 + \sigma^2_V$. The variance of ε is, therefore, $\sigma^2 = \sigma^2_u + \sigma^2_V$ (22).

Battese and Corra (7) have defined γ ratio, as $\gamma \equiv \sigma^2 / \sigma^2_S$ which has value between zero and one. It is convenient for estimation of parameters of the stochastic frontier model.

Until recent years, a two-step approach was used to investigate the impacts of socio-economic factors on producers' technical efficiency (17, 22). In this approach, the parameters of stochastic frontier production function are estimated first and then the level of predicted technical inefficiencies, obtained from the estimated stochastic frontier, are regressed upon a vector of various socio-economic factors such as age and education of the manager So, the first stage involves the specification and estimation of the stochastic frontier production function and the prediction of the technical inefficiency effects and the second stage involves the specification of a regression model for the predicted technical inefficiency effects. However, specifying the technical efficiencies, as dependent variable, in a regression model contradicts the assumption of identically distributed technical efficiency effects in the stochastic frontier (6, 19). So, Kumbhakar *et al.* (19) and Reifschneider and Stevenson (25) proposed a model which permits the simultaneous investigation of both the parameters of stochastic frontier and impacts of socio-economic factors on the level of technical efficiency of study farmers in a single step maximum likelihood (ML) procedure.

METHODOLOGY

In this study, the single stage model was used in the analysis of cross section data on the production of wheat in Ferydan region, Isfahan province. The maximum likelihood estimates of the parameters of this model was estimated by the use of the computer program 'FRONTIER 4.1' (11).

Farm level data used in the present study are from farms in the Ferydan region, Isfahan province, which were collected through a survey, using a well-designed and pretested questionnaire. The sample survey was conducted in the mid-1999, for the year 1997-1998. Sample farmers were selected in two stages. First, to minimize the effects of biological and socioeconomic variability, a cluster of three villages was selected as being fairly typical of the study site. Second, a cross section of 86 farmers were chosen from those villages, at random, and interviewed. Wheat is the major source of income in the study region, and is the main source of carbohydrates in human diets in Iran. So, the technical efficiency of wheat farmers are investigated in this study.

Following Battese *et al.* (8), the stochastic frontier model for wheat farmers was defined by a modified version of Cobb- Douglas function. The equation can be written in logarithmic form as:

$$Ln\ Y_i = \beta_0 + \beta_1 Ln\ X_1 + \beta_2 Ln\ X_2 + \beta_3 Ln\ X_3 + \beta_4 Ln\ X_4 + \beta_5 Ln\ X_5 + \beta_6 Ln\ X_6 + \beta_7 Ln\ X_7 + \beta_8 Ln\ X_8 + \beta_9 Ln\ X_9 + \beta_{10} Ln\ X_{10} + \beta_{11} D_1 + V_i - U_i$$

where Y represents the total production of wheat (kg); X_1 is the total land area under wheat (ha); X_2 and X_3 are the total number of labors (family and hired) in man-days and the total hours of agricultural machinery used in production and harvesting of wheat, respectively X_4 and X_5 are, the quantities of nitrogen and phosphorous fertilizers applied for wheat production (kg) respectively; X_6 denotes the amount of wheat seed (kg); X_7 denotes the amount of pesticides (liter) used for wheat; X_8 represents the irrigation frequency; X_9 represents the number of sessions which farmer has attended extension classes; X_{10} represents the number of land parcels and D_1 is a dummy variable. $D_1 = 1$ if farmer was an owner and $D_1 = 0$ otherwise. i refers to the ith farmer. U_i's which capture the effect of technical inefficiency, are assumed to be truncated normal obtained by truncation of a normal distribution with variance, σ^2, and mean, μ_i, defined by Battese *et al.*(8)

$$\mu_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i}$$

where Z_1, Z_2 and Z_3 represent years of farming experience, education of the farmer (years of schooling) and ratio of adult males to the total family size, respectively.

From the stochastic function coefficients, the technical efficiency for production of a specific farm (TE_i) can be calculated by the ratio of actual output to the maximum possible output defined by the frontier, using the same input factor. So, farm-specific technical efficiency of the ith farm can be specified as:

$$TE_i = Y_i / f(x_i; \beta)\exp(V_i) = \exp(-U_i)$$

RESULTS AND DISCUSSION

The results of the maximum-likelihood estimates (MLE's) of the stochastic frontier function and inefficiency model are shown in Table 1. The parameters of stochastic frontier indicated that the coefficients of land area, labor, agricultural machinery, irrigation and extension were positive and statistically significant, indicating that higher quantities of above inputs were associated with higher levels of wheat production. The extension had a relatively large elasticity indicating any change in the number of meetings with extension service can have significant impact in wheat production.

Table 1. MLEs of the stochastic frontier function for study farmers.

Parameters	Coefficients	t-ratio
β_0	1.35	0.86
β_1	0.68	3.23*
β_2	0.21	2.97*
β_3	0.19	2.86*
β_4	0.12	0.85
β_5	0.10	0.78
β_6	0.18	1.04
β_7	0.07	0.66
β_8	0.17	2.67*
β_9	0.32	2.92*
β_{10}	-0.34	-3.34*
β_{11}	0.07	0.21
δ_0	-3.14	-0.91
δ_1	-0.23	-2.97*
δ_2	-0.35	-3.78*
δ_3	-0.03	-0.15
$\sigma^2_s \equiv \sigma^2 + \sigma^2_v$	1.89	3.11*
$\gamma \equiv \sigma^2 / \sigma^2_s$	0.97	6.32*
Log-likelihood	-25.86	

Indicates significant effect at a 5 % level.

The estimates for the elasticities of fertilizers, pesticides and seed were positive, but the values were not significantly different from zero. The coefficient of degree of land fragmentation were negative and statistically significant. Thus farms with higher degree of land fragmentation tended to have lower level of production. So, a policy leading to consolidation of holdings could be beneficial in generating gains in wheat production. The coefficient of land ownership did not appear to have any significant effect on the production of wheat in the study region. However, omitting these variables from the model did not change the values of other coefficients significantly.

In the efficiency model, the coefficients of formal schooling and farming experience were negative and statistically significant, indicating that greater technical knowledge increased output presumably by increasing productivity of labor and capital. The ratio of adult males elasticity was estimated to be negative, but the value was not statistically significant.

The value of γ was estimated to be close to one, indicating the stochastic nature of technical inefficiency. This suggests that the MLE's of stochastic frontier production function is preferred to ordinary least squares (OLS) estimation of traditional production function.

Results of the generalized likelihood ratio tests of various hypotheses regarding parameters of variables of the stochastic frontier inefficiency model are given in Table 2, using the chi-square statistic. Results indicated that, first null hypothesis was rejected (Table 2) which suggests that the stochastic frontier production function is preferred to OLS estimation. The second hypothesis was also rejected, indicating the significant effect of variables specified in the inefficiency model on the levels of technical efficiency of wheat farmers.

Table 2. Generalized-likelihood ratio test for parameters of the inefficiency model†.

H_0 assumption	Chi-square		Decision
	Estimated value	Table value (95%)	
$\gamma = 0$	18.25	5.99	Rejected H_0
$\delta_1 = \delta_2 = \delta_3 = 0$	52.37	7.82	Rejected H_0

† Source: Author's calculation.

The distribution of the technical efficiency index is presented in Table 3. The mean level of efficiency for these sample farms was estimated to be 67%, with almost 60% of the farms having a technical efficiency index below the mean level. The minimum estimated technical efficiency for wheat farmers was 21% and the maximum 94%.

Results of this study suggested that, there is considerable potential for increasing the technical efficiency of wheat farmers at the existing levels of farmers' resources and technology. Policies and programs aimed at improving technical efficiency include extension and education programs. Also, higher adult male ratio increaseed efficiency, perhaps because of the labor shortage in the study region in peak season. Results of the single stage stochastic frontier production function model, demonstrated that fragmented land decreased technical efficiency. Thus, a policy leading to consolidation of holdings could be beneficial in generating gains in wheat production.

Table 3. Distribution of technical efficiency for wheat farms†.

Efficiency interval	Number of farms	% of farms
0.20-0.29	3	3.49
0.30-0.39	8	9.30
0.40-0.49	9	10.47
0.50-0.59	12	13.95
0.60-0.69	22	25.58
0.70-0.79	18	20.93
0.80-0.89	9	10.47
0.90-0.95	5	5.81
Mean	0.67	
Minimum	0.21	
Maximum	0.94	

† Source: Author's calculation.

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