Technical Efficiency of Improved and Traditional Wheat Varieties in Paktia, Afghanistan: A Comparative Stochastic Frontier Production Function Analysis

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Abstract

Afghanistan is an agrarian country and agriculture is the mainstay of national economy and rural livelihood. Majority of the farmers are engaged in subsistence farming and wheat is their main producing cereal crop. This study assessed the potential factors affecting low wheat productivity and large yield gaps in different production systems using a comparative stochastic frontier production function model. The study is documented on cross-sectional data of 235 randomly selected wheat growers in Ahmad Aba and Said Karam district of Paktia, Afghanistan. The result indicates a wide range of variation in the technical efficiencies (0.3-0.9) across the observations. Nevertheless, the difference in mean TE between the two groups is statistically significant. Evidently, the improved wheat varieties users are more technically efficient (78%) in comparison to that of the traditional ones (72%). Moreover, the gamma score shows that the differences between observed and potential frontier production are primarily due to the managerial variables that include age, education, gender, household size, extension visits, and land quality. Hence, the potential yield gap can be reduced using improved wheat variety, furthermore enhancing productivity within traditional varieties prerequisites the adoption of new technology as the level of output approached the production frontier.

Key Terms: Technical efficiency, stochastic frontier, wheat varieties, Afghanistan

1. Introduction

Although agriculture is the mainstay of the national economy and primary source of food and income generation for rural households in many developing countries, its contribution to self-sufficiency and poverty alleviation is minimal. Afghanistan is a landlocked developing country, where about 80% of the households are directly relying on agriculture. Wheat is the major producing cereal crop in the country; although the country's food production has been hovering between 2.6 and 5.2 million tons in the former decade, the massive gap between domestic production and consumption has made imports indispensable to feed its 35 million populations (Tajiv Sharma and Mahboobullah Nang, 2018). Due to the opportunistic behaviors of main trading neighbor countries, the domestic food supply is continuously at risk, hence the government realized that the food supply problem hinges on enhancing crop productivity through introducing new production inputs, mainly fertilizer, and improved seeds varieties.

In the last one and half decade, wheat production has been growing at 7.3% per annum driven primarily by the introduction of highly productive varieties and improved production input efficiency (Srinivas T., *et al*., 2017). Moreover, wheat is cultivated under both irrigated and rainfed conditions in the country. 52% of the total wheat area is allocated to irrigated wheat cultivation, contributing to 91% of the total wheat production (3.07 mt); on the other hand, 48% of the cultivatable land is covered by rainfed wheat amounting to only 9% of the total wheat production (0.3 mt) (Srinivas T., *et al*., 2017). Moreover, the adoption of improved wheat varieties and associated technology is presumed to be a cause of variation in the wheat productivity across the country. Empirical results of various regional studies demonstrate that low yielding cultivars are the main reason for low wheat productivity in South Asia (Ortiz Ferrara *et al.*, 2007; Rizvi *et al*., 2012; Srinivas *et al.*, 2010; Thapa *et al.*, 2009). Also, Omobowale *et al.*, (2009) study reveals that low level of improved input endowment is the major cause of low productivity in agriculture.

In 2019, the domestic wheat production was 4.89 million tons, where the average wheat productivity was 1,930 kg per ha (CSIA, 2019). It is indicating that wheat productivity is substantially lower throughout the county in comparison to that of the neighboring nations. Hence, farm specific efficiency analysis provides essential insights into growers' potential to improve agricultural yield. Nevertheless, estimating farm-specific efficiency has been a subject of consideration to various empirical studies in the former decades (Coelli *et al.*, 2002; Alene & Hassan 2006; Haji 2007; Ndlovu *et al*., 2014). Majority of the previous researches have been carried out on efficiency estimation rather than making the potential comparison between the technological differences employed in the production process. Therefore, this study aims to assess the current status of TE and determines the factors that limit the level of TE of improved wheat varieties (IWV) users and traditional wheat varieties (TWV) users, in the Southeast of Afghanistan.

2. Study area, data and descriptive statistics

This study is documented on cross-sectional household-level data. A two-stage random sampling procedure is used to collect primary data for Ahmad Aba and Said Karam districts of Paktia Province, 2020. The stud area is chosen for its appropriate soil conditions, high frequency of wheat cultivation, and higher awareness level of farmers from the modern agricultural technology perspective. Consequently, five villages have been selected from each district, and a well-structured questionnaire is used to collect the relevant information to measure TE for improved and traditional wheat growers separately. Nevertheless, 95 improved wheat seeds users and 140 traditional wheat seeds users are selected to sum up a total of 135 respondents in the study area. It is worth noticing, that the field survey has been covered production attributes, socio-economic factors, and farm-specific variables.

Table 1 specifies the study data that has been used in estimating the stochastic frontier production function and technical inefficiency model. The result shows that average output under improved wheat varieties production function is 1235.79 kg, this amount of output is produced with 0.46 ha of land, 9.88 man-day labor, 54.16 kg of seed, 29.43 kg of fertilizer, 2.83 liters of agro-chemical, and 8471.52 AFN of equipment capital. Nevertheless, the average difference in output and inputs is in favor of the null hypothesis inferring that the mean difference in output and inputs are not statistically significant between the two groups of study.

The descriptive result reveals that sampled farmers are middle-aged, where the average age for improved and traditional seeds users is 42 and 44 years old, respectively. Also, the majority of farming households are male-headed. Also, the result reveals that the sampled farmers have low education levels, whereas the improved seeds users have more years of schooling compared to that of the traditional ones, and the mean disparity between the two groups is statistically significant at 1% alpha level. It is implying that education has assisted farmers to adopt IWV.

Also, the average household size is significantly varying between the two groups. Thereby, smaller households are more likely to adopt IWV, and it can infer that most of the larger households are growing wheat for subsistence purposes, hence they are risk-averse in adopting new technology. Also, it is evident from the descriptive statistics that on average, 49% of the improved seed users have accessed extension visits, which is significantly higher compared to 19% of the traditional ones. The result is concluding that technical knowledge is a prerequisite for the successful adoption of seeds technology.

Table 1: Descriptive statistics and variables description used in SFA and inefficiency model

Variable	Variables Description	Traditional (140)		Improved (95)		Difference	p-value
		Mean	SD	Mean	SD		
Production function variables (135)							
Output	Total wheat production of a farm (kg)	1235.79	572.65	1214.43	582.10	21.36	0.680
Land	Farm size under wheat cultivation (ha)	0.46	0.16	0.46	0.16	0.00	0.822
Labor	Total number of labor (man day/ha)	9.88	6.14	9.77	5.97	0.11	0.837
Seed	Amount of wheat seeds applied (kg/ha)	54.16	29.01	54.86	29.41	-0.70	0.782
Fertilizer	Amount of fertilizer applied into wheat (kg/ha)	29.43	26.53	30.33	27.16	-0.90	0.698
Chemical	Amount of agro-chemical applied (lit/ha)	2.83	5.06	3.09	5.02	-0.26	0.555
Equipment	Equipment purchased for wheat growing [a]	8471.52	6084.89	8616.6	6496.89	-145.13	0.790
Technical efficiency model variables (135)							
Age	Age of the household head (year)	44.54	30.05	42.73	14.22	1.81	0.405
Education	Number of years of schooling	1.86	3.07	3.10	3.87	-1.24	0.000***
Gender	1 if farmer is male, 0 otherwise	0.72	0.45	0.71	0.45	0.01	0.919
HH size	Number of persons living in a family	25.90	11.93	23.93	12.04	1.97	0.045**
Off- farm Income	Income earned from non-agricultural sources (AFN)	1161.86	428.78	1190.30	438.40	-28.44	0.477
Member	1 if farmer is cooperative member, 0 otherwise	0.36	0.48	0.35	0.48	0.01	0.773
Extension	1 if farmer access extension, 0 otherwise	0.19	0.39	0.42	0.49	-0.23	0.000***
land plots fragments	Number of plots allocated for wheat cultivation	2.25	1.05	2.24	1.03	0.01	0.930
Land Quality	Land response to yield on Likert-scale from 1 to 5 (1 is best, and 5 is worst)	2.64	1.36	3.00	1.25	-0.36	0.003**

*, **, *** Significance at 10%, 5%, and 1% alpha level.
Source: authors' survey, 2020

Note: all value of the variable used in the CDPF are documented here as actual value before the logarithmic transformation.

[a] Monetary value are in Afghanistan local currency (AFN), the national currency, where 1 USD equivalent to 76 AFN in 2020.

3. Analytical tools

3.1. Stochastic frontier analysis

The stochastic frontier production function was used to analyze technical efficiency for the two groups of IWV and TWV separately. In this study, the stochastic frontier production function is used which is developed by AIGNER, *et al.*, (1977), the general structure of the equation for a cross-sectional model is given as follows.

$$Y_i = f(X_i, \beta) Exp(V_i - U_i), i = 1, \ldots, N \quad (1)$$

Where, Y_i indicates the yield produced on the i^{th} plot, X_i reveals a vector of production inputs employed on the i^{th} pattern, and β is a vector of unknown parameters to be estimated. V_i indicates the random component and pertaining all the factors that are out of the farming household control. Finally, U_i indicates a random variable pertaining technical inefficiency in the production process, and U_i has an independent and normal distribution, σ_v^2 ($|N(\mu_i, \sigma_u^2)|$), where

$$\mu_i = \delta_0 + \sum_{m=j}^{N} \delta_{mi} Z_{mi} \quad (2)$$

Here, Z indicates a vector of farm-related characteristics that influences production inefficiency, and δ_i presents the study parameters to be estimated.

The SPF analysis is carried out for the maximum attainable output. The general structure of the model is given as follows.

$$TE = Exp[\frac{E(u)}{\varepsilon}] \quad (3)$$

Here, TE refers to the potential of a farmer that could produce relative to maximum output given a particular amount of inputs and production technology. This approach has been used by various empirical studies to estimate technical efficiency and analyze the factors affecting the inefficiency of farmers (Gimbol *et al.*, 1995; Abrar Suleiman, 1995; Getu Hailu, *et al.*, 1998; Aigner *et al.*, 1977; Bakucs *et al.*, 2014; Battese and Corra, 1977; Elrashid *et al.*, 2013; Farrell, 1957; Ferit, 2013; Kalirajan and Shand, 1989; Kutala, 1993; Meeusen and Van Den Broeck, 1977; Parikh and Shah, 1994; Reddy and Sen, 2004; Sharma and Datta, 1997; Taylor and Shonkwiller, 1986).

Aigner *et al.*, (1977) has been used a stochastic frontier approach, and arguing that the noise term has two elements, $\varepsilon i = vi + ui$. Where, vi represents the uncontrollable symmetrical disturbance, such as measurement errors, probable shock, and statistical error. Though, vi is assumed to be independently distributed as $vi \sim N(0, \sigma 2)$. On the other hand, ui is a non-negative error term representing the technical inefficiency of the farmers, and assumed to be independent of vi . Moreover, as mentioned ui is a non-negative error component, inferring that the output of each observation ought to be situated on or below the production frontier (Battese and Broca, 1997). Nonetheless, variance terms given in the estimation of the stochastic production frontier model are clearly defined as bellow in equation (4) and equation (5).

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \quad (4)$$

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2} \quad (5)$$

It is worth noticing that equation (1) defines only the availability of inefficiency, while rest of the empirical modeling is not specified. Hence, in most of the empirical studies two distinctive approaches have been used to estimate the stochastic frontier production model, that include two-steps SF estimation, and single-step SF estimation approach. In the former one, the initial step is to estimate the stochastic production frontier in order to predict farm level technical inefficiency using Equation (1). In the second stage, a regression analysis is conducted employing Equation (2). Nevertheless, the two-steps estimation is associated with serious problems (BATTESE AND COELLI, 1995; KUMBHAKAR *et al.*, 1991). Some of the problem arising from two-steps estimation that includes the probability of correlation between inputs and technical inefficiency; moreover, as the technical inefficiency is one-sided, hence OLS estimation might not be reasonable; in addition, as the inefficiency (u_i) estimates should be non-negative, thereby in the second step the interpretation of the residual term is imprecise (KUMBHAKAR *et al.*, 1991). Eventually, in this study we used a direct or single-step approach to estimate stochastic production frontier and inefficiency models, simultaneously. In this approach, the exogenous factors influencing technical inefficiency are incorporated directly into the PF, where it is specified as follows.

$$Y_i = f(X_i, Z_i, \beta)\exp(V_i - U_i) \quad (6)$$

It is evident from the above Equation (6), that the variables are categorized into two distinctive clusters: the production inputs related variables (X_i), and the inefficiency attributes (Z_i).

3.2. Empirical study models

The parameters of SF production function (equation 1), and the attributes of technical inefficiency (equation 2) are estimated simultaneously with the Maximum-Likelihood Estimation (MLE) employing the statistical package Frontier 4.1 (COELLI, 1996). The general form of translog production function is identified as:

$$\ln(Y_i) = \beta_0 + \sum_{k=1} \beta_k \ln(X_{ik}) + \frac{1}{2} \sum_{k=1} \sum_{j=1} \gamma_{jk} \ln(X_{ij}) \ln(X_{ik}) - U_i + V_i \quad (7)$$

$$U_i = Z_i \delta + \omega_i \quad (8)$$

Where, Y_i is the logarithm of the value of output, X_i presents the logarithm of the value of production function inputs. The inefficiency attributes are presented by Z_i (the description of study variables is given in the preceding Table 1).

4. Result and discussion

The Cobb-Douglas stochastic frontier and technical inefficiency models are estimated jointly, and the results are presented in Table 2. The stochastic production frontier estimates indicate that all of the explanatory variables are directly related to the output and statistically significant under the improved wheat varieties model. On the traditional model side, land, labor, seeds, fertilizer, chemical and equipment are found to be positive and significant, while agrochemical are inversely related to wheat production. The negative coefficient of the chemical is indicating that its response to yield is poor in the study area. Perhaps the growers use improperly or overdoses of the chemical, hence the production is adversely affected by it.

Furthermore, return to scale documents economies of scale (for both categories), it is denoting that the duplication of output per acre would need less than doubling of the production inputs; implying that currently, farmers are inefficient in resource utilization, hence the production can be enhanced with more proper use of current resources and technology. Moreover, gamma γ (ratio of the variance of technical efficiency to the total variance of output) measures the contribution of the noise with respect to the model errors. Gamma value for improved and traditional model is estimated at 0.79 and 0.84, respectively; it is indicating that 79% and 84% of the difference between the observed and frontier yield is primarily due to the management of available resources.

Table 2: Maximum likelihood estimates of the stochastic production frontier and technical inefficiency model for improved and local wheat varieties

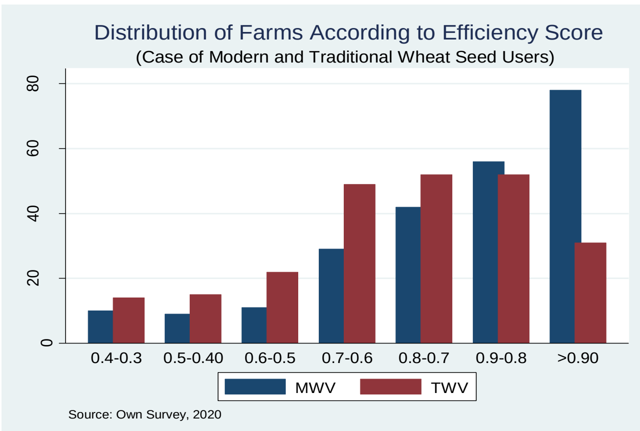
Variable	Parameter	IWV Coefficient	IWV Standard-error	IWV t-ratio	TWV Coefficient	TWV Standard-error	TWV t-ratio
SF function estimates							
Output		7.67	0.24	31.96***	7.41	0.04	185.25***
Land	β_1	1.23	0.04	30.75***	1.18	0.02	59.00***
Labor	β_2	0.17	0.02	8.50***	0.19	0.01	19.00***
Seed	β_3	0.01	0.02	0.50***	0.03	0.01	3.00***
Fertilizer	β_4	0.001	0.001	1.00***	0.001	0.001	1.00**
Chemical	β_5	0.001	0.001	1.00***	- 0.001	0.001	-1.00***
Equipment	β_6	0.04	0.02	2.00***	0.05	0.01	5.00**
Inefficiency estimates							
Age	δ_1	-0.02	0.01	-2.00***	-0.02	0.00	-10.38**
Education	δ_2	-0.20	0.05	-4.00***	-0.12	0.06	-1.99**
Gender	δ_3	0.15	0.14	1.07**	0.33	0.31	1.07
Household size	δ_4	-0.01	0.01	-1.00**	0.03	0.01	2.52**
Off-farm income	δ_5	0.00	0.00	-0.07	0.00	0.00	2.12
Cooperative membership	δ_6	-0.16	0.32	-0.49**	0.23	0.19	1.21
Extension	δ_7	-0.53	0.25	-2.12**	-0.65	0.42	-1.54**
Fragmentation	δ_8	0.16	0.06	2.67**	-0.05	0.14	-0.33
Land quality	δ_9	0.22	0.07	3.14***	0.79	0.22	3.61**
Variance parameters							
Sigma-squared	σ^2	0.30	0.05	6.00	1.83	0.50	3.69
Gamma	γ		0.79			0.84	
Log-likelihood function			42.40			-13.42	
Mean technical efficiency			0.78			0.72	

Note: ***, ** and * are indicating ($p < 0.01$), ($p < 0.05$) and ($p < 0.01$), respectively.

Source: Author's Field Survey, 2020

4.1. Technical efficiency

Table 3 summarize average technical efficiency and the potential output that can be obtained by enhancing the technical efficiency level using the current production inputs and technology. The result shows that TE is ranging from the lowest of 32% to the highest of 96% in the study area. The mean technical efficiency index for IWV and TWV is found to be roughly 78%, and 71%, respectively. Also, the study findings are consistent with that of our pre-expectation that IWV is technically more efficient.



Njeebullah Tota Khail (2016) conducted a study who has documented the mean technical efficiency for wheat farmer 64% in Paktia, Afghanistan. The study result is implying that on average the improved and traditional farmers are operating only 22%, and 29% below the production frontier, respectively. In spite of the moderate TE level, there is still more room for enhancing the technical efficiency of farms, whereas per hectare the potential output can be increased by 348.6 kg for IWV and 342.5 kg for IWV without additional inputs through more efficient use of current resources and technology.

Table 3. Characteristics of TE between improved and traditional models

Efficiency characteristics	IWV	TWV	Difference
Average TE (%)	0.78	0.71	0.07***
Maximum TE (%)	0.96	0.95	0.01
Minimum TE (%)	0.32	0.35	-0.03
Actual average output (kg/ha)	1,235.8	1,214.4	21.4
Potential output (kg/ha)	1,584.4	1,556.9	27.4
Potential increment in output (kg/ha)	348.6	342.5	6.03

Source: Study data, 2020

In figure 1, we provide a comparable frequency distribution of farms according to their technical efficiency scores. Clearly it can be observed that about 78 of improved and only 31 of traditional growers are operating above 90% efficiency level. Also, about 29 of traditional and a higher proportion (49) of improved wheat farmers are ranged between 0.7 and 0.6 TE level. As a whole, the result is concluding that a considerably higher percentage of improved seeds users are approaching closer to the production efficiency frontier compared to that of the traditional seeds users.

4.2. Technical inefficiency

Age is used as a proxy for learning-by-doing and farmers' experience in wheat-growing. Furthermore, the result is in favor of the alternative hypotheses that there is an indirect relationship between inefficiency and age of household head. Obviously, as the age of farmers' increases inefficiency diminishes, but up to a certain point of age, after that inefficiency and age are directly related to each other. The study result is in line with Msuya, Hisano and Nariv (2008); Shafiq and Rehman (2000); and Amos (2007) stating that as farmers grew older, they gain more experience and leads to being more efficient in farming.

With respect to the household size, the coefficient is negative and significant only for MWV, while it is contrasting in its effects regarding the TWV model. The result is indicating that households with fewer members are more technically efficient than those with more members in growing TWV, possibly because, larger families exert pressure on the limited cash resources accessible to the farming household. The result is consistent with the findings of Mango *et al.*, (2015) stating that household size has a negative effect on farmers' TE.

The coefficient of membership in cooperative is negative and significant for improved wheat farmers, whereas it is positive and non-significant under the improved seeds model. The negative effects of the agricultural cooperative on technical inefficiency suggest that farmers involved in farmers' groups are more efficient than the non-member. Probably, those farmers who has membership in agricultural cooperatives are more likely to receive valid information regarding efficiency-enhancing technologies via farmer networks. The study finding is in line with Tessema *et al*., 2016, stating that well-functioning farmer networks enhance technology diffusion among farming communities and lead to obtaining higher TE.

We found a similar result with Sibiko (2012); Olarinde (2011); Obwona (2000); Seyoum, Battese and Fleming (1998) that extension services have a negative and significant influence on technical inefficiency for both study cases. Idiong (2007) also observed a similar result, and asserting that the informal teaching and learning process contributes to farmers in upgrading their technical knowledge, therefore positively impacts their production efficiency. On the other hand, various empirical studies have documented that access to extension does not influence farmer technical inefficiency significantly (Omondi and Shikuku 2013; Oladimeji and Abdulsalam, 2013; Alemu et al. 2009).

The coefficient of land quality highlights that the estimate is inversely related to technical inefficiency for both study models. The result is necessitating appropriate land quality to get maximum output with current production inputs and technology. On the other hand, having fertile soil, and not getting the full benefit out of it is negatively influencing technical efficiency.

5. Conclusion

The study used a single-step estimation of stochastic production frontier and inefficiency models, simultaneously. Moreover, a comparison is made between improved and traditional wheat farms in the two districts of Paktia, Afghanistan. The mean technical efficiency is found to be 78% and 71% for improved and traditional wheat varieties farmers, respectively. Hence, the potential to increase production by improving technical efficiency is roughly 345 kg per hectare. Nonetheless, the difference in mean technical efficiency between the two models is statistically significant. Whereas, the improved seeds users are more likely to be closer to the production frontier. Moreover, on average inputs response to yield is higher (more elastic) in the improved model in comparison to that of traditional ones. The result is implying that modern seeds shifts the production frontier outwards in the study area. Besides, return to scale is increasing for both scenarios, hence doubling the inputs can give more than double of the production. The required interventions for enhancing production efficiency in the study area, that includes: provision of training for farmers to improve their skills, on-field agronomical practices and water management. Moreover, an increase in output by enhancing efficiency is limited for traditional farmers in comparison to that of the modern farmers. Hence, the adoption of improved seed varieties may push the production frontier upward, whereas a good combination with other inputs is expected. Eventually, in the future further studies can be carried out on scale and cost efficiencies in the study area, to provide more comprehensive implications for policymakers and other relevant stakeholders.

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