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Environmental Efficiency Analysis of Basmati Rice Production in Punjab, Pakistan: Implications for Sustainable Agricultural Development

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The intensive use of chemicals worked as a catalyst to shift the production frontier but the most critical factor of maintaining a clean environment was totally ignored. The present study attempts to estimate the environmental efficiency of rice production by employing the translog stochastic production frontier approach. The data are collected from five major Basmati rice growing districts (Gujranwala, Sheikupura, Sialkot, Hafizabad, and Jhang) of Punjab in 2006. Chemical weedicides and nitrogen are treated as environmentally detrimental inputs. The mean technical efficiency index is sufficiently high (89 percent) but the environmental efficiency index of chemical weedicides alone is 14 percent while the joint environmental efficiency index of chemical weedicides and nitrogen is 24 percent implying that joint environmental efficiency is higher than chemical weedicide alone. It indicates that substantial reduction (86 percent) in chemical weedicide use is possible with higher level of productivity. Moreover, it is likely to contribute a considerable decrease in environmental pollution which is expected to enhance the performance of agriculture labour. The reduction in chemical weedicides will save Rs 297 per acre and Rs 1307.3 million over all from the rice crop in Punjab, improving the profitability of rice growing farmers by the same proportion. Empirical analysis indicates that reduction in environmental pollution together with higher level of profitability in rice production is achievable.

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1. INTRODUCTION

Rice is one of the most important food crops that augment and earn foreign exchange for the national economy.. It contributes more than two million tonnes to our food requirements and is a major source of employment and income generation in the rice growing areas of the farm land. Rice is the third largest crop in terms of area sown, after wheat and cotton. It was cultivated on over 2.9 million hectares in 2008. Accounting for 5.9 percent of the total value added in agriculture and about 1.3 percent to GDP [Pakistan (2009a)] its importance in the national economy is obvious. Pakistan has two major rice-

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producing provinces, Punjab and Sindh. Both provinces account for more than 88 percent of total rice production. Punjab, due to its agro-climatic and soil conditions has assumed the position of a major centre of Basmati rice production, accounting for nearly all the Basmati rice the country produces.

It is well documented that the use of fertiliser and pesticides (insecticides, weedicides and herbicides) in agriculture has increased manifolds since the introduction of the so-called green revolution. The intensive use of inputs has worked as a catalyst to shift the production frontier of almost all grain crops to feed the growing population but the most critical factor of maintaining a clean environment has been totally ignored. Pesticides play an important role in raising agricultural yields in developing countries. They offer the most attractive low cost method of increasing output per hectare of land and give the farmer a high economic return for his labour and investment. The use of pesticides has considerably increased in developing countries however its advantages seem to have not been fully exploited [Nguyen, *et al.* (2003)]. It is observed that the quantity of agrochemicals used in the agricultural system of Pakistan has increased more than four times just in seventeen years i.e., from 1990 to 2007. The total quantity of agrochemicals consumed increased from 20213 tonnes in 1990 to 94265 tonnes in 2007 and in value terms, the consumption increased from 5536 million Rupees to 10534 million Rupees for the same period [Pakistan (2009b)]. The negative impact of these agrochemicals on human productivity, environment and ground water quality has been neglected in the past, posing a grave threat to the sustainability of agriculture production system.

The increasing awareness about the role clean environment plays in human productivity has intensified the demand to eliminate or minimise the negative externalities of different production systems. Like any other production system, agriculture also generates positive and negative externalities. The challenge for scientists is to minimise or eliminate the negative externalities to sustain the clean environment for future generations while increasing the productivity level through modern technologies or reducing environmental pollution by sustaining productivity levels with the given set of technologies. Fertiliser, pesticides, weedicides and herbicides are the major inputs that cause environmental and ground water pollution in agriculture sector. These inputs could be re-allocated in a way that environmental pollution was significantly reduced by keeping output levels within a given framework of production technologies and available resources.

A significant body of literature exists dealing with the technical and allocative efficiency in different crops and in different regions [Good, *et al.* (1993); Ahmed and Bravo-Ureta (1996); Wilson, *et al.* (1998); Wadud (1999); Wang and Schmidt (2002); Larson and Plessman (2002); Villano (2005); Abedullah, *et al.* (2007)] but little work has been done to estimate the environmental efficiency of agro-chemicals (weedicide, pesticide, herbicide and fertiliser) in agricultural production system [Reinhard, *et al.* (1999); Zhang and Di-Xue (2005) and Wu (2007)] which is expected to play an important role in the reduction of environmental pollution. According to our knowledge there is no study in respect of Pakistan that deals with environmental efficiency. The present study hopefully would fill this gap. The objective of the present study is to estimate the environmental efficiency of chemical weedicides and fertiliser in rice production by employing a stochastic production frontier approach.

The scheme of the paper is as follows. The next section presents the conceptual framework and delineates the empirical model with variable specification to explain the estimation procedure of technical and environmental efficiency. This section also explains the selection of sample and the data collection procedure. Empirical results are presented and implications are derived in the subsequent section. Section 4 discusses the limitation of data. The summary and conclusion is presented in the last section.

2. METHODOLOGY AND DATA COLLECTION PROCEDURE

The methodology is defined in two steps: conceptual framework and empirical model. The conceptual framework discusses general procedure adopted to estimate the technical and environmental efficiency while the empirical model explains the details of production function specification and mathematical manipulation employed to estimate environmental efficiency. The last part of this section explains the data collection procedure used for empirical analysis.

2.1. Conceptual Framework

There are two main approaches (with a number of sub-options under each) to measure technical efficiency (TE). These include, stochastic frontier (parametric approach) and data envelop analysis (DEA), also named as non-parametric approach. These two methods have a range of strengths and weaknesses which may influence the choice of methods, in particular with regard to application and constraints. The advantages and disadvantages of each approach have been discussed by Coelli (1996), Coelli and Perelman (1999). The present study is employing a stochastic frontier production approach introduced by Aigner, *et al.* (1977); and Meeusen and van den Broeck (1977), later on followed by a number of studies. Following their specification, the stochastic production frontier can be written as,

$$y_i = F(x_i, \beta)e^{\varepsilon_i} \qquad i = 1,2,\ldots\ldots\ldots\ldots N \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where, y_i is output for the i-th farm, x_i is a vector of k inputs, β is a vector of k unknown parameters, ε_i is an error term. The stochastic frontier is also called "composed error" model, because it postulates that the error term ε_i is decomposed into two components: a stochastic random error component and a technical inefficiency component as follow,

$$\varepsilon_i = v_i - u_i \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where, v_i is a symmetrical two sided normally distributed random error that captures the stochastic effects beyond the farmer's control (e.g., adverse weather, natural disasters and what the farmer might call 'his luck')., measurement errors, and other statistical noise. It is assumed to be independently and identically distributed $N(0, \sigma_v^2)$. Thus, v_i allows the frontier to vary across farms, or over time for the same farm, and therefore the frontier is stochastic. The term u_i is one sided ($u_i \geq 0$) efficiency component that captures the technical efficiency of the i-th farmer. The variance parameters of the model are parameterised as:

$$\sigma_s^2 = \sigma_v^2 + \sigma_u^2; \gamma = \frac{\sigma_u^2}{\sigma_s^2} \text{ and } 0 \leq \gamma \leq 1 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

The parameter γ must lie between 0 and 1. The maximum likelihood estimation of Equation (1) provides consistent estimators for β, γ, and σ_s^2 parameters. Hence, Equation (1) and (2) provide estimates for v_i and u_i after replacing ε_i, σ_s^2 and γ by their estimates. Multiplying by e^{-vi} both sides of Equation (1) and replacing β's with maximum likelihood estimates, yields stochastic production frontier as:

$$y_i^{\bullet} = F(x_i, \beta^{\otimes})e^{-u_i} = y_i e^{-v_i} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

where, $y_i^{\bullet}$ is the observed output of the i-th farm adjusted for the statistical random noise captured by v_i [Bravo-Ureta and Rieger (1991)]. All other variables are as explained earlier and $\overset{\otimes}{\beta}$ is the vector of parameters estimated by the maximum likelihood estimation technique. The technical efficiency (TE) relative to the stochastic production frontier is captured by the one-sided error components $u_i \geq 0$, i.e.

$$TE = e^{-u_i} = \left[\frac{y_i}{F(x_i, \beta^{\otimes})e^{v_i}}\right] \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

The technical efficiency index in Equation (5) can be defined as the ratio of the observed to maximum feasible output which is estimated by employing the traditional stochastic production frontier approach while according to Reinhard, *et al.* (2000, 2002) the environmental efficiency index can be defined as the ratio of minimum feasible to the observed use of an environmentally detrimental input, given technology and the observed levels of output and conventional inputs.

Pittman (1983) was the first to consider environmental effects as undesirable outputs while estimating the Törnqvist index of productivity change. However, undesirable outputs cannot be priced in the markets because markets do not exist for such products; hence the modeling of undesirable products is feasible only if the undesirable outputs can be valued by their shadow prices. The author used econometric techniques to estimate shadow prices of demand for biochemical oxygen generated in the process of converting wood pulp to paper for thirty Michigan and Wisconsin mills, but it is observed that shadow prices are constant across all the observation. Following Pittman (1983), Fare, *et al.* (1989) and Fare, *et al.* (1993) also modeled environmental effects as undesirable outputs. All these studies include environmental effects in the output vector, and then to obtain inclusive measures of technical efficiency, and occasionally, productivity change, incorporate the generation of one or more environmental effects as by-products of production process [Reinhard, *et al.* (1999)]. However, Pittman (1981) is the first who modeled pollution as an input in the production function and later his approach is refined and modified by Haynes, *et al.* (1993), Haynes, *et al.* (1994), Hetemäki (1996), Boggs (1997) and Reinhard, *et al.* (1999). These seminal works have considered environmental effects as a conventional input rather than as an undesirable output which distinguished their study from the earlier literature. Recently this approach has been adopted by Reinhard, *et al.* (2002), Zhang and Xue (2005) and Wu (2007). Following the later group of studies we also incorporated environmental effects (weedicide and fertiliser) as a conventional input in the production process. Different studies have used different variables as environmental determinant according to their objectives and availability of data. We consider weedicides and fertiliser as environmentally detrimental in rice production however since pesticides are being used only by a small number of farmers (less than 15 percent) and on an average its impact on the production process is not expected to be significant. Following Reinhard, *et al.* (1999) we estimated technical and environmental efficiency separately.

The mathematical representation of environmental efficiency can be written as:

$$EE = \min \{\Phi : F(X, \Phi Z) \geq Y\} \leq 1 \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

where, $F(X, \Phi Z)$ is the new production frontier and $(X, Z) \in R_{+}$ (a set of positive real numbers) while X and Z are, respectively a vector of conventional and environmentally detrimental input and $Y \in R_{+}$ is yield estimated by employing maximum likelihood estimation technique as defined earlier in Equation 1. To obtain the environmental efficiency index, a new frontier production function as defined in Equation 6 could be developed by replacing the observed environmentally detrimental input vector Z with ΦZ and setting $u_i = 0$, representing a function at full technical efficiency. The environmental efficiency is explained by employing the definition of Reinhard, *et al.* (2000); Reinhard *et al.* (2002) as EE = $\Phi Z/Z$ and then by taking natural logarithm on both sides of the equation, it can be written with more detail as below:[1]

$$\text{Ln EE} = \text{Ln } \Phi Z - \text{Ln} Z = \text{Ln}(\Phi Z/Z) = \text{Ln}\Phi \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

Where, "LnEE" is the logarithm of environmental efficiency and it is equal to the logarithm of new frontier function with $u_i = 0$ minus the original frontier function when $u_i \neq 0$.

2.2. Empirical Model

There is only one output in our case and therefore, as discussed by Wu (2007) we estimate a stochastic production frontier rather than a stochastic distance function to relate the environmental performance of individual farms to the best of environment-friendly farming. To minimise the misspecification of model we have used a stochastic translog production frontier and under the assumption of one environmentally detrimental variable X_7 (which is represented by Z due to environmentally detrimental variable), the translog production frontier is defined as below:

$$\begin{aligned} LnY = {} & \beta_0 + \beta_1 Ln X_1 + \beta_2 Ln X_2 + \beta_3 Ln X_3 + \beta_4 Ln X_4 + \beta_5 Ln X_5 + \beta_6 Ln X_6 + \\ & \beta_7 Ln Z + 0.5\beta_{11} Ln^2 X_1 + 0.5\beta_{22} Ln^2 X_2 + 0.5\beta_{33} Ln^2 X_3 + 0.5\beta_{44} Ln^2 X_4 + \\ & 0.5\beta_{55} Ln^2 X_5 + 0.5\beta_{66} Ln^2 X_6 + 0.5\beta_{77} Ln^2 Z + \beta_{12} Ln X_1 Ln X_2 + \\ & \beta_{13} Ln X_1 Ln X_3 + \beta_{14} Ln X_1 Ln X_4 + \beta_{15} Ln X_1 Ln X_5 + \beta_{16} Ln X_1 Ln X_6 + \\ & \beta_{17} Ln X_1 Ln Z + \beta_{23} Ln X_2 Ln X_3 + \beta_{24} Ln X_2 Ln X_4 + \beta_{25} Ln X_2 Ln X_5 + \\ & \beta_{26} Ln X_2 Ln X_6 + \beta_{27} Ln X_2 Ln Z + \beta_{34} Ln X_3 Ln X_4 + \beta_{35} Ln X_3 Ln X_5 \\ & \beta_{36} Ln X_3 Ln X_6 + \beta_{37} Ln X_3 Ln Z + \beta_{45} Ln X_4 Ln X_5 + \beta_{46} Ln X_4 Ln X_6 + \\ & \beta_{47} Ln X_4 Ln Z + \beta_{56} Ln X_5 Ln X_6 + \beta_{57} Ln X_5 Ln Z + \beta_{67} Ln X_6 Ln Z + (\nu - u) \qquad \ldots \quad (8) \end{aligned}$$

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[1] According to Reinhard, *et al.* (2002) and Reinhard, *et al.* (2000) the environmental efficiency is the ratio of minimum feasibility to an observed input which is environmentally detrimental.

Where Ln represents the natural logarithm, Y is the yield in maunds per acre, X_1 is tractor hours used for land preparation, X_2 is amount of seed in kg, X_3 is the number of irrigations, X_4 is the amount of labour in hours per acre, X_5 is per acre active nutrient of Phosphorus and Potash (PK) in kg, X_6 is per acre active nutrients of nitrogen (N) in kg, and Z is the cost of chemical weedicide in Rupees per acre and it is also considered as the environmentally detrimental variable. The Equation (8) can be estimated by employing Frontier Version 4.1 developed by Coelli (1994). The new stochastic frontier function as discussed above in empirical framework can be obtained by replacing Z with ΦZ in Equation (8) in such a way that technical inefficiency of each farmer approaches to zero (i.e., u_i =0) that exists in the original frontier function (Equation 8). It should be noted that Φ is environmental efficiency index. Hence, the new translog function can be written as,

$$\begin{aligned} LnY = \; & \beta_0+\beta_1 LnX_1+\beta_2 LnX_2+\beta_3 LnX_3+\beta_4 LnX_4+\beta_5 LnX_5+\beta_6 LnX_6+ \\ & \beta_7 Ln\Phi Z+0.5\beta_{11} Ln^2 X_1+0.5\beta_{22} Ln^2 X_2+0.5\beta_{33} Ln^2 X_3+0.5\beta_{44} Ln^2 X_4+ \\ & 0.5\beta_{55} Ln^2 X_5+0.5\beta_{66} Ln^2 X_6+0.5\beta_{77} Ln^2 \Phi Z+\beta_{12} LnX_1 LnX_2+ \\ & \beta_{13} LnX_1 LnX_3+\beta_{14} LnX_1 LnX_4+\beta_{15} LnX_1 LnX_5+\beta_{16} LnX_1 LnX_6+ \\ & \beta_{17} LnX_1 Ln\Phi Z+\beta_{23} LnX_2 LnX_3+\beta_{24} LnX_2 LnX_4+\beta_{25} LnX_2 LnX_5+ \\ & \beta_{26} LnX_2 LnX_6+\beta_{27} LnX_2 Ln\Phi Z+\beta_{34} LnX_3 LnX_4+\beta_{35} LnX_3 LnX_5 \\ & \beta_{36} LnX_3 LnX_6+\beta_{37} LnX_3 Ln\Phi Z+\beta_{45} LnX_4 LnX_5+\beta_{46} LnX_4 LnX_6+ \\ & \beta_{47} LnX_4 Ln\Phi Z+\beta_{56} LnX_5 LnX_6+\beta_{57} LnX_5 Ln\Phi Z+\beta_{67} LnX_6 Ln\Phi Z+v \qquad \cdots \qquad \cdots \qquad (9) \end{aligned}$$

By subtracting Equation (8) from Equation (9) and with little mathematical manipulation the result can be written as:

$$\begin{aligned} & 0.5\beta_{77}\left[Ln\Phi Z-LnZ\right]^2+\left[\beta_7+\beta_{17} LnX_1+\beta_{27} LnX_2+\beta_{37} LnX_3+\beta_{47} LnX_4\right. \\ & \left.+\beta_{57} LnX_5+\beta_{67} LnX_6+\beta_{77} LnZ\right]\left[Ln\Phi Z-LnZ\right]+u=0 \qquad \cdots \qquad \cdots \qquad \cdots \qquad (10) \end{aligned}$$

By employing the result of Equation (7) in Equation (10) it can be modified as follow:

$$0.5\beta_{55}[LnEE]^2+\left[\beta_7+\beta_{17} LnX_1+\beta_{27} LnX_2+\beta_{37} LnX_3+\beta_{47} LnX_4+\beta_{57} LnX_5\; \beta_{67} LnX_6+\beta_{77} LnZ\right][LnEE]+u \qquad \cdots \qquad (11)$$

Now Equation (11) can be solved for LnEE by using the quadratic equation formula as below:[2]

$$\begin{aligned} LnEE= & \left[-\left(\beta_7+\beta_{17} LnX_1+\beta_{27} LnX_2+\beta_{37} LnX_3+\beta_{47} LnX_4+\beta_{57} LnX_5+\right.\right. \\ & \left.\beta_{67} LnX_6+\beta_{77} LnZ\right)+\left\{\left(\beta_7+\beta_{17} LnX_1+\beta_{27} LnX_2+\beta_{37} LnX_3+\beta_{47} LnX_4+\right.\right. \\ & \left.\left.\left.\beta_{57} LnX_5+\beta_{67} LnX_6+\beta_{77} LnZ\right)^2-2\beta_{77} U_i\right\}^{0.5}\right] \Big/ \beta_{77} \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad (12) \end{aligned}$$

The environmental efficiency "EE" from Equation (12) can be estimated just by taking the exponent of this equation i.e.

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[2] In the quadratic formula there are both positive and negative (±) outside the under- root term but we took only positive because $u_i = 0$ only if we will consider the positive sign outside the under-root term.

$$EE = \exp(LnEE) = \Phi = \left(\Phi Z \big/ Z\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

It should be noted that Φ is the environmental efficiency index as discussed earlier. In case of two environmentally detrimental variables (active nutrients of nitrogen and cost of chemical weedicide) the description for "LnEE" as described in Equation (12) is changed as follow:

$$\begin{aligned} LnEE = \Big[& -\big(\beta_6 + \beta_7 + \beta_{16} Ln X_1 + \beta_{26} Ln X_2 + \beta_{36} Ln X_3 + \beta_{46} Ln X_4 + \beta_{56} Ln X_5 + \\ & \beta_{66} Ln X_6 + \beta_{17} Ln X_1 + \beta_{27} Ln X_2 + \beta_{37} Ln X_3 + \beta_{47} Ln X_4 + \beta_{57} Ln X_5 + \\ & \beta_{77} Ln X_7 + \beta_{67} Ln X_6 + \beta_{67} Ln X_7\big) + \Big\{\big(\beta_6 + \beta_7 + \beta_{16} Ln X_1 + \beta_{26} Ln X_2 + \\ & \beta_{36} Ln X_3 + \beta_{46} Ln X_4 + \beta_{56} Ln X_5 + \beta_{66} Ln X_6 + \beta_{17} Ln X_1 + \beta_{27} Ln X_2 + \\ & \beta_{37} Ln X_3 + \beta_{47} Ln X_4 + \beta_{57} Ln X_5 + \beta_{77} Ln X_7 + \beta_{67} Ln X_6 + \beta_{67} Ln X_7\big)^2 - \\ & 4\left(0.5\beta_{66} + 0.5\beta_{77} + \beta_{67}\right) u_i\Big\}^{0.5}\Big] \Big/ \left(\beta_{66} + \beta_{77} + 2\beta_{67}\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (14) \end{aligned}$$

In case of translog production function the elasticities are not the coefficient of production function as in case of Cobb-Douglas. However, the elasticity of output with respect to different inputs in case of translog production function can be estimated by taking derivative of Equation (8) with respect to logarithm of any specific input as shown below:

$$\begin{aligned} \frac{\partial Ln Y}{\partial Ln X_1} = \frac{\partial Y}{\partial X_1} * \frac{X_1}{Y} = & \beta_1 + \beta_{11} Ln X_1 + \beta_{12} Ln X_2 + \beta_{13} Ln X_3 + \beta_{14} Ln X_4 + \beta_{15} Ln X_5 \\ & \beta_{16} Ln X_6 + \beta_{17} Ln X_7 \end{aligned}$$

It should be noted that X_7 has been represented by Z in Equation 8 and the above equation can be written in more general form as follow:

$$\frac{\partial Ln Y}{\partial Ln X_j} = \frac{\partial Y}{\partial X_j} * \frac{X_j}{Y} = S_j = \beta_j + \sum_{i=1}^{7} \beta_{ji} Ln X_i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (15)$$

where, "i" stands for the number of explanatory variables. The cross elasticity of substitution for input factor "j" and "k" can be written by following the formula developed by Ferguson (1969) as follow:

$$H_{jk} = \left[\beta_{jk} \big/ \left(S_j + S_k\right)\right] + 1 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (16)$$

A positive elasticity of substitution implies that two input factors "j" and "k" are complementary while a negative elasticity of substitution indicates a competitive relationship between two inputs.

2.3. Data Collection Procedure

Analysis is carried out by using primary data on input-output quantities and prices from 500 farm households' belongings to five major basmati rice growing districts in terms of production—"Gujranwala, Sheikupura, Sialkot, Hafizabad, and Jhang" of

Punjab Province [Pakistan (2005)]. From each of these districts 100 farmers are selected by choosing 25 from each tehsil. Four teshils from each district (because most of the districts in our sample have four or less than four tehsils) and 2 villages from each teshil are randomly selected. From the first village in each teshil 12 farmers and from the second village 13 farmers are randomly selected, in order to make 25 from each teshil. The number of villages in each tehsil increased accordingly where districts have less than four tehsils in order to maintain the sample of 100 farmers from each district. A well structured and field pre-tested comprehensive interviewing schedule is used for the collection of detailed information on various aspects of rice farmers in 2006. The mean value of inputs and output are reported in Table 1. Only fifteen percent farmers in our sample are using pesticides and that is why it is not reported in the table and neither it is considered as an environmentally detrimental variable.

Table1

Summary Statistics of the Sample

Variables	Mean	Median	Maximum	Minimum	Std. Dev
Yield (Mounds/Acre)	35.0	35	55.0	18.0	5.7
Tractor (Hours)	3.8	3.5	12.3	0.5	1.7
Seed (Kg)	5.0	4.0	6.0	2.5	0.8
No. of Irrigations	8.0	10.0	16.0	5.0	3.2
Labour (Hours)	180.0	175.0	220.0	142.0	36.3
Nutrients of PK (Kg)	22.5	23.0	57.5	0.0	9.4
Nutrients of N (Kg)	34.5	32.0	70.5	0.0	9.8
Weedicide Cost (Rs)	345.1	275.0	400.0	40.0	33.7

3. RESULTS AND DISCUSSIONS

The results of Maximum Likelihood Estimates (MLE) for translog production function are reported in Table 2 which can be used to test the null hypothesis that no technical inefficiency exists in rice production. It should be noted that the values of log-likelihood function for the stochastic frontier model and the OLS fit are calculated to be 237.40 and 229.22, respectively and reported in Table 2. This implies that the generalised likelihood-ratio statistic for testing the absence of technical inefficiency effect from the frontier is calculated to be LR = –2*(229.22–237.40) = 16.36 which is estimated by the Frontier 4.1 and reported as the "LR" test of the one sided error. The value of likelihood-ratio "16.36" exceeds the critical value of "10.371" obtained from Table 1 of Kodde and Palm (1986) for the degree of freedom equal to 5 at five percent level of significance. It should be noted that degree of freedom is equal to the number of restriction in null hypothesis. The log likelihood ratio test indicates that technical inefficiency exists in the data set and therefore, null hypothesis of no technical inefficiency in rice production is rejected.

Table 2

Coefficients of Translog Production Function with Maximum Likelihood Estimation (MLE) Technique

Parameters	Coefficients	t-ratio	Parameters	Coefficients	t-ratio
B_0	–0.63	–0.39	B_{17}	0.01	0.39
B_1	–0.35	–1.24	B_{23}	0.41	2.43
B_2	–1.49	–1.40	B_{24}	–0.05	–0.37
B_3	0.85	1.64	B_{25}	–0.01	–0.43
B_4	1.03	3.18	B_{26}	–0.06	–0.90
B_5	0.18	1.08	B_{27}	0.04	0.43
B_6	0.09	0.65	B_{34}	0.04	0.29
B_7	0.32	1.14	B_{35}	0.00	–0.06
B_{11}	–0.12	–2.42	B_{36}	–0.03	–0.55
B_{22}	0.37	0.53	B_{37}	–0.08	–0.80
B_{33}	–0.42	–1.69	B_{45}	–0.02	–0.75
B_{44}	–0.10	–0.76	B_{46}	–0.05	–1.04
B_{55}	0.02	2.29	B_{47}	–0.04	–0.54
B_{66}	0.00	–0.34	B_{56}	0.00	0.82
B_{77}	–0.01	–0.42	B_{57}	–0.01	–0.97
B_{12}	–0.03	–0.42	B_{67}	0.05	1.16
B_{13}	0.08	1.05	sigma-squared	0.07	1.72
B_{14}	0.02	0.37	gamma	0.81	7.41
B_{15}	–0.01	–0.63	Log Likelihood	237.4	
B_{16}	0.01	0.48			

The parameters of translog stochastic frontier production are reported in Table 2. These results of production function are employed to estimate the elasticities of output with respect to different inputs as explained in Equation 14 and summary statistic of these output elasticities are reported in Table 3. The output elasticities of tractor hours (used in land preparation) and irrigation are negative, while that of seed, labour, PK (active nutrients of phosphorus and potash), N (active nutrients of nitrogen) and cost of

Table 3

Output Elasticity of Translog Function

Variables	Mean	Median	Maximum	Minimum	Std. Dev
Tractor (Hours)=X_1	–0.09	–0.10	0.13	–0.25	0.06
Seed (Kg)=X_2	0.07	0.06	0.72	–0.37	0.13
No. of Irrigations= X_3	–0.11	–0.12	0.57	–0.44	0.13
Labor (Hours)=X_4	0.28	0.26	0.83	0.12	0.08
Nutrients of PK (Kg)=X_5	0.09	0.10	0.17	–0.08	0.04
Nutrients of N (Kg)=X_6	0.03	0.04	0.09	–0.30	0.03
Weedicide Cost=X_7	0.07	0.07	0.23	–0.39	0.07

weedicide are positive. The elasticity of tractor hour is negative but it is not clear why it is so. The coefficient of tractor hour is 0.09 with negative sign and it implies that by increasing one percent of tractor hours, the yield declines by 9 percent. In order to explain its negative sign, more specific soil related information is required which is missing in our data set. The elasticity of seed is positive in rice production. Rice is a water intensive crop and it requires high quantities of water compared to other crops. Such a large quantity of water is not available from irrigated sources and therefore, farmers depend more on ground water in rice production areas. The quality of ground water is poor in the rice zone areas and the negative elasticity of number of irrigations is due to poor ground water quality. But if we had information on the distribution of number of irrigations from canal water and ground water, it would have made our statement more reliable. However, the negative elasticity coefficient for irrigation reflects wasteful irrigation practices and expenditures as well as posing environmental problems. It also emphasises the need for farmers' education in crop irrigation, need for testing the quality of tubewell water and its suitability for irrigation. The use of unfit tubewell water may be posing an environmental problem as well. The elasticity of labour and active nutrients of PK and active nutrients of N are positive which are 28, 9 and 3 percent respectively and these results are according to prior expectations. It implies that if labour, active nutrients of PK, and active nutrients of N are increased by 100 percent then output will increase by 28, 9 and 3 percent, respectively, implying that the contribution of labour is higher than the joint contribution of fertiliser PK and N nutrients. Rice is a labour intensive crop and that is why elasticity of labour is highest and positive followed by active nutrients of nitrogen. The elasticity of weedicide is also positive implying that if the cost of weedicide increases by 100 percent then it contributes to increase in yield by 7 percent.

The cross elasticities of substitution are estimated by employing Equation 15 and results are reported in Table 4. The negative value of cross elasticities of substitution indicates a competitive relationship while the positive value reflects the complementary relationship between the two inputs. It is observed that tractor hours and seed, tractor hours and labour, seed and labour, seed and active nutrient of PK, number of irrigations and active nutrients of N, and active nutrients of phosphorus and potash "PK" and active nutrients of nitrogen "N" all have competitive relationship, while all others have complementary relationship. Competitive relationship between two inputs indicates that decline in one input can be compensated with the other, implying that inputs are substitutable in the production process. Complementary relationship implies that output can be raised by increasing both the inputs simultaneously.

The technical efficiency of rice production in Pakistani Punjab is estimated by employing Equation 8 and results are summarised in Table 5. The results indicate that technical efficiency of rice production is reasonably high ranging from 0.59 to 0.97 with an average value of 0.89. This implies that rice production could be increased up to 11 percent from the given set of resources, just by using the available resources more efficiently. It is observed that 62 percent farmers are technically more than 90 percent efficient and only 12 percent farmers are technically less than 80 percent efficient, implying that distribution of farmers is skewed towards high technical efficiency, and that is why average technical efficiency is reasonably high.

Table 4

Cross Elasticities of Substitution

	Mean	Median	Maximum	Minimum	Std. Dev.
X_{12}	–0.09	–0.10	0.13	–0.25	0.06
X_{13}	0.07	0.06	0.72	–0.37	0.13
X_{14}	–0.11	–0.12	0.57	–0.44	0.13
X_{15}	0.28	0.26	0.83	0.12	0.08
X_{16}	0.09	0.10	0.17	–0.08	0.04
X_{17}	0.03	0.04	0.09	–0.30	0.03
X_{23}	0.07	0.07	0.23	–0.39	0.07
X_{24}	–2.70	3.29	1845.27	–2702.15	185.83
X_{25}	–10.53	7.47	855.04	–7736.51	364.13
X_{26}	3.98	0.14	1152.59	–21.05	56.08
X_{27}	4.79	1.53	2168.90	–237.88	97.89
X_{34}	52.13	–2.70	25342.45	–731.92	1137.34
X_{35}	6.69	–1.05	1622.54	–118.89	99.61
X_{36}	–6.34	–19.34	60618.75	–24943.67	3403.14
X_{37}	1.52	–0.15	822.60	–152.75	47.67
X_{45}	1.12	0.59	240.20	–54.80	14.70
X_{46}	5.26	–12.80	9777.10	–1452.65	509.44
X_{47}	2.00	5.13	1277.58	–2738.88	151.12
X_{56}	–0.63	0.10	107.96	–149.27	15.12
X_{57}	1.11	1.07	11.87	–8.40	1.28
X_{67}	12.40	5.93	1206.11	–656.76	112.03

Table 5

Technical Efficiency Estimates

Value	Count	Percent	Cumulative Count	Cumulative Percent
[0.6, 0.69]	6	1.2	6	1.2
[0.7, 0.79]	56	11.2	62	12.4
[0.8, 0.89]	126	25.2	188	37.6
[0.9, 1]	312	62.4	500	100
Total	**500**	**100.0**	**500**	**100.0**

As discussed earlier we have assumed the cost of chemical weedicide and active nutrients of nitrogen (N) as environmentally detrimental variables. The environmental efficiency of chemical weedicide is estimated by employing Equation 12 and 13 and results are reported in Table 6. The mean environmental efficiency of chemical weedicide in our sample group is only 0.14, ranging from 0.00 to 0.73, implying that environmental efficiency is considerably less than technical efficiency. Our finding reveals that the average level of rice output can be sustained or even increased by reducing 86 percent of chemical weedicide use. Such substantial reductions in chemical weedicide use will not only increase profitability of rice production by decreasing cost of Rs 296.7 per acre but it is also expected to significantly contribute in the improvement of

Table 6

Environmental Efficiency Estimates for Weedicide Only

Value	Count	Percent	Cumulative Count	Cumulative Percent
[0.0, 0.09]	266	53.2	266	53.2
[0.1, 0.19]	103	20.6	369	73.8
[0.2, 0.29]	56	11.2	425	85
[0.3, 0.39]	24	4.8	449	89.8
[0.4, 0.49]	15	3	464	92.8
[0.5, 0.59]	24	4.8	488	97.6
[0.6, 0.69]	9	1.8	497	99.4
[0.7, 0.79]	3	0.6	500	100
Total	**500**	**100.00**	**500**	**100.00**

environmental quality.[3] The significant reduction in environmental pollution is expected to increase the productivity of other resources such as land and labour. Rice was grown on 4.4 million acres of land in Punjab in 2006 [Pakistan (2006)]. Hence, Rs 1307.3 million can be saved each year from the reduction in use of chemical weedicide in Punjab with higher level of output. From the frequency distribution of environmental efficiency, it is observed that 93 percent farmers have less than 50 percent environmental efficiency and remaining 7 percent farmers fall in the range of 50 to 80 percent category of environmental efficiency. There is no farmer in our sample who has more than 80 percent environmental efficiency of chemical weedicide use. The distribution of joint environmental efficiency of chemical weedicide and active nutrients of nitrogen "N" is depicted in Table 7. It is observed that average joint environmental efficiency is almost double (0.24) the average environmental efficiency of weedicide alone (0.14). The higher environmental efficiency score of two detrimental variables might be due to more efficient and judicial use of nitrogen in rice production. The higher environmental efficiency of nitrogen use leads to improvement in the joint effect of two detrimental variables but still substantial scope exists to improve environmental efficiency that can be explored. It appears there is a lot of wasteful expenditure in the use of these chemicals which needs to be economised. It is obvious that the use of fertilisers has assumed great importance in farm production and perhaps is the principal component of the out of pocket expenditures in the production of rice. Our results revealed that a large amount of nitrogen could also be saved with improvement in environmental conditions and higher level of output.

[3] Rs 60 = $1.

Table 7

Environmental Efficiency Estimates for Weedicide and Fertiliser

Value	Count	Percent	Cumulative Count	Cumulative Percent
[0.0-0.09]	37	7.4	37	7.4
[0.1-0.19]	105	21	142	28.4
[0.2-0.29]	230	46	372	74.4
[0.3-0.39]	106	21.2	478	95.6
[0.4, 0.49]	20	4	498	99.6
[0.5, 0.59]	2	0.4	500	100
Total	**500**	**100.00**	**500**	**100.00**

4. LIMITATION OF DATA

It should be noted that primarily this data was collected for another study and at the time of data collection the focus was not on environmental efficiency. This would mean that important information that a study on environmental efficiency would require was not obtained. Especially, in order to justify the negative sign of the elasticity of irrigation we should have had more detailed information on sources of irrigation which is missing in our case. Similarly, we do not have detailed information on soil characteristics of the farms which is again required to justify the negative sign of the elasticity of tractor hours used for land preparation. Hence, future researchers should be mindful of these weaknesses while organising their study.

5. SUMMARY AND CONCLUSION

The present empirical study is based on a sample data of 500 rice farmers collected from five major rice growing districts in Punjab. First of all, we tested the presence of technical inefficiency in our data set and we rejected the null hypothesis of no technical inefficiency in our sample data. The output elasticity of tractor hours and irrigation is negative, while the output elasticity of seed, labour and active nutrients of PK and active nutrients of N, and weedicide cost is found to be positive. The cross elasticities of substitution for different inputs are also estimated in order to observe the nature of relationship between different inputs in the production process. On an average technical efficiency is found to be 89 percent in our sample farmers.

Environmental efficiency is estimated by assuming a single (chemical weedicide) and two environmentally detrimental variables (chemical weedicide and active nutrients of nitrogen) in major rice production districts of Punjab. The environmental efficiency of chemical weedicide is found to be 14 percent only. It suggests that a substantial improvement in resource allocation can be made by reducing 86 percent of chemical weedicide in rice production with higher level of output. It could help to improve the profitability of Rs 296.8 per acre in rice production that totals to an expected saving of Rs 1307.3 from the reduction in the use of chemical weedicides. Moreover, it is likely to alleviate the problem of environmental pollution by sustaining the productivity of the agriculture system. Moreover, it is expected to increase the productivity of agricultural labour. The joint environmental efficiency of two detrimental variables (chemical weedicide and active nutrient of nitrogen) is 24 percent which is almost 71 percent higher than the single detrimental variable (chemical weedicide). This might be due to the reason that though fertiliser is being used more efficiently in rice production but still substantial scope exists that can be explored. Nitrogen which is a major source of cash input can be substantially saved without affecting the level of output, and with higher level of environmental quality.

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