

Technical Efficiency in Seed Potato Production Systems in Uganda

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Abstract: This study established the level of technical efficiency and its determinants among the informal and formal seed potato producers in the southwestern highlands agro-ecological zone of Uganda. A multi-stage sampling procedure was employed to select 636 households (499 informal seed producers and 137 formal seed producers) from which data was collected for two seasons using a semi-structured questionnaire. Data was analyzed using the stochastic frontier approach with a one-step approach. Maximum likelihood estimates for the efficiency parameters showed that both informal and formal seed potato producers were not fully efficient. The mean technical efficiency for informal and formal seed potato producers was 81.4 and 80.4 percent respectively. In terms of yield loss, informal and formal seed potato producers respectively lost an average of 981 and 1,208 kg/acre of seed potato tubers due to inefficiency factors. Specifically, off-farm income source, scale of production, seasonal variation, access to extension services and seed producer being male positively influenced informal seed producers' technical efficiency while producers' level of education and seed potato variety diversity negatively influenced their efficiency. For formal seed producers, technical efficiency was influenced positively by producers' education and negatively by household size. The study suggests that there is an opportunity to improve technical efficiency of informal and formal seed producers by 19 and 20 percent respectively. Therefore, this calls for increased investment in developing and promoting high yielding varieties, provision of extension services, input intensification and addressing gender issues in seed potato production in the context of limited arable land.

Keywords: *Stochastic frontier, technical efficiency, seed potato system, informal and formal producers*

1. Introduction

Potato (*Solanum tuberosum*, L.) is a crop of major economic importance worldwide (FAO, 2008; Gebremedhin & Getachew, 2016). In terms of global production, the potato is the third most produced food crop after rice and wheat (Haverkort & Struik, 2015). Global total potato production exceeds 380 million metric tons per year (FAOSTAT, 2017). It is estimated that over a billion of people worldwide feed on potatoes (Haverkort & Struik, 2015). In Uganda, the potato is the third most consumed root and tuber crop after cassava and sweet potato (Tatwangire & Nabukeera, 2017). The Uganda National Agricultural Sector Strategic Plan of 2015/16 -2019/20 recognizes potatoes to be among the crops with huge potential to increase incomes and food security (MAAIF, 2016). The contribution of potatoes to income and food security in Uganda is however compromised by low yields at farm level estimated at 7.1 tonnes per hectare (FAOSTAT, 2014) compared to the 20 tonnes per hectare that is reportedly achievable at research stations in Uganda (Byarugaba et al., 2017). A key ingredient in the efforts to increase potato yields is timely access to adequate quantity of good quality seed given that good quality seed can contribute to a yield increase of between 20 and 25 percent (Gildemacher et al., 2009). In Uganda, there are two seed potato production systems (formal and informal seed potato production systems).

In the formal seed system, seed potato producers obtain basic seed from research which they multiply under supervision from research to ensure that quality seed is produced. On another hand, in the informal seed system, seed potato producers use home saved seed of previous season or from markets or neighbors and multiply it under no guidance. The seed produced by formal seed potato producers meets less than 1 percent of the national demand (Thiele et al., 2011; Aheisibwe et al., 2015). This demand can be met through expanding and increasing the productivity of the seed potato sub-sector. Expanding the seed potato sub-sector requires bringing more land under seed potato production which is not sustainable given the increasing arable land scarcity due to population increase. Therefore, increasing production per unit resource also known as technical efficiency provides a more feasible and sustainable strategy to meeting the current

and future demand for seed potato. Technical efficiency focuses on analyzing how farmers combine their inputs to produce a level of output in an efficient way (Coelli et al., 2005).

In a bid to increase productivity of the seed potato sub-sector, the government of Uganda through National Agricultural Research Organization (NARO) has focused on generating and promoting new improved potato varieties and innovations for quality seed potato production. However, despite these efforts, over 95 percent of the seed potato used by farmers in Uganda comes from the informal seed system (Kinyua et al., 2008; Aheisibwe et al., 2015). This is attributed to the limited ability of research and its associated formal seed potato system to meet the existing seed potato demand. Determining whether the seed potato production system is operating at maximum capacity requires evidence about its technical efficiency of the actors given that most of the seed potato produced should ideally be supplied. However, majority of the past studies have focused on the technical efficiency of potatoes without separating seed and ware potatoes and hence with limited attention on the level and determinants of technical efficiency of both formal and informal seed potato producers (Bonabana-Wabbi et al., 2013; Kipkoech et al., 2015; Tiruneh et al., 2017). This study therefore aimed at assessing the level and determinants of technical efficiency of farmers in the formal and informal seed potato production systems in south western highlands agro-ecological zone (SWHAEZ) of Uganda. From a policy perspective, this study is pertinent in steering debate on most feasible policy options to bridge the seed potato supply gap through enhancing technical efficiency of seed potato producers in SWHAEZ region and beyond. The rest of the paper proceeds as follows: the next section presents literature review. This is followed by research methodology, results and discussion and finally conclusions and policy implications.

2. Literature Review

Although literature on efficiency analysis provides many approaches to estimating level of technical efficiency among smallholders, this study employed stochastic production frontier approach with inefficiency variables to examine the level and determinants of technical efficiency among seed potato producers in Uganda. Most common approaches to estimating technical efficiency include; the Data Envelopment Analysis (DEA), Malmquist Index and stochastic production frontier (SPF). Unlike DEA and Malmquist Index, the stochastic production frontier approach allows for deviations from the frontier to be attributed to both inefficiency and the inevitable statistical noise, making it closer to reality (Battese & Coelli, 1988; Sharma et al., 1999; Constantin & Martin, 2009). Therefore, this study adopted a stochastic production frontier to estimate technical efficiency of seed potato producers because it addresses inefficiency and also recognizes the fact that random shocks do exist and may affect seed potato produced. This study further utilized statistical procedures to select the most appropriate model and distribution form so as to deal with the major limitations of SPF approach pointed out by Battese and Coelli (1995). Within the stochastic frontier models, some studies have used either a Cobb-Douglas or Transcendental or both depending on the data. Currently, two stochastic modeling approaches are prevalent: 1) including inefficiency variables in the stochastic frontier model also known as single-step estimation; 2) two-step estimation approach. Nonetheless, various studies have employed both approaches to estimate technical efficiency and its determinants.

For instance, Amadou (2007) used a single-step stochastic frontier approach, a translog stochastic production frontier with technical inefficiency variables and found out that coffee farmers had a mean technical efficiency of 89.6 percent and coffee production was exhibiting increasing returns to scale. The study further indicated that education level of coffee farmers in Cote d'Ivoire among other factors had a negative and significant effect on technical inefficiency. A similar study by Mburu et al. (2014) employed a two-step Cobb-Douglas estimation approach among wheat farmers in Kenya and found out that large scale wheat farmers were more efficient than small scale counterparts with technical efficiency of 85 and 91 percent respectively. The two studies conclude that more educated farmers are able to perceive, interpret and respond to new information and adopt improved technologies such as fertilizers, pesticides and planting materials much faster than their less educated counterparts. On the contrary, a study conducted by Srisompun and Isvilanonda (2012) on Thailand rice farmers found out that formal education had an insignificant effect on technical efficiency improvements in rice production. This is also in agreement with study findings by Okoye et al. (2016) in Central Madagascar. Other studies such as Simonyan et al. (2011) in Nigeria reported a strong competing

effect for women in terms of diverting skills to off-farm employment opportunities as their education level increases.

Adeyemo et al. (2010) simultaneously estimated the parameters of the Cobb-Douglas stochastic production frontier model and inefficiency model and found out that technical efficiency of cassava farmers ranged between 88.7-100 percent with mean technical efficiency of 89.4 percent. The study revealed that age of the farmer contributed negatively to technical efficiency in cassava production in Ogun State, Nigeria. Similarly, a study conducted by Srisompun and Isvilanonda (2012) in Thailand using a two-step estimation procedure with Cobb-Douglas production frontier found out that age of the farming household head had a negative and statistically significant effect on technical efficiency. These different studies fronted two arguments to justify the negative influence of age on technical efficiency. First, they argued that older farmers were less able to meet the labor demands associated with uptake of new technologies. Secondly, they also observed that older farmers did not easily adopt improved technologies because they were more conservative and more strongly attached to their traditional practices than the young ones. Contrary to the above, there are other studies such as Kidane et al. (2015) in Tabora region of Tanzania and Tiruneh et al. (2017) in Welmera district, Ethiopia which have reported a positive influence of age on technical efficiency. Such disagreements among different studies about the relationship between age and technical efficiency suggest that the influence of age on technical efficiency varies according to the enterprise and context.

Various studies have also found farming experience to be an influential factor of technical efficiency. A study conducted by Ajibefun et al. (2006) using a one-step estimation approach with translog production frontier revealed that rural farmers were more technically efficient than urban farmers with technical efficiency of 65 and 57 percent respectively. The study found out that years of farming experience among other factors had a negative effect on technical inefficiency. This implies that the more the farming experience, the higher the level of technical efficiency. Similar findings were obtained by Ogundari and Ojo (2007) who found out that farming experience positively affected technical efficiency among small scale food crop farmers in Nigeria. On the contrary, Adeyemo et al. (2010) utilizing a one-step stochastic frontier procedure with Cobb-Douglas production function found out that farming experience contributes negatively to technical efficiency, implying that the more the years spent in farming, the higher the degree of inefficiency. In terms of farm size, Srisompun and Isvilanonda (2012) study among rice farmers in Thailand employing a two-step stochastic frontier approach with Cobb-Douglas model specification demonstrated that technical efficiency in the crop year 1987/88 was higher than that of 2007/08 by 16.2 percent.

The study further showed that farmers with larger farm sizes were more technically efficient than those with smaller farms. Similar study findings were obtained by Kidane et al. (2015) when they used the two-step stochastic frontier estimation with Cobb-Douglas model to determine the technical efficiency of tobacco farmers in Tabora region of Tanzania. These findings suggest that farmers operating on large scale are more likely to enjoy economies of scale that enable them to produce more outputs with low costs. However, in a study done by Trujillo and Iglesias (2013) in Colombia, land acreage and technical efficiency were found to be inversely related, implying that the larger the land acreage under production the lower the level of efficiency. In this present study, scale of production was adopted instead of farm size because most of the seed potato producers are smallholder farmers characterized by limited arable land. In exploring the impact of crop diversification on technical efficiency, various studies have used Herfindahl index and the Ogive index as measures of concentration of output or specialization (Coelli & Fleming, 2004; Manjunatha et al., 2013; Ahmadzai, 2017) while others have used number of crops (Haji, 2007; Ebong et al., 2009; Ogundari, 2013).

In this study however, number of potato varieties was used as a proxy for seed potato variety diversity. Empirical studies examining crop diversification and technical efficiency at farm level have mixed conclusions. For instance, Ebong et al. (2009) using a one-step stochastic frontier approach with Cobb-Douglas model in Nigeria found out that urban farmers had a mean technical efficiency of 81 percent. Their study indicated that crop diversity among other factors had a negative influence on technical efficiency. On the contrary, Ogundari (2013) and Ahmadzai (2017) employed a two-step stochastic approach with a translog production frontier to study small scale cassava farmers in Nigeria and crop farmers in Afghanistan. The two studies found out that cassava farmers and afghan crop farmers had a mean technical efficiency of 81 and 72

percent respectively. These studies reported that crop diversity among other factors had a positive influence on technical efficiency. The rather mixed influence of crop diversity on technical efficiency could be attributed to contextual differences such as resources available and agricultural practices used which vary from farm to farm.

Household size on the other hand has been reported to positively influence technical efficiency. For example, in the study by Mohammed using a Cobb-Douglas production frontier and inefficiency model simultaneously found out that technical efficiency of sorghum producers in Nigeria varied widely between 15.6 to 92.1 percent with a mean technical efficiency of 72.6 percent. The study findings revealed that bigger households tend to show better technical efficiency. This agrees with the findings by Ayinde et al. (2015) among maize producers in Ogun state of Nigeria and Kidane et al. (2015) among tobacco farmers in Tanzania. The explanation for this behavior is that a bigger household would have more labor for carrying out farming activities in timely fashion, thus making the production process more efficient. Regarding farmers' access to extension services, Asante et al. (2013) jointly estimated a Cobb-Douglas stochastic production frontier with inefficiency model and found out that tomato farmers in Ghana had a mean technical efficiency of 85.4 percent. The study reported that farmers who had accessed extension services were more technically efficient than those that had not received such services. This is in agreement with Julie et al. (2017) whose study employed a one-step stochastic frontier approach with Cobb-Douglas model among specialized and diversified vegetable farmers in Cameroon. These studies demonstrated that access to extension services had a significant negative effect on technical inefficiency.

This suggests that farmers with access to extension services are more technically efficient than those without. Farmers' contact with extension agents is expected to directly or indirectly raise the awareness, sense of objective evaluation and the possibility of use of improved techniques of production. Gender has also been hypothesized in many studies as a significant factor that influences technical efficiency. For instance, in a study conducted among potato farmers in South Western Uganda by Bonabana-Wabbi et al. (2013), potato farmers were found to have a mean technical efficiency of 75 percent. In the study, male headed farming households were found to be less technically efficient than their female counterparts. Similar findings were obtained by Addison et al. (2016) using a one-step stochastic estimation with translog production frontier among rice farmers in Ashanti region of Ghana. However, a study by Kidane et al. (2015) in Tabora region of Tanzania employing a two-step stochastic frontier approach with Cobb-Douglas model found out that male maize farmers were more technically efficient than female farmers. Drawing from the above discussions, this study included the gender aspect to examine technical efficiency differentials among seed potato producers in the study area. Another factor believed to influence the level of technical efficiency is distance to the market. For instance, a study conducted by Chikobola (2016) using a one-step stochastic estimation with translog profit frontier among ground nut producers in Zambia revealed that distance to the market had a negative effect on efficiency. In their study, farmers who were located far from the market often had limited access to input and output markets and market information, eventually leading to inefficient production.

Chikobola further argued that longer distance to the market translated into higher transaction costs which discouraged farmers from participating in market oriented production. These findings by Chikobola (2016) are consistent with those of Abdulai and Huffman (2000) study focusing on rice farmers in Nigeria. From the review, it is also apparent that technical efficiency varies from one commodity to another and across locations and is influenced by various factors. The review however further indicates that there exist contradictions in the estimation procedure and direction of influence of the factors on technical efficiency. For instance, scholars disagree on the direction and level of influence of some of the factors such as level of formal education, age, farming experience, crop diversification, farm size and gender on technical efficiency. This implies that examination and interpretation of technical efficiency and its determinants have to be context specific. This present study therefore focused on technical efficiency of seed potato producers within a resource constrained context in the SWHAEZ so as to contribute to the filling of existing gaps in the knowledge about technical efficiency and its determinants in seed potato sub-sector. This study thus adopted a one-step stochastic frontier approach to investigate the level of technical efficiency among formal and informal seed potato producers, the sources and drivers of (in) efficiencies and how these influence technical efficiency of seed potato producers in Uganda.

3. Methodology

Empirical Model of The Stochastic Production Frontier: This study employed a stochastic production frontier function as proposed by Aigner et al. (1977), Battese and Coelli (1995) to handle cross sectional data. These studies based on the Cobb-Douglas function and transcendental logarithmic (translog) functions that could be specified as production functions. Following Aigner et al. (1977), the general econometric model for a stochastic frontier model is specified as:

$$y_i = f(x_i, \beta) \exp(\varepsilon_i) \quad (1)$$

Where: Y_i = The value of seed potato produced in kg; the suitable functional form such as Cobb Douglas or translog can be employed; X_i = Vector variable inputs (labor, seed, fertilizer and pesticide), β = the parameter of the estimate. In this study, the appropriate functional forms were tested using the log likelihood ratio test (LR) statistic in equation (4). Based on the result, farm-level Cobb-Douglas and translog production frontiers were adopted for formal and informal seed potato producers respectively. According to Aigner et al. (1977), ε_i is an error term derived as;

$$\varepsilon_i = v_i - \mu_i \quad (2)$$

Where v_i = the systematic component which represents random disturbance term due to factors outside the scope of the farmers; μ_i = the one sided disturbance term used to represent technical inefficiency and is independent of v_i . Again v_i is a symmetrical two sided normally distributed error term that captures the stochastic effect outside farmer's/farm's control for example weather, natural disaster, measurement errors and other statistical noise. It is assumed to be independently and identically distributed $N(0, \delta_v^2)$. Thus v_i allows the production function frontier to vary across farms at a given point in time and over time for the same farm and therefore the production frontier is stochastic. The term μ_i is a one sided ($\mu_i > 0$) inefficiency component that captures the technical inefficiency of the i^{th} farmer. The one sided error term can follow different distributions such as exponential (Meeusen & van Den Broeck, 1977), half normal (Aigner et al. (1977), truncated normal distribution (Stevenson, 1980) and the gamma density (Greene, 1980). Both v_i and μ_i cause actual production to deviate from the frontier production function (Xu & Jeffrey, 1998). The inefficiency model is specified as:

$$\mu_{it} = z_{it}\delta + w_{it} \quad (3)$$

Where δ 's are unknown parameters to be estimated, Z_1 = sex of the seed producers (1= male 0=female), Z_2 = producers' education (1 = ≥ 12 years of schooling, 0 otherwise), Z_3 = experience of the producer (years in seed production), Z_4 = Household size (persons), Z_5 = off-farm income source (1=had access, never), Z_6 = variety diversity (1=seed producer grows more than one variety, 0 otherwise), Z_7 = access to extension (1=had access, 0 = never), Z_8 = scale of production (1= ≤ 1.5 acres under seed potato, 0 otherwise), Z_9 = seed source distance (kilometres) and Z_{10} = seasonal preference (1= season 2, 0 = season 1). Whether or not the inefficiency effects existed was verified using log-likelihood ratio (LR) test statistic computed from equation (4).

$$\chi^2 = -2[\log(L(H_0)) - \log(L(H_1))] \quad (4)$$

Where χ^2 has a chi-square distribution; $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null hypothesis (Ordinary Least Squares (OLS) model) and the alternative hypothesis (Stochastic Production Frontier (SPF) model) respectively. Maximum Likelihood Estimates (MLE) for all the parameters of the SPF model in equation (1) for each category of seed potato producer together with the inefficiency variables in equation (3) were jointly estimated with the use of Frontier 4.1 computer program (Coelli, 1996). Following Battese and Coelli (1988), technical efficiency estimation is given by the mean of the conditional distributional of inefficiency term μ_i given ε_i as defined by equation (2). According to Coelli et al. (2005),

equation (5) is an alternative predictor for technical efficiency and is shown to be optimal in the sense that it minimizes the mean squared error.

$$TE_i = E[\exp(-\mu_i) | \varepsilon_i] = [\Phi(\frac{\mu_i^*}{\sigma_*}) / \Phi(\frac{\mu_i^*}{\sigma_*})] \exp\{\frac{\sigma_*^2}{2} - \mu_i^*\} \quad (5)$$

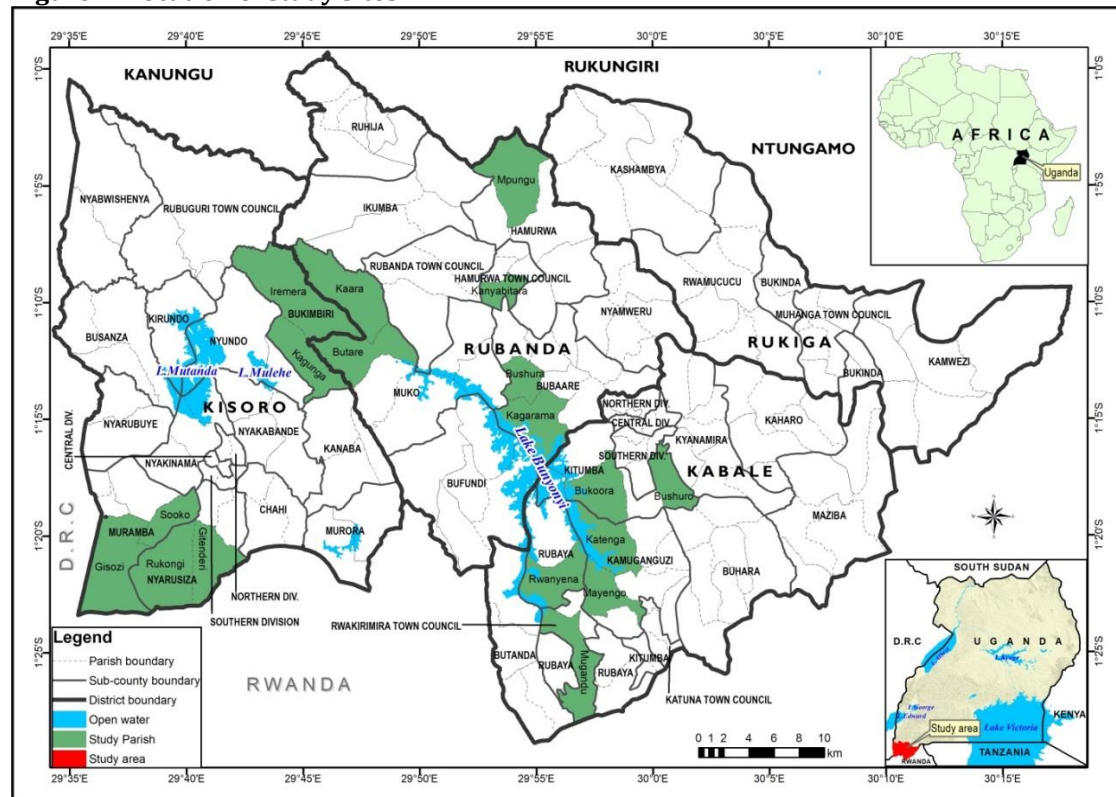
Where $\mu_i^* = -\varepsilon\sigma_\mu^2/\sigma^2 = -\varepsilon\gamma$, $\sigma_*^2 = \sigma_v^2\sigma_\mu^2/\sigma^2 = \sigma^2 \frac{\sigma_\mu^2(\sigma^2 - \sigma_\mu^2)}{\sigma^2\sigma^2} = \sigma^2\gamma(1 - \gamma)$ and $\Phi(x)$ is the pdf of the standard normal variable evaluated at x , $\gamma = \sigma_\mu^2/\sigma^2$ is the fraction of the variance of the inefficiency to total variance (σ^2) and σ_v^2 is the variance parameter that denotes deviation from the frontier due to noise. Thus the farm-specific technical efficiency (TE) can be defined as the ratio of the observed output (y_i) to the corresponding frontier output (y_i^*), conditional on the levels of inputs used by the farm (Battese & Coelli, 1995). Thus the technical efficiency of farm i in the context of the stochastic frontier production function is given as:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{E(y_i | \mu_i, x_i)}{E(y_i | \mu_i = 0, x_i)} = E[\exp(-\mu_i) | \varepsilon_i] \quad (6)$$

Where Y_i is the observed output and Y_i^* is the frontier output, v_i is the standard error term while μ_i is the measure of the efficiency that follows a truncated normal distribution such that $0 \leq TE \leq 1$. Thus if seed potato producers achieve their maximum output, then they would be technically efficient and this means that $\mu_i = 0$.

Study Area and Data: The data used in the study were collected from the districts of Kabale, Kisoro, Rubanda that constitute part of south western highland agro-ecological zone (SWHAEZ). The SWHAEZ located in south western Uganda has predominantly high altitude ranging from 1200 to 2350 meters above sea level. The zone receives bimodal rainfall pattern ranging from 1000 – 1500 mm per annum and temperature range is 10 – 30°C (Kashaija & Wagoire, 2008). The surveyed three (3) districts of SWHAEZ have been selected because they account for about 50 percent of potato production in Uganda (UBOS, 2017a).

Figure 1: Location of study sites



Sample selection and sampling procedure: Multi-stage sampling technique was used to select the study sites and specific farmers within to participate in the study. In the first stage, purposive selection of three (3) districts and three (3) sub-counties in south western highland agro-ecological zone (SWHAEZ) was done on the basis of concentration of potato production. In the selection of study districts and sub-counties, preference was given to areas of highest concentration of potato production. Information about the concentration of potato production of the districts and sub-counties was obtained from the respective district's production departments. The second stage involved purposive selection of two (2) parishes from each of the potato producing sub-counties. Selection of the parishes was also based on potato production with preference being given to the highest potato producing parish in each sub-county. The third and final stage involved generating a sampling frame for seed potato producers from which a proportionate random sampling was used to draw the final sample for the study. The sampling frame included all names of seed potato producers in all 18 selected parishes. The names of the seed potato producers in each parish were generated through consultations with the sub-county agricultural officer, the local government parish council chairpersons and parish farmers' fora chairperson for the selected parishes.

Through this procedure the sampling frame generated comprised 411 names of seed potato producers (Table 1). This target population was identified and selected based on intensity of seed potato production activities in the respective parishes. In order to ensure representativeness of the sample, the researcher randomly selected at least 75 percent of seed potato producers from each parish and this gave rise to the total sample of 288 using the formula developed by Cochran (1977) in equation (7). Where s = required sample size, Z^2 = is a constant value of 3.841 (the square of the Z-value of 1.96 for 95 percent confidence level), p = estimated proportion of the population of 0.75 (i. e 75 percent of the seed potato producers), $q = 1-p$, e = desired level of precision (0.05). The calculated sample size of 288 was increased by 10 percent to cater for non-responses making a total of 318 seed potato producers (Table 1).

$$s = \frac{Z^2 pq}{e^2} \quad (7)$$

Table 1: Number of seed potato producers selected from each parish

Districts	Sub counties	Parishes	Total seed producers	Sampled seed producers
Kisoro	Bukimbiri	Kagunga	30	23
		Iremera	31	24
	Nyarusiza	Gitenderi	24	18
		Rukongi	6	5
	Muramba	Gisozi	12	9
		Sooko	12	9
Kabale	Kamuganguzi	Katenga	52	41
		Mayengo	29	22
	Rubaya	Rwanyena	26	20
		Mugandu	33	25
	Kitumba	Bukoora	17	13
		Bushuro	10	8
Rubanda	Bubaare	Kagarama	18	14
		Bushura	20	15
	Muko	Kaara	5	4
		Butare	29	22
	Hamurwa	Mpungu	28	21
		Kanyabitara	29	25
Total			411	318

Data Collection and Analysis: Data were collected on output (seed potato produced), input use, socio-economic, farm specific and institutional variables for two most recent cropping seasons (season 1 and 2). The data was collected using a semi-structured questionnaire that was pre-tested on 10 farmers from Nyamweru sub-county in Rubanda district) which was later on excluded in the study sites to avoid contamination of the sample. The results of the pre-test helped to further fine-tune the questionnaire in terms of logical flow of the interview. Data was then analyzed with Frontier version 4.1 (Coelli, 1996).

4. Results and Discussion

Farmers Socio-Economic and Demographic Characteristics: Informal and formal seed potato producers were characterized and compared in terms of their sex, producers' education level, household size, off-farm income sources, experience in seed potato production, seasonal preference, scale of seed potato production, seed potato variety diversity and distance to seed potato source (Table 2).

Table 2: Summary statistics for socio-economic and farm specific variables in the study area

Variable	Units	Informal producer Percent (%)	seed	Formal producer Percent (%)	seed	Chisq. (χ^2)	P-value
Sex of the producer	1=Male, 0 =female	92.2		86.9		3.733*	0.052
Producers' education	1 $\geq$ 12yrs in school, 0 otherwise	63.7		63.5		0.002	0.962
Off-farm income source	1=had access, 0= never	53.3		52.6		0.024	0.876
Scale of seed production	1= $\leq$ 1.5 acres, 0 = >1.5 acres	78.8		78.8		0.001	0.985
Seed variety diversity	1= >1 variety, 0=1 variety	31.3		37.2		1.741	0.187
Extension services	1=had access, 0= never	24.9		31.4		2.372	0.124
Seasonal preference	1=season 2, 0 = season 1	50.1		49.6		0.009	0.923
		Mean	Std. Dev	Mean	Std. Dev		P-value
Household size	Persons	6.00	2.00	6.00	3.00		0.241
Experience	years	9.00	5.00	8.00	5.00		0.179
Distance to seed source	Kilometers	3.70	10.78	3.23	7.11		0.630

Note: *, ** and *** show significance at 10, 5 and 1% level, respectively

Results in Table 2 show that potato seed production in SWHAEZ is dominated by male farmers. Specifically, 92 percent and 87 percent of the informal and formal seed producers respectively were males. The results indicate that there were significantly more males among the informal seed potato producers than in the formal seed potato producers ($p=0.052$). These results generally indicate that males dominate both formal and informal seed potato systems. This could be attributed to males' better access to and control over resources like land and finances that are needed for seed potato production. With regard to seed producers' education, about 64 percent of both formal and informal seed potato producers had completed at least ordinary level of education (12 or more years of schooling). The results further indicate that there was no statistically significant difference between formal and informal seed potato production in terms of years of schooling (Table 2). Table 2 further shows that less than 50 percent of both categories of seed potato producers had one or more off farm income sources. This indicates that the majority of both categories of seed potato producers solely depended on agricultural production for income. About 79 percent of both informal and formal seed potato producers were operating on seed potato farms of 1.5 acres or less. This shows that the most of formal and informal seed potato producers were operating on a small-scale as indicted by the size of land allocated to seed potato production. This implies that efforts to increase supply of seed potato in SWHAEZ need to focus on increasing productivity in a context of limited arable land.

About 31 percent and 37 percent of the informal and formal seed potato producers respectively produced more than one variety of seed potatoes. This limited seed potato variety diversity among both categories of farmers reduces farmers' capacity to meet the diverse needs of potato farmers in terms of varieties. More still, about 25 and 31 percent of the informal and formal seed producers had received extension services from the extension agent. However, there were no significant differences among informal and formal seed potato producers with regard to access to extension services. In terms of household size, experience in seed potato production and distance to seed potato source, there were no significant differences between the informal and formal seed potato producers. Both categories of seed potato producers had an average of six members in their households. This is slightly higher than the national average of about five (UBOS, 2017b). With regard to experience in seed potato production, the informal and formal seed potato producers had nine and eight years respectively. Both categories of seed potato producers were located between 3-4 kilometers from their sources of basic seed potato. This shows that the seed potato producers had access to the potato seed sources (whether formal or informal).

Agro-Input Use Among Formal and Informal Seed Potato Producers: Seed potato production requires different inputs in varying quantities. An independent samples t-test was used to establish whether significant differences existed between the formal and informal seed potato producers in terms of seed potato output and quantities of input used per acre in the production of seed potato (Table 3).

Table 3: Descriptive statistics for farm output and inputs of seed potato production in the study area

Input	Units	Informal seed producer		Formal seed producer		p-value
		Mean	Std. Dev	Mean	Std. Dev	
Yield	Kgs/acre	4293	4372	4957	5378	0.135
Labor	Person days/acre	142.32	88.33	148.48	87.74	0.469
Seed Planted	Kgs/acre	874.72	773.23	846.02	802.18	0.703
Fertilizer	Kgs/acre	81.34	101.79	66.68	80.14	0.120
Pesticide	Litres/acre	5.30	5.44	4.41	3.93	0.075

Results in Table 3 indicate that there are no statistically significant differences between formal and informal seed potato producers in terms of seed potato output. Both categories of farmers obtained slightly more than 4,000 kilograms per acre of seed potato output which is slightly more than half of the 8,000 kilograms per acre (20,000 kilograms per hectare) that is obtainable at research station (Byarugaba et al., 2017). With regard to quantities of inputs used in seed potato production, Table 3 further show that there were no significant differences between the two categories of seed potato producers in terms of quantities of inputs used except for quantities of pesticide. Specifically, the informal seed potato producers used significantly higher amounts of pesticides than their formal counterparts ($p=0.075$). The higher amounts of pesticides used by informal seed potato producers could be attributed to the fact that the seed they plant is normally produced from their last season's harvests or from local markets which may already be diseased and or less resistant to pests and diseases and thus the need for more spraying. The results in Table 3 indicate high standard deviations which depict existence of wide farmer to farmer disparities in terms of seed potato output and quantities of inputs per acre. The results however further indicate that the both categories of seed potato producers use low amounts of inputs compared to what is recommended for optimal productivity. For instance, with regard to quantity of fertilizer applied per acre, both categories of seed potato producers were applying 60-80 kilograms per acre compared to recommended 120 kilograms per acre (Balde et al., 2013; Emmanuel et al., 2016). Application of inputs in rates that are lower than the recommended compromises the productivity as well the profitability.

Choice of Appropriate Functional Form: In order to ensure that inefficiency effects are stochastic, a generalized likelihood ratio (LR) test was conducted to test for presence of inefficiency effects. The null hypothesis was that inefficiency effects are not present ($H_0: \gamma = 0$) against the alternative hypothesis that inefficiency effects are present ($H_1: \gamma \neq 0$). For all the two models (informal and formal seed potato producers), the null hypothesis of no inefficiency effects was rejected at 5 percent level (Table 4). This implied the existence of inefficiency effects on seed potato farms and hence the traditional OLS was not an

adequate representation of the sample data. Furthermore, the second hypothesis which proposed that the explanatory variables in the inefficiency model have no effect was rejected at 5 percent level suggesting that the 10 variables included in the model for both informal and formal seed potato producers significantly contributed to the inefficiency effect in the model. The third hypothesis was set out to test whether Cobb-Douglas production was appropriate specification for the data. Based on the likelihood ratio test, the hypothesis of Cobb-Douglas was rejected at 5 percent level for informal seed potato producers and failed to reject the null hypothesis for formal seed potato producers (Table 4).

Table 4: Tests of hypotheses for parameters of the translogarithmic stochastic frontier production function and technical inefficiency model

Null Hypothesis	Log likelihood	LR Statistic	Critical Value	Decision
Ho: $\gamma = 0$			Mixed $\chi^2_{10,0.05}$	
Informal seed producers	-509.934	24.05	17.670	Reject Ho
Formal seed producers	-124.970	27.78	17.760	Reject Ho
Ho: $\delta_0 = \delta_1 = \dots = \delta_{10} = 0$			$\chi^2_{10,0.05}$	
Informal seed producers	-506.489	25.47	18.31	Reject Ho
Formal seed producers	-106.521	60.93	18.31	Reject Ho
Ho: $d_{ik} = d_{ki} = f_{ik} = f_{ki} = 0; i \leq k = 1, \dots, 10$			$\chi^2_{10,0.05}$	
Informal seed producers	-519.222	20.35	18.31	Reject Ho
Formal seed producers	-136.984	17.79	18.31	Fail to reject Ho

Note: Mixed $\chi^2_{10,0.05}$ values were taken from Kodde and Palm (1986, pp. 1246)

Empirical estimates of the Stochastic Frontier Production and Technical inefficiency: In order to establish the factors that account for the inefficiency, a technical inefficiency model was simultaneously run with the stochastic production frontier using Frontier 4.1 program. A truncated normal distribution of the inefficiency term (μ_i) was assumed and estimated. The overall technical inefficiency effects are evaluated in terms of parameters associated with δ and γ (Table 5). The estimates of the variance parameters δ^2 and γ for both informal and formal seed producers were significantly different from zero at 1 and 10 percent levels. Specifically, the values of variance parameter gamma (γ) of 0.64 and 0.36 for both informal and formal seed potato producers suggest that inefficiency effects are significant in determining the levels and variations of seed potato produced. This further implies that 64 and 36 percent of the variation in seed potato produced by informal and formal seed potato producers respectively is due to the differences in technical efficiency rather than random variability. The results further depict that the systemic variations that were unexplained by the production function are the dominant source of errors (Musaba & Bwacha, 2014). Table 5 reports the results of the frontier model (top panel) and the inefficiency model (bottom panel) for non-neutral specifications for both informal and formal seed potato producers. Before the estimation, all variables in the top panel were normalized by their respective sample means which makes it possible to interpret the first order coefficient estimates of the translog model directly as partial elasticities for the individual inputs (Coelli et al., 2005; Ogundari, 2013; Kahiluoto & Kaseva, 2016; Ahmadzai, 2017; Holtkamp & Brümmer, 2017).

Specifically, with the translog estimation for informal seed producers, quantity of seed planted was found to be significant at 1 percent with elasticity of 0.506, followed by labor and pesticide with elasticities of 0.388 and 0.092 respectively. This means that a unit increase in the amounts of seed, labor and pesticide used per acre respectively resulted into a 0.51 percent, 0.39 percent and 0.10 percent increase in the quantity of seed potato produced per acre. Regarding the interactions, amount of seed and fertilizer used per acre, labor and amount of fertilizer used per acre as well as labor and pesticide per acre had a positive influence on seed potato produced though not statistically significant. This suggests that if seed producers used more of these inputs it would lead to higher seed potato yields. This result further indicates the productivity enhancing potential of these inputs when they are used jointly. With Cobb-Douglas estimation for formal seed producers, overall all inputs are inelastic. This means that a unit increase in the number of man days results

into a 0.53 percent increase in seed potato output per acre. Similarly, unit increases in the amounts of seed potato used per acre also result into a 0.45 percent increase in seed potato output per acre (Table 5).

Table 5: Estimated stochastic production frontier and technical inefficiency models for seed potato producers in SWHAEZ

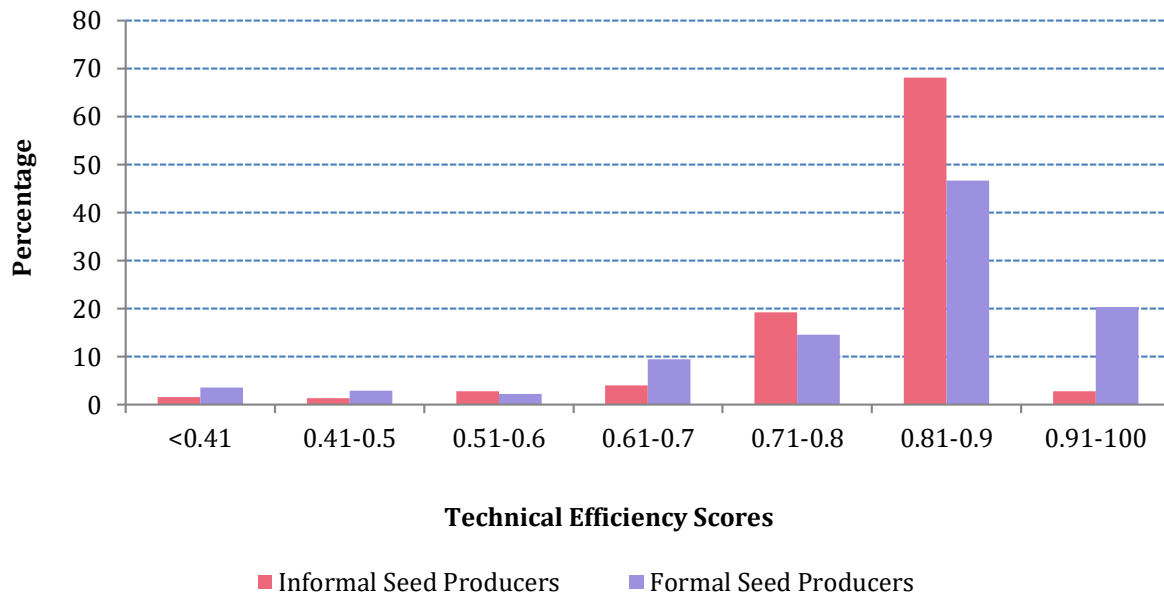
Variables	Parameters	Informal Seed Producers (n=499)		Formal Seed Producers (n=137)	
		Coeff	Std. error	Coeff	Std. error
Production Frontier		Translog		Cobb-Douglas	
Constant	β_0	0.079	0.081	0.188	0.159
InLabor(X_1)	β_1	0.388***	0.071	0.530***	0.123
InSeed(X_2)	β_2	0.506***	0.062	0.451***	0.065
InFertiliser(X_3)	β_3	0.001	0.060	0.035	0.087
InPesticide(X_4)	β_4	0.092**	0.046	0.026	0.087
$\frac{1}{2} (\ln X_1)^2$	d_1	0.031	0.168		
$\frac{1}{2} (\ln X_2)^2$	d_2	0.147**	0.066		
$\frac{1}{2} (\ln X_3)^2$	d_3	-0.132**	0.070		
$\frac{1}{2} (\ln X_4)^2$	d_4	-0.037	0.070		
$\ln(X_1) \times \ln(X_2)$	f_1	-0.033	0.103		
$\ln(X_1) \times \ln(X_3)$	f_2	0.037	0.091		
$\ln(X_1) \times \ln(X_4)$	f_3	0.069	0.078		
$\ln(X_2) \times \ln(X_3)$	f_4	0.007	0.069		
$\ln(X_2) \times \ln(X_4)$	f_5	-0.073	0.061		
$\ln(X_3) \times \ln(X_4)$	f_6	-0.019	0.063		
Inefficiency Model					
Constant	δ_0	0.358	0.531	-0.768	0.898
Sex	δ_1	-1.823**	0.899	-0.841	0.752
Education	δ_2	1.243**	0.460	-1.139**	0.491
Experience	δ_3	-0.034	0.023	-0.039	0.036
Household size	δ_4	0.018	0.039	0.348***	0.094
Off-farm income	δ_5	-0.916**	0.452	-0.077	0.401
Variety diversity	δ_6	1.292**	0.672	-0.347	0.512
Extension services	δ_7	-0.605**	0.357	-1.191	0.745
Scale of production	δ_8	-2.103**	0.972	0.441	0.666
Seed distance	δ_9	0.191	0.012	-0.027	0.030
Seasonal preference	δ_{10}	-1.439**	0.719	0.096	0.389
Variance parameters					
Sigma squared	σ^2	1.107***	0.189	0.498***	0.161
Gamma $\gamma = \sigma_\mu^2 / \sigma^2$	γ	0.635***	0.082	0.357*	0.224
LR test of $\delta_\mu = 0$	χ^2	24.05***		27.77***	

Note: *, ** and *** show significance at 10, 5 and 1% level, respectively

These findings regarding elasticities for different inputs for informal and formal seed potato producers suggest that seed and labor are the core inputs for improved productivity in seed potato production. These results are in agreement with those of Ologbon et al. (2012) study in Nigeria and Kidane et al. (2013) among small scale farmers in Tanzania. The returns to scale (RTS) parameter obtained by summing all the input elasticities was about 0.987 and 1.041 for informal and formal seed potato producers respectively (Table 5). These returns to scale (RTS) estimates are approximately equal to 1, suggesting that seed potato production

in SWHAEZ exhibits constant returns to scale. This implies that an increase in all inputs available to the seed potato producers leads to an equal proportionate increase in seed potato output. This finding further emphasizes the need for seed potato producers to use the recommended rates of the inputs in order to optimize production. However, elasticities and RTS do not offer clear insights about the technical efficiency of informal and formal seed potato producers which relates to how the output they obtain compares with the maximum possible within their circumstances. Therefore, the next section focused on estimation of level technical efficiency of formal and the informal seed potato producers.

Figure 2: Technical efficiency scores for informal and formal seed potato producers



Results in Figure 2 show that about 94 percent of the informal seed producers had a technical efficiency above 60 percent while about 91 percent of the formal seed potato producers had an efficiency score over 60 percent. Similarly, about 6.5 and 3.0 percent of the formal and informal seed potato producers respectively were operating below 50 percent of their efficiency levels. Results further indicate that farmers who produced seed potato from informal sources slightly had a higher technical efficiency than those who produced seed potato from formal sources. Specifically, informal seed producers had an average technical efficiency of 81.4 percent while formal seed producers had 80.4 percent (Table 7). These results compare well with Musaba and Bwacha (2014) study among small scale maize producers in Zambia but are comparatively higher than those of Prasanna and Lakmali (2016) study among smallholder potato producers in Sri Lanka. Although the mean technical efficiency for the informal seed producers was higher than their formal counterparts, there was no significant difference at 5 percent level (Table 6). This result concurs with that of another study in Nigeria conducted by Ogundele and Okoruwa (2006) who found out that there were no differences in technical efficiencies between farmers planting traditional rice varieties and those planting improved rice varieties. The similarity of the informal and formal seed potato producers in terms of technical efficiency could be attributed to the fact that both of categories of farmers are smallholder farmers producing seed potato in the same context (agro-ecological conditions) and using limited amounts of productivity enhancing technologies (Table 3).

Table 6: Two sample t-test for mean difference in technical efficiency between informal and formal seed potato producers

Null hypothesis	Pr(T>t)	T-statistic	Decision
H ₀ : $\mu_1 = \mu_2 = 0$	0.384	0.872	Fail to reject H ₀

Estimated Seed Potato Yield Loss Due to Inefficiency and Potential Output Among Seed Producers: In order to measure the yield loss due to inefficiency for the two categories of seed potato producers, both the actual seed produced and the potential seed production were computed using equation (6). According to Mor and Sharma (2012), the loss due to inefficiency is the difference between potential seed production and the actual seed potato produced. Table 7 provides an account of the potential as well as the yield loss in seed potato production in SWHAEZ.

Table 7: Estimates of potential seed potato production and yield loss among seed potato producers.

Variables	Informal seed producers			Formal seed producers		
	Mean	Min	Max	Mean	Min	Max
Observed seed potato yield (kg/acre)	4,293	320	40,000	4,957	400	40,000
Technical efficiency estimates	0.814	0.225	0.920	0.804	0.118	0.953
Computed Yield Frontier (kg/acre)	5,274	1,422	43,478	6,165	3,390	41,973
Computed Yield loss (kg/acre)	981	1,102	3,478	1,208	2,990	1,973

The mean potential yield was computed to be 5,274 and 6,165 kg/acre for the informal and formal seed potato producers respectively. The potential yield is computed based on the assumption that the average seed producer had an efficiency level of 100 percent without introducing any other improved inputs and management practices. Therefore, on average each informal and formal seed potato producer lost 981 and 1,208 kg/acre of seed potato tubers respectively due to technical inefficiency. This translates into an income loss of 1,373, 400 and 1,691, 200 Uganda shillings (UGX) per acre per season for informal and formal seed potato producers at the current average price of seed potato of 1, 400 UGX per kg. This is in agreement with study findings by Balde et al. (2014) among rice producers in Guinean Coastal area. These results suggest that seed potato productivity can be increased by at least 1,200 and 980 kilograms per acre for the formal and informal seed potato producers respectively without introducing any other improved inputs and management practices. This however requires proper identification and tackling of the factors that influence technical efficiency in seed potato production.

Sources of inefficiency: In the interpretation of the results in inefficiency model (bottom panel) Table 5, positive signs of the coefficients indicate a decrease in technical efficiency since technical inefficiency is the dependent variable. The reverse is true for negative signs of the coefficients. Results in Table 5, indicate that informal seed potato producers' technical efficiency was also positively influenced by the sex of the seed potato producer being male. A male informal seed potato producer was found to be 1.8 times more technically efficient than his female counterpart. This could be due to the fact that male farmers have more access and control over the productive resources such as household land, labor and finance compared to the female seed potato producers. Similar findings regarding males' higher technical efficiency were also reported among bean farmers in North and South Kivu (Ross et al., 2009) and among rice farms in Central Thailand (Taraka et al., 2012). These findings generally suggest a need to address the gender differences between males and females especially with regard to access and control over resources and services in order to enhance technical efficiency.

Regarding off-farm income, having one or more off-farm income sources increased the farmers' technical efficiency by about 92 percent. Off-farm income sources enhance technical efficiency possibly through enabling farmers to acquire the external inputs to improve the productivity of their seed potato enterprises. This concurs with the findings of Abebe (2014) in Ethiopia. However this finding contradicts Onyenekwe and Okorji (2015) who found out that off-farm work negatively affected technical efficiency of rice farmers in Nigeria. This mixed influence of off-farm income sources on farmers' technical efficiency calls for careful analysis of off-farm income sources to optimize synergies and minimize competition between such income sources and farming activities. Results in Table 5 further indicate that the technical efficiency of informal seed potato producers is inversely related to their scale of production. Specifically, farmers engaged in seed potato production on a small scale (up to 1.5 acres of land under seed potato production) were about 2.1 times more technically efficient than those having seed potato farms above 1.5 acres. The inverse relationship between

scale of seed potato production and technical efficiency may be attributed to the capital intensive nature of quality seed potato production.

Seed potato production is capital intensive in that it requires strict adherence to various management practices such as; application of fertilizers, use of clean basic seed, proper spacing, timely planting, weeding, disease and pest management. Our results concur with those of Rahman et al. (2012) whose study on rice farmers in Bangladesh found out that small farms attained higher technical efficiency than medium and larger sized farms. Additionally, technical efficiency of an informal seed producer who had access to extension services was 61 percent more than that one who did not have any access to extension services and this result was statistically significant at 5 percent. This positive influence of access to extension services on technical efficiency is attributed to farmers' access to technical support in terms of knowledge and other production related informational materials about the use of inputs. Similar results were also reported among smallholder bean and maize farmers by Sibiko et al. (2013) and Mango et al. (2015) in Eastern Uganda and Zimbabwe respectively. In terms of seasonal preference, informal seed potato producers in season 2 were about 1.4 times more technically efficient compared to season 1 and this was statistically significant at 10 percent. This is attributed to differences between the two seasons in terms of climatic conditions that informs farmers' investment decisions in seed potato production. Season 2 is associated with long rains while season 1 (March to June) has short rains.

As a result, informal seed potato producers invest more in seed potato production in season 2 (September to December) so as to take advantage of the favorable rainfall conditions (Gildemacher, 2012; Kagoda et al., 2013). Results further show that for the informal seed potato producers, level of education had a negative influence on their technical efficiency. Specifically, the technical efficiency of an informal seed potato producer who had completed at least 12 years of formal education was about 1.2 times lower than that of his/her counterpart that had less than 12 years of formal education. This is in agreement with the study findings by Okoye et al. (2016) in central Madagascar and Srisompun and Isvilanonda (2012) in Thailand who found out that formal education had an insignificant effect on technical efficiency improvements. These studies suggest that more educated farmers tend to work part-time on their farms because of other livelihood options. However, these findings are inconsistent with those of Weir and Knight (2000) in rural Ethiopia, and Baruwa and Oke (2012) in Ondo state of Nigeria. Unlike for informal seed potato producers, the technical efficiency of formal seed producers was enhanced by their level of education. Results indicate that the technical efficiency of formal seed potato producers who had at least 12 years of schooling was 1.1 times more than that of their counterparts with less than 12 years of schooling.

The reason for increase in technical efficiency due to education level is partly attributed to the fact that farmers who have more formal education are able to access, analyze and properly use various types of technical information. These findings are consistent with those of Weir and Knight (2000) and Baruwa and Oke (2012) who found out that education enhances the ability of the farmers to acquire and make judicious use of information about production and management of inputs. The differential influence of education on the technical efficiency among informal and formal seed potato producers could be attributed to the differences between these two categories of farmers in terms of access to technical information on seed potato production. More still, results in Table 5 show that informal seed producers who had grown two or more seed potato varieties were 1.3 times less technically efficient than those that had grown one variety and the result was statistically significant at 5 percent. This negative influence of seed potato variety diversity on technical efficiency is attributed to the fact that growing many varieties compromises adherence to various management practices such as application of fertilizers and spraying regime specifications among others. Similar findings were reported by Ebong et al. (2009) in their study among oil palm producers in Akwa Ibom State, Nigeria.

On the contrary, Ahmadzai (2017) reported that crop diversity had a positive influence on technical efficiency among crop farmers in Afghanistan. Nonetheless, studies examining crop diversification and technical efficiency at farm level have mixed conclusions. This could be attributed to contextual differences such as resources available and agricultural practices used which vary from farm to farm. Regarding the influence of household size on technical efficiency, results in Table 5 show that household size had a negative influence on

technical efficiency among formal seed producers. The coefficient corresponding to household size indicated that when household size increased by one member, technical efficiency reduced by about 35 percent. This implies that formal seed potato producers with large household sizes were associated with a reduced technical efficiency in seed potato production and this result was statistically significant at 1 percent level. Similar findings are reported by Danso-Abbeam et al. (2012) in their study in Bekwai district in Ghana and inconsistent with the findings of Mango et al. (2015) among smallholder maize producers in Zimbabwe.

5. Conclusion and Policy Implications

The findings and discussions above show that there is a considerable yield and income loss between actual and potential seed potato production due to inefficiency factors. Although informal potato seed producers have a mean technical efficiency greater than the formal ones, there was no significant difference statistically, and both formal and informal seed potato producers still fall below their full potential seed potato production. This signals presence of barriers to maximization of technical efficiency and productivity growth for both categories of seed potato producers. The findings revealed that seed and labor have a positive and significant effect on seed potato output for both categories of seed potato producers. The study further identified that off-farm income source, small scale of production, access to extension services, seasonal variation and farmers' sex being male were important variables for increased technical efficiency among informal seed potato producers while producers' higher education level was a key factor for enhanced technical efficiency among the formal seed potato producers. However, higher education levels and higher variety diversity compromised technical efficiency of informal seed potato producers and household size for the formal counterparts. Based on the level and analysis of the sources of technical (in) efficiency, the study suggests a number of policy implications.

First, seed potato producers have the potential of improving their performance, on average in terms of input intensification through adoption of productivity enhancing technologies and practices such as quality seed, fertilizers and pesticides so as to optimize the productivity of the available limited land. Secondly, there is need for increased investment in the development and promotion of high yielding farmer preferred varieties that are more customized to biophysical and socio-economic context of farmers. This might also require research and extension to intensively empower seed potato producers to increase their knowledge through various on-farm and on-station demonstrations as well as supporting farmers to access the varieties. The study further advocates for the need to strengthen research and extension linkages to enable smallholder seed potato producers obtain regular customized technical knowledge and other production related informational materials about the use of inputs and the associated management practices. With strong research-extension interface, seed potato producers can be supported to implement their production and productivity decisions in time and this would boost their current levels of efficiency. Lastly, there is need to identify and address gender differences in terms of engagement in seed potato production targeting more females. Therefore, gender responsive programs that recognize women participation as seed potato producers need to be explored as part of the efforts to reduce inefficiency levels in the study area.

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