Technical Inefficiency of Smallholder Wheat Production System: Empirical Study from Northern Ethiopia

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Abstract

This paper estimates the level and determinants of technical inefficiency of wheat producers based on data collected from 320 randomly selected wheat-producing farm households in four districts of Tigray regional state, Northern Ethiopia. Technical efficiency in wheat production was estimated using Cobb-Douglas stochastic production frontier model while a technical inefficiency model was estimated to identify sources of inefficiency. The mean technical efficiency of wheat producers was estimated to be only 57%. Given the present state of technology and input level, the result suggests that there is plenty of scope to increase wheat output (efficiency). The technical inefficiency model results suggest that there is an opportunity to reduce inefficiency in wheat production; and in this regard, farmer education, livestock size, and access to market information were found to have a counter effect on inefficiency. These factors represent human capital, production assets and improved information access for enhanced decision-making capabilities as important areas of intervention to reduce inefficiency. Overall, the results indicate the important role that sources of information and knowledge play in reducing technical inefficiency.

Keywords: Wheat producers, technical inefficiency, Cobb–Douglas, stochastic frontier function
JEL Codes: Q12

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1. Introduction

Cereal production and marketing are the single largest agricultural sub-sector in Ethiopia's economy, providing livelihood means for millions of smallholder households. In Ethiopia, cereals account for roughly 60% of rural employment, 73% of the total cultivated land, more than 40% of a typical household's food expenditure, and more than 60% of total caloric intake (Rashid and Negassa, 2012). Among cereals, wheat is one of the main staple crops in Ethiopia in terms of both production and consumption, which makes the country the second largest producer of wheat in sub-Saharan Africa. At national level, 1.63 million ha of cultivated land was used for wheat production by about 4.84 million smallholder farmers (CSA, 2013).

In Ethiopia, wheat is grown mainly in the highland areas of Oromia, Amhara, Southern Nations, Nationalities and Peoples (SNNP) and Tigray regions (CSA, 2013). Currently, wheat production and marketing has received higher attention by the Government of Ethiopia (GoE) as well as by Non-governmental organizations (NGOs) (EAAPP, 2009). Government support for wheat production and marketing is especially channeled through research and extension on new and improved wheat technologies. As part of this, the country has become a center of research excellence for wheat research in Eastern Africa (EAAPP, 2009).

However, wheat production systems in Ethiopia are riddled with several problems leading to inefficiencies in wheat production and marketing. Among the major problems, significant imperfections in wheat input and output markets, traditional technologies, low labor and land productivity and limited management capability of producers, are particularly recognized (Rashid and Negassa, 2012; Gebreselassie et al., 2017). Despite the wide-ranging obstacles, the most important problem in wheat production systems in Ethiopia is the limited used of improved production technology and the ensuing technical inefficiency (Rashid and Negassa, 2012; Gebreselassie et al., 2017).

In this regard, several studies were conducted to estimate the level of technical efficiency of smallholder farmers in Ethiopia (such as Asmare, 1998; Seyoum et al., 1998; Mohammad et al., 2000; Temesgen and Ayalneh, 2005). These studies showed that there are wide efficiency differences among small-scale farmers in Ethiopia, ranging from 0.39 to about 0.95 (see also Mesay et al., 2013). Such results need to be looked at within the production contexts that may be unique and more localized.

While poorly-functioning wheat markets, use of traditional technologies, low labour and land productivity and poor management capability also characterize dryland wheat production systems in northern Ethiopia, the effect of erratic rainfall in relatively dry and highland areas on wheat production and efficiency may be more pronounced. This is especially true for wheat producing highland but moisture stressed areas in the Tigray Regional State, which is the focus of this study. The study area is characterized by low rainfall, high climatic variability (rainfall and temperature). In a similar context to this, Gebregziabher et al. (2016) argue that farmers in arid and semi-arid highland areas of Amhara Regional State in northern Ethiopia are already experiencing moisture stress leading to shorter growing seasons, lower yields and reduced suitable land for agriculture. Technical efficiency studies in such wheat production contexts are limited. With this in the hindsight, this study aims at contributing to the limited knowledge on production efficiency of smallholder farmers in a such a difficult production environment.

More specifically, this paper contributes to the literature on technical efficiency in two respects. One, this study was based on wheat production systems in moisture stressed highland areas of Ethiopia where unique and localized attributes affect efficiency of wheat production. Wheat production in the dryland parts of Ethiopia involve production systems under water-deficient and less favorable climatic, agro-ecological and bio-physical conditions that are in stark contrast to the production systems considered by previous studies conducted in high rainfall and favorable environmental conditions. Secondly, unlike many previous studies that adopted either parametric or non-parametric approaches, this paper combined parametric with non-parametric methods to assess the robustness of the results. Specific sources of inefficiency that contribute to loss in wheat production in the drylands of northern Ethiopia have been analyzed in this paper.

2. Theoretical Framework and Methods

The main motivation of this study was to measure the technical efficiency of wheat production and explore the responsiveness of wheat yield to different inputs. The observed variations in this responsiveness are modeled from the perspective of differences in the production technology and inputs that are used by farms, differences in the levels of efficiency of the production processes and differences in the context in which production takes place. We describe this responsiveness of wheat yield to inputs and efficiency as follows.

2.1 Stochastic Production Frontier Model and Method

To study efficiency (and from there inefficiency), one of the most widely applied parametric approaches is Stochastic Frontier Analysis (SFA) that follows a defined production function. The model involves a composite error term that accounts both for the statistical noise in the data as well as the inefficiency in production (Coelli, 1995). Any deviation from the efficient frontier (ideal outputs from a given input set at given level of technology) is attributed to both the stochastic disturbance such as errors in measurement, topography, weather and effects of other unobserved and uncontrollable variables, as well as the individual-specific factors that affect inefficiency (Coelli, 1995).

Once the individual inefficiency levels are estimated, the major factors causing the inefficiency can easily be identified from the model. One of the limitations of this parametric method is the imposition of restrictive assumptions about the functional forms of the production function and the distribution of random errors. Nonetheless, SFA has been commonly used for analyzing agricultural efficiency both in developed and developing countries. Greene (2008) provides a detailed and comprehensive discussion of different variants of SFA models.

In this study, a stochastic frontier production function was used to model the efficiency in wheat production. The stochastic frontier production function is specified as:

$$\ln y_i = \beta_0 + \sum_{k=1}^{k} \boldsymbol{\beta}'_k \ln \mathbf{I}_k + v_i - u_i \tag{1}$$

Where y_i represents the yield of the ith wheat producer, $\mathbf{I}_k$ is the vector of inputs, and the $\boldsymbol{\beta}$ is the vector of parameters that must be estimated. Following this, the model estimated has the following form:

$$\ln yield_i = \beta_0 + \beta_1 \ln(\text{land}_i) + \beta_2 \ln(\text{DAP}_i) + \beta_3 \ln(\text{UREA}_i) + \beta_4 \ln(\text{seed}_i) + \beta_5 \ln(\text{ploughing}_i) + \beta_6 \ln(\text{weeding}_i) + \text{v}_i - u_i \quad \textbf{(2)}$$

where $\ln yield_i$ is the log of the amount of wheat that is produced in kilograms per tsimad[4]; $\ln(\text{land}_i)$ is the log of the area of land in tsimad used for wheat production, $\ln(\text{DAP}_i)$ and $\ln(\text{UREA}_i)$ represent the log of DAP and UREA applied in kilogram on wheat production; $\ln(\text{seed}_i)$ is the log of the amount of wheat seeds in kilogram used per tsimad; $\ln(\text{ploughing}_i)$ is the log of the number of workers per day working on ploughing and $\ln(\text{weeding}_i)$ is the log of the number of workers per day working on weeding for wheat production. Whereas the values of v_i represent the occurrences that cannot be controlled by the farmer, the values of u_i represent the technical efficiency of wheat production and composed of a mean and a variance with normal distribution truncated at zero (Juan and Wilman, 2014).

Each individual farm's technical efficiency performance is then compared with the estimated frontier. The level of technical efficiency of each farm is then given by:

$$TE_i = {y_i}/{y_i^*} = f(x_i : \beta)\exp(v_i - u_i) / f(x_i : \beta)\exp(v_i) = \exp(-u_i) \quad \textbf{(3)}$$

where $\exp(-u_i)$ ranges between zero and one and is inversely related to the level of the technical efficiency effect. Based on this, maximum likelihood was used to estimate the parameters of the stochastic frontier production function. The random effect dominates the variation between the frontier output level and the actually obtained output level. If y_i is close to zero, it implies that the random effect dominates the variation between the frontier output level (y_i^*) and the actually obtained output level (y_i). Conversely, if

[4] *Tsimad* is a local unit used to measure land size and equivalent to 0.25 hectare (2500m^2).

y_i is close to one, it can be assumed that the variations in outputs are determined by technical efficiencies (Abate and Kebebew, 2011).

Equation 3, which is used to estimate technical efficiency, can indirectly be used to generate values for inefficiency. Given these data, the inefficiency model can be specified generically as;

$$TIE_i = \mathbf{X}_i'\boldsymbol{\theta} + \varepsilon_i \tag{4}$$

where TIE denotes technical inefficiency, and $\mathbf{X}$ is the vector of variables that are hypothesized to be sources of technical inefficiency with their corresponding vector of estimates, $\boldsymbol{\theta}$. The error term is assumed to be normally distributed with zero mean and constant variance. Equation 4 was then estimated using OLS[5].

The technical efficiency estimated using stochastic frontier model gives information mainly on the efficiency level of the average farmer (i.e., average efficiency in wheat production). Sometimes, additional insight can be obtained by computing technical efficiency estimate that captures an efficiency frontier based on which all other wheat producing farmers can be compare to (Ruggiero, 2007). The method that allows such comparison is the Data Envelopment Analysis (DEA), which is non-parametric model and does not require prior functional specification and distributional assumptions. In this study, we used this model to further examine the technical efficiency of white producers relative to the most efficient producer. In the end, we used the results from DEA for comparison with the results of the stochastic frontier we used for interpretation purposes.

[5] The technical inefficiency model estimated using OLS was subjected to omitted variable bias test and heteroskedasticity test. The null hypothesis of no omitted variable bias [F(3, 302) = 1.94; Prob > F = 0.1227] and no heteroskedasticity [chi2(1) = 0.1; Prob > chi2 = 0.7537] could not be rejected.

3. Data

The wheat growing areas in Tigray vary in agroecology (climatic and biophysical conditions), market access and land-related endowments, all of which may influence wheat production and efficiency. To account for these differences and select a representative sample, multi-stage sampling procedure was used. In the first stage, potential wheat growing districts and peasant associations (PAs) within these districts were selected purposively. As the interest was to study technical inefficiency variations among wheat producing farm households, there was a need to concentrate on those districts that focus on wheat production. In the second stage, households were stratified into groups of farm households (based on the strata of income/wealth: better off, medium and poor) in order to select representative sample of all income groups. In the third stage, a sample of 320 wheat producing farm households were randomly selected based on probability to proportional size (PPS) sampling method. Proportional sampling was made possible by obtaining population data from each of the selected peasant associations. For data collection, five enumerators were selected and trained on the purpose and contents of the questionnaire. The questionnaire was pre-tested on 12 farm households. Once useful feedback from the pre-test was incorporated in the questionnaire, the main household survey was carried out during June to August 2016[6] in the 4 districts and 8 kebelle's covered by the study. The study districts included are Degua-Temben, Ganta-Afeshum, Emba-Alaje and Ofla, which constitute the major wheat producing areas in the Tigray Regional State. Crop production is the main sources of income in the study areas. The major crops grown are wheat, barley, teff, beans, peas, lentil, sorghum and maize. However, wheat is the dominant crop in the highlands of Tigray Regional State in general and in the study areas in particular. Almost all farm households in the study areas grow wheat. Data collected included, among others, socio-economic and demographic characteristics, farm and production data related to yield and input use, farm

[6]Although the survey was conducted during the cropping season of the 2016 period (June to August), data about production, inputs and related information were from the previous cropping calendar.

management, physical features such as arable land quality and major challenges of technology adoption, and market problems.

Based on theoretical suggestions and previous studies, the variables that are often considered to be sources of inefficiency are related to household and farm-specific characteristics, including age, education level, gender, family size, access to credit, extension contact, membership in cooperatives, market information and livestock ownership. Age and educational level of household head are often used as proxy for experience in farming that could be correlated with efficiency. Age of household head is expected to be negatively correlated with inefficiency as farmers would develop their experience and learning from the experience with age (Coelli and Battese, 1996; Rahman, 2002). The positive relationship may, however, not be linear in the sense that after a certain age level, the inefficiency would increase again (Liewelyn and Williams, 1996), and hence the inclusion of age squared that will show whether the relationship with age is quadratic. Education in terms of years of schooling is expected to be negatively correlated with inefficiency. Farmers with higher education tend to learn the skills and develop the knowledge to manage factors of production better and process information more effectively for production purposes, which in turn may reduce inefficiency in production. It is hypothesized that there may exist differences in technical inefficiency among male and female-headed households. Differences in resources ownership and the control over production inputs and management of these inputs, which the female-headed households are worse off might lead female-headed households being more technically inefficient. With household size, it is hypothesized that technical inefficiency decreases. More household members may translate into pooling labor for production, and the sheer size in household is expected to contribute to efficiency (inefficiency).

Access to credit was hypothesized to negatively correlate with technical inefficiency. Technical inefficiency of wheat production is decreases with the increase in farmers' access to credit. Most subsistence farmers are poor and experience credit constraints and subsequently may not be in a position to increase agricultural productivity significantly. Extension contact was hypothesized to be negatively correlated to technical inefficiency. Farmers who have readily accessible extension education are presumed to acquire relevant and up-to-date knowledge and skills as well as information regarding wheat production, input supply and management, marketing and other aspects that may reduce technical inefficiency. Membership of multi-purpose cooperatives was another factor that was hypothesized to reduce technical inefficiency by facilitating farmers' access to essential information, such as new production techniques, market, credit facilities, and also training related to wheat production. This eventually would enhance farmers' ability to apply innovation, manage their production resources more effectively and reduce inefficiency. Access to market information is an important factor that was hypothesized to be negatively correlated with technical inefficiency. Market information is crucial for decision making on how, when and where to purchase inputs used for wheat production and sell wheat products. Livestock ownership is a proxy for wealth status and was hypothesized to be negatively correlated with technical inefficiency. Livestock as key assets can serve as sources of liquidity to purchase agricultural inputs and equipment used for wheat production. This in turn is expected to increase productivity and efficiency and by translation reduce technical inefficiency.

4. Results and Discussion

Given the difficult climatic and agro-ecological conditions of wheat production in the study area, wheat productivity was found to be low. The average wheat productivity was 7.59 quintal per tsimad (equivalent to 3.04 tons per hectare). This is similar to the average productivity of wheat farmer in Kenya, India and Bangladesh. This average wheat yield was obtained by using 37.2 kg/tsimad (148.8kg/ha) of seed, 29.6 kg/tsimad (118.4kg/ha) of DAP, 30.1 kg/tsimad (120.4kg/ha) of UREA, an average of 3.6 times of ploughing and an average of 30.1 labor days.

On average farm households allocate about 1.43 tsimad (0.36 ha) of their land for wheat production. This is a high proportion of land allocated for wheat given the small average land holding of about 0.75 ha in the Tigray region. Households owned an average of 3.22 tropical livestock unit (TLU) of livestock. This livestock size, key resource for wheat farming (through services to ploughing, threshing and manuring) is also similar to the national (Ethiopia) average. Only about 119 (37%) of households obtained credit during the study period. This, however, does not necessarily indicate lack of access. Many households may not have been interested in obtaining credit in the first place.

The average number of contacts made by extension staff with wheat producing households for wheat crop-related information per year was 7. This is not sufficient compared to what is required. The common practice is also that information about wheat is discussed when extension agents meet farmers to discuss other issues. So, the actual period of time may be longer. About 233 (72.8%) households were members of multi-purpose cooperatives. Many farmers were organized through cooperatives both for input and wheat output marketing related benefits. Access to markets does not come easy as, on average, a household spends about 60 minutes (1hr) traveling on foot to reach the nearest market from their residence.

Table 1: Summary statistics of variables used in the stochastic frontier and inefficiency models

Continuous variables	Unit	Mean	Std. Dev.	Minimum	Maximum
Age	Years	48.2	13.6	18	83
Family size	Number	5.34	1.97	1	11
Education level	Years of schooling	2.51	3.16	0	10
Yield	Kg per tsimad	759.1	636.4	100	4500
Wheat land size	Tsimad	1.43	0.99	0.08	6
Amount of improved seed used	Kg per tsimad	37.2	8.8	12.5	50
DAP used	Kg per tsimad	29.6	12.7	10	50
UREA used	Kg per tsimad	30.1	12.7	12.5	50
Ploughing frequency	Number	3.60	0.65	2	7
No. of labor used for weeding	Number per tsimad	30.1	23.8	3	180
Extension advice frequency	Number	7.79	9.38	0	60
Livestock ownership	Tropical Livestock Unit (TLU)	3.22	2.63	0	22.9
Distance to the nearest market	Minutes	60.9	39.23	5	240
Dummy variables					
Gender (1=male-head; 0=female-head)		0.734	0.44	0	1
Credit for wheat production (1=access; 0=otherwise)		0.372	0.48	0	1
Membership of MP-cooperative (1=member; 0=non-member)		0.728	0.45	0	1
Market information (1=have access; 0=otherwise)		0.531	0.50	0	1

Source: Own computation, 2016

4.1 Technical Efficiency

First, the robustness of results was tested using likelihood ratio test. The test result $(\chi^2(1) = 1.64)$ indicated the constant elasticity assumption of the Cobb-Douglas yield function could not be rejected at the 5% significance level, based on which we interpreted yield results in response to production inputs. Following this, efficiency model was estimated. The average technical efficiency of the farm households was estimated to be only 57%, with household-level technical efficiencies ranging from 20% to 97%, indicating that farmers are only producing on average 57% percent of the maximum possible output level, given the state of technology (Table 2). The variations in technical efficiency among farmers indicate the sub-optimal use of production inputs by wheat producers. Farmers vary in their endowment and use of land, labor, seed, and soil fertility enhancing inputs for wheat production, which were found to be significantly correlated with yield. Optimal combination of these inputs in this case would enable the most technically inefficient farmer to enhance wheat yield by 79 per cent [i.e., 1−(20/97) = 0.7938]. Moreover, optimal combination of these inputs would enable the average farmer to increase wheat yield by 41 per cent [i.e., 1−(57/97) = 0.4124] to achieve the technical efficacy level of its most efficient counterpart. Overall, results show significant inefficiency, demonstrating the opportunity for farmers to increase productivity depending on their specific observable and unobservable characteristics.

The stochastic frontier analysis helps shade light into the average technical efficiency of the sample of farms when examined from the perspective of production (output-oriented efficiency). To get a different perspective on the variations in technical efficiency of different farms as compared to the most efficient farm in the sample, data envelopment analysis that focuses on input use results was used. Results from input-oriented two-stage DEA show that the efficiency score (theta) of all the DMUs (wheat producers) ranged between 65.6 to 1%. This range for instance indicates that the least efficient farm (with efficiency score of 65.6%) would need to reduce overall input use by 34.4% to become efficient. The mean efficiency from DEA was estimated to be 88.7%, indicating that on average the farms would need to reduce aggregate input use by 11.3% to achieve efficiency. These results suggest the existence of significant inefficiency in the use of inputs by farms, which in turn point out the possibility for increasing wheat output with improved use and management of production inputs.

Table 2: Technical efficiency and distribution of wheat producers at different efficiency levels

Variable	No. of observations	Mean	Std. Dev.	Min	Max
Efficiency	316	0.569	0.171	0.205	0.969
Range of technical efficiency		**Frequency**		**Percent**	
0- 0.25		5		1.58	
0.251- 0.50		120		37.97	
0.51- 0.75		135		42.72	
> 0.75		56		17.72	
Total		316		100.00	

Source: Own computation, 2016

Technical efficiency estimate from Data Envelopment Analysis

Variable	No. of observations	Mean	Std. Dev.	Min	Max
Efficiency (theta)	316	0.887	0.085	0.656	1

Source: Own computation, 2016

Districts vary in different agro-ecological and socioeconomic characteristics, which may exhibit variations in technical efficiency. Comparison of the mean technical efficiency across districts was made using ANOVA and results show that there is no statistically significant difference in mean technical efficiency among districts (0.553 for Degua-temben, 0.473 for Ganta-afeshum, 0.686 for Emba-alaje and 0.564 for Ofla). Classifications of technical efficiency levels were also made and results show significant variation among different groups of households. A significant number of the farm households (close to 40%) operate at half of their production potential or lower. The indication is that a large number of wheat producer farmers faced worse inefficiency problems, where they could not even produce half of their potential. This clearly shows the possibility of increasing productivity and efficiency among large number of farm households. Only about 17.7% of wheat producer farmers operated at efficiency levels of greater than 75% (Table 2). Even for these groups of farmers, there is a great deal of room to increase efficiency.

4.2 Inputs' Role on Wheat Yield

In the stochastic frontier and efficiency models for wheat producers, the maximum likelihood estimates were defined by equations 1 and 3 as presented in Table 3 above. As expected, the major inputs are found to be key means of production that could increase efficiency. Land size, UREA fertilizer, amount of different improved seeds, ploughing frequency and weeding frequency for wheat production were found to have statistically significant positive effect on wheat yield. The coefficient of wheat land size was significant and positive, implying that an increase in land allocation for wheat would increase the wheat output. Though the result related to land shows the potential contribution of land to production, increasing land size would not be easy in the study area. Land rental and lease are allowed which offer potential to increase land size, which could be attractive to more efficient farmers (Almeida and Buainain, 2016, Kemper et al., 2018).

As an important factor of production, improved wheat seeds play key role in improving productivity. The marginal elasticity of 0.10% related to wheat seeds might look very small (Table 3). It nonetheless underlines the importance of improved seeds. Shiferaw et al. (2008) and Qian and Zhao (2017) in this regard underline the role of improved seed varieties who found that on average farmers who used improved seeds obtained more yield than farmers who did not use improved seeds. The scale of production and seed quality emanating from such improved seeds cannot be overemphasized as the supply of wheat seed with the reasonable price to the farmers would increase wheat production. In this regard, the wider scale expansion of formal and informal seed exchange system of seed distribution by research centers for demonstration and pre-scaling up activities needs to be continued for serving the smallholder wheat seed demands. This needs to be complemented by enhancing the multiplier effects of revolving seed model in increasing improved seed to poor smallholder farmers.

Table 3: Technical efficiency and inefficiency determinants

Variables	**Coefficient**	**t-statistic**
Output model		
Constant	4.427***	14.5 (0.306)
Land size per tsimad (lnland)	0.420***	5.28 (0.080)
Improved seed per tsimad (lnimpsedamt)	0.102**	2.12 (0.048)
DAP used in kg per tsimad (lnfertiDAP)	0.030	0.56 (0.054)
UREA used in kg per tsimad (lnfertUREA)	0.189***	2.63 (0.072)
Ploughing frequency per tsimad (lnplougnum)	0.703***	5.00 (0.141)
Labour used for weeding per tsimad (lnNumlab_weed)	0.008***	5.31 (0.002)
σ_v	0.326	(0.035)
σ_u	0.448	(0.075)
Likelihood ratio test for $\sigma_u = 0;\ \chi^2(1) = 4.99$	Prob $>= \chi^2 = 0.013$	
Inefficiency model		
Constant	0.630 ***	4.96 (0.127)
Age	-0.004	-0.70 (0.005)
Age-squared	0.001	0.66 (0.001)
Education level	-0.007**	-1.92 (0.003)
Gender	-0.014	-0.57 (0.024)
Family size	0.004	0.67 (0.006)
Credit access	-0.015	-0.73 (0.020)
Extension contact	-0.000	-0.80 (0.001)
Membership in MP-cooperative	-0.017	-0.75 (0.023)
Market information	-0.054***	-2.77 (0.019)
Livestock ownership	-0.014***	-3.48 (0.004)

Source: Own computation, 2016 Note: ** and *** indicate significance at 5 and 1% levels of significance respectively. Values in parentheses are standard errors.

Further, results emphasize the role of land preparation, management and soil fertility enhancing methods and inputs in increasing productivity. Ploughing and weeding frequency as land preparation and management activities play positive roles in increasing output. Optimal land preparation has the potential to increase yield. The largest effect of ploughing on yield may be attributed to creating an enabling soil and soil microbes for wheat production. While increased ploughing frequency beyond the optimum level would disturb soil structure and might cause negative consequences on wheat production, it nonetheless emphasizes the importance of repeated (3–4 times) ploughing. As expected, labor input in terms of weeding positively contributes to wheat yield. Every labor man-day per tsimad invested in weeding wheat farmlands helps eliminate competition for key soil nutrients (such as water and nutrients). The access created to more nutrients and water by as much weeding frequency as possible would eventually lead to an increase in wheat productivity.

As it is commonly the case, UREA fertilizer was found to have a positive and significant effect on yield. This is true although farmers often fail to use the recommended rate of UREA fertilizer, which would have further increased wheat yield. On the other hand, DAP fertilizer was found to have no statistically significant effect on wheat yield. While there could be several explanations for this, one thing that caught our imagination is that most of Tigray and the specific districts where the study took place have shortage of phosphorus while nitrogen endowment is relatively good (ATA, 2014). Farmers failure to apply recommended rate of fertilizer (including DAP fertilizer) may be one important reason for why DAP fertilizer did not have effect on wheat yield.

4.3 Determinants of Technical Inefficiency

The likelihood ratio test for the significance of the inefficiency parameter is found to be statistically significant at 1% level (with Prob(chi-bar2) = 0.005), which indicates that the variation in wheat yield, in addition to variations in input use, was probably due to the inefficiency effects of farmers' specific attributes. Out of the ten variables used, three variables (education level, access market information and total livestock ownership) were found to have a negative and statistically significant effect on technical inefficiency of wheat farmers (Table 3).

The coefficient of education level in years of schooling has a negative effect on technical inefficiency. This means inefficiency is likely to decrease with education, ceteris paribus. This may be because education improves the ability of farm households to make informed decision about the use of production inputs and increase their access to information. Moreover, with education, farm households are likely to build management capabilities and systems; and hence implement such skills for better use of resources and inputs while producing wheat (Geta et al., 2013; Berhanu et al., 2015). This is expected to reduce inefficiencies, and by implication can lead to higher wheat yield. In relation to this, Asogwa et al. (2012), Geta et al. (2013) and Mesay et al. (2013) argue that education reduced inefficiency as it increased access to agricultural information and encouraged farmers to adopt and utilize improved inputs (such as fertilizers and crop varieties) which in turn enabled higher production.

Results further indicate that farmers who readily access market information are likely to be less inefficient as compared to those who do not have access to market information. This market information can be useful in helping farmers assess the market and locate demand bases to sell their wheat with reasonable price. If farmers have access to market information, they would reasonably know where, when and by how much to sell their wheat. If farmers have access to market information, they would be highly encouraged to allocate additional farmland to wheat as they have the confidence of earning reasonably higher price, for example; by selling their wheat to multipurpose cooperatives and flour factories, which fetch higher returns than individually selling to outlets in the local market.

Livestock size was the other variable that was found to have statistically significant at 1% significance level and negative effect on technical inefficiency. This result implies more livestock brings lower technical inefficiency of wheat production. This might be because livestock provide drought power, cash to finance input expenses; and manure as fertilizer, all of which can enhance production. Furthermore, possession of large number of livestock indicated greater overall wealth and capacity. This in turn may create capacity to reduce inefficiency. For example, livestock in a mixed farming system, are also used for ploughing and threshing, both of which play significant roles in reducing inefficiency (see also Mohammed et al., 2000; Beshir et al., 2012). Therefore, governmental strategies that enable farmers to own such kind of productive assets (livestock namely Oxen) using different methods; for instance, arranging oxen purchased by credit would have a positive effect in reducing farmers inefficiency or enhancing their efficiency so that they can produce wheat on time at a maximum possible frontier using the same level of resources (inputs) that they are currently using.

5. Concluding Remarks

This paper assessed technical efficiency and determinant factors of inefficiency among wheat-producing farm households in four districts of Tigray Regional State in northern Ethiopia. Data on wheat yield, inputs and socioeconomic characteristics were collected from wheat growing farm households for this purpose. A Cobb-Douglas stochastic frontier production function was estimated and used to investigate relationship between yield and production inputs. In addition, an inefficiency model was estimated to identify the sources of inefficiency in the wheat production system.

As it appears, level of technical efficiency in the wheat production systems is significantly lower. The mean technical efficiency was estimated to be only 57%, indicating significant loss in the wheat production systems. There are even wheat-growing farm households whose technical efficiency is as low as 20%, showing considerable potential to increase the production and productivity of wheat. As it turns out, efficiency of the wheat production system can be improved depending on the sources of the inefficiencies, such as addressing the sources of inefficiency or effective supply and management of production inputs (like fertilizer and land preparation or ploughing).

Technical inefficiency is pervasive and some of the most important household-specific attributes that govern technical inefficiency were educational achievement, access to market information and livestock size. These key features play mitigating roles in countering technical inefficiency as they represent human capital, production capabilities, and information. These household-level attributes may be key to pooling production resources and building economies of scale and improved production management capability that helps reduce inefficiency. This depicts the picture that if the necessary technical and managerial skills are not in place, smallholder wheat production systems would continue to be riddled with inefficiencies in production. This is because farm households would continue to have limitations in the key skills and capabilities that embolden them to counter inefficiencies. In this regard, the role of education and information cannot be overemphasized in countering inefficiency. Hence, the current rural adult education programs which are practical oriented, need special attention and be strengthened, although this affects not only wheat production systems but also important to improve agricultural efficiency in general.

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