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Technical efficiency determinants of potato production: A study of rain-fed and irrigated smallholder farmers in Welmera district, Oromia, Ethiopia

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Increasing productivity through enhanced potato production efficiency could be an important move towards food security. In Ethiopia potato (*Solanum tubersum* L.) production levels and rates have been increasing due to the development and dissemination of improved potato technologies. Despite these efforts by the government, smallholders' potato productivity has remained below potential. However, empirical studies conducted to estimate level of efficiencies and to identify its determining factors in potato production which would guide policy makers in their efforts to do up its productivity are sparse. The purpose of this study was to analyze the technical efficiency, yield loss due to inefficiency and factors affecting efficiency of rain-fed and irrigated potato farmers in Welmera district of Oromia region, Ethiopia. A two stage sampling procedure involving purposive and random selection of the district, kebeles and samples was used to collect data from 72 households (40 from rain-fed and 32 irrigated) using structured questionnaires during 2009/2010 cropping season. The stochastic frontier and translog functional form with a one-step approach were employed to analyze efficiency and factors affecting efficiency in potato production. The maximum likelihood estimates for the inefficiency parameter showed that both most rain-fed and irrigated potato farmers in the study area were not efficient. The mean technical efficiency (TE) was found to be 81 and 68%, and about 4057 and 6185 kg of potato tubers per hectare were lost due to inefficiency factors for and/or from rain-fed and irrigated potato farmers, respectively. Variables such as education, soil condition and seed tuber size affected TE of both rain-fed and irrigated potato farmers, while age of the household head affected irrigated potato farmers' TE positively and significantly indicating that experience through age matters in irrigated potato production. The finding implies that there is an opportunity to improve technical efficiency among the rain-fed and irrigated potato farmers by 19 and 32%, respectively. Improving potato productivity needs owing cares of technical efficiency and farm and household socioeconomic characteristics that influenced technical efficiency in smallholder potato production. Train producers to use appropriate seed tuber size and maintain their soil fertility condition by extension and increase the educational level of the household heads through appropriate literacy.

Key words: Stochastic frontier, technical efficiency, rain-fed and irrigated potato, Welmera.

INTRODUCTION

Potato (*Solanum tubersum L*.) is a root crop and ranks first in its volume of production and consumption followed by cassava, sweet potato and yam in Ethiopia. It has a huge potential to contribute for the national economy, improve food security and income for smallholder farmers through its value-added products. Moreover, Gildemacher et al. (2009) reported the return on cash investment was more than 100% which enables growers reduce cash losses and the return on family labor was higher than the opportunity cost of work. Potato can grow in main season occurs from June to September and belg season (short rain season) occurs from February to May and irrigation (sometimes referred to as off-season). However, the irrigated potato is officially categorized under short rain season production. CSA (2016) indicated that the majority (70.6%) of the area was allocated to short season potato production and the rest 23.6 and 5.7% of the area allocated for main season and off-season (irrigation) potato production. In most irrigable lands, horticultural crops in general, potato in particular play an important role contributing to rural households' income generation and food security (Demelash, 2013; Bogale and Bogale, 2005). It is confirmed that the revenue from potato able to be much ten times higher than grains (Oumer et al., 2014).

The Ethiopian government has given more emphasis to potato research and development to boost production and productivity. Accordingly, about 32 potato varieties were released by the national research system and disseminated to the beneficiaries with its production packages, and reported as they are under production (MoA, 2016), evidenced by the study of Tesfaye et al. (2013) and Limenih et al. (2013), found significant level of adoption and determinant factors. Following these efforts, the production and productivity of potato is steadily increasing over years, while the area allocated to potato went constant (about 0.05 ha per household). According to CSA (2010, 2011, 2012, 2013, 2014, and 2015), the productivity of the main season of potato at a national level increased from 8.2 ton to 13.4 ton per ha, though the attainable yield is well above 25 ton under progressive farmers' fields and 35 ton per ha under on-station (Tesfaye et al., 2013) which indicates there exist gaps between current potato yields and potential yields.

This indicates that crop yields and productivity are not only inevitably affected by weather conditions, quality of seeds and varieties, amount of fertilizers and farming practices used, and/or level of adoptions but also the efficiency of production (Tiruneh and Geta, 2016; Debebe et al., 2015; Alemu et al., 2014; Yami et al., 2013; Ahmed et al., 2012); efficiency reflects the effectiveness and describes the quality of managing the farm. There has been limited number of empirical studies conducted to estimate level of efficiencies and identify its determining factors for major crops including potato (Beshir et al., 2012) and reported a significant level of inefficiencies. Thus, literature on technical efficiency of potato farming is still insignificant and very little is known whether smallholder potato growers are efficient or not in Ethiopia, and to the best of the author's knowledge there were no similar studies started in the study area.

Therefore, this study was proposed to fill this gap with the objective of analyzing technical efficiency of rain-fed and irrigated potato smallholder farmers and its determinant factors, and compute yield loss due to inefficiency.

METHODOLOGY

Study area and data

Taking into account both representativeness and cost of data collection, this study is based on cross-section primary data collected from a total of 72 randomly selected households in Welmera district of Oromia region, Ethiopia. A two stage sampling procedure was used involving purposive selection of a district followed by potato producing kebeles[1] (five kebeles, 3 from main season and 2 from irrigated potato producing kebeles), and finally simple random selection of sample households (40 households from rain-fed and 32 irrigated) from a list of potato growers prepared in both production systems data gathered using structured questionnaires filled by trained enumerators during 2009/2010 cropping season. The collected data from the household include yield of potato, inputs used like area, labor, oxen, seed, inorganic fertilizers and fungicide; plot characteristics such as soil fertility status, rotation and seed tuber size; socioeconomic like age and education of the household head and family size.

Analytical model

Technical efficiency of a farm household has commonly been defined as the ratio of observed outputs to its frontier outputs, maximum output level harvested with inputs at hand and current technology. In short, it is the ability of a producer to achieve maximum output from a given set of inputs (Coelli et al., 2005). Technical efficiency is often modelled either using stochastic frontier analysis (SFA) or data envelopment analysis (DEA) (Charnes et al., 1978; Farrell, 1957). This study is interested in SFA because of the ease in the interpretation and the ability to capture noises from possible external factors and measurement errors. Many different literatures on technical efficiency studies have used Cobb-Douglas or Trans-log frontier production function depending on data fit (Tiruneh and Geta, 2016; Alemu et al., 2014). Some previous studies also used two steps and some other used one step approach to analyze technical inefficiency effects (Yuya, 2014; Jema and Andersson, 2006). It is the interest of this study to use translog frontier function and a one-step approach to run the models simultaneously. Therefore, according to Aigner et al. (1977) and Meeusen and Broeck (1977), the translog production function (1) and the inefficiency equation (2) stated as follows are simultaneously used for its flexibility (places no restriction) and simplicity of running the model.

$$lnY_i = \beta_0 + \sum_{i=1}^{5} \beta_i lnX_i + \frac{1}{2}\sum_{i=1}^{5}\sum_{j=1}^{5} \beta_j \left(lnX_i\right)\left(lnX_j\right) + \left(\nu_i - \upsilon_i\right) \quad (1)$$

where i=1, 2, - - - n1=40 (main season), n_2=32 (irrigation) and X = vector of five input variables.

Based on the model, a stochastic frontier model for potato farmers is given by:

$$\begin{aligned} \ln(output)_i &= \beta_0 + \beta_1 \ln(area)_i + \beta_2 \ln(seed)_i + \beta_3 \ln(costche)_i + \beta_4 \ln(lab)_i + \beta_5 \ln(oxen)_i + 1/2\,\beta_{11} \ln(area)^2 + 1/2\,\beta_{22} \ln(seed)^2 + 1/2\,\beta_{33} \ln(costche)^2 \\ &+ 1/2\,\beta_{44} \ln(lab)^2 + 1/2\,\beta_{55} \ln(oxen)^2 + \beta_{12} \ln(area) \ln(seed) + \beta_{13} \ln(area) \ln(costche) + \beta_{14} \ln(area) \ln(lab) + \beta_{15} \ln(area) \ln(oxen) \\ &+ \beta_{23} \ln(seed) \ln(costche) + \beta_{24} \ln(seed) \ln(lab) + \beta_{25} \ln(seed) \ln(oxen) + \beta_{34} \ln(costche) \ln(lab) + \beta_{35} \ln(costche) \ln(oxen) + \beta_{45} \ln(lab) \ln(oxen) + vi - u_i \end{aligned}$$

[1]Kebele is the lowest administrative unit under Ethiopian condition.

The stochastic frontier analysis approach specifies technical efficiency as the ratio of the observed output to the frontier output, given the state of available technology, and presented as follows:

$$TE = \frac{F(X_i;\beta).\exp(v_i - u_i)}{F(X_i;\beta).\exp(v_i)} = \exp(-u_i) \quad (2)$$

where F $(X_i;\beta).\exp(v_i-u_i)$ is the observed output (Y) and F $(X_i;\beta).\exp(v_i)$ is the frontier output(Y^*). Following Battese and Coelli (1995), the error term (v_i) permits random variations in output due to external (weather and diseases) factors, and is assumed to be identically, independently and normally distributed with mean zero and constant variance (σ_v^2); that is, $v_i \sim N(0, \sigma_v^2)$. The u_i is the inefficiency component of the error term and a one-sided positive (u>0) random variable and assumed to be independently distributed as truncations at μ of the normal distribution and variance (σ_u^2), that is, $u_i \sim N(\mu_i, \sigma_u^2)$, however, if $u_i = 0$, the assumed distribution is half-normal.

The specification of inefficiency model for potato individual producer at a plot level is given as:

$$\mu_i = \delta_0 + \sum_{j=i}^{6} \delta_j Z_{ji} \quad (3)$$

$\mu_i = \delta_0 + \delta_1 agehh + \delta_2 eduhh + \delta_3 famsize + \delta_4 solfert + \delta_5 precucrop + \delta_6 seedtubsize$

Technical efficiency estimates derived from parametric stochastic production frontier (SPF) was regressed using computer software FRONTIER 4.1C (Coelli, 1996) program.

Definition of variables

Variables often considered in the analysis of technical efficiency of farmers included input variables, household and farm characteristics (Tiruneh and Geta, 2016; Geta, 2013; Beshir et al., 2012; Coelli et al., 2005). In this study, based on a review of relevant literature, a range of input variables, household and plot characteristics were hypothesized to influence technical efficiency of potato smallholder farmers.

RESULTS AND DISCUSSION

Descriptive statistics

Table 1 shows the results of descriptive statistics for production and efficiency variables. The average yield was 17,260 and 13,143.8 kg/ha with high yield variability for sample rain-fed and irrigated potato production greater the national average (CSA, 2010). The mean area allocated for potato production was 0.32 and 0.345 ha, the average amount of seed used was 2102 and 1987.5 kg/ha, similar to the recommendation (Tesfaye et al., 2013), the average investment cost of fertilizers and fungicides was 2,667.68 and 2,158 Birr/ha, the average man-days was about 296.5 and 207.4 per ha, and the average oxen days used was 42.8 and 29.56 per ha for rain-fed and irrigated potato production. Labor productivity is higher in irrigated system while the average yield of rain fed is higher. The maximum yield is also higher in rain fed with a value of higher standard deviation showing also higher yield variability. The higher labor productivity in irrigated potato might be due to the use of hired labor that could be supervised efficiently than rain fed potato in which family labor is mainly used. It is believed that age, education, family size, soil condition, rotation practices and seed tuber size can influence technical efficiency of the farm communities. The average age of the household heads is 42.5 and 35.9 years for rain-fed and irrigated potato growers, respectively showing relatively younger population of irrigated potato growers. Education levels of the household heads are between 0 and 7 and 0 and 4 years of schooling showing low level of education. The average family size is about 6 persons for both rain-fed and irrigated potato farming communities. About 90 and 44% of the potato plots are fertile, 100 and 37.5% of the household used rotation practice and 70 and 28% of households used medium sized seed tubers for rain-fed and irrigated potato growers respectively indicating that rain-fed potato growers relatively used more recommended agronomic practices than the irrigation growers, this might happen because irrigated potato growers are less accessed in terms of production technologies and information.

Parameter estimates

Table 2 shows the results of simultaneously estimated stochastic frontier function and inefficiency effects model using Frontier 4.1C program. The likelihood ratio test showed that trans log stochastic frontier model best fit the data evidenced with the calculated chi-square value of 51.134 and 15.03, while the theoretical value is 14.853 in 5% of significant level with 8 degrees of freedom for both rain-fed and irrigated potato from Table 1 of Kodde and Palm (1986), because stochastic has a mixed chi-square distribution. The coefficients inputs like area, seed, labor, and oxen days were positive in both farming systems, while coefficient of the investments on fertilizers and fungicides was positive in rain-fed and negative in irrigated potato farms, this might be due to inappropriate use of fertilizers. Some farmers reported that they did not use urea and fungicides on their irrigated potato plots. The coefficients of area, labor and oxen days had a positive sign and significant at 1% significant level. Some of the coefficients of interaction terms between and within

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Table 1. Summary statistics for production and efficiency variables (Own Survey Results, 2010).

Variable	Rain-fed potato				Irrigated potato			
	Mean	Std. Deviation	Min.	Max.	Mean	Std. Deviation	Min.	Max.
Production								
Yield (kg/ha)	17260	6502	6900	33300	13143.8	3820.56	6700	21600
Area (ha)	0.32	0.157	0.1	0.75	0.345	0.33	0.1	2
Seed (kg/ha)	2102	438.8	1200	3000	1987.5	335.8	1500	2700
Cost of fertilizers & fungicide (Birr)	2667.68	940.26	1344	5062.5	2158	1037.9	1008	5400
Labor (man-days/ha)	296.5	94.63	164	520	207.4	48.9	116	305
Oxen (days/ha)	42.8	8.98	22	55	29.56	11.49	0	58
Efficiency								
Age (years)	42.5	12.25	22	74	35.9	9.6	20	59
Education (years)	3.53	2.25	0	7	1.88	1.4	0	4
Family size (persons)	6.35	2.2	1	11	5.69	2.95	1	11

	Labels	Frequency	Percent	Frequency	Percent
Soil condition	Fertile=1	36	90	14	43.8
	Less fertile=0	4	10	18	56.2
	Total	40	100	32	100
Rotation	Yes=1	40	100	12	37.5
	No=0	0	0	20	62.5
	Total	40	100	32	100
Seed tuber size	Medium=1	28	70	9	28.1
	Otherwise=0	12	30	23	71.9
	Total	40	100	32	100

inputs were associated with yield positively, while others negatively indicating that considering the interaction between inputs in agriculture is paramount. The 0.869 and 0.999 value of gamma evidenced that inefficiency effect significantly existed among potato farmers in both farming conditions indicating that there was poor management of resources by growers. The mean technical efficiency was 81% (between 50 and 96%), while 68% (between 52 and 91%) for sample households of rain-fed and irrigated potato farmers in the study area suggesting that given the current state of inputs and technology level, there is a room of increasing potato yield up to 19 and 32% on average in rain-fed and irrigated potato production, respectively. Therefore, improving technical efficiency of smallholder potato farmers can improve productivity of potato in the study area.

Factors influencing technical efficiency

The existence of inefficiency factors was confirmed with all the values of the coefficients different from zero (Table 2). The negative sign of age of the household head and significant at 5% significance level as the expectation suggested that relatively elder farmers have the benefit to manage inputs properly in irrigated potato farmers, this might be due to the nature of the farm practice that needed skills acquired through experience. The coefficient of education was negative and significant at 1% significance level as a priori expectation suggesting educated farmers often sought better agricultural technologies and information, and utilization. This result is in line with the study by Tiruneh and Gata (2016) and Geta et al. (2013) and against the study by Bogale and Bogale (2005). The positive sign of family size but insignificant might suggest that families with more persons resulted in more congested family labor; this is in line with work done by Bogale and Bogale (2005). The negative sign of soil condition and significant 1% significant level as expected implied that fertile soil helps farmers ease preparation of farms. Negative sign of rotation in rain-fed and positive sign in irrigated potato farms but not significant may indicate that farmers used inappropriate rotation practices especially in irrigated condition. The negative sign of seed tuber size and

Table 2. Results of trans log-efficiency model for potato production (Model Result, 2010).

Variable	Rain-fed potato			Irrigated potato	
	Parameters	Coefficient	t-ratio	Coefficient	t-ratio
Production					
Constant	β_0	-0.531	-0.531	0.491	0.496
Ln (area)	β_1	0.646	3.918***	0.826	8.379***
Ln (seed)	β_2	0.110	0.822	0.253	0.264
Ln (cost of fertilizers & fungicide)	β_3	0.486	1.917**	-0.549	0.658
Ln (labor)	β_4	0.488	2.545***	0.196	2.157***
Ln (oxen)	β_5	0.191	20.070***	0.723	7.552***
Ln $(area)^2$	β_{11}	0.325	2.112**	0.072	0.301
Ln (area)Ln(seed)	β_{12}	-0.698	-1.944*	-0.149	-2.281**
Ln (area)Ln(cost)	β_{13}	-0.770	-0.342	-0.652	-0.288
Ln(area) Ln(labor)	β_{14}	0.493	1.849*	0.522	0.715
Ln(area) Ln(oxen)	β_{15}	-0.700	-1.737*	0.347	0.502
$Ln(seed)^2$	β_{22}	0.301	0.700	0.208	5.153***
Ln(seed)Ln(cost)	β_{23}	0.122	1.979**	0.290	0.554
Ln(seed)Ln(labor)	β_{24}	0.112	1.956	-0.357	-4.566***
Ln(seed)Ln(oxen)	β_{25}	-0.287	-4.866***	0.167	3.100***
$Ln(Cost)^2$	β_{33}	0.297	0.967	0.182	1.285
Ln(cost)Ln(labor)	β_{34}	-0.159	-3.047***	0.450	0.870
Ln(cost)Ln(oxen)	β_{35}	-0.106	-0.305	-0.550	-1.404
$Ln(labor)^2$	β_{44}	0.293	0.076	0.144	2.506***
Ln(labor)Ln(Oxen)	β_{45}	-0.148	-0.231	-0.298	-3.593***
$Ln(oxen)^2$	β_{55}	0.516	1.768*	0.247	0.535
Efficiency					
Constant	δ_0	0.100	0.129	0.829	0.301
Age	δ_1	0.650	0.847	-0.167	-2.199***
Education	δ_2	-0.171	4.247***	-0.133	12.344***
Family size	δ_3	0.280	0.909	0.224	0.574
Soil condition	δ_4	-0.246	-5.174***	-0.278	14.768***
Rotation	δ_5	-0.215	-0.218	0.189	0.639
Seed tuber size	δ_6	-0.319	3.388***	-0.227	5.266***
Sigma squared	σ^2	0.056	1.526*	0.431	5.265***
Gamma	γ	0.869	8.751***	0.999	13.722***
Likelihood Ratio Test	LR	51.134***	-	15.030***	-

*, ** and *** show significant at 10, 5 and 1%, respectively.

significant at 1% significance level suggested that the use of medium sized seed tuber helps farmers to increase productivity as per recommendation (Tesfaye et al., 2013).

Distribution of technical efficiency scores

Table 3 shows the frequency distribution of technical efficiency scores. There was no technical efficiency score less than 0.5 in both potato farming conditions. The majority (37.5%) of rain-fed potato growers score between 80 and 90% efficiency level, while 47% of irrigated potato farmers score between 60 and 70% both around their mean. About 20% of the household score greater than 90% efficiency level in rain-fed potato production while only 3% of the household score >90% efficiency level indicating that rain-fed potato farmers are more efficient than their counter parts, irrigation farmers.

Yield gaps due to inefficiency

Table 4 shows the estimates of potato yield gap due to

Table 3. Frequency distribution of efficiency estimates (Model Result, 2010).

Range of efficiency estimates	Rain-fed potato		Irrigated potato	
	Frequency	Percent	Frequency	Percent
<50	0	0	0	0
50-60	3	7.5	5	16
60-70	4	10	15	47
70-80	10	25	9	28
80-90	15	37.5	2	6
>90	8	20	1	3
Total	40	100	32	100
Mean	0.81	-	0.68	-

Table 4. Estimates of potato yield gap due to inefficiency (Own Computation).

Variable	Rain-fed potato			Irrigated potato		
	Mean	Min.	Max.	Mean	Min.	Max.
Observed yield (kg/ha)	17260	6900	33300	13143.8	6700	21600
Technical efficiency estimates	0.81	0.5	0.96	0.68	0.52	0.91
Computed Frontier yield (kg/ha)	21308.64	13800	34687.5	19329.12	12884.6	23736.3
Computed yield loss (kg/ha)	4048.64	6900	1387.5	6185.32	6184.6	2136.3

inefficiency. This part is the uniqueness of this study, no studies have ever been attempted to estimate the yield gaps resulted from efficiency differentials among farmers. The mean potential yield computed to be 21,308.6 and 19,3329 kg/ha, if the average farmer had an efficiency level of 100% in rain-fed and irrigated potato production without the requirement of additional inputs and technology. However, the increase in potential (frontier) yield was much higher for farmers who had the lowest level of efficiencies (from 6,900 to 13,800 kg/ha for rain-fed and 6,700 to 12,884.6 kg/ha if had 100% efficiency level). Therefore, about 4,048.6 and 6,184.6 kg/ha of yield was lost due to inefficiency effects, on average.

Conclusion

The objective of this study was to analyze technical efficiency of rain-fed and irrigated potato smallholder farmers and its determinant factors, and compute yield loss due to inefficiency. A trans log stochastic frontier and inefficiency effects model was used to analyze the cross-sectional inputs, outputs and socioeconomic data collected from randomly selected households for 2009/2010 cropping season in Welmera district of Oromia region. The inefficiency was observed to exist among smallholder farmers. The efficiency ranges from 50 to 96% among rain-fed potato farmers, while 52 to 91% for irrigated potato farmers which reflected that farmers in the study area experienced irregular farm practices. This study revealed that about 4,048.6 and 6,184.6 kg/ha of yield gap was lost due to inefficiency effects for rain-fed and irrigated potato production. The study identified factors which contributed to the efficiency of potato smallholder growers. Education, soil condition and size of seed tuber were significant determinants that influenced potato production efficiency in rain-fed and irrigated potato farms. Age, a proxy variable for farm experience was significant factor that influenced technical efficiency of households in irrigated potato production.

The findings suggest that improving potato productivity needs owing cares of technical efficiency and farm and household socioeconomic characteristics that influence technical efficiency in smallholder potato production. Train producers to use appropriate seed tuber size and maintain their soil fertility condition and increase the educational level of the household heads through appropriate literacy.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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