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Full Length Research Paper

Technical efficiency in resource use: Evidence from smallholder Irish potato farmers in Nyandarua North District, Kenya.

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There has been a consistent decline of Irish potato production in Kenya which challenges the food security status of the country. This paper used data from a field survey using a random sample of 127 smallholder potato producers from Nyandarua North District to assess technical efficiency in resource use and to identify the underlying determinants of variations in production efficiency. A dual stochastic parametric decomposition technique was used to derive technical efficiency indices while a two-limit Tobit model was used to examine the effects of socio-economic characteristics and institutional factors on the derived technical efficiency indices. Results show that resource use is subject to decreasing returns to scale while the mean technical efficiency is 67%. Education, access to extension, access to credit and membership in a farmers' association and innovations positively and significantly influence technical efficiency. Therefore, Innovative institutional arrangements that enhance extension and farmer training, accompanied with improved access to credit are likely to enhance potato production efficiency.

Key words: Efficiency, food insecurity, productivity, stochastic frontier function, Kenya.

INTRODUCTION

Accelerating agricultural growth remains one of the most important objectives policy makers face in less developed countries, where agricultural productivity is low, population growth rates are high and the ability to import food are severely constrained (Leggese et al., 2004). In Kenya, the development policy for the medium term (2000 - 2030) continues to recognizes agriculture as an important sector for the Kenyan economy, with priority centred on food security initiatives and provision of employment opportunities (Okuro et al., 2000). For the agricultural sector to play this central role in the economy, rapid growth in output and productivity are critical and the role of Irish potato in the subsector is important as well.

Irish potato is the second most important food crop in Kenya after maize (MoA, 2007; Ministry of Planning, National Development (MoPND) and Vision 2030, 2008). The crop is grown by approximately 500,000 smallholder farmers on about 100,000 hectares annually; its consumption is growing particularly among urban consumers (MoA, 2007, 2006). The average production is about 1 million tonnes with an average production of 7.3 metric tonnes per hectare (mt/ha). Improving productivity in the Irish potato sub-sector, reducing food insecurity and poverty are major policy objectives of the government. Although investments have been made in research and development in an effort to improve Irish potato productivity of smallholder farmers, these efforts have focused on development and adoption of high yielding varieties (MoA, 2006). Yet low productivity remains a major challenge - the average national farm level yields

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Abbreviations: mt/ha, Metric tonnes per hectare; **RLS,** restricted least squares; **TE,** technical efficiency.

of 7.3 metric tonnes per hectare (mt/ha) compares unfavorably with on research station yields of 25 - 35 mt/ha and a potential of 14.5 - 20 mt/ha under farm-level conditions (Kenya Agricultural Research Institute (KARI), 2005). This implies that technological advances generated through research have not widely translated to increased efficiency and improved resource productivity.

This study aimed at establishing the current levels of technical efficiency of smallholder Irish potato producers and at factors that influence levels of farm production and technical efficiency using data from a major potato growing area (Nyandarua District) in central Kenya highlands. The objective was primarily to provide insights into constraints that hamper improved potato production thus identify avenues for possible policy intervention towards improved Irish potato production in Kenya. We are not aware of any study that has inquired into small holder technical efficiency in Irish potato production in Kenya and this study aimed to fill that knowledge gap.

METHOD

The study area

The study was conducted in Nyandarua North District, one of the major Irish potato growing districts in Kenya. Of the approximately 100,000 ha of land under Irish potato cultivation in Kenya. 17,500 ha (17.5%) are located in Nyandarua North District (MOA, 2007). The district falls within the central Keyan highlands with an altitude range of between 2,350 and 3,000 m above sea level. The average diurnal temperature is 22°C (Jaetzold et al., 2006).

The district generally receives reliable rainfall. The average annual rainfall is 1,000 mm with a bimodal distribution: the long rains in the area fall in March - July and short rains in October to December. Soils are predominantly humic andosols with high to moderate fertility. The population is 90% rural-based consisting of 55,228 households with a mean household size of 4 persons (Jaetzold et al., 2006). According to the 1999 population census, population of Nyandarua North District had 249,280 persons consisting of 122,584 males and 126,696 females. Land ownership is predominantly freehold in the study area and small-scale farms are predominate. The average land size per household is about 1 ha (Jaetzold et al., 2006). The main economic activity of most households with is farming with dairy production being the dominant enterprise followed by Irish potato production. The other major cash crops include: wheat, pyrethrum and horticultural crops such as cabbages, garden peas and carrots (MOA, 2007).

Data

A survey of the production practices and household characteristics of smallholder Irish potato producers was conducted in June 2008. Data were obtained from 127 Irish potato producers. Although the Irish potatoes are grown in two seasons, a single production season was selected in order to minimize seasonal effects on variations in input use and yield. A two - stage sampling technique was used. First, two sub-locations were selected from each of the locations on a random basis. Secondly, a random sample of 127 households from 31 sub - locations was selected for the survey. Data were collected using a structured questionnaire. The questionnaire was designed and pre-tested in the field for its validity and content, and to make overall improvement of the same and in line with the objectives of the study. Data were collected on output levels, This include: input use, and socio-economic and institutional variables. Irish potato output comprising of quantities sold and those retained for consumption and as seeds, (measured in 110 kg bags); labour input, which was measured as the number of person - days for different operations (that is, land preparation, planting, weeding, Spraying, harvesting, sorting) for all hired and family labour, with one person-day being equal to 8 h of labor; The seed variable was measured as the total physical quantity of seeds in kilograms, comprising that purchased and that produced on-farm the quantity of fertilizer used, was measured as total measured in kilograms; and finally, the was measured as total kilograms applied. Finally, land area devoted to Irish potato production, measured in hectares. Additional data on average district-wide input and output prices for input and output was collected as well.

In addition information on socio-economic characteristics and institutional factors including age, gender, education, and experience of the household head as well as on access to credit and extension w variables was also collected. The age variable was included to test the hypothesis that younger farmers are more receptive to innovations and therefore may bear a positive impact on productivity and efficiency results, *cateris paribus*.

Farmers' experience, level of education and access to extension, potential sources of technical efficiency, were included as variables for measurement. Farmers' experience was measured by the number of years that the household head has spent in producing Irish potatoes. Education level of the household head is a continuous variable and was measured in years of formal schooling of the household head. Education is generally postulated to have a positive impact on efficiency. Access to extension was estimated using the number of visits to the farm by extension workers. Other explanatory variables were measured as dummies. Gender was included as a binary, which was set as 1 for male headed households and 0 for female to test the influence of gender on technical efficiency. Access to credit was included as a binary variable that equals to 1 if farmer had access to credit and 0 otherwise to test the relationship between credit use and technical efficiency. A positive relationship is postulated between access to credit and technical efficiency. Access to credit permits a farmer to enhance technical efficiency by overcoming financial constraints for the purchase of higher quality variable inputs, such as fertilizer or new technological package such as high-yielding seeds (Abdulai et al., 2001). To explore the relationship between technical efficiency and the membership in a farmer' associations, the membership variable was also included as a binary. It takes the value 1 if the producer was a member of a farmers' association and zero otherwise.

The model

Following Bravo-Ureta and Pinheiro (1997), we use a parametric stochastic efficiency decomposition approach to measure the technical efficiency in Irish potato production. This is an extension of Kopp and Diewert (1982) efficiency estimation procedure. The advantage of this approach is the application of a stochastic frontier model with a disturbance term specification that captures noise, measurement error, inefficiency component and exogenous shocks beyond the production unit. The stochastic frontier production function model is specified as follows:

$$Y_i = f(X_i;\beta) + \varepsilon_i \qquad (1)$$

Where Y_i measures the quantity of output; X_i is a vector of the input quantities; β is a vector of parameters to be estimated; $f(X_i;\beta)$ is a frontier production function; and ε_i, is a composite error term (Aigner at al.. 1977). Following Aigner et al. (1977), the composite error term is given as:

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

Where v_i is assumed to be independently and identically distributed as v~N (0. σ_v^2) random error and represents random variability in production that cannot be influenced by producers , and μ_i is a non-negative random variable associated with technical inefficiency in production and is independently and identically distributed (iid) as half-normal, μ~N(0. σ_μ^2). The frontier production function f (X_i; β) measures the maximum potential output for a given input vector, X_i. Both v_i and μ_i cause actual production to deviate from the frontier (Xu et al., 1998).

Using a Cobb-Douglas functional specification to model Irish potato production technology, the frontier production function in equation (1) is an estimated using maximum likelihood estimation procedure which provides estimators for β and variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_\mu^2$ and $\gamma = (\sigma_\mu^2 / \sigma^2) \in [0,1]$*. To empirically measure efficiency, deviations from the frontier are separated into a random (v) and an inefficiency (μ) component. Following Jondrow et al. (1982) and given the distribution and independence assumptions on v_i and μ_i, is in addition to the fitted values of ε_i, the conditional mean of μ_i is estimated as:

$$E(\mu_i \mid \varepsilon_i) = \sigma_* \left[\frac{f^*(\lambda\varepsilon_i/\sigma)}{1 - F^*(\lambda\varepsilon_i/\sigma)} - \frac{\lambda\varepsilon_i}{\sigma} \right]. \qquad (3)$$

Where $\sigma_* = \sigma_v \sigma_\mu / \sigma$, f^* is the standard normal density function and F^* is the distribution function both functions being evaluated at $\lambda\varepsilon/\sigma$. Therefore, equation (1) and (3) provide estimates of v and μ after replacing ε, σ and λ by their estimates.

According to Bravo-Ureta and Pinheiro (1997), the i^{th} firm efficiency is measured using adjusted output. This output is derived by subtracting the random error, v_i , from both sides of equation (1) thus:

$$Y_i^* = f(X_i;\beta) - \mu_i = Y_i - v_i \qquad (4)$$

Where Y_i^* is the adjusted output of the i^{th} firm; and μ_i is obtained from equation (3). The adjusted output Y_i^* is then used to derive the i^{th} firm technically efficient input vector X_{it} by simultaneously solving equation (4) and the observed input ratios $X_1/X_i = k_i$ ($\forall_i$ > 1). where k_i is equal to the observed ratio of the two inputs in the production of Y_i^*. The observed and technically efficient costs of production of the i^{th} firm are equal to $\Sigma X_i P_i$ and $\Sigma X_{it} P_i$, respectively. These cost measures are used to compute the technical (TE) efficiency index for i^{th} firm as follows:

$$TE_i = \sum X_{it} P_i / \sum X_i P_i \qquad (5)$$

To determine the relationship between socio-economic and institutional factors and the computed indices of technical efficiency a second step analysis (Binam et al., 2003; Bravo-Ureta and Pinheiro, 1997) was performed where a two-limit Tobit equation is estimated. A two-limit Tobit model was adopted because technical efficiency of an individual farm is the ratio of the observed output to the corresponding frontier output conditional on the level of input used. Therefore technical efficiency scores lie within the range of 0 to 1.

RESULTS AND DISCUSSION

The basic characteristics of sample farms are presented in Table 1. The results show that the land area allocated to Irish potato was small at an average of 0.34 hectares. The average age of the sample farmers was 47 years, while the mean household head's farming experience was 14 years and 9 years of formal education. The farm size in the sample was between 0.51 - 24.49 ha with a mean of 2.46 ha and a standard deviation of 3.06. On average, the sample farms reported a mean yield of 97.55 bags/ha while the yields vary between a low of 62.05 and a high 185 bags/ha, suggesting considerable room for improving Irish potato yields. On average, 154 man-days/ha of labor, 1592.10 kg/ha of seed and 238.12 kg/ha of fertilizer are used by farmers. Only 35% of the total sample of farmers had access to credit while 42% belonged to a farmers' association. Households received an average of one extension visit per year.

The maximum likelihood parameter estimates of the stochastic production are presented in Table 2. The generalized likelihood ratio test shows that the computed Chi-square is 7.12 while the critical value of the Chi-square at 5% level of significance with 1 degree of freedom equal to 3.84. Thus the null hypothesis was rejected. This implies that the inefficiency effects are significant in determining the level and variability of output of Irish potato producers. The estimated variance parameter of the model (γ) of 0.85 is significantly different from zero at 1% level. This implies that the one-sided random inefficiency component strongly dominates the measurement error and other random disturbance indicating that about 85% of the variation in farm output from the frontier between farms mainly arose from farm's practices rather than random variability. The results showed the expected signs of the coefficients of the stochastic production frontier and all the parameter estimates were statistically significant (Table 2). The following elasticities were obtained: plot size 0.373 (P<0.01), labour 0.205 (P<0.05), seed 0.175 (P<0.1), fertilizer 0.071 (P<0.01) and agrochemicals 0.031 (P<0.01). The sum of the output elasticities is 0.855 implying decreasing returns to scale. The Restricted Least Squares (RLS) regression was formally used to test the null hypothesis that the production frontier exhibits constant returns to scale. The calculated *F* statistic

* Gamma (γ) is the proportion of the total variance of the observed output from the frontier attributable to technical inefficiency. Gamma takes values between zero (0) and one (1) and is generated when running FRONTIER 4.1. Software (Coelli, 1996)

Table 1. Descriptive statistics for a sample of Irish potato producers in Nyandarua North District. Kenya.

Variable	Unit	Mean	Std. Dev
Output	Bags[a]/ha	97.55	39.16
Plot size	Hectares	0.34	0.215
Labour	Man-days/ha	154.19	53.90
Seed	Kilograms/ha	1592.10	639.22
Fertilizer	Kilograms/ha	238.12	145.34
Pesticides	Grams/ha	1377.86	1441.93
Age of household head	Years	47.06	10.643
Level of education	Years	9.59	3.003
Experience of producer	Years	14.13	8.232
Extension visit	No. of visits	1.09	1.362
Family size	Persons	4.82	1.706
Farm size	Hectares	2.46	3.057
Characteristics of hh head		**Frequency**	**Percent**
Gender of household head			
Male		89	70
Female		38	30
Access to credit			
Yes		44	35
No		83	65
Belongs to farmer association			
Yes		53	42
No		74	58

[a]1 Bag = 110 kgs; hh is household head

Table 2. Average production function and stochastic production frontier for Irish potato producers in Nyandarua North District. Kenya.

Variables	Ordinary least squares estimates	Stochastic frontier estimates
Intercept	0.639(0.747)	1.506**(0.617)
Plot size	0.260(0.146)	0.373***(0.127)
Labour	0.241**(0.103)	0.205**(0.095)
Seed	0.216**(0.113)	0.176**(0.089)
Fertilizer	0.082***(0.024)	0.071***(0.022)
Pesticides	0.033***(0.012)	0.031***(0.010)
Function coefficient	0.832	0.855
F statistic model	55.80	
F-statistic CRTS	7.287	
σ_μ		0.491
σ_ν		0.203
σ^2		0.282
γ		0.854***(0.074)
Log-likelihood	-50.32	-46.76
Adj. R^2	0.70	
N	127	

The figures in parentheses represent standard errors. CRTS means Constant Returns to Size.
*, **, *** significant at the 10, 5, and 1% level, respectively.

followed by labour. Agrochemicals recorded the lowest elasticity. This suggests that productivity would be higher if more land is brought under Irish potato production.

The frequency distribution of the estimated technical efficiency indices are presented in Table 3. The predicted technical efficiency indices varied from 0.21 to 0.93 with a mean of 0.67, which suggests there was significant technical inefficiency in Irish potato production in the study area. This implies that potato farmers can reduce their inputs by about 33% without reducing output by improving on the current levels of technical efficiency. By improving technical efficiency, sample farms would reduce their production costs and consequently increase gross margin of potato production. The estimated mean technical efficiency of 0.67 suggests that were an average farmer in the sample to achieve the technical efficiency (TE) level of the most efficient counterpart, then the average farmer could realize a 28% cost savings (that is 1-[66.7/92.9x100]). The frequency distribution of the farm specific technical efficiency indices showed that 7% of the sample farms were operating at a technical efficiency below 0.40 while 69% of farms had a technical efficiency level of more than 0.60 (Table 3). The parameters of the two-limit Tobit model are presented in Table 4. Based on the results the household head's level of education, access to extension, access to credit, and membership in a farmers' association, each has a positive and significant coefficient. The coefficients obtained implied that these factors positively influenced technical efficiency.

Table 3. Frequency distribution of technical efficiency estimates for a sample of Irish potato producers in Nyandarua North District. Kenya.

Efficiency (%)	No.	%
>85	13	10
>80≤85	13	10
>75≤ 80	24	19
>70 ≤ 75	18	14
>65 ≤ 70	8	6
>60 ≤ 65	13	10
>55 ≤ 60	7	6
>50 ≤ 55	5	4
>45 ≤ 50	10	8
>40 ≤ 45	7	6
>35 ≤ 40	4	3
>30 ≤ 35	3	2
>25 ≤ 30	0	0
>20 ≤ 25	2	2
>15 ≤ 20	0	0
>10 ≤ 15	0	0
>10	0	0
Sample size (N)	127	
Mean (%)	66.7	
Min. (%)	21.2	
Max. (%)	92.9	

The results show that farmers with more years of formal schooling were more efficient than their counterparts (Table 4). Similar results have been reported in studies which have focused on the association between formal education and technical efficiency (Uaiene and Arndt, 2009; Bozoglu and Ceyhan, 2007; Bravo-Ureta and Pinheiro, 1997). In general, 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 counterparts. This result is consistent with the findings by Abdulai and Eberlin (2001) which established that an increase in human capital will augment the productivity of farmers since they will be better able to allocate family-supplied and purchased inputs, select and utilize the appropriate quantities of purchased inputs while applying available and acceptable techniques to achieve the portfolio of household pursuits such as income.

The positive coefficient for the access to extension variable implied that regular extension visits by extension workers led to improved technical efficiency. Access to extension variable had a positive significant coefficient in relation to technical efficiency, implying that technical efficiency increases with the number of visits made to the farm household by extension workers. Similar results were reported by Bozoglu and Ceyhan (2007) for vegetable farmers in Turkey and Nchare (2007) for coffee farmers farmers in Cameroon. The result is also consistent with findings by Seyoum et al. (1998) who found a 14% difference in technical efficiency between farmers who had access to extension services and those who did not in a study on farmers within and outside the Sasakawa-Global 2000 project. Extension workers play a central role in informing, motivating and educating farmers about available technology.

Further results show that there was a positive and statistically significant effect of credit use on technical efficiency at 1% level (Table 4), implying that increasing credit use would enhance technical efficiency of sample farms. This is consistent with the findings by Abdulai and Eberlin (2001) for farmers in Nicaragua and Alene et al. (2003) for farmers in Ethiopia. Dolisca and Jolly (2008) found farm households who used credit in Haiti to be more technically efficient than their counterparts. Availability of credit is an important factor for attaining higher levels of efficiency. Access to credit permits farmers to enhance efficiency by overcoming liquidity constraints which may affect their ability to purchase and apply inputs and implement farm management decisions on time hence increasing efficiency. It is therefore important that credit constrained smallholder farmers be facilitated to access loans at reasonable costs in order to purchase farm inputs such as inorganic fertilizers and pesticides. There was a positive and significant difference between

Table 4. Two-limit Tobit model estimates for factors affecting technical efficiency of Irish potato producers in Nyandarua North District. Kenya (Dependent variable = Technical Efficiency indices).

Variable	Coefficient	Std. Dev.	*t*-value
Constant	3.909***	0.372	10.52
Gender of household head	0.069	0.051	1.35
Age of producer	-0.10	0.100	-0.99
Education level of producer	0.161**	0.068	2.34
Experience of producer	0.056	0.040	1.42
Contact with extension agents	0.045**	0.020	2.23
Access to credit	0.166***	0.054	3.07
Membership in a farmers association	0.193***	0.058	3.29
Log-likelihood		-16.05	
N		127	

*,**, *** significant at the 10, 5, and 1% level, respectively.

membership in a farmers' association and technical efficiency (P < 0.1), suggesting that farmers who belong to an organization are likely to benefit from better access to inputs and to information on improved farming practices. Being a member in farmers' association may lead to sharing of information on farming technologies which tends to influence the production practices of members through peer learning. This could be explained by the fact that farmers' associations have the potential to shorten the marketing chain by directly connecting small producers to markets; better coordinate production and marketing activities and facilitate farmer access to production inputs at fair prices (Shiferaw et al., 2008).

Furthermore Amudavi et al. (2009) found that participation in local groups has inefficiency reducing effect and participation in local groups provide avenues for information and technology transfer by extension agents for group members to make appropriate farming decisions thus enhancing productivity and efficiency. Similar results for farmers in Canada and Cameroon are reported in Amara et al. (1999) and Binam et al. (2005), respectively. However, Binam et al. (2003) found a negative and statistically significant relationship between membership in a farmers' association and technical efficiency for coffee farmers in Cote d'Ivoire. This finding is consistent with local practice where farmers prefer to allocate family and collective labour to cocoa farms first and hence they cannot execute improved agronomic practices on coffee production on time thereby negatively influencing productivity and technical efficiency (Binam et al., 2003). With respect to age, gender and household head's experience, however, this study found no statistically significant relationship. This is possibly because these variables do not directly influence efficiency but rather indirectly through decisions on variable input use levels

Conclusions and Implications

This paper has estimated the technical efficiency levels for a random sample of potato farmers Kenya highlands using a stochastic parametric efficiency decomposition technique. Socio-economic (age, gender. education level and experience) and institutional factors (access to credit contact with extension and membership in a farmers' association) influencing the differences in observed levels of technical efficiency were also determined. The results indicate a significant variation in technical efficiency among sample households. Estimated farm-specific technical efficiency indices ranged from 0.21 - 0.93 with a mean of 0.67 which implies considerable production inefficiency. There is therefore a substantial potential for enhancing profitability by reducing costs through improved efficiency. By operating at full technical efficiency levels, on average, the sample producers would be able to reduce their costs by about 33%. This potential cost saving in production costs will translate into enhanced profitability and additional income for the Irish potato producers.

The findings also show that the level of education of the household head, number of extension visits, access to credit, and membership in a farmers' association are significant variables for improving the level of technical efficiency. The positive impact of education on technical efficiency indicates that increase in human capital will enhance the farmer's ability to receive and understand information relating to new agricultural technology. The implication of the positive impact of education is particularly important for Kenya where free primary education is being implemented as one of the government policies which will ensure increased enrollment in primary schools (MOPND, 2004). Since there might be limited opportunities of raising the level of education of farmers in the short term, intensifying farmer training programmes through various innovative and vocational education programs and extension delivery systems would be more practical. In the medium-term, policies should be geared towards promoting formal education as a means of enhancing efficiency in agricultural production. The positive effect of access to extension services implies that enhancing smallholder farmers' access to information and new technologies will improve the level of technical efficiency. Policy makers should therefore focus on innovative institutional arrangements that enhance extension and farmer training such as: (i) use of group approach; (ii) farmer-led extension such as. Farmer field schools; and (iii) strengthening mass media to supplement and complement extension workers efforts besides extensive use of information and communications technology (ICT) to support agricultural extension.

Technical efficiency and access to credit are positively and significantly related, which suggests that farmers with greater access to formal credit are able to obtain higher technical efficiency than otherwise. Institutional arrangements that aim at reducing transaction costs of providing farmers with greater access to credit would therefore have the potential of increasing technical efficiency. To enhance access to appropriate credit packages. efforts should be directed at: (i) advocating for appropriate legislation to encourage commercial and microfinance institutions to accommodate small agricultural producers; (ii) supporting mobilization of financial resources through savings and credit organization (SACCOs) and other community based lending systems; and (iii) supporting the revival of and strengthening of existing cooperatives. Since membership in a farmers' association seems to positively influence technical efficiency. this implies that policy makers need to foster the formation and development of farmers' associations, and improve efforts by government and non-governmental organizations in building the capacity of farmers in community mobilization and management skills. To exploit the expected benefits of access to information more effectively, such producer associations formed should be federated at all levels. up to national level. In general, this study shows that substantial productivity gains can be obtained by improving the technical efficiency of Irish potato producers. This implies that the government and other stakeholders should facilitate the creation of an appropriate institutional environment that would improve farmer's accessibility to effective extension services as well as improved access to formal credit.

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