Wheat Productivity, Efficiency, and Sustainability: A Stochastic Production Frontier Analysis

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Pakistan Institute of Development Economics

2002

The Pakistan Development Review
41:4 Part II (Winter 2002) pp. 643–663

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1. INTRODUCTION

The agriculture sector plays a crucial role in the overall development of the country. The sector shares about 24 percent of the GDP and employs about 44 percent of the workforce in the country. Crops sub-sector is the major contributor towards agriculture, sharing more than 53 percent of the value-added. Wheat, being the staple food of Pakistanis, carries immense importance: it contributes about 12 percent of sector value-added, is sown on about 37 percent of the total cropped area, and shares 80 percent in consumption of food grains, while its share in food grain production is around 70 percent. As primary diet, wheat alone shares about 50 percent of the total calories' and proteins intake in Pakistan, and contributes about 8 percent of the total fat consumed [FAO (Various Issues]. Consequently, overall dietary well being of our people especially the urban and rural poor is largely dependent on the performance of wheat economy.

Despite serious efforts made by the wheat breeders in developing new high-yielding varieties during the past three decades, wheat production in Pakistan remained short of demand and thus import has been the only alternative to fill the gap. The present wheat requirement of the country is more than 20 million tonnes. It has been estimated that by the year 2020 wheat import would rise up to 15 million tones costing 2 billion US dollars [PARC (1996)]. The situation could worsen further if Pakistan fails to achieve a higher level of growth rate in wheat production and sustain it. Under the present wheat production system and productivity scenario the realisation of this objective appears to be highly unlikely [Byerlee and Siddiq (1994); Rajaram, *et al.* (1998)].

Average wheat yield that ranged between 2000 kg/hectare to 2500 kg/hectare during the 1990s is much lower than the actual potential in spite of the fact that the input use level per acre is moderately high in Pakistan [Byerlee (1992)]. While, economically achievable yield as suggested by the on-farm wheat trials is around

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3500 kg/hectare [Aslam, *et al.* (1989); Byerlee (1992); Byerlee, *et al.* (1986)]. Wheat yields may also differ on the farmers' fields having the same location, soil type, access to irrigation water and sources, and the similar varieties and level of fertiliser. The major sources of yield variation are the differences in management practices followed at these farms, which in turn contributes to 'technical efficiency gap'. Citing few studies [e.g., Fan (1991); Lin (1992); Thirtle, Hadley, and Townsend (1995); Kalirajan, Obwona and Zhao (1996)], Pingali and Heisey (1999) argued that the existence of higher technical inefficiencies could fully offset the potential gains of highly superior technologies. Ahmad and Ahmad (1998) and Ahmad (2001) using district level data for Punjab, Pakistan, found similar results where negative growth rates in technical efficiencies partially or fully smoothed away the gains from technological progress. In order to accomplish sustained growth in agriculture, efficiency and productivity differentials have to be reduced by improving the knowledge, education, management skills of the farming communities, and development of infrastructure [Pingali and Heisey (1999); Ghura and Just (1992)].

It is also frequently being argued in the literature that productivity of the rice-wheat cropping system is not sustainable, because of the land resource degradation. The stagnating/declining wheat yields is indicative of this serious concern [Pingali and Heisey (1999)]. Consequently, future gains in productivity also depend on improving the utilisation efficiency of the agricultural resource base particularly land and water: which requires greater access to information and improvement in management potential of the farmers [Rejesus, Smale, and Heisey (n.d.)]

Various studies have been conducted to examine the issues of productivity and technical efficiency using wheat crop data for different countries. These studies can be classified into three groups based on the methodologies used. First group applied non-frontier approach incorporating non-conventional inputs directly in the response function to see their impact on productivity [e.g., Salam (1976); Butt (1984); Jamison and Mook (1984); Feder, *et al*. (1987); Azhar (1991); Iqbal, Azeem, and Ahmad (2001)]. These studies used an average response function assuming that all wheat farmers in the sample are 100 percent efficient. Moreover, the average production function approach does not distinguish between allocative and economic efficiencies because it ignores the aspect of technical efficiency, while the latter could result in greater loss than the allocative inefficiency [Hussain (1999)]. This problem can be avoided using production frontier technique.

The second group of studies used frontier function approach to measure technical inefficiency [e.g., Battese, Malik and Broca (1993); Ahmad and Ahmad (1998)] and some of the authors predicted the inefficiency measures from the first step (i.e., frontier function) and then regressed these on various farmer and/or farm-specific attributes to examine the determinants of inefficiency [e.g., Hussain (1989)]. The third group of studies including Battese, Malik, and Gill (1996) and Battese and Coelli (1995) criticised this two-step modelling approach on the ground that it violates one of the basic assumptions that of 'identically independently distributed technical inefficiency effects in the stochastic frontier'. They proposed a one-stage modelling approach in which technical inefficiency effects are function of various observable factors such as age, education, access to extension services and credit, etc. Applications of this methodology can be found Battese, Malik, and Gill (1996); Battese and Broca (1997) and Ngwenya, Battese and Flemming (1997). The latter study uses the wheat data from South Africa, while the first two studies essentially use the same data set for the wheat crop belonging to four districts—Faisalabad, Attock, Badin and Dir, of Pakistan and found average technical efficiencies of wheat farmers varying between 0.57 in Badin to 0.79 in Faisalabad. The major drawback of this study is that the data used in the analyses does not represent the various cropping system of Pakistan, and was also deficient in information required for explaining the farm inefficiencies. Following Battese and Coelli (1995), the present paper applies the one-stage modelling approach to a more comprehensive data representing various cropping systems of Pakistan and extends the scope of the analyses by exploring the issues of farm-size and efficiency relationship, and sustainability of the rice-wheat cropping system in comparison with the cotton-wheat zone.

The paper is organised as follows. The data and empirical model is given in Section 2. The results are discussed in Section 3. The conclusions and important policy implications are presented in Section 4.

2. THE DATA AND EMPIRICAL MODEL

2.1. The Data

This study uses data from a Fertiliser Use Survey 1997-1998[1] conducted by the Pakistan Institute of Development Economics for the National Fertiliser Development Centre, Planning and Development Division, Government of Pakistan. The details about the survey and the procedures can be found in NFDC (2000). However, a brief description about the sample is given in this paper.

This survey covers three out of four provinces of Pakistan namely NWFP, Punjab and Sindh.[2] A total of 18 *tehsils* (sub-districts) were selected—10 from Punjab, 5 from Sindh and 3 from NWFP.[3] The selection of these *tehsils* was based

[1]The year 1997-98 was a good agriculture year with an overall growth rate of 5.9 percent for the sector. Wheat production recorded a 12 percent increase while its yield increased by 8.3 percent during the year. The results may not be applicable to bad wheat years.

[2]The reason for this selection was that more than 98 percent of the total fertiliser use is in these three provinces.

[3]The selected *Tehsils* in Punjab province include Lodhran, Arifwala, Chishtian, Hifizabad, Kabirwala and Sammundari from irrigated region, Mianwali and Rajanpur from partially irrigated zone, and Attock and Chakwal from the rainfed region. *Tehsils* selected from Sindh include Khairpur, Nawabshah and Shahdadpur as having perennial irrigation, and Mirpurkhas and Thatta from partially irrigated zone. In case of NWFP, Charsada, Swat and Kulachi were selected from perennially irrigated, partially irrigated and rainfed regions, respectively. For the purpose of present analysis, Attock, Chakwal and Kulachi were dropped because these *tehsils* belong to rainfed region.

on the cropping pattern, water availability and the intensity of fertiliser use. Consequently, the selected sub-districts represent the average condition of the respective provinces fairly well. Six villages from each *tehsil* and 22 farmers per village were chosen for detailed interview. The overall sample thus was 2368 respondents from the three provinces. Out of this sample, 2228 farmers were growing wheat on their farms. About 44 cases were found deficient in displaying reliable farm level information. From the remaining sample, 1828 wheat farmers belong to irrigated areas in Punjab, Sindh and NWFP, which serves the basis of this study.

2.2. Empirical Model

Wheat production frontier is written as:

$$\begin{aligned} \ln(\text{wheat}) = {} & \beta_0 + \beta_1 \ln(\text{Warea}) + \beta_2 \ln(\text{NPK})\ \beta_3\, \text{DNPK} + \beta_4 (\text{P/NPK}) + \beta_5 \ln(\text{Seed}) \\ & + \beta_6 \ln(\text{FYM}) + \beta_7\, \text{DFYM} + \beta_8\, \text{Dcanal} + \beta_9\, \text{Dtubwell} + \beta_{10}\, \text{DcanTub} \\ & + \beta_{11} (\text{RiceA/CultA}) + \beta_{12} (\text{CottA/CultA}) + \beta_{13}\, \text{Dlodh} + \beta_{14}\, \text{Darifw} \\ & + \beta_{15}\, \text{Dchish} + \beta_{16}\, \text{Dhafad} + \beta_{17}\, \text{Dkabirw} + \beta_{18}\, \text{Dmianw} + \beta_{19}\, \text{Drajpur} \\ & + \beta_{20}\, \text{Dsamund} + \beta_{21}\, \text{Dkhpur} + \beta_{22}\, \text{Dmirpur} + \beta_{23}\, \text{Dnawabs} \\ & + \beta_{24}\, \text{Dshahd} + \beta_{25}\, \text{Dthata} + \beta_{26}\, \text{Dcharsad} + V_i - U_i \quad \ldots \quad \ldots \qquad (1) \end{aligned}$$

where:

ln(Wheat)	Is natural log of wheat output per acre in *maunds* (1 *maund*=40kg);
ln(Warea)	Natural log of area under wheat in acres;
ln(NPK)	Natural log of fertiliser nutrients [i.e., nitrogen (N), phosphorus (P) and potash (K)] applied per acre of wheat—when NPK>0, otherwise zero;
DNPK	Dummy variable representing value equal to one if NPK is equal to zero, and assumes zero for positive values of NPK.;
P/PK	Ratio of phosphorus nutrients to total NPK used per acre;
ln(Seed)	Natural log of seed applied per acre;
ln(FYM)	Natural log of farm yard manure used per acre if the quantity of FYM is greater than zero, and the variable assumes zero for zero values of FYM;
DFYM	Dummy variable assuming value of one when FYM is equal to zero, and for positive values of FYM the DFYM is equal to zero;
Dcanal	Dummy variable showing value of one when the source of irrigation for wheat is canal alone, otherwise zero;[4]

[4]The data set we are using for the present study contain information about the sources of irrigation only.

Dtubwell	Dummy variable showing value of one if the source of irrigation for wheat is tubewell, otherwise zero;
DcanTub	Dummy variable showing value of one if the sources of irrigation are canal plus tubewell, otherwise zero;
RiceA/CultA	Ratio of area under rice crop to total cultivated area;
Cotton/CultA	Ratio of area under cotton crop to total cultivated area;
Dlodh to Dcharsad	District dummies assuming value one if the farm is located in the specific district, otherwise zero;[5]

V_is are assumed to be independent and identically distributed normal random errors having mean zero and variance σ_v^2 and are also distributed independently of U_i. Where U_is are non-negative technical inefficiency effects representing management factors and are assumed to be independently distributed with mean u_i and variance σ^2 [Battese, Malik, and Gill (1996)]. The *i*th farm exploits the full technological production potential when the value of U_i comes out to be equal to zero, and the farmer is then producing at the production frontier beyond which he cannot produce. The greater the magnitude of U_i far away will be the farmer from the production frontier and be operating more inefficiently [Drysdale, Kalirajan, and Zhao (1995)].

The u_i is function of farm- and farmer-specific attributes that can be written as

$$u_i = \delta_0 + \delta_1 Age + \delta_2 Educ1 + \delta_3 Educ2 + \delta_4 Educ3 + \delta_5 Educ4 + \delta_6 OwnTen + \delta_7 Tenant + \delta_8 Exten + \delta_9 Fmdist + \delta_{10} Credit + \delta_{11} Farmsize \quad \ldots \quad (2)$$

Where:

Age	Age of the farmer in years;
Educ1	Dummy variable showing value of Educ1=1 if the farmer has education up to primary, otherwise zero;[6]
Educ2	Dummy variable showing value of Educ2=1 if the farmer has middle level education, otherwise zero;
Educ3	Dummy variable showing value of Educ3=1 if the farmer has matric level education, otherwise zero;
Educ4	Dummy variable showing value of Educ3=1 if the farmer has greater than matric level education, otherwise zero;
OwnTen	Dummy variable showing value of OwnTen =1 if the farmer is owner-cum tenant, otherwise zero;
Tenant	Dummy variable showing value of Tenant =1 if the farmer is tenant, otherwise zero;
Exten	Dummy variable showing value of Exten =1 if the farmer consulted the extension agent or any other agricultural expert for guidance, otherwise zero;

[5]Dlodh, Darifw, Dchish, Dhafad, Dkabirw, Dmianw, Drajpur, Dsamund, Dkhpur, Dmirpur, Dnawabs, Dshahd, Dthata, and Dcharsad stand for Lodhran, Arifwala, Chishtian, Hifizabad, Kabirwala, Sammundari, Mianwali, Rajanpur, Khairpur, Mirpurkhas, Nawabshah, Shahdadpur, Thatta and Charsada.

[6] The data include information only about the level of education and not schooling in years.

Fmdist	Distance of farm from the main market town in kilometres;
Credit	Credit obtained in rabi season by the farmer from any source [per cultivated acre]; and
Farmsize	Farm size in acres;

The technical efficiency of production for the ith farm can be computed as

$$TE_i = \exp(-U_i) = Y_i / Y_i^* \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

Where Y_i is the observed farm output and Y_i^* is maximum possible output using the given level of inputs.

3. RESULTS AND DISCUSSION

3.1. Production Frontier Estimation and Hypotheses Testing

The maximum likelihood estimates of the parameters of the stochastic production frontier and inefficiency model are estimated using Frontier 4.1 computer programme written by Tim Coelli of University of New England, Australia. Before proceeding to examine the parameter estimates of the production frontier and the factors that affect the inefficiency of the farmers, we need to investigate the validity of the model used for the analysis. The results of the tests of hypotheses are reported in Table 1. These tests are performed using generalised likelihood-ratio statistics, *LR*, which is defined as: $LR = -2 \ln[L(H_0) / L(H_1)]$, where $L(H_0)$ and $L(H_1)$ are the values of the log likelihood function under the specifications of the null and alternate hypotheses, respectively. The *LR* test statistic has an asymptotic chi-square distribution with degrees of freedom equal to the difference between the number of parameters in the unrestricted and restricted models.

Table 1

Tests of Hypotheses

Hypotheses	Log Likelihood Function	Test Statistics χ^2	Critical Value: $\chi^2_{0.95}$	Decision
General Model	–996.47			
H_0: $\gamma=\delta_0=\delta_1=\ldots=\delta_{11}=0$	–1144.23	295.52	22.36	Rejected
H_0: $\delta_1=\delta_2=\ldots\ldots=\delta_{11}=0$	–1023.23	53.52	19.68	Rejected
H_0: $\delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$	–1059.68	126.42	9.49	Rejected
H_0: $\beta_{13}= \ldots\ldots= \beta_{26}=0$	–1117.41	242.02	23.68	Rejected

The first null hypothesis that we tested is H_0: $\gamma=\delta_0=\delta_1=\ldots=\delta_{11}=0$[7], which specifies that the technical inefficiency effects are not present in the model. This implies that the stochastic frontier production function is not different than the traditional average production function, which can be estimated using OLS procedure. This null hypothesis is rejected (see Table 1). The second null hypothesis which is tested is H_0: $\delta_1=\ldots=\delta_{11}=0$ implying that the farm-level technical inefficiencies are not affected by the independent variables included in the model. This hypothesis is again rejected. This result reveals that the variables present in the inefficiency model have collectively significant contribution in explaining technical inefficiency effects for the wheat farmers. Consequently, it is appropriate to include them in the model. The third tested hypothesis is H_0: $\delta_2=\delta_3=\delta_4=\delta_5=0$, which demonstrates that the education variables do not influence the technical inefficiency effects. This hypothesis is also rejected postulating that the farmers' education plays a significant role in reducing farming inefficiency.

To capture the geographical effects like differences in soil quality, cropping pattern, rainfall, temperature, infrastructure and other social indicators, we used *tehsil* dummy variables. Given that the production frontier incorporating the inefficiency effects, we tested the null hypothesis of H_0: $\beta_{13}=\beta_{14}=\beta_{15}=\ldots=\beta_{26}=0$. This hypothesis suggests that wheat output per acre does not vary from *tehsil* to *tehsil*. This hypothesis is also rejected.

3.2. Parameter Estimates of the Production Frontier and the Issue of Sustainability

In total 41 parameters were estimated in the stochastic production frontier model including 27 in the stochastic frontier model, 12 in the inefficiency model and the remaining two parameters σ_s^2 and γ relate to variances of the random variables, V_i and U_i. The estimate of γ is 0.949 and is statistically significant at the one percent level (Table 2). This indicates that farm productivity differentials predominantly relate to the variance in management.

Out of 41 estimated parameters, 34 are statistically significant—29 are significant at least at five percent level and the remaining 5 are significant at 10 percent level. The coefficient of area under wheat is negative and is statistically significant. This implies that wheat farmers face diminishing returns to scale. All the three coefficients of fertiliser related variables have positive signs as expected and are also statistically significant. The coefficient of variable *P* to NPK ratio is of particular interest. The estimate is positive and significant at the 10 percent level. This result implies that as the *P* to NPK ratio improves wheat productivity increases

[7]The parameter, γ, is defined by $\gamma = \sigma^2/\sigma_S^2$, where $\sigma_S^2 = \sigma^2+\sigma_v^2$ [Battese, Malik, and Gill (1996)].

Table 2

Parameter Estimates of the Stochastic Production Frontier

Variables	Parameters	OLS Coefficient	OLS *t*-ratio	Frontier Function Coefficient	Frontier Function *t*-ratio
Stochastic Production Frontier					
Constant	β_0	–0.0392	–0.1249	0.9913***	3.7455
Ln(Warea)	β_1	–0.0212	–1.4610	–0.0565***	–4.3641
Ln(NPK)	β_2	0.3488***	12.9770	0.2754***	12.3139
DNPK	β_3	1.0839***	7.3219	0.8868***	6.9817
P/NPK	β_4	0.1866**	2.1234	0.1405*	1.8695
Ln(Seed)	β_5	0.2192***	3.1838	0.2048***	3.5786
ln(FYM)	β_6	0.0630**	2.2672	0.0304	1.3253
DFYM	β_7	0.2150	1.6320	0.0647	0.5915
Dcanal	β_8	0.4124***	2.8374	0.4045***	3.1869
Dtubwell	β_9	0.5156***	3.3970	0.4688***	3.5463
DcanTub	β_{10}	0.5045***	3.4310	0.4807***	3.7316
RiceA/CultA	β_{11}	–0.1243*	–1.9093	–0.1505***	-2.7591
Cotton/CultA	β_{12}	0.1105**	2.3639	0.0607	1.5647
Dlodh	β_{13}	–0.1641**	–2.0448	–0.1782***	–2.6638
Darifw	β_{14}	0.3378***	4.5880	0.2709***	4.3404
Dchish	β_{15}	0.0789	1.1166	0.1133*	1.8390
Dhafad	β_{16}	0.1989***	2.8493	0.1884***	3.1818
Dkabirw	β_{17}	–0.1363*	–1.7856	–0.1433**	–2.2276
Dmianw	β_{18}	0.0452	0.6105	0.0221	0.3448
Drajpur	β_{19}	–0.1716**	–2.1748	–0.1661**	–2.4878
Dsamund	β_{20}	0.2566***	3.7696	0.2191***	3.7537
Dkhpur	β_{21}	–0.4041***	–5.6470	–0.2862***	–4.5876
Dmirpur	β_{22}	–0.1034	–1.4152	–0.1216**	–1.9835
Dnawabs	β_{23}	–0.1805**	–2.4512	–0.0850	–1.3585
Dshahd	β_{24}	–0.2214***	–2.8024	–0.2016***	–3.0185
Dthata	β_{25}	–0.1594**	–2.2001	–0.1121*	–1.8264
Dcharsad	β_{26}	–0.0176	–0.2545	0.0400	0.6615
Inefficiency Effects					
Constant	δ_0			–1.3633***	–2.6880
Age	δ_1			0.0085***	2.7976
Educ1	δ_2			–0.3423***	–2.6256
Educ2	δ_3			–0.3439**	–2.2261
Educ3	δ_4			–1.1637***	–4.6019
Educ4	δ_5			–0.6391***	–3.2118
Own-Tenant	δ_6			–0.1348	–0.9395
Tenant	δ_7			–0.2939***	–2.6430
Extension	δ_8			–0.3086*	–1.7871
Fmdist	δ_9			0.0191***	3.0711
Credit	δ_{10}			–0.0002*	–1.8662
Farmsize	δ_{11}			–0.0356***	–16.5166
Variance Parameters					
	σ_s^2			1.0871***	5.5913
	γ			0.9492***	99.0779

significantly. The coefficient of seed variable[8] is also significant and carries positive sign. Both the parameter estimates of farm-yard-manure related variables are statistically non-significant. However, farm-yard-manure use shows positive relationship with wheat yield.

Three irrigation dummy variables are used in the wheat production frontier model, while un-irrigated farms are considered as base. The coefficients for all the three irrigation dummies are statistically significant. The magnitudes of the parameter estimates show that wheat productivity varies from one source of irrigation to another: canal is a less flexible source, while tubewell and tubewell plus canal are relatively more reliable sources and provides timely supply of water throughout the cropping season and thus results in higher farm productivity. The data shows that average (geometric) wheat production per acre is 18 *maunds* (40kg=1 *maund*) on farms where canal water is the only source of irrigation, 20.3 *maunds* on farms having tubewell irrigation only and 22.71 *maunds* on farms having access to both canal and tubewell sources of irrigation.

Most of the parameter estimates of the *tehsil*-specific dummy variables are significant implying that wheat yield per acre varies from one region to another. The major causes of this difference may be due to variations in land quality, cropping pattern, rainfall, and access to physical infrastructure in different *tehsils*.

To see the impact of the extent of double cropping on wheat productivity—where wheat is sown after rice, we used a variable that is defined as the ratio of area under rice to the total cultivated area at the farm. The parameter estimate of rice-cultivated area ratio is negative and significant at the one percent level. This result shows that production per acre declines significantly as the proportionate area under rice increases on the farm. In addition to delayed wheat crop sowing,[9] the reasons for this outcome are degradation and depletion of land resources caused by continuous cultivation of rice crop year after year [Cassman and Pingali (1993); Pingali, Hussain and Gerpacio (1997); Ahmad, Ahmad, and Gill (1998)]. Rice and wheat rotation (i.e., rice-wheat-rice) dominates in the system with coverage of over 72 percent of the cultivated area [Ashraf (1984-85)]. This system also has the highest cropping intensity of 173 percent among all the cropping zones of Pakistan [Pakistan (1990)], which has a considerable depressing effect on crop productivity [Ahmad and Qureshi

[8]Variety and sowing date are the other important factors that may influence wheat production on a farm. Information on these variables was missing in the survey data. Therefore, these variables could not be included in the Model. The statistics regarding wheat acreage show that area under high yielding wheat varieties was reasonably high (93.5 percent) in late 1990s. Moreover, variables like ratio of rice and cotton area to wheat area included in the model capture effect of late sowing. Therefore, effect of excluding variety and late sowing variables would have little effect on estimates if any.

[9]A delay of one day in planting of wheat beyond the proper sowing time reduces yield by 1 percent Assuming average of 2500 kg wheat yield per hectare, every 15 days delay in sowing reduces farm yield by 375 kg/hectare [Byerlee and Siddiq (1994)].

(1999)]. Both of these crops (i.e., rice and wheat) are shallow-rooted and heavily extract nutrients from the same layer soil. Thus, both crops require the nutrients to be present preferably in the upper 6 inches layer of the soil for their proper and efficient absorption. Moreover, the applications of fertiliser doses are not only less than the desired/recommended quantities but their uses are unbalanced as well in terms of ratio of NPK nutrients. The blend of these problems lead to negative net balance of all the major as well as micro nutrients in the soil, and this situation would continue to worsen since the extraction of nutrient contents is faster than the rate it is being replenished [Zia, *et al.* (1992)]. As a consequence, the sustainability of rice-wheat system turning out to be a serious threat in ensuring food security in Pakistan.

The parameter estimate of the ratio of cotton area to the total farm cultivated area variable is positive and is however statistically non-significant implying no association between proportionate area under cotton and wheat yields. This result is contrary to our expectations. The harvesting season of the cotton crop and the sowing timings of wheat overlap to some extent. Consequently, wheat sowing in cotton fields is also delayed. The reasons for this contradictory result could be the prevalence of cotton leaf curl virus during 1997-98 crop season and relatively more remunerative support price of wheat might lead to early vacation of cotton fields resulting into timely sowing of wheat over comparatively greater proportion of wheat acreage.[10] Moreover, cotton is deep-rooted crop and enjoys greater nutrient absorption area particularly in the lower soil layers and relatively more nutrients remain unused in the upper 6 inches' soil layer for the next crop in rotation like wheat, which is a shallow-rooted crop.

3.2. Technical Efficiencies of Wheat Farmers

The technical efficiencies of the sampled wheat farmers were obtained using Equation 3. As mentioned earlier, technical inefficiency effects are significant and thus the technical efficiencies of sampled farmers are less than one. The cost accrued to the wheat farmers due to the existence of technical inefficiencies is huge ranging from 92 percent to 4 percent in terms of loss in output. The unshaded area in Figure 1 indicates the technical inefficiency, while the shaded area represents the technical efficiency. The unshaded area amounts to 32 percent loss in output on the average due to technical inefficiency.

The parameter estimates of the variables used in the inefficiency model are provided in Table 2. The age of the farmers, which is an important factor in decision-making, has a significant positive effect on farm inefficiency implying that as age increases the farm efficiency declines. The reason for this relationship may be due to

[10]Another reason appears to be the higher use of chemical fertiliser per acre of wheat crop grown on cotton farms probably to cover up the yield losses due to late sowing. Per acre use of fertiliser on wheat crop is positively correlated (i.e., 0.28) with the ratio of cotton area to farm cultivated area and is negatively correlated with the rice area to cultivated area ratio.

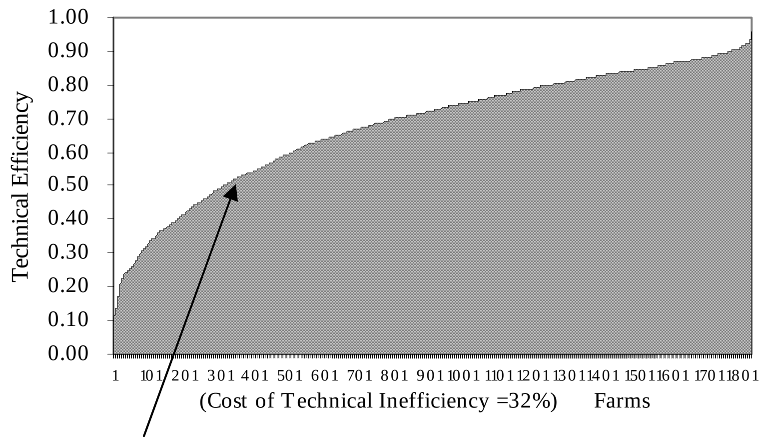

Fig. 1. Cost of Technical Inefficiencies.

the fact that the aged farmers may be unwilling to take risk and evade frequent experimentation with the new technologies.

The parameter estimates of the education dummy variables carry negative signs and are statistically significant at least at the 5 percent level. This result very clearly demonstrates that the farmers' education emerges as an important factor in enhancing agricultural productivity. This result is in line with Battese, Malik, and Gill (1996), while Hussain (1989) found no association between education and wheat farm inefficiency. Educated farmers usually have better access to information about prices, and the state of technology and its use. Better-educated people also have higher tendency to adopt and use modern inputs more optimally and efficiently [Ghura and Just (1992)]. It is more likely that the farmers with higher educational status are more perceptive to agriculture expert advice.

The extension variable has a negative sign and is also statistically significant. This result shows that the farmers who are in touch with the agricultural extension department in order to seek advice are more efficient in agricultural production. Hussain (1989) found no significant relationship between agricultural extension and wheat production inefficiency.

The farm to market distance variable has a significant and positive association with inefficiency. This result implies that the farm efficiency and thus the productivity would significantly increase with development of market and road infrastructure. Better access to roads expands output markets on the one hand and increases demand for modern inputs on the other [Ghura and Just (1992)]. According to FAO and IFA (1999), the utilisation of purchased inputs would have been higher in developing countries if the supply outlets were made available to the farming communities at a walking distance. There are research evidences showing positive relationship between use of chemical fertiliser and farm to market distance [e.g., Jha and Hojjati (1993); Ahmad, Chaudhry and Chaudhry (2000)].

The parameter estimate of the credit variable is negative and significant at the 10 percent level implying that the relaxation of financial constraint of the farmers increases farming efficiency. The reason is that the adoption and use intensity of purchased inputs usually depends on the adequacy of the working capital. This is specifically true for the marginal farmers operating very small holdings in developing countries like Pakistan. They are the one who are trapped in the vicious circle of financial hardships. The credit availability eases these financial constraints and helps in buying inputs and thus their application at the proper time. Therefore, in order to reduce the farm inefficiencies the farmers have to be provided with easy excess on favourable terms to credit particularly through formal institutional channels.

Tenurial arrangements and the farm size are the other factors playing significant role in determining the farm level inefficiencies. The parameter estimates of the tenurial status variables show that the tenants are statistically more efficient than the owner and owner-cum tenants. For the tenants, insecurity and financial stringency are considered to be the critical factors dissuading them from investing in activities such as improvements in land and managerial capabilities. Nonetheless, the tenants generally operate small landholdings and are usually under economic pressure like paying rent/share, facing high variable costs and saving something for the families' survival. As a consequence, the tenants tend to struggle more to achieve higher production potential.

The parameter estimate of farm area variable is negative and is highly statistically significant implying that the large farmers are relatively more technically efficient than the small farmers. A perusal of Figure 2 shows that technical efficiency, use of chemical fertiliser, access to canal and tubewell as dual source of irrigation, farmers' education, and access to agricultural extension are all positively associated with the farm size. Figure 2 also indicates that the technical efficiency is positively associated with the level of fertiliser use and access to irrigation source—canal plus tubewell.

Figure 3 suggests that the farmers are technically more efficient in Punjab with an average efficiency of 0.70 than their counterparts in Sindh and NWFP having average technical efficiencies of 0.66 and 0.63, respectively. The major reasons for this difference appears to be better access to the quality irrigation water, higher literacy among farming community, greater link with agricultural extension department, use of more balanced fertiliser nutrients.[11]

[11]*Punjab Averages:* NPK=70kg/acre, P/NPK=0.31, Seed=48kg/acre, Canal use only=30 percent of farmers, Canal+TW both=60 percent of farmers, literate = 62 percent of farmers, Extension contacts = 14 percent of the farmers;

Sindh Averages: NPK=76kg/acre, P/NPK=0.28, Seed=53kg/acre, Canal use only = 89 percent of farmers, use of Canal+TW both = 9 percent of farmers, literate = 47 percent of the farmers, Extension contacts = 3 percent of farmers;

NWFP Averages: NPK=63kg/acre, P/NPK=0.23, Seed=44kg/acre, Canal use only = 92 percent of farmers, use of Canal+TW both = 4 percent of farmers, literate = 40 percent of the farmers, Extension contacts = 5 percent of farmers.

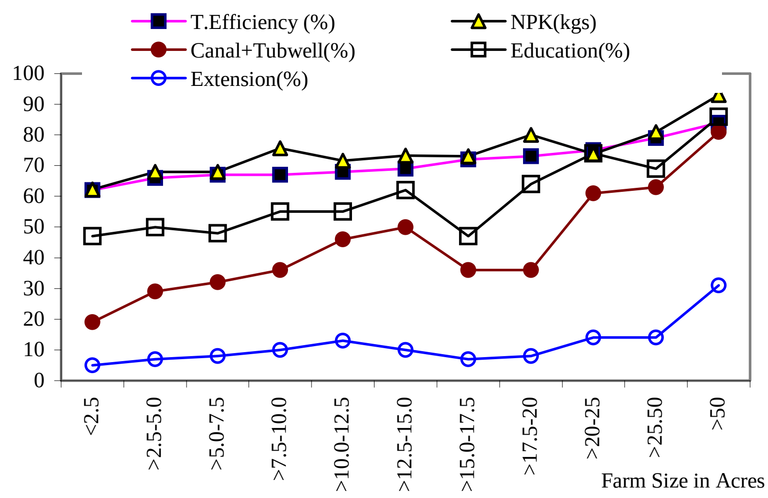

Fig. 2. Farm Size, Efficiency, and Inputs.

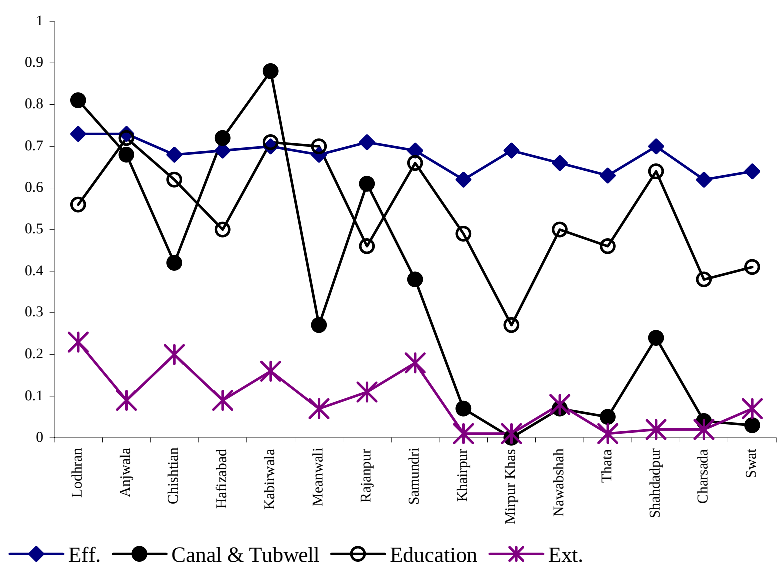

Fig. 3. Technical Efficiency (Eff), Agricultural Extension (Ext), Education, and Irrigation Facilities in Different Tehsils.

4. CONCLUSION AND POLICY IMPLICATIONS

The paper uses the farm-level survey data and estimates the stochastic frontier production function incorporating inefficiency effects. Sufficient evidence of positive relationship between wheat productivity and higher and balanced use of fertiliser nutrients is present. Wheat productivity is significantly higher on farms having access to more reliable irrigation system—i.e., canal and tubewell both, as compared to the non-irrigated farms and the farms relying only on a single relatively less ensured source of irrigation, i.e., either canal or tubewell.

The results also indicate that wheat productivity has a strong inverse relationship with the proportionate farm area devoted to rice crop. The reasons for this negative relationship could be the degradation and depletion of land resources caused by practicing the same crop rotations years after years, and the prevalence of higher cropping intensity. This scenario is expected to worsen further due to the fact that the rate of extraction of nutrient contents from the soil is much higher than it is being replenished. If unnoticed, the situation will raise serious concerns about the sustainability of the rice-wheat cropping system and the food security goals.

On the other hand wheat productivity appears to have no association with the proportionate farm area under cotton. This result is due to the fact that farmers in cotton-wheat system apply higher doses of chemical fertiliser on both wheat and cotton crops. Moreover, cotton crop is deep-rooted, while wheat crop is shallow-rooted and thus do not compete for nutrients exclusively from the same layers of the soil as rice and wheat in rice-wheat system.

The results of efficiency analysis show that the average technical efficiency is about 68 percent and thus an average farmer is producing 32 percent less than the achievable potential output. Technical inefficiency is negatively associated with the farm size. The obvious reasons for this relationship could be that the larger farmers possess higher education and have greater access to better irrigation arrangements, extension services, and apply higher doses of chemical fertiliser with more balanced nutrients. Moreover, they are usually financially better off and thus are in a position to use and adopt modern technologies more efficiently and effectively. The farmers who have greater access to credit and are located closer to the markets are more efficient than those having relatively less access to credit and are situated at a grater distance from the markets. In short, these results imply that the small farmers are not only producing at a lower level but are also operating relatively farther from the production frontier. This indicates that there is considerable scope to expand output and also productivity by increasing production efficiency at the relatively inefficient farms and sustaining the efficiency of those operating at or closer to the frontier.

The results also reveal that wheat farmers in Punjab are comparatively more efficient than their counterparts in Sindh and the NWFP. The reasons for this disparity are that the farmers in Punjab are better off in terms of having irrigation and agricultural extension facilities, and are also more educated.

It is the well-established fact that input and output prices play a critical role in determining crop profitability, choosing appropriate production technologies and the supply of agricultural commodities. Chhibber (1988); Thomas and Chhibber (1992) and Ghura and Just (1992) argue that only the price incentives are not adequate to boost supplies of agricultural commodities unless these measures are supplemented with continued investment in rural infrastructure (i.e., roads, markets and financial institutions etc.), enhancing general education as well as agricultural education, and improving agricultural research and extension system. The results of our study summarised above are strongly supportive of these arguments and call for attention of the policy-makers and the planners to give top priority to strengthening of rural and agricultural supporting institutions in order to enhance agricultural productivity.

These efforts should particularly be targeted towards increasing welfare of the marginal and the small farmers in order to help them move not only along the production function but also up closer to the frontier. However, the futuristic answer lies in encouraging investment in corporatising the input and processing sectors, and other agro-based employment-generating industries that would encourage marginal and inefficient farming communities to select relatively more rewarding work [Ahmad (2001)]. This would let other farmers improve their farm size to a viable production unit. However, there is a need for an in depth study to determine an optimal farm size in different cropping systems and provinces.

Besides, preserving sustainability of our cropping systems, averting mining of nutrients and thus soil degradation and improving land productivity require following measures to be undertaken efficiently and more effectively: (1) the use of green manuring, and rotation with leguminous crops; (2) the use of balanced mixture of major nutrients like nitrogen, phosphorus and potash; (3) encouraging the use of Gypsum where the underground water is brackish; and (4) popularising the adoption of reduced or zero tillage technology particularly in rice-wheat cropping system to avoid yield losses due to delayed sowing.

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