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Technical efficiency of wheat farmers and options for minimizing yield gaps in Afghanistan

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Abstract

Afghanistan is a net importer of wheat which is the staple food in the country. In order to improve the levels of food sufficiency, prevailing large yield gaps in wheat need to be reduced. This study assessed the reasons/factors influencing low wheat productivity and/or large yield gaps in different production systems in five major wheat-producing provinces in Afghanistan using a stochastic frontier production function model. The results indicated that the mean technical efficiency of wheat farmers was 0.67, and there was clear scope to improve wheat production by 33% in the short run with the same level of inputs. The potential yield gap could be reduced if adoption of good agricultural practices such as the use of improved wheat varieties with recommended seed rates was promoted through more effective transfer of technologies (training and extension) in the target provinces. Such efforts would help improve domestic wheat production and reduce dependency on wheat imports.

Keywords

Stochastic frontier production function, wheat, yield gap

Introduction

Wheat is the staple cereal crop and accounts for 82% of total cereal consumption in Afghanistan. For the last 15 years, wheat production has been growing at 7.3% per annum (compound growth rate (CGR)) driven primarily by the introduction of high yielding varieties and enhanced input efficiency. In spite of this growth, there is still significant deficit in overall food grain production and in wheat in particular resulting in food insecurity. On average, the country imports 30–35% of wheat to meet its domestic consumption food demand. As reported in the Statistical Year Book of Afghanistan (2011–2012), the annual cereal demand was 6.3 million tons (mt) including the wheat demand for 5.18 mt. Wheat is grown under both irrigated and rainfed conditions in Afghanistan. Irrigated wheat covers around 52% of the total wheat area, amounting to 91% of the total wheat production, that is, 3.07 mt. Conversely, rainfed wheat covers 48% of the area and contributes only 9%, that is, 0.3 mt of total wheat production. Overall, average wheat productivity is low in both irrigated (2.65 t ha⁻¹) and rainfed (0.298 t ha⁻¹) systems. Wheat production is more productivity driven rather than area driven as evident from the annual CGRs of wheat area (2.5%), production (6.9%) and yield (4.2%) between 2001 and 2013. Yield gaps are much wider in the rainfed than irrigated systems. Therefore, efforts to minimize the yield gap would help in enhancing food self-sufficiency and food security for poor

households in Afghanistan. In spite of concerted efforts from public and international research and development organizations, the dissemination and adoption of improved wheat varieties and associated good agricultural practices have not been promoted as much as would have been expected. Regional studies show low seed/variety replacement as one of the major reasons for low wheat yields in South Asia (Ortiz Ferrara et al., 2007; Rizvi et al., 2012; Srinivas et al., 2010; Thapa et al., 2009).

Therefore, the focus is on identifying the major constraints to wheat productivity and the poor levels of technology dissemination. Documentation of constraints will help in future policy planning, prioritizing technological interventions and identifying the need for agroecology-specific improved varieties. This study was planned to assess the efficiency of wheat farms in Afghanistan and

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to document the factors influencing their efficiency. The major priorities of the survey included identifying the efficiency levels of wheat farmers in different production systems, the factors influencing efficiency levels and then prioritizing the technological interventions/good agricultural practices needed to reduce yield gaps in different provinces. The study was conducted in the major wheat growing provinces including Baghlan, Balkh, Bamyan, Nangarhar and Takhar, which collectively contribute nearly 25% of total wheat production both under irrigated (0.30 million ha) and rainfed (0.25 million ha) areas, respectively, and produce 0.90-mt wheat (Central Statistics Organization, 2012).

Methodology

Stochastic frontier production function

In this study, the stochastic frontier production function approach was used to estimate the production function and measure the technical efficiency (TE) of wheat farms in different production systems. TE for each farm can be calculated as follows:

$$TE = \text{Exp} \left[\frac{E(u)}{\varepsilon} \right]$$

A number of studies (Aigner et al., 1977; Bakucs et al., 2014; 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 Shonkwiler, 1986) have carried out this approach to estimate TE and to determine the factors that influence the efficiency of farmers in the agricultural sector. These studies have identified the determinants of TE by regressing the predicted efficiencies obtained from an estimated stochastic frontier on a number of farmer-specific factors, such as age, level of education and land ownership. TE identifies the most efficient producers and measures the performance of other producers accordingly. A technically efficient farmer is one who is adopting good agricultural practices. Thus, TE is the ratio of actual production to the maximum possible production given the level of inputs used. Using the data collected, the following stochastic frontier production function [equation (1)] and the technical inefficiency effects defined in the model [equation (2)] were estimated as follows:

$$\ln Y_i = \beta_1 + \beta_2 \ln K_i + \beta_3 \ln L_i + \beta_4 \ln SR_i + V_i - U_i \quad (1)$$

$$U_i = \delta_1 + \delta_2 \ln FS_i + \delta_3 \ln W_i + \delta_4 \ln WR_i + \delta_5 \ln Age_i + \delta_6 \ln TAS_i + \delta_7 VD_i + \delta_8 LOD_i + \delta_9 ED_i + \delta_{10} PSD_i \quad (2)$$

where

Y_i = Wheat yield (t ha⁻¹) for i th farm per hectare.
 β_1 = Constant.

K_i = Amount of capital used for inputs other than labour and seed per hectare of wheat cultivation by i th farm in US dollar.

L_i = Labour days per hectare by i th farm.

SR_i = Seed rate (kg ha⁻¹) used by i th farm.

Variables used in the inefficiency model are as follows:

FS_i = Family size (number of persons) of i th farmer.

W_i = Total wheat area in hectare cultivated by i th farm.

WR_i = Ratio of wheat area to total cultivated area by i th farm.

Age_i = Age of i th farmer.

TAS_i = Technology adoption score for i th farm in wheat cultivation.

VD_i = Dummy variable that captures the use of improved variety of wheat by i th farm ($VD = 1$, if the farmer uses improved wheat variety, 0 otherwise).

LOD_i = Dummy variable that captures the ownership of wheat land by i th farm ($LOD = 1$, if wheat is cultivated in owned land, 0 otherwise).

EDU_i = Dummy variable that captures the education level of i th farmer ($EDU = 1$, if the farmer is literate, 0 otherwise).

PSD_i = Dummy variable that captures production system in which wheat is cultivated by i th farmer ($PSD = 1$, if wheat is cultivated under irrigated production system, 0 otherwise).

V_i = Symmetric component of error term which captures randomness outside the control of the farmer such as droughts and floods.

U_i = Non-negative random variable which is under the control of farmer.

Data collection

Purposive and multistage random sampling methods were adopted to collect the information on the identified variables from the target provinces where the International Center for Agricultural Research in the Dry Areas project activities were planned. Dahaneh-ye Ghowri and Puli Khumri districts in Baghlan; Kholm in Balkh; Rodat in Nangarhar; Punjab and Yakawlang in Bamyan and Taloqan in Takhar were the districts from which data was collected. Two hundred randomly selected farmers from five pre-selected provinces (about 40 farmers in each province) were selected from the districts and villages due to reasons of security and accessibility and then surveyed to estimate the TE of wheat production. A structured and pretested questionnaire was used to collect the information from the farmers on selected variables in both irrigated and rainfed production systems. About 33 farmers in these provinces have been cultivating wheat both in irrigated and rainfed production systems. Thus, there are about 150 and 116 farmers cultivating wheat in irrigated and rainfed production systems, respectively, in the total sample size.

The data on agricultural output and inputs, such as seed, fertilizer, labour and prices; other explanatory variables,

Table 1. Summary statistics of variables used in the stochastic frontier production function model for wheat-producing farms in Afghanistan.^a

Variable	Unit	Mean	Maximum	Minimum	Standard deviation
Stochastic frontier production function model					
Wheat yield	Kilogram per hectare	2394.81	8400.00	127.50	1188.56
Capital	US dollar	641.45	1467.00	313.00	182.38
Labour days	Man days	58.59	130.00	25.00	18.04
Seed rate	Kilogram per hectare	135.91	225.00	50.00	31.98
Inefficiency model					
Family size	Number of persons	8.61	14.00	3.00	2.61
Wheat area	Hectare	2.32	40.00	0.08	3.63
Total cultivated area	Hectare	4.40	54.00	0.10	6.26
Ratio of wheat area to total cultivated area	Number	0.63	1.00	0.08	0.31
Age	Years	49.55	89.00	20.00	12.17

^aAuthor calculations from survey data in 2013.

such as wheat area, total cultivated area, land ownership and variety (improved and local) of type used in wheat cultivation in different production systems; socioeconomic (literacy level, age of farmers and family size) and institutional variables such as extension contacts were collected for the 2012–2013 wheat season. **AQ1** Technology adoption score for each farmer was estimated using average weights for different technologies collected from scientists with experience in wheat breeding and management practices. Scientists were asked to give weights/score (0 to 1 scale) based on the effect of technologies like variety, planting month, seed rate, recommended dose of urea and diammonium phosphate (DAP) on the yield of wheat. If a farmer used a higher or lower than recommended seed rate, the technology adoption score for that farmer for that technology was zero. The cumulative score (the score/weight allocated by scientists) for all the technologies adopted correctly only was considered to determine the technology adoption score. This is not captured in variable K_i . Based on the practices followed in wheat cultivation, technology adoption score was calculated for each farmer. Capital in wheat cultivation is the monetary value of different inputs used in wheat production estimated using input prices. Summary statistics of variables used in the efficiency and the inefficiency models such as mean, minimum, maximum and standard deviation were estimated.

Results and discussion

Summary statistics for all the variables in the empirical model (Table 1) showed high levels of variability as evident from their high standard deviation. It also provides an indication on the extent of differences in the use of inputs in wheat production among sample farmers.

Cobb–Douglas production function and marginal effects

The maximum likelihood estimates of the parameters of the Cobb–Douglas stochastic frontier production function and TE models were generated using Frontier version 4.1 software (Coelli, 1996). Parameter estimates together with

their corresponding standard errors and *t*-ratios are presented in Table 2. As the estimate for the variance parameter ($\gamma = 0.83$) was significantly different from zero implying that the inefficiency effects are significant in determining the level and the variability of wheat-producing farms, and therefore, output-oriented TE is important in explaining total variability of output produced. The remaining portion (0.17) arises from factors outside the control of the farmer (diseases, floods and weather).

The analysis through estimated model indicated that wheat production exhibits increasing returns to scale (1.23). The expected values of the logged coefficients are 1.26 for capital and -0.68 for labour. The sum of two coefficients was 0.58 indicating that wheat production would expand by more than half with respect to the capital and labour marginal productivity analysis. Capital included the monetary value of all inputs other than seed and labour used in wheat production. Capital is more productive than labour as seen from their respective coefficients that are significant at 1% level. Positive and negative marginal productivity of capital and labour, respectively, signifies the fact that wheat farms in the target provinces should adopt more of capital intensive techniques with less labour involvement in order to maximize wheat production in the target provinces. The data analysis concludes that farmers should stop using more labour for carrying out different farm operations in wheat production, as marginal productivity of labour is negative (-0.68). This is due to excess use of family labour on account of no alternative employment opportunities. A similar study to investigate the efficiency of wheat and faba bean production in the Northern State of Sudan by Ali et al. (2012) reported that both capital and labour were significantly enhancing wheat production. Elrashid et al. (2013) revealed that capital, seed rate and fertilizer were significantly enhancing wheat production in Northern State of Sudan.

Similarly, seed rates also have a significant influence at 1% level on wheat productivity. Farmers used an average seed rate of 151 and 116 kg ha⁻¹ in irrigated and rainfed production systems against the recommended seed rate of 140 and 70 kg ha⁻¹, respectively. The difference between actual seed rate and recommended seed rate used in both

Table 2. Parameter estimates of the production function and inefficiency model.^{a,b}

Parameter	Coefficient	Standard error	t Ratio	Significance
Production function				
Intercept (β_1)	-0.39	0.71	-0.55	
Capital (β_2)	1.26	0.12	10.91 ^c	
Labour (β_3)	-0.68	0.11	-6.30 ^c	
Seed rate (β_4)	0.65	0.11	6.02 ^c	
Inefficiency model				
Intercept (δ_0)	0.88	0.141	6.22 ^c	0.000
Family size (δ_1)	-0.06	0.031	-1.99 ^d	0.047
Wheat area (δ_2)	0.05	0.010	4.79 ^c	0.000
Ratio of wheat area to total cultivated area (δ_3)	0.04	0.014	2.43 ^c	0.016
Farmer's age (δ_4)	-0.03	0.036	-0.93	0.351
Technology adoption level (δ_5)	0.001	0.003	0.36	0.721
Variety dummy (δ_6)	0.04	0.019	2.35 ^d	0.020
Land ownership dummy (δ_7)	-0.02	0.024	-0.74	0.457
Education dummy (δ_8)	0.02	0.018	0.88	0.381
Production system dummy (δ_9)	0.12	0.024	5.13 ^c	0.000
Sigma squared (σ^2)	0.40	0.05	7.91 ^c	
Gamma (γ)	0.83	0.05	17.47 ^c	
Log-likelihood function	-146.68			

^aCalculated by authors from field survey data (2013).

^bDependent variable is the natural logarithm of the wheat yield (kg ha⁻¹)

^cSignificance at 1% level.

^dSignificance at 5% level.

production systems was significant ($p = 0.001$), indicating real disparities between farmers all of whom used excess quantities of seed. Rainfed wheat farmers have been using on an average 166% more seed, while irrigated wheat farmers are using on an average 108% more seed than recommended. This implies a risk aversion behaviour of farmers to ensure good plant stand and survival. Elrashid et al. (2013) and Amin et al. (2007) **QAQ2** reported similar results that farmers usually practice more seed rate than recommended. Excess cost for the seed over and above the recommended seed in both production systems increases the total cost of wheat production. Farmers apply both urea and DAP in irrigated and rainfed wheat. However, farmers were using only 82 and 64% of the recommended quantity of urea and DAP in irrigated and rainfed systems, respectively. The reason for low fertilizer use is probably due to cost being an expensive input apart from problems such as timely availability of quality fertilizers. Therefore, there is scope to increase the use of fertilizers in wheat production in target provinces if efforts are made to increase its timeliness and availability.

Technical inefficiency model

Effects of the explanatory variables on the TE of wheat farms were captured in the inefficiency model. Four variables in the regression equation (family size, wheat area and variety and production system dummies) are statistically significant at different significance levels (1 and 5%). Positive and significant coefficient associated with variety type indicated that the use of improved variety decreased the TE which is not on par with theoretical expectations. It is not the improved variety alone that can contribute in increasing TE; farmers should also adopt associated

agronomic management practices which only then can improve the TE of the farmer. Only 33% farmers in the irrigated production system and 10% of rainfed wheat farmers used improved wheat varieties in the target provinces whose technology adoption score was less than 0.8. This highlights the possibility of increasing the TE through the use of improved wheat variety and the associated agronomic practices. The TE is negatively affected by the farmer's family size. This means that a farmer with a small family size can pay more attention to wheat farms to enhance TE. The TE of wheat farms in the target provinces decreased with increase in wheat area as evident from the positive and significance of the coefficient associated with wheat area. Average wheat area is more for rainfed wheat farmers (3.97 ha) whose TE was less (0.64) compared to irrigated wheat farmers (1.05 ha) with TE of 0.70. Thus, farmers can pay more attention when wheat farms are small in the target provinces.

The average land holding size of sample wheat farms was only 2.32 ha, while total cultivated area was 4.4 ha. Farmers use major share of their cultivable holding (63% of total cultivated area) for wheat cultivation in the target provinces. It is interesting to reveal that proportion of wheat area in the total holding size is more in rainfed production system (70%) compared to irrigated production system (58%). This indicates that farmers were using land for other crops (vegetables) in addition to wheat under the irrigated production system, while in the case of the rainfed production system, farmers have been cultivating a larger area under wheat due to lack of sufficient alternative options. However, the positive and significant coefficients for the production system dummy indicate that TE decreases when farmer cultivates wheat under irrigation which is against theoretical expectation. This is probably

Table 3. Distribution of TE groups based on production system.

TE groups	Number of farms	Mean TE	Actual yield ^b (t ha ⁻¹)	Potential yield ^a (t ha ⁻¹)	Potential yield gap (t ha ⁻¹)	Yield gap (%)
Irrigated wheat farms						
< 0.4	4	0.33	1.01	2.85	1.84	183
0.41–0.50	5	0.45	1.28	2.77	1.49	117
0.51–0.60	22	0.56	2.07	3.68	1.61	78
0.61–0.70	43	0.66	2.63	3.98	1.35	51
0.71–0.80	40	0.75	3.25	4.33	1.08	33
0.81–0.90	35	0.85	4.01	4.70	0.69	17
> 0.91	1	0.93	8.4	9.01	0.61	7
Overall	150	0.70	2.99	4.16	1.18	39
Rainfed wheat farms						
< 0.4	10	0.25	0.65	2.65	2.00	308
0.41–0.50	13	0.44	1.05	2.37	1.33	127
0.51–0.60	19	0.56	1.22	2.18	0.96	78
0.61–0.70	23	0.67	1.44	2.16	0.72	50
0.71–0.80	31	0.75	2.00	2.65	0.65	32
0.81–0.90	19	0.84	2.52	3.00	0.48	19
> 0.91	1	0.91	2.8	3.09	0.29	10
Overall	116	0.64	1.63	2.51	0.87	54
All farms						
< 0.4	14	0.27	0.75	2.71	1.95	260
0.41–0.50	18	0.45	1.11	2.48	1.37	124
0.51–0.60	41	0.56	1.68	2.99	1.31	78
0.61–0.70	66	0.66	2.22	3.35	1.13	51
0.71–0.80	71	0.75	2.71	3.60	0.89	33
0.81–0.90	54	0.85	3.48	4.10	0.62	18
> 0.91	2	0.92	5.60	6.05	0.45	8
Overall	266	0.67	2.39	3.44	1.04	44

TE: technical efficiency.

^aPotential yield is the estimated yield from the frontier production function.

^bActual yield is the observed yield.

due to the fact that irrigated wheat farmers did not practice a recommended irrigation schedule resulting in the decreased TE.

Factors influencing TE

The average TE of wheat farmers in the study area was 67%, indicating that it was possible to increase wheat production by 33% through improvements at the farm level with the same amount of inputs in the short run. TEs varied between 13% (rainfed wheat farm) and 93% (irrigated wheat farm). The highest TE was recorded in an irrigated production system that is consistent with the theoretical expectation. The average TE of irrigated wheat farms was 70% compared to 64% for rainfed farms in the target provinces. The average technology adoption score in irrigated wheat farms was 0.42 compared to 0.25 for the rainfed wheat farms. The coefficient associated with technology adoption score was positive although not significant in the inefficiency model.

The potential yield gaps (yield gap as a percentage over observed yield) due to technical inefficiencies are substantial with 54% in irrigated wheat farms compared to 39% in rainfed farms. It is high for the farms with a low TE range. It is 260% for farms which are in the 0.0–0.40 range and 124% for the farms in the 0.4–0.5 TE range. This gap is noticeably different for rainfed farms compared to irrigated farms. It is 308 and 127% for rainfed farms which are in the

0.0–0.40 range and 0.40–0.50 range, respectively, while it is 183 and 117% for irrigated farms in the same TE range (Table 3). The positive coefficient for the variable indicates that the variable is reducing the TE of the farmer. However, in the inefficiency model, the coefficient for the technology adoption score was non-significant. The potential yield gap of 1.04 t ha⁻¹ can be reduced if farmer technology adoption is increased with the same level of inputs through effective transfer of technologies (training and extension activities) in the target provinces.

As evident from Table 4, the TE was high for farmers who participated in training given by different NGOs [AQ3] on good agricultural practices in wheat and having extension contacts; this can be observed in both production systems. Similarly with the increase in the TE, the average technology adoption score for farmers in the same TE range also increases. The average technology adoption score for farmers with a TE less than 0.4 was 0.24, while it was 0.55 for farmers in the TE range of 0.81–0.90. The proportion of farmers having an extension contact also increased with an increased range in TE.

Finally, the methodological limitations in using stochastic frontier production function need to be recognized. These include the maximum likelihood does not allow assessing the reliability of inferences in small samples; the absolute level of TE is quite sensitive to distributional assumptions, but rankings are less sensitive; an assumption regarding to a specific functional form of stochastic frontier

Table 4. Distribution of TE groups and the technology level and linkages with extension and participation in training.

TE groups	Number	Mean TE	Technology adoption score	Farmers participated in trainings (%)	Farmers with extension contact (%)
Irrigated wheat farms					
< 0.4	4	0.33	0.10	25	25
0.41–0.50	5	0.45	0.36	0	0
0.51–0.60	22	0.56	0.32	14	32
0.61–0.70	43	0.66	0.23	12	21
0.71–0.80	40	0.75	0.46	15	30
0.81–0.90	35	0.85	0.68	20	31
> 0.91	1	0.93	0.9	100	100
Overall	150	0.70	0.42	15	27
Rainfed wheat farms					
< 0.4	10	0.25	0.30	40	40
0.41–0.50	13	0.44	0.31	23	31
0.51–0.60	19	0.56	0.16	11	32
0.61–0.70	23	0.67	0.23	9	17
0.71–0.80	31	0.75	0.25	19	32
0.81–0.90	19	0.84	0.30	16	53
> 0.91	1	0.91	0.00	0	0
Overall	116	0.64	0.25	17	33
All farms					
< 0.4	14	0.27	0.24	36	36
0.41–0.50	18	0.45	0.32	17	22
0.51–0.60	41	0.56	0.25	12	32
0.61–0.70	66	0.66	0.23	11	20
0.71–0.80	71	0.75	0.37	17	31
0.81–0.90	54	0.85	0.55	19	39
> 0.91	2	0.92	0.45	50	50
Overall	266	0.67	0.34	16	30

TE: technical efficiency.

is required *a priori*. A wrong choice of production function may influence the results, and the simple production frontier model does not permit the prediction of the TEs of agribusinesses that produce multiples outputs.

Conclusion

The study indicated that TE of wheat farms increased when farmers used recommended agricultural practices in different production systems in wheat. Potential yield gap can be reduced with the same level of inputs if the farmers' technology adoption is increased through effective transfer of technologies (training and extension activities) in the target provinces. There is also scope to reduce the excess seed rate and labour used in both production systems which would reduce cost of wheat production substantially. Such efforts could also bring down wheat imports with enhanced domestic wheat production.

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