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ESTIMATION OF TECHNICAL EFFICIENCY ON WHEAT FARMS IN NORTHERN INDIA – A PANEL DATA ANALYSIS

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ABSTRACT

In this paper an attempt has been made to estimate farm level technical inefficiency on wheat farms in Haryana State, India. This paper applies stochastic frontier production function for wheat farmers using unbalanced panel data for three years from 1996-97 to 1998-99. The farm level panel data was collected from 200 farmers spread over in each year forming 592 total observations. The frontier function involves inputs such as human labour, fertilizers, irrigation expenditure, seeds, land area and capital expenditure. All the estimates have expected signs. The results showed that the null hypothesis of absence of technical inefficiency effects was rejected indicating that the traditional average response function was not an adequate representation of the data given the specification of stochastic frontier model. The farm specific technical efficiencies estimated were observed to be time varying. The technical efficiency showed wide variation across sample farms ranging from 0.4346 to 0.9598 in the 3rd year of the study period. The mean technical efficiency was found to deteriorate through the years in wheat production. It declined from 0.9172 in 1st year to 0.9025 in 3rd year. The mean technical efficiency indicates that the realized output could be increased by about 10 percent without any additional resources. More than 2/3rd of total sample farmers had technical efficiency above 0.90. Various socio-economic and technological factors may be responsible for the observed inefficiency and further rise in inefficiency in

wheat production. Because of lack of information/data on these factors, this aspect has not been studied in the present paper, which could have provided an insight into the factors for policy framework.

INTRODUCTION

Wheat is one of the major cereal crops in India. The wheat production in Haryana state of India had increased from 869 lakh tones in 1966 to 9669 million tones in 2001, registering an increase of about 29 percent per annum. The share of wheat area in total cropped area showed a consistent increase in the state and it occupied about 35 per cent of the gross cropped area in 2001. As the possibility for cultivating additional land under the crop is almost nil, further increase in production is possible only through improvement in productivity of the crop. In this context technical efficiency in production of a crop is of paramount importance. The policy makers can either attempt to enhance the uptake of improved technologies relevant particularly to the small-scale agricultural production by improving Research and Development processes, or they can take steps, which enable the farmers to improve technical efficiency in production. While the former probably require a long time, considerable funds and efforts but are likely to yield long run benefit. Else, raising technical efficiency offers more immediate goals at modest costs, if it can be shown that substantial inefficiencies are present in agricultural production. Such research efforts are, therefore, based on an analysis of technical inefficiencies in production of wheat crop by farmers. Therefore, an attempt has been made in this paper to investigate farm specific technical efficiency for wheat in Haryana, India.

ANALYTICAL TOOLS

Stochastic frontier production function

A measure of technical efficiency was first introduced by Farrell (1957). A more satisfactory means of estimating technical efficiency viz., stochastic frontier model was independently formulated by Aiger et. al.(1977) and Meeusen and van den Broeck (1977) which improved the estimation of technical efficiency by incorporating both statistical noise representing uncontrolled exogenous factors and technical efficiency. Jondrow et. al. (1982) made it possible to estimate technical efficiency for each farm. Many studies on frontier production function are based on cross section data. The studies such as (Pit and Lee, 1981; Battese and Coelli, 1988; Battese and Coelli, 1992; Rajasekharan and Krishnamoorthy, 1999; Mythili and Shanmugan, 2000), etc have made use of cross section cum time series data.

The present study uses the stochastic frontier production function approach to measure the technical efficiency in wheat production. In the analysis of farmer efficiency/ inefficiency, it is not the average of observed relationships between farmers' inputs and outputs that is of interest but the maximum possible output that is obtainable from a given combination of inputs. Thus, Frontier production function can be defined as the maximum feasible, or potential output that can be produced by a firm with a given level of inputs and technology.

The general specification of frontier production function considered is defined by

$$Y_{ht} = \exp(X_{ht}\hat{a} + V_{ht} - U_{ht}) \qquad (1)$$

Where: Y_{ht} represents the output for the h-th firm in the t-th time period; X_{ht} is a (1xK) vector of inputs for the h-th firm in the 't' time period; β is a (Kx1) vector of parameters that describe the transformation process, the V_{ht} are assumed to be independent and identically distributed random error which have normal distribution with mean zero and unknown variance σ^2_v; and
the U_{ht} are non-negative unobservable random variables associated with the technical inefficiency of production, such that, for the given technology and levels of inputs, the observed output falls short of its potential output.

The model developed by Battese and Coelli (1992) has been employed as it can accommodate unbalanced panel data associated with a sample of H firms over T time periods. Also it provides a measure of technical efficiency for the same farm, in each time periods considered. Following the model, U_{ht} can be defined as:

$$U_{ht} = \{\exp[-n(t - T)]\}U_{h}, \qquad (2)$$

where η is an unknown parameter to be estimated; and U_h , h = 1,2....N, are non- negative random variables that are assumed to be independently and identically distributed obtained by truncation of the normal distribution with unknown mean, μ, and unknown variance σ^2_u.
U_{ht} decreases, remains constant or increases as 't' increases depending upon whether $\eta > 0$, $\eta = 0$ or $\eta < 0$, respectively.

The parameters of stochastic frontier production function model are estimated by maximum likelihood (ML) method using the computer programme, Frontier version 4.1 (See Coelli, 1994). Testing whether technical inefficiency effects are not present in the model is of great interest. This is expressed by H_0: $\tilde{a} = 0$, where the parameter, $\tilde{a}$ is defined by $\tilde{a} = \sigma^2 / (\sigma^2_v + \sigma^2)$
$\sigma^2_s = \sigma^2_v + \sigma^2$ and $\tilde{a} = \sigma^2/\sigma^2_s$

The $\tilde{a}$ - parameter has value between zero and one. The $\tilde{a}$ is zero when u_{ht} equals to zero (full technical efficiency). If this is the case, the Ordinary Least Square (OLS) estimates are also ML estimates. The null hypotheses that the technical inefficiency effects are time invariant and that they have half normal distribution are defined by H0: $\eta = 0$ and H0: $\mu = 0$, respectively. If parameter η is positive, the technical efficiency of the sample farm increases over time and vice versa. However, if η is zero, then the farm effect will be constant over time. Similarly, if parameter μ is zero, then farm effect would have a half normal distribution instead of a truncated normal distribution. The hypotheses are tested using the generalized likelihood- ratio test statistic.

Model specification

In this study, the stochastic frontier production function of Cobb-Douglas form was specified. Due to advantages over the other functuional forms, it is widely used in the frontier production function studies (Kalirajan and Flinn, 1983; Dawson and Lingard, 1989; Coelli and Battese, 1996, etc.)

The stochastic frontier production function of Cobb-Douglas type is defined in logarithmic form as:

$$Ln\,(Y_{ht}) = \beta_0 + \beta_1\, Ln\,(HL_{ht}) + \beta_2\, Ln\,(F_{ht}) + \beta_3\, Ln\,(IRR_{ht}) + \beta_4\, Ln\,(S_{ht}) + \beta_5\, Ln\,(L_{ht}) + \beta_6\, Ln\,(C_{ht}) + V_{ht} - U_{ht} \qquad (3)$$

Where: the subscript h and t refer to the h-th farmer and t-th observation, respectively.

Ln represents the natural logarithm (ie. to base e)
Y represents the quantity of wheat (in kg)
HL represents the total human labour (in mandays)
F represents the quantity of fertilizer (kg of NPK)
IRR represents irrigation expenditure (in Rs.)
S represents value of seeds (in Rs.)
L represents land area (in hectares)
C represents capital expenditure
V_{ht} -U_{ht} are the random variables defined above.

The technical efficiency of the h-th farmer in the t-th year of observation can be calculated as:

$$TE_{ht} = \exp\,(-\mu_{ht}) \qquad (4)$$

The technical efficiency of a farmer is between zero and one and is inversely related to the level of the technical inefficiency effect. The technical efficiency can be predicted using the Frontier programme which calculates the maximum-likelihood estimators of the predictor for equation (4) that is based on its conditional expectation (cf. Battese and Coelli, 1993).

THE DATA

The data used are compiled under the Comprehensive Scheme on "Cost of Cultivation of Principal Crops" in Haryana, India. The farm level panel data for the years 1996-97, 1997-98 and 1998-99 was used for the estimation of the model. The survey on Cost of Cultivation of Principal Crops is undertaken under the auspicious of the Directorate of Economics and Statistics, Ministry of Agriculture, Govt. of India. In Haryana state, the scheme is being implemented by CCS Haryana Agricultural University, Hisar, India. The farm level data is collected by adopting multi-stage stratified random sampling techniques. Under this scheme, the Haryana State has been classified into three zones according to the agro-climatic factors such as rainfall, irrigation pattern, soil characteristics, etc. The selection of tehsils, cluster of villages and farm households from each zone form the first, second and third stage of sampling units, respectively. The data are collected from 10 farms each from 30 cluster of villages from all the three zones which form a total sample of 300 farms each year. For the present study, 70 per cent of the total clusters from each zone have been selected. In totality 20 clusters, which constituted 200 farms formed the total sample in each year for compilation of the required information. Hence, the panel data cover 600 farmers for the three year periods. For some years, a few observations did not undertake wheat cultivation or were non existent. Therefore, the data set consists of 200 farm units constituting 592 total observations for all the three years. The required information on physical input-output data, factor-product prices, and other related variables were collected from the scheme for arriving at the objectives of the study.

RESULTS AND DISCUSSION

The maximum-likelihood estimates of the parameters in the Cobb-Douglas stochastic frontier production function, given the specification for the technical inefficiency effects are presented in Table 1. Besides estimating the general form in conjunction with the panel data, some restricted forms were also estimated and tested.

The estimates for parameters of the time varying inefficiencies model indicate that the technical inefficiency effects tend to increase over time since the parameter η is estimated to be negative (–0.1545). For deciding the most appropriate model, various hypotheses were tested using likelihood-ratio (LR) statistic. The tests of hypotheses associated with the models are presented in Table 2. The LR test (χ^2) rejects the null hypothesis that $\mu = \gamma = \eta = 0$. The LR statistic (λ) is 26.16 which is significant at 5 percent probability level implying thereby that traditional average response function was not an adequate representation for the data given the specification of the stochastic frontier model. Thus, inefficiencies of production can not be assumed to be absent from the stochastic frontier production function for the given level of technology used by farmers. The null hypotheses that H_0: $\mu = \eta = 0$, H_0: $\eta = 0$ and H_0: $\mu = 0$, the technical inefficiency effects are time invariant and have half normal distribution are also rejected. Thus, given the specification of Cobb-Douglas production function, the above tests of hypotheses indicate that the preferred model is the model with time varying inefficiency effects (model 1).

All the factor inputs involved for the stochastic frontier production function have positive signs and are statistically significant at 5 percent level, except fertilizer and irrigation expenditure. The parameter σ and γ terms are positive and statistically significant at 5 per cent level which indicated that the observed output significantly differed from frontier output due to factors which are within the control of farmers. This implies that, the average production function estimated using the OLS was not the right estimate of the production function in the present case. The intercept value of the ML estimate, which is greater than the OLS estimate further shows that, the estimate of frontier production function lies above the average function. The variance ratio showed that only about 67 per cent of the differences between the observed output and the frontier level of output was caused by differences in firm's technical efficiencies, while the remaining variation is due to factors out of the control of farm households.

The coefficients of input variables in Cobb-Douglas production function are elasticities of mean output with respect to the different inputs used. The elasticities of mean output are presented in Table 3. Elasticities of output for human labour, seeds, land and capital expenditure have expected signs and are significantly greater than zero at 5 per cent level under both model specifications i.e. OLS and ML estimation (μ and η unrestricted) with time varying technical efficiency. The elasticities with respect to fertilizer and irrigation expenditure were positive but statistically non-significant. The empirical results in Table 3 indicated that the land had the major influence on output. The elasticity of frontier (best practice) production with respect to land under wheat was estimated to be 0.61. This indicated that, if area under wheat were to be increased by 1 percent, then the total wheat production were estimated to increase by 0.61 percent. Further, the elsticity of human labour were estimated to be 0.14. The elsticity of output in respect of fertilizer, seeds and irrigation were quite low, at 0.034, 0.089 and 0.0066, respectively. The returns to scale parameter for the Cobb- Douglas production frontier was estimated by the sum of the elsticities of the six variables. It was found that the wheat cultivation in the state experienced constant returns to scale, as the sum of input elasticities was 1.01.

Technical inefficiencies

A production process is technically inefficient if maximum output is not produced from a given bundle of inputs. The technical efficiencies of farmers for technical inefficiency effects were predicted and were time varying. It implies that farm specific technical efficiency vary over time. Because of the large number of observations involved, the individual technical efficiency values are not presented. For better indication of the distribution of individual efficiencies, a frequency distribution of predicted technical efficiencies within ranges of 0.05 for each year are presented in Table 4. The farm specific technical efficiency showed wide variations. The predicted mean technical efficiencies for wheat farms were estimated to be 0.9172 in 1st; 0.9151 in 2nd and 0.9025 in 3rd years of study data. The estimated mean technical efficiency indicated that on an average the sample farmers in Haryana tend to realize about 91 percent of their technical abilities. In other words, we can say that on an average the sample farmers in Haryana were producing wheat upto about 91 per cent of the potential (stochastic) frontier production levels, given the levels of their inputs and technology currently being used. It means that about 9 percent of technical potential are not realized.

There were about 87, 82 and 74 percents of the total sample farms in the 1st, 2nd and 3rd years, respectively who belonged to the most efficient category (> 0.90) and only one farmer one each in first year and second year and three farmers in third year had technical efficiency less than 0.70. It is also clear from the Figure 1 that distribution of technical efficiency for farmers in all the years was closely clustered near between 0.90 to 0.95 indicating high technical efficiency of the farmers. One farmer was observed to have technical efficiency equal to 0.5416, 0.4812 and 0.4346 in 1st, 2nd and 3rd years, respectively. It was found that this farm belonged to the same farmer each year. An examination of technical efficiency of individual farmers revealed that the technical efficiency had declined over the years. The negative value of η (-0.1545) further confirmed that the technical efficiency tend to decline over years.

CONCLUSIONS

The estimated stochastic frontier production function for wheat farmers in Haryana using unbalanced panel data for three years showed that the traditional average response function, which does not account for technical inefficiency of production, was not an adequate representation of the data. The farm specific technical efficiency estimated were time varying and tend to decline over time. The technical efficiency showed wide variation across sample farms (ranging from 0.4346 to 0.9598) in the 3rd year of the study period. The mean technical efficiency declined from 0.9172 in 1st year to 0.9025 in 3rd year, which indicates that average technical efficiency deteriorated through the years in wheat production. The mean level of technical efficiency implies that the realized output could be increased by about 10 percent without any additional resources. It was also clear that more than 2/3rd of total sample farmers had technical efficiency above 0.90. Various socio-economic and technological factors may be responsible for the observed inefficiency and further rise in inefficiency in wheat production. Because of lack of information/data on these factors, this aspect has not been studied in the present paper, which could have provided an insight into the factors for policy framework. The likely policy to deal with bridging the gap between potential and actual yield may be through improving the extension advice, farmers' training and research.

Authors biographical details

Dr. S.K. Goyal is an Assistant Professor (Agricultural Economics) having about 10 years teaching/research experience. Has one book and about 25 research papers to his credit published in different journals of repute. Worked in the University of Bonn, Bonn (Germany) as Alexander von Humboldt Fellow for one year during 2001-2002.

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Table 1: Estimates of stochastic frontier production function for wheat farms (panel data) in Haryana

Variable	Parameter	OLS	ML estimates Model 1	Model 2	Model 3	Model 4
Human labour	β_1	0.1719* (0.0278)	0.1403* (0.0274)	0.1508* (0.0284)	0.1469* (0.0284)	0.1397* (0.0272)
Fertilizer	β_2	0.0319 (0.0460)	0.0344 (0.0437)	0.0310 (0.0458)	0.0339 (0.0456)	0.0295 (0.0416)
Irrigation expenditure	β_3	0.0020* (0.0079)	0.0066 (0.0079)	0.0054 (0.0081)	0.0062 (0.0081)	0.0064 (0.0080)
Seeds	β_4	0.0811* (0.0270)	0.0891* (0.0270)	0.0855* (0.0267)	0.0887* (0.0269)	0.0846* (0.0258)
Land	β_5	0.5889* (0.0697)	0.6133* (0.0654)	0.6040* (0.0685)	0.5999* (0.0681)	0.6195* (0.0648)
Capital expenditure	β_6	0.1373* (0.0243)	0.1282* (0.0247)	0.1357* (0.0244)	0.1370* (0.0242)	0.1310* (0.0225)
Constant	β_0	1.0345* (0.4109)	1.2835* (0.3853)	1.2331* (0.4047)	1.2039* (0.4019)	1.3237* (0.3881)
	σ^2	0.0536	0.1322* (0.0221)	0.0655* (0.0058)	0.0704* (0.0076)	0.1132* (0.0216)
	γ	-	0.6694* (0.0579	0.3108* (0.0694)	0.3652* (0.0785)	0.6169* (0.0939)
	μ	-	-0.5951* (0.1390)	-	-	-0.5285* (0.2004)
	η	-	-0.1545* (0.0743)	-	-.1056* (0.0806)	-
	Loglikeli-hood	29.72	42.80	36.74	37.60	22.17

Note: 1. Model 1 is with μ and η unrestricted, Model 2 is with μ and η restricted, Model 3 is with μ restricted and Model 4 is with η restricted.

2. *Figures in the parentheses indicate standard errors.*
3. *Significant at 1 percent probability level

Table 2: Likelihood-ratio tests of hypotheses for parameters of the stochastic frontier production function for wheat farms in Haryana

Null Hypothesis	Loglikelihood	λ	Critical value	Decision
Given Model	42.80			
$\mu = \gamma = \eta = 0$	29.72	26.16	10.50	Reject
$\mu = \eta = 0$	36.74	12.12	5.99	Reject
$\mu = 0$	37.60	10.40	3.84	Reject
$\eta = 0$	22.17	41.26	3.84	Reject

* The critical value for this test involving $\gamma = 0$ is obtained from Table of Kodde and Palm (1986, p1246)

Table 3: Elasticities of mean output under OLS and MLE specification

Elasticity with respect to	Model specification	
	OLS	MLE
Human labour	0.1719	0.1403

Fertilizer	0.0319	0.0344
Irrigation expenditure	0.0020	0.0066
Seeds	0.0811	0.0891
Land	0.5889	0.6133
Capital expenditure	0.1373	0.12
Returns to scale	1.01	1.01

Table 4: Relative frequency distribution of technical efficiency of wheat farmers in Haryana

Technical efficiency	First year		Second year		Third year	
	Frequency	% age to total farmers	Frequency	% age to total farmers	Frequency	% age to total farmers
≤0.65	1	0.50	1	0.51	1	0.51
0.65-0.70	-		-		3	1.52
0.70-0.75	1	0.50	3	1.53	2	1.01
0.75-0.80	3	1.51	3	1.53	6	3.04
0.80-0.85	9	4.52	10	5.10	7	3.55
0.85-0.90	12	6.03	19	9.69	33	16.75
0.90-0.95	124	62.31	142	72.45	140	71.06
0.95-0.99	49	24.62	18	9.18	5	2.53
Mean	0.9172		0.9151		0.9025	
Minimum	0.5416		0.4892		0.4346	

Maximum	0.9719		0.9674		0.9598	
Total number of sample farmers	199		196		197	

Figure 1: Distribution of technical efficiency of wheat farmers in Haryana