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TECHNICAL EFFICIENCY OF COTTON FARMERS IN THE VEHARI DISTRICT OF PUNJAB, PAKISTAN*

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Data on cotton farmers is analysed using a stochastic frontier production function model, in which technical inefficiency effects are assumed to be a function of other observable variables related to the farming operations. Although most cotton farmers have high technical efficiency of production in the Vehari district; there is a significant proportion of the sample farmers who have much lower levels of technical efficiency. Technical inefficiency of cotton production tends to decrease for farmers who first irrigated their crop and then performed rogging, but inefficiencies tends to increase with more interculture operations.

I. Introduction

Agriculture is the backbone of the Pakistan economy, because it contributes to the economic and social wellbeing of the whole nation, through its influence on the gross domestic product, employment and foreign exchange earnings. Cotton and wheat are the most important crops in the agricultural sector, as each contributes about 29 per cent of value-added in major crops in Pakistan. These proportions are about twice those for rice (16 per cent) and sugarcane (14 per cent), in terms of constant factor prices, using 1980-81 as the base period.

Ahmad and Battese (1997), discussed aspects of the importance of cotton in the Punjab, and in the national economy, as a whole. The latter study investigated the effects of various factors on the incidence of cotton leaf curl virus (CLCV) in the Punjab, using data from the sample farmers in the 1993-94 cropping year. Cot-

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ton production in the Punjab accounts for about 82 per cent of the cotton production in Pakistan. Hence, the reduced yields, which result from CLCV disease, have very serious consequences on provincial and national economies. At present, about 126 textile mills are closed and the textile industry has defaulted on loans of about 126 billion rupees [Anonymous, (1998)].

Yields of cotton crops vary with the variety that is grown by the farmers. However, the average yields have generally varied between 16 and 20 maunds[1] per acre. In 1994-95, the two frequently used varieties, MNH 93 and CIM 240, had an average yields of 19.61 and 17.68 maunds, respectively [ASSRC, (1996)]. The present yields of cotton are thus of great significance to the government and the agricultural specialists. Hence, the Agriculture Department of the Punjab initiated a modest survey in 1997 to estimate the average yields of cotton and the different varieties being used in a region in the Punjab, during the 1996-97 agricultural season. In the empirical analysis of this data, the paper presents an efficiency analysis of data on cotton farmers in Pakistan, involving the use of stochastic frontier production functions.

II. Stochastic Frontiers and Efficiency Measurement

The measurement of the efficiency of production has been an important area of research over the last two decades. Parikh and Shah (1996) presented a review of the various approaches to efficiency measurement and conducted empirical analyses of cross-sectional data from 397 sample farmers in the North-West Frontier Province of Pakistan. In their stochastic frontier analysis, a two-stage approach was used. In the first-stage analysis, a Cobb-Douglas stochastic frontier production function was estimated. The total value of agricultural output per acre was modelled in terms of five input variables, namely, cost of manure, cost of fertilisers, wages for human labour, cost of animal labour and tractor costs (all on a per acre basis).[2] The technical efficiencies of production were also estimated using the approach of Jondrow, et al. (1982). In the second-stage of the analysis of Parikh and Shah (1996), the estimated technical efficiencies were regressed on various farm- and farmer-specific variables, which were considered appropriate in explaining variations in technical efficiencies for the sample farmers.

The two-stage analysis of explaining levels of technical efficiency (or inefficiency) was criticised by Battese and Coelli (1995) as being contradictory, in the assumptions made in the separate stages of the analysis. In this paper, we follow

[1] The maund (equal to 37.324 kilograms) is the traditional measure of yield used by Pakistani farmers.

[2] This assumes that the production funetion, involving total value of production per farm, modelled in terms of input levels, including area of land, has constant returns to scale. In this case, the production function can be estimated with all variables expressed in per acre values.

the Battese and Coelli (1995) approach of modelling both the stochastic and the technical inefficiency effects in the frontier, in terms of observable variables, and estimating all parameters by the method of maximum likelihood, in a single-step analysis.[3]

III. Data and Variables

The Adaptive Research Section of the Agriculture Department of the Punjab designed a survey of cotton farmers in the Vehari district, which is one of the major producing districts in the cotton zone in the Punjab. The Vehari district comprises three tehsils (sub-districts), Vehari, Burewala and Melsi. The Vehari tehsil was chosen at random as the tehsil to be involved in the survey. Of the 219 villages in this tehsil, ten villages were selected by simple random sampling, from which samples of five cotton farmers were selected. The questionnaire for the survey was constructed to ask for details about the cotton operations on the farms. In particular, there was interest in cotton varieties grown, the yields obtained, and the use of inputs, such as fertiliser, seed, irrigation, pesticides, etc., during the Kharif season of the year. Information was also obtained on some basic personal characteristics of the sample farmers. Data on a total of 45 sample farmers were obtained in the survey. The output and input data were obtained on a per acre basis in the survey.[4]

A basic summary of the values of the key variables, which are defined in the econometric model in the next section, is given in Table 1 (the values are on per farm basis). The average yield of cotton per acre on a per farm basis was about 10.7 maunds. However, the average cotton production over the whole area, on which cotton was grown for the 45 farmers, was 13.88 maunds per acre.[5] This is somewhat less than the yields of cotton obtained in previous years. The difference may be due to the effect of the CLCV disease or of the fact that the sample did not represent the population of farms involved. Of the 45 cotton farmers in our sample data, about half grew more than one variety of cotton, during the 1996-97 agricultural year. Presumably these farmers wanted to diversify their cotton varieties in an effort to minimise the possible effects of the CLCV disease on their cotton crops.

The average area on which cotton was grown on the sample farms was 26 acres, but the size varied from a small farm of 1.5 acres to the very large one of 350

3 An introduction to stochastic frontier model for efficiency analysis [Coelli, Rao and Battese (1998), Chapter 8], is discussed in detail by Kumbhakar and Lovell (1999).

4 This is presumably considered to be the best way of ascertaining the data from the farmers, because the input variables are designed on a per acre basis. However, there is likely to be some measurement error in the yields reported, relative to the total production actually achieved on the farms.

5 This average is the total cotton production for the 45 farms divided by the total area under cotton. It is *not the same* as the arithmetic mean of the average yields per farm.

TABLE 1

Summary Statistics for the Sample Cotton Farmers in 1996-97

Variable	Sample Mean	Standard Deviation	Mini-mum	Maxi-mum
Cotton Yield (maunds/acre)	10.70	5.50	3.50	24.6
Area of Cotton (acres)	26.00	56.60	1.50	350.0
Proportion of Cotton Area	0.81	0.13	0.43	1.0
Seed Sown (kgs/acre)	7.60	1.30	5.00	10.0
Pesticide Cost (Rupees/acre)	1207.00	749.00	150.00	3465.0
Irrigations (number)	6.29	0.99	4.00	8.0
1st Irrigation (days from sowing)	36.50	4.00	30.00	45.0
Intercultures (number)	2.27	0.75	1.00	4.0
Rogging Dummy (yes=1, no=0)	0.36	0.48	0.00	1.0

Note: The values are on *per farm basis*. Thus, the average cotton production per acre is the average of per acre values over 45 farmers in the sample. A weighted average would be a better measure of yield per acre.

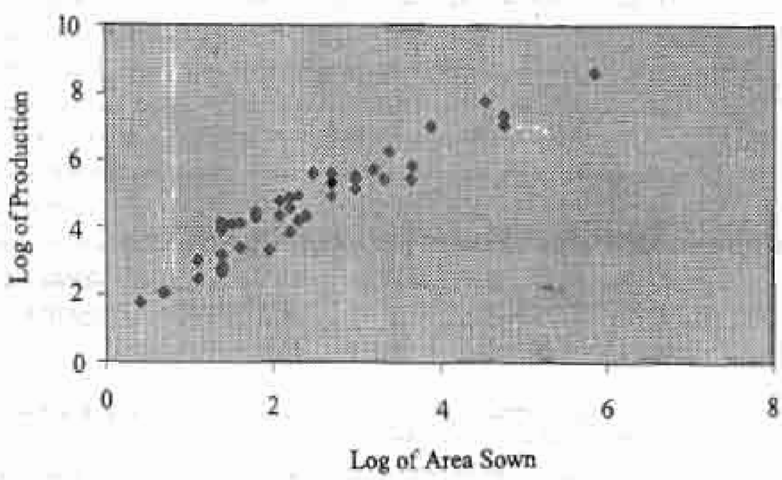

Figure 1

Cotton Production and Area Sown

acres. A graph of the logarithm of total cotton production against the logarithm of the area of cotton sown is presented in Figure 1. It is evident that the total cotton production is closely represented by a linear function in logarithms. This indicates that an empirical model for the total production of cotton on farms is likely to be approximated by a Cobb-Douglas production function involving area of cotton grown by the farmers.

The percentage of the area operated by the farmers, which was devoted to cotton in the Kharif season, varied from 43 to 100 per cent per farmer, with the average being 81 per cent. These statistics indicate that the sample farmers mainly grew cotton.

The application of seed per acre varied between 5 and 10 kgs for the 45 farmers. The cost of pesticides used in spraying the cotton crops varied considerably for the sample farmers, from 150 to about 3,500 rupees per acre per farmer, the average being about 1,200 rupees per acre. The number of times the farmers irrigated their cotton crops in the season varied between 4 and 8, the average being about 6. The irrigation input variable for the subsequent empirical analysis is obtained by multiplying the number of irrigations by the area under cotton. This assumes that the quantity of irrigation applied is effectively the same over all the acres irrigated.

Other input variables were also considered for possible inclusion in the empirical analysis. These variables included the amount of nitrogen used, amount or incidence of use of farmyard manure, the use of weedicides, the type of soil involved, and whether deep tillage was used in preparing the soil for the cotton crop. Although these are potentially useful variables, no significant effects were found whether deep tillage or farmyard manure were used or not (29 per cent used deep tillage and only 20 per cent used some farmyard manure). Further, about 24 per cent of the farmers used weedicides to control weeds in their cotton fields. The number of sprayings of pesticides varied considerably, between 1 and 8, such that the distribution was bimodal at 2 and 7 sprayings, with the median being 5 sprayings.

The variables, the number of days to the first irrigation, the number of intercultures conducted, and whether rogging was performed, are considered to be relevant in describing the inefficiency of production among the sample cotton farmers. The first irrigations of the cotton crops for the sample farmers occurred at 4 different number of days (namely 30, 35, 40 and 45) from sowing. The median and modal value of 35 was used by about half of the farmers, while about 30 per cent of farmers waited until 40 days. Thus, 80 per cent of the farmers irrigated 35 or 40 days after sowing their cotton crops.

All farmers conducted intercultures, which are operations for the purpose of removing weeds and making the soil more porous. Intercultures are also useful in reducing the lodging of the cotton plants, during the growing season. The number of intercultures varied between 1 and 4, such that the median and modal value was 2.

Only about 36 per cent of the sample farmers conducted rogging, which involves the removal of weak and diseased plants by human labour. This indicates that this practice was not widespread among the sample farmers.

Other variables which were considered to explain variation in the inefficiency of production of cotton farmers in the preliminary analysis, were proportion of the operated area sown to cotton, and the age and education levels of the farmers. The sample farmers had a wide range of age between 21 and 73 years; with the average being about 42 years. The average educational level of the farmers for formal schooling was 6.7 years. However, about 25 per cent of the farmers had no formal schooling, about 20 per cent had primary education and about 18 per cent had at least 12 years of formal education. This indicates a wide range of educational levels among the selected farmers.

IV. Frontier Model

The stochastic frontier Cobb-Douglas production function model, involving 4 inputs and 3 explanatory variables for the inefficiency effects in the stochastic frontier was considered. The Cobb-Douglas production function was found to be an adequate representation of the data, given the specifications of the corresponding translog frontier model. The stochastic frontier model is defined by:

$$\ln(Y_i) = \beta_0+\beta_1 \ln(X_{1i}) + \beta_2 \ln(X_{2i}) + \beta_3 \ln(X_{3i}) + \beta_4 \ln(X_{4i}) + V_i-U_i \qquad (1)$$

where ln represents the natural logarithm; the subscript, i denotes the i-th farmer in the sample, i=1, 2, ..., 45; Y represents the total cotton production (in maunds) for the farmer,[6] X_1 represents the total area of cotton (in acres); X_2 represents the total quantity of cotton seed (in kgs) sown; X_3 represents the total cost of pesticides (in Rupees) applied to the cotton;[7] X_4 represents the quantity of irrigation water applied to the cotton crop, which is defined as the number of irrigations times the area of cotton grown.[8] The β_ks, k = 0, 1, 2, 3, 4, are unknown parameters for the production function; the V_is are random errors associated with measurement errors in the production of cotton reported, or the combined effects of input variables not included in the production function, where the V_is are assumed to be independent

[6] The analysis was conducted on the total cotton production for the seven varieties, CIM240, CIM1100, CIM448, MNH93, Crishma, BH36 and FH634, for which data was coded. These varieties were the only ones grown, by almost all the sample farmers.

[7] The data set contained only the total value of pesticides used by farmers. This takes no account of the variation in the quality of pesticides sold in the market, which is a problem in Pakistan.

[8] If the number of irrigations were used as an explanatory variable, rather than the quantity of irrigation applied, the elasticity of land would be incorrectly estimated.

and identically distributed $N(0, \sigma^2_v)$ random variables; the U_is are non-negative random variables associated with technical inefficiency of production of the farmers, assumed to be independently distributed, such that the technical inefficiency effect for the i-th farmer U_i is obtained by truncation (at zero) of the normal distribution with mean, μ_i, and variance, σ^2, such that

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

where Z_1 denotes the number of days from sowing to the first irrigation; Z_2 denotes the number of intercultures performed during the growing season; Z_3 denotes the dummy variable for rogging, with value one if rogging was undertaken, and zero, otherwise; and the δs are unknown parameters to be estimated.

This stochastic frontier model is estimated using the computer program, FRONTIER 4.1, written by Coelli (1996).[9] The parameters of the frontier model are estimated, such that the variance parameters are:

$$\sigma^2_s = \sigma^2_v + \sigma^2 \tag{3}$$

and

$$\gamma = \sigma^2 / \sigma^2_s \tag{4}$$

where the γ-parameter has a value between zero and one.

Because of the relatively small number of sample observations, it was not possible to effectively estimate a model with a much larger number of parameters. Various other combinations of variables were investigated, but those defined above appeared to give more satisfactory results.

V. Empirical Results

The maximum-likelihood estimates of the parameters of the Cobb-Douglas model, defined by equations (1) and (2), are presented in Table 2.

The maximum-likelihood estimates of the coefficients of the 4 input variables and the 3 explanatory variables in the inefficiency model have values that exceed their corresponding estimated standard errors (hence the so-called "t-statistics" exceed one, in each case). The generalised likelihood-ratio test of the null hypothesis; that the coefficients of the explanatory variables in the inefficiency model, defined by equation (2), $H_0: \delta_1 = \delta_2 = \delta_3 = 0$; is equal to 4.514, which is significant at the 25 per cent level. Although this is a much larger level of significance than is generally

[9] FRONTIER 4.1 can be downloaded from the Internet by accessing the homepage for the Centre for Efficiency and Productivity Analysis at the University of New England, Armidale, NSW, Australia. http://www.une.edu.au/econometrics/cepa.htm.

used, there is some evidence that preliminary tests of significance should be conducted at a much higher level [e.g., Bancroft, (1968)]. Hence, we do not conclude that the explanatory variables for the technical inefficiency effects have zero coefficients for the production of cotton by the farmers involved. Obviously, the small number of sample farmers implies that the precision of estimation of the parameters of the stochastic frontier model is quite poor.

The coefficients of the input variables in the production function are elasticities of mean production with respect to the different inputs for the Cobb-Douglas model, defined by equations (1) and (2). The empirical results in Table 2 imply that the elasticity of *frontier* (best practice) production with respect to land under cotton is estimated to be 0.42. This indicates that, if the area under cotton is increased by one per cent, then the total production of cotton is estimated to increase by 0.42 per

TABLE 2

Maximum-likelihood Estimates for the Parameters of the Cobb-Douglas Stochastic Frontier Production Function Model for Cotton Farmers

Variable	Coefficient Estimate		Standard Error	
Production Frontier				
Constant	–0.980	(–0.73)	0.810	(0.93)
Area of Cotton	0.420	(0.53)	0.420	(na)
Seed Sown	–0.650	(–0.67)	0.260	(0.29)
Pesticide Cost	0.504	(0.448)	0.098	(0.086)
Irrigation	0.680	(0.70)	0.330	(0.40)
Inefficiency Model				
Constant	0.400	(0.70)	0.670	(0.77)
Days to First Irrigation	–0.021	(–0.028)	0.020	(0.025)
Number of Intercultures	0.190	(0.15)	0.120	(0.12)
Dummy for Rogging	–0.510	(–0.40)	0.290	(0.19)
Variance Parameters				
$\sigma_s^2 = \sigma_v^2 + \sigma^2$	0.066	(0.068)	0.022	(0.018)
$\gamma = \sigma^2 / \sigma_s^2$	0.090	(0.06)	0.260	(0.23)
Log (Likelihood)	–1.992	(–2.622)		

Note: The estimates in brackets are estimates assuming the model has constant returns to scale.

cent. This value is obtained by using a particular production function, which involves only 3 other variables: seed, pesticide cost and irrigation.

The elasticity of the cost of pesticides is estimated to be about 0.50, which is the second largest elasticity after that for irrigation (0.68). The higher elasticity for cost of pesticides may be associated with the fact that the more costly pesticides are likely to be of better quality. It is common knowledge that the generic sprays, generally available to farmers, tend to be the less effective ones.

The negative elasticity estimate for seed implies a reduction in cotton production with an increased quantity of seed sown for the sample of farmers. This indicates that farmers sowed too much seed, which resulted in overcrowding of the plants and a more conducive environment for weeds and insects to flourish, which in turn resulted in less effective spraying for insects. It is likely that the cotton plants obtained with overcrowding, due to increased seeding rates, were taller plants with little or no boll formation on the lower part of the plants, which led to less cotton production. It therefore appears that, in general, the cotton farmers need to reduce the quantity of seeds presently being sown.

The negative coefficient of the inefficiency variable, *days to first irrigation*, indicates that the greater the number of days from sowing to the first irrigation, the smaller the technical inefficiencies for the cotton farmers. Presumably, this indicates that the later irrigation permitted the plants to be better established. However, increasing the number of intercultures on the cotton crop increased the level of the technical inefficiency of production. Finally, the negative estimate for the coefficient of the dummy variable for rogging indicates that the cotton farmers, who performed rogging, were more technically efficient than farmers who did not.

The estimate for the variance parameter, γ, associated with the variance of the inefficiency effects was only 0.09, which does not appear to be significantly greater than zero, given the estimated standard error of 0.26. Given the assumptions of the translog model, which corresponds to the Cobb-Douglas model of equations [(1) and (2)], the likelihood-ratio statistic for testing the null hypothesis of no technical inefficiency effects, was equal to 7.11. This exceeds the critical value, 6.03, for the 25 per cent level of significance, obtained from Table 1 [Kodde and Palm (1986)], for 5 degrees of freedom. Therefore we reject the null hypothesis of no technical inefficiency effects in the stochastic frontier.[10]

The returns-to-scale parameter for the Cobb-Douglas production frontier estimated by the sum of the elasticities of the four input variables is 0.956. By imposing constant returns to scale in the model, estimates for the elasticities for seed, pesticide cost and irrigation are obtained by estimating the stochastic frontier model, in

[10] The smaller value of 4.51 for the likelihood-ratio statistic, obtained using the Cobb-Douglas model, is due to the extra variation in the random errors, resulting from deleting the second-order variables in the translog model to obtain the Cobb-Douglas model.

which yield per acre is expressed in terms of seed per acre, pesticide cost per acre and number of irrigations. The parameters of this model are presented in parenthesis next to the corresponding estimates for the traditional Cobb-Douglas model (Table 2). The estimates obtained differ slightly from those for the non-constant-returns-to-scale model, [equation (1)]. The generalised likelihood-ratio statistic for testing constant returns to scale is calculated to be 1.260. This is not significantly different from zero, and indicates that the null hypothesis of constant returns to scale could not be rejected for cotton farming in the Vehari district.

The predicted technical efficiencies of the cotton farmers in the sample, obtained by using the Cobb-Douglas model, are given in Table A1 (Appendix). These values range from 0.699 to 0.991, with the mean technical efficiency estimated to be 0.93. This implies that, on an average, the cotton farmers in the Vehari district were producing cotton at about 93 per cent of the potential (stochastic) frontier production levels, given the levels of their inputs and the technology currently being used.

There were 60 per cent of the sample farmers who had technical efficiencies greater than 0.95. There was about 25 per cent of the farmers with technical efficiencies less than 0.9. A relative frequency distribution of the predicted technical efficiencies of the 45 cotton farmers is presented in Figure 2 for the technical efficiencies in ranges of width 0.025. This figure indicates that, although there were very high relative frequencies of the technical efficiencies above 0.95, there were also some farmers who were quite poor in their technical efficiency performance.

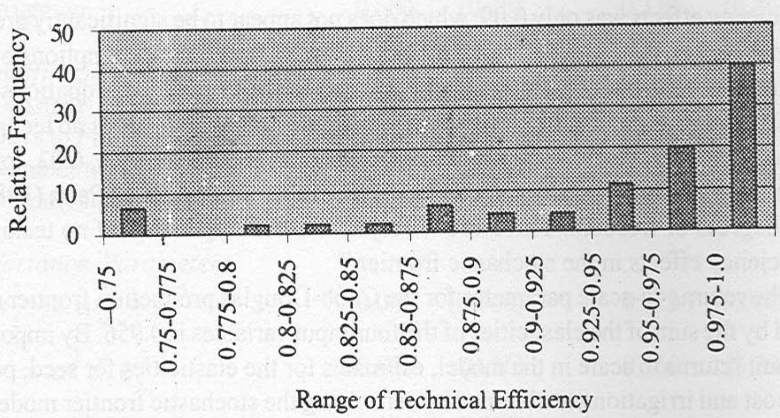

Figure 2

Relative Frequency Distribution of Technical Efficiencies of Cotton Farmers

VI. Conclusions

The empirical results obtained from the cotton farmers in the survey indicates that the elasticities of mean cotton production (for the best practice production) were highest for irrigation (0.68), followed by pesticides (0.50) and area of land (0.42). However, the elasticity for seed was negative, which indicates that less seed should be sown on a per acre basis. The decrease in sowing rate is presumably a better option than extensive thinning of plants.

Irrigation has a positive effect on cotton yields, especially when the flowers appear and fruiting of the bolls takes place. However, the timeliness of the irrigation is also important for efficiency of the production of cotton. The estimates for the inefficiency model indicate that delaying the first irrigation is associated with higher technical efficiency of cotton production, which may be due to development of the root system, when the cotton crops is under some moisture stress. It is expected that the later irrigated crops are more vigorous and perform better when infested with pests and diseases. Early irrigation frequently implies that local weeds, such as 'Eit sit', grow more and inhibit the growth of cotton crops.

The increase in number of intercultures reduces the technical efficiency of production. This is associated with greater disturbance to growth of the cotton plants and the dropping off the flowers and bolls. Intercultures should, therefore, be substituted with the use of weedicides to control weeds.

The practice of rogging of the cotton crops results in a decrease in the technical inefficiency of cotton production. The removal of weak and diseased plants also implies less likelihood of attack of the CLCV disease.

The technical efficiency of the cotton farmers is less than 0.9 for about 25 per cent of the sample farmers. Since the situation in the cotton crops is serious at the moment, all means of increasing productivity and efficiency of production should be encouraged.

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APPENDIX

TABLE A-1

Technical Efficiencies of Sample Cotton Farmers Obtained Using the Cobb-Douglas Stochastic Frontier Production Function Model

Farmer Number	Technical Efficiency	Farmer Number	Technical Efficiency	Farmer Number	Technical Efficiency
1	0.909	16	0.973	31	0.988
2	0.981	17	0.894	32	0.981
3	0.946	18	0.979	33	0.985
4	0.927	19	0.873	34	0.699
5	0.981	20	0.798	35	0.980
6	0.709	21	0.957	36	0.989
7	0.926	22	0.988	37	0.871
8	0.973	23	0.975	38	0.958
9	0.971	24	0.991	39	0.972
10	0.828	25	0.987	40	0.983
11	0.802	26	0.924	41	0.980
12	0.970	27	0.937	42	0.950
13	0.982	28	0.984	43	0.970
14	0.986	29	0.925	44	0.733
15	0.985	30	0.860	45	0.876

Mean Technical Efficiency is estimated to be 0.93.