academicJournals

Vol. 7(3), pp. 92-99, March, 2015
DOI: 10.5897/JDAE2014.0606
Article Number: 3D112E650604
ISSN 2006-9774

http://www.academicjournals.org/JDAE

Journal of Development and Agricultural Economics

Full length Research Paper

Technical efficiency of traditional African vegetable production: A case study of smallholders in Tanzania

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Received 12 September, 2014; Accepted 9 February, 2015

Traditional African vegetables are receiving more attention for their significant contribution to food and nutrition security and enhanced livelihoods of smallholders. Although demand is increasing for these nutrients-dense crops, the production of traditional vegetables in Tanzania remains low. Technical innovations can reduce yield gaps and increase the productivity of traditional vegetable crops. This paper measures the technical efficiency of farm households that produce traditional vegetables in Tanzania using a Cobb-Douglas stochastic frontier production function. This study reports data from a primary survey of 181 households that cultivated traditional vegetables in five regions (Arusha, Tanga, Morogoro, Dodoma and Dar es Salaam) of Tanzania. The results show that overall mean technical efficiency is 67%. It indicates that if the average farmer of the sample could achieve the technical efficiency level of most efficient counterpart, then average farmers of the sample could increase their output by 27% with better use of available production resources given the current state of technology. Farmers were observed to be more technically efficient in the Arusha region than in the other study regions. Possible reasons for the observed regional difference include agroclimatic variability, access to extension services, and infrastructure facilities. A linear relationship exists between farm size and technical efficiency. The study concludes that strengthening farmer associations to encourage knowledge sharing and enhancing the existing cluster approach to farming may help to improve technical efficiency.

Key words: Smallholders, inefficiency, resource use, inputs, technology.

INTRODUCTION

In Tanzania, 80% of households are primarily engaged in the agricultural sector (World Bank, 2014), in which large number of farmers are smallholders (operating on <2 ha) who mostly grow traditional vegetables (Weinberger and Msuya, 2004). Recently, traditional vegetables have received more attention for their

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significant contribution to food and nutritional security and enhanced livelihood of smallholders (Afari-Sefa et al., 2012). Although demand is increasing for these important crops, the productivity of traditional vegetables in most regions of Tanzania is quite low due to incidence of pests and diseases, absence of efficient control measurements and limited availability and use of high quality seed, leading a significant yield gap (Weinberger and Msuya, 2004). Technical innovations can reduce yield gaps and increase the productivity of traditional vegetable crops. Improving agricultural productivity is crucial for improving the livelihood of farming communities in Tanzania as smallholders typically underutilize resources in their farming activities (Msuya, 2008). Some authors have argued for the adoption of new technologies designed to enhance farm output and income as a means to accelerate economic development (see for example, Schultz, 1964; Kuznets, 1966; Hayami and Ruttan, 1985). However, output growth is determined not only by technological innovations but also by the efficiency with which available technologies are used (Nishimizu and Page, 1982). The potential importance of efficiency as a means of fostering production has motivated a substantial number of research studies focusing on agriculture (Bravo-Ureta and Pinheiro, 1993).

In developing countries, agriculture and crop-level production efficiencies have been extensively investigated by measuring technical efficiency, economic efficiency and allocative efficiency (Ali and Choudhry, 1990; Parikh et al., 1995; Coelli and Battese, 1996). In sub-Saharan African, only a few studies have been conducted on technical efficiency, particularly for staple crops (Abdulai and Huffman, 2000; Duvel et al., 2003; Abdulai and Tietje, 2007; Asogwa et al., 2011). Of these studies, only Msuya and Ashimogo (2006) measured technical efficiency and its determinants for sugarcane farmers in Tanzania. Most studies analyzed the efficiency of production of major food crops, including maize, rice and wheat in farming systems where monocropping is the dominant cropping pattern with known crop-specific allocations of inputs such as land, labor and fertilizer. Based on a recent literature review, and to the best of our knowledge, no studies have measured technical efficiency for farmers who grow mostly traditional vegetables in Tanzania. The literature specified that in developing countries, farmers do not reach optimal levels of efficiency due to the inefficiency of resource allocation. Hence, the allocation of resources to improve production is important. The objective of our study was to measure the technical efficiency (TE) of farm households that grow traditional vegetables. Based on our objective, the following hypotheses were constructed and examined: (i) Farm output value significantly and positively increases with increase in inputs; (ii) A significant inverse relationship exists between farm size and TE. These hypotheses were tested with a Cobb-Douglas stochastic frontier production function. Farm size, for the purpose of this study, was grouped into four categories, namely marginal (0-1 ha), small (1-<2 ha), medium (2-<4 ha) and large farm holders (>4 ha) based on net operated area.

MATERIALS AND METHODS

A purposive sampling technique was used to select 181 farm households that primarily cultivate traditional vegetables in five administrative regions of Tanzania namely Arusha, Tanga, Morogoro, Dodoma and Dar es Salaam (Figure 1). A semi-structured questionnaire was used to survey the households between March 2013 and May 2013. Socioeconomic characteristics, land use, demographics, cropping patterns and inputs, and output data were collected during the cropping season, from March 2012 to February 2013.

Empirical model

Technical efficiency was measured using the Cobb-Douglas stochastic frontier production function. This approach was originated by Debreu (1951) and extended by Farrell (1957), Aigner et al. (1977) and Meeusen and Broeck (1977). The approach offers some advantages over other methods such as Data Envelopment Analysis, non-parametric approach, and non-frontier approach. Data Envelopment analysis is more appropriate for the industrial, rather than the agricultural sector. The non-parametric approach assumes that there is no fixed form for the frontier, which is a major disadvantage of the model (Ali and Byerlee, 1991). Compared to the non-frontier approach, the stochastic approach is easy to measure and interpret, consistent with most agricultural production efficiency studies, and captures a variation from the frontier due to random effect and technical inefficiencies (Ali and Byerlee, 1991; Duvel et al., 2003; Abdulai and Tietje, 2007; Asogwa et al., 2011; Rajendran, 2014). Technical efficiency is defined as the maximum output that can be produced from a specified set of inputs, given the existing technology available to the farmer (Koopmans, 1951). Therefore, use of resources is an important factor in the agriculture production process. Efficiency plays an important role in maximizing output with a given set of inputs and technologies, thereby resulting in increased income to the farmer.

Model specifications for stochastic frontier production function

We followed two types of econometric models in our study. First, we determined the effect of input use on output values of farm households using the Cobb-Douglas production function estimated using the ordinary least squares method. Second, we estimated the technical efficiency level of traditional vegetable farm households in Tanzania using the Cobb-Douglas stochastic frontier production (SFP) function. The parameters of stochastic frontier production functions model were estimated by using the maximum likelihood function, implemented in STATA version 11.0 econometric software.

The specification for SFP can be written as follows:

$$Ln\, Y_i = \beta_0 + \sum_{k=1}^{N} \beta_n \ln X_{ki} + D_i + v_i - u_i \quad (1)$$

i = 1,.....N (Number of farm households), k = 1,.....N (Number of inputs); Ln is the natural logarithm with base *e*. Output Y: Y = value

Figure 1. Map of Tanzania showing study regions. Source: www.mapsofworld.com

of output of traditional vegetable crops per household (in Tanzanian Shilling currency i.e TZS) Inputs X: X_1 = Land: Net operated area per farm household. X_2 = Total cost of seed per farm (in TZS); X_3 = Total cost of manure per farm (in TZS); X_4 = Total cost of fertilizer per farm (in TZS); X_5 = Total cost of chemicals per farm (in TZS) X_6 = Total cost of irrigation per farm (in TZS) X_7 = Total cost of labor per farm (in TZS); X_8 = Total cost of machinery (tractor and other rented equipment per farm (in TZS); X_9 = Share of irrigated area.

Land represents total area of under irrigation and unirrigated land (in hectares), which explains farm size as well. It implies that the larger the farm size, the greater the opportunity to apply new technologies and have a better output value. The implication is that medium and large farms derive more gains from application of more capital than do small farms and also depend on possibility of large share of irrigated land to total land size. Therefore, Rajendran (2014) argued that the share of irrigated land area influences output value, particularly, the value of vegetable production and hence the inclusion of share of irrigated area as an independent variable in the estimation is required. Inputs such as cost of seeds, chemicals and inorganic fertilizer will significantly influence output values (Coelli and Battese, 1996). The dependent variable is a value of output of crops per household. The reason behind using output value rather than output by itself is that quality differences can be taken into account (Abdulai and Tietje, 2007). Taking account of production of all crops is more useful than single-crop production in the production function, because the single-crop production functions do not account for indirect production benefits (Sharma, 1992). The reason for including inputs as an independent variable is that farmers maximize their outputs from specified sets of inputs (seeds, chemical fertilizers, pesticides, manure and machinery) where each input has a significant influence on crop production (Coelli and Battese, 1996).

Table 1. Summary statistics of input costs (USD) and share of input costs (%).

Seed cost	Manure cost	Chemical fertilizer cost	Pesticide cost	Irrigation cost	Other cost	Labour cost	Total cost
14	58	84	95	75	48	93	467
3%	12%	18%	20%	16%	10%	20%	100%

Source: Primary Survey

RESULTS

A large share of the cost stream comes from the quantities of chemical fertilizers, pesticides and labor used (Table 1). The cost of family labor was imputed from the market wage for hired labor. It is possible that those chemical fertilizers are in short supply during peak seasons, which leads to higher prices in the open market. High labor cost could be attributed to labor migration from farm to non-farm activities, which creates labor shortages for on-farm activities and also takes away the most productive labor from farm production. Results from the stochastic frontier production analysis (Table 2) can be interpreted based on γ- parameters proposed by Battese and Corra (1977), who explained that the total variation of output from the frontier can be attributed to technical inefficiency and lies between zero and one. Further, Coelli (1996) argues that if $\gamma = 0$, it implies that the traditional average response function is an appropriate representation of the data, which can be consistently estimated by a Cobb-Douglas average production function via the ordinary least squares method.

To avoid the occurrence of multicollinearity in the regression estimations, this paper evaluated two models (model 1 and 2). In the first model, input costs of seeds, pesticides, manure, inorganic fertilizer, labour cost (including family labour) and net operated area were combined to avoid collinearity with share of irrigated land. In the second model, various input costs were treated independently along with share of irrigated land. However, the results show that in both models, estimates of the γ-parameter are 0.91 and 0.86 for the Cobb-Douglas stochastic frontier production models on normal distribution, respectively. Furthermore, the likelihood ratio (LR) test results were estimated at 18.93 for model 1 and 13.91 for model 2, both of which are significant at the 5 and 1% probability levels. The significant level indicates that the technical inefficiency effects are a significant component of the total variability of total crop output in the study area, and hence inefficiency effects are a stochastic process. In sum, the hypothesis tested proved the presence of inefficiency and stochastic process in the frontier model.

The parameters of the stochastic frontier production function were estimated using the maximum likelihood approach assuming a half-normal distribution, while parameters of the average Cobb-Douglas production functions (Table 2) were estimated by the ordinary least squares approach (Table 3). The similarities of the slope parameters across equations confirm that the frontier function represents a neutral upward shift of the average production function.

Coelli and Battese (1996) argue that the parameters of estimates of the stochastic production frontier model need to be discussed in terms of output elasticities evaluated at the mean values with respect to the various inputs. We evaluated our results for the two models based on estimates of parameters obtained with the average Cobb-Douglas production function (Table 3), which reports the elasticities of mean value of output for various inputs used in farming activities. The results show that the coefficients are of coefficients are of the expected signs and most of them are statistically significant.

DISCUSSION

The elasticity of mean value of farm output for seed turns out to be insignificant in model 1, but after excluding net operated area in model 2, coefficient of seed cost became significant in model 2. This implies that the cost of seed is an important factor for farmers to increase their value of output. Although seed prices have a significant impact on output value, the value of the coefficient is lower than the coefficient of other inputs after excluding net operated area. Price may not be sensitive to farmers to increase their output value, as they mostly used own-saved seeds (Rohrbach et al., 2003; Afari-Sefa et al., 2013). Interestingly, the elasticity for fertilizer, labor and share of irrigated area under cultivation is higher compared to other inputs (chemicals, manure and seeds).

A test of equality among coefficients was conducted (Table 3). The null hypothesis was accepted through test of equality in models 1 and 2, hence the constant returns to scale is observed. The observance of a constant return-to-scale implies an increase in value of output per unit increase in input, suggesting that farmers are not using their resources efficiently. This means that farmers can still increase their level of output at the current level of resource allocation, and that production efficiency among farmers would result in higher farm output in the study area. Policies that encourage technical efficiency among farmers would bring about an

Table 2. Results of Cobb-Douglas stochastic frontier production function based on normal distribution.

Dependent variable: Ln (value of farm output)	Model 1 Model 2	Model 2
Independent variables:		
Ln values		
Ln seed cost	0.009	0.023*
Ln pesticides cost	-0.005	0.001
Ln manure cost	0.166***	0.230***
Ln inorganic fertilizer cost	0.296***	0.295***
Ln labor cost (includes family labor cost)	0.344***	0.322***
Share of irrigated area		0.233*
Ln net operated area	0.129	
_constant	4.395***	3.788***
lnsig2v		
_cons	-2.630***	-2.336***
lnsig2u		
_cons	-0.355	-0.502**
Statistics		
N (Number of observation)	181	181
sigma_v	0.268	0.311
sigma_u	0.837	0.778
sigma2	0.773	0.702
lambda	3.119	2.502
γ=(σ_u^2)/σ^2	0.91	0.86
Likelihood-ratio test of sigma_u=0: chibar2(01)	18.93**	13.91***
Test of hypotheses		
The inefficiency effects are not present H0: γ = β0 = …= βn = 0	Null rejected	Null rejected
Decision	Presence of inefficiency proceed for TE through frontier estimates	Presence of inefficiency proceed for TE through frontier estimates
The inefficiency effects are not stochastic H0: γ=0 (Based on Chibar2 stat)	Null rejected	Null rejected
Decision	Inefficiency effects are stochastic	Inefficiency effects are stochastic

Significant level: *** p<.01; ** p<.05; * p<.10; γ parameter is used to test whether the technical inefficiency affects output or not. Source: Authors' calculation

increase in farm output in the study area; therefore, it is necessary to understand the level of technical efficiencies by regions and farm size.

Technical efficiencies

The estimated mean value of the technical efficiency of the farm households studied is reported in Tables 4 and 5 by regions and farm size, respectively. These predictions are derived from the estimated model 2 (Table 2). The estimated mean technical efficiencies differ slightly across regions and farm size. Overall, the estimated mean technical efficiency is 0.67 (Table 4). Several reasons may account for the observed variation in technical efficiencies from the regions studied. Huang and Bagi (1984) note that these differences may be due to different approaches

Table 3. Cobb-Douglas production function (ordinary least squares).

Variable	Model 1	Model 2
Overall		
Ln of seed cost	0.036	0.042***
Ln pesticides cost	0.002	0.007
Ln of manure cost	0.209***	0.258***
Ln of inorganic fertilizer cost	0.405***	0.354***
Ln labour cost (including family labour)	0.331***	0.302***
Share of Irrigated area to total operated area		0.335***
Ln of net operated area	0.050	
Constant	2.282***	2.330***
N	181	181
r2	0.84	0.85
r2_a	0.84	0.84
Test of equality - constant returns to scale (CRS)		
$\sum\beta i$	1.03	1.30
F-Stat	0.32	0.22
Prob > F	0.5741	0.234
H0: Null Hypothesis ($\sum\beta i = 1$)	Accepted null	Accepted null
Returns to scale	Constant return to scale	Constant return to scale

Source: Authors' calcuation

Table 4. Mean level of technical efficiency by regions.

Regions	Mean	p50	sd	Min	Max	N	Equal variance t-test*
Dodoma	0.60	0.69	0.25	0.06	0.92	57	
Arusha	0.79	0.75	0.13	0.29	0.94	57	0.0101**
Tanga	0.72	0.74	0.15	0.19	0.91	20	0.0125**
Morogoro	0.70	0.75	0.13	0.27	0.91	25	0.032**
Dar	0.54	0.66	0.17	0.02	0.84	22	0.052**

Significant level: *** p<0.01; ** p<0.05; * p<0.10 (Base Dodoma region). Source: Authors' calcuation

Table 5. Mean level of technical efficiency by farm size.

Farm size	Mean	p50	sd	Min	Max	N	Equal variance t-test*
Small farm (0-2	0.66	0.73	0.21	0.06	0.92	139	0.0162**
Middle farm (2ab	0.69	0.73	0.13	0.4	0.86	32	0.0321**
Large farm (4ha	0.74	0.76	0.09	0.58	0.91	10	
Total	0.67	0.73	0.2	0.06	0.92	200	

Significant level: *** *p*<0.01; ** *p*<0.05; * *p*<.10 (Base large farm). Source: Authors' calcuation

employed. Specific attributes of each location (agroclimatic and soil variables, access to markets, extension services, etc.) play a role in technical efficiencies (Battese and Coelli, 1988). Coelli et al. (1998) indicate that over-estimates of technical efficiency might also be related to the higher number of input-output variables. Technical efficiency depends on the assumed distributional form of the one-sided error in the functional form (Haji, 2006). Finally, the difference may be due to the type of crops and cultivation method (Bagi, 1982).

The computed mean of technical efficiency (Table 5) shows insignificant differences between small, medium and large farms. However, it indicates that large farms are more efficient than small or medium farms. The literature points to a similar situation in the agrarian sector of other developing countries (Huang and Bagi, 1984), with variations from crop to crop. Based on the computed mean technical efficiency, the results indicate that the Arusha region is technically more efficient in agricultural resource use than the other four study regions in the study. The observed differences is attributed to the fact that, the Arusha region falls under the Northern Highlands agroclimatic zone and experiences bimodal rainfall of 760-1200 mm per annum (usually from October- December and March-May). Therefore, farmers obtain good precipitation for vegetable cultivation.

In Tanzania, the major possible reasons for the observed regional differences include agroclimatic variability, access to extension services, and infrastructure facilities. The test for equality of technical efficiency indicated that there were statistically significant differences in the technical efficiency across farm size, with larger landholdings having higher observed values than smallholdings. It indicates that other than the use of machinery, large-scale farmers put in more material inputs than small-scale farmers, which results in increased productivity. Therefore, medium and large farms gain more by the application of more capital compared to smallholdings. This may be because smallholders cannot make use of improved or better inputs due to limited land area and other constraints.

Conclusion

Overall, the efficiency level pattern across farm size increases with increasing farm size, which implies that large farms are technically more efficient than small and medium farms. This rejects our null hypothesis that technical efficiency is inversely related with the farm size. The mean technical efficiency is directly related to farm size. Individual technical efficiencies indicate that most of the farmers used their resources inefficiently in the production process, and were not obtaining maximum output from their inputs.

Opportunities thus exist for improving current technical efficiency levels. Technical efficiency among farm households could be increased by 33% (that is, maximum TE *minus* mean TE). This would enable farmers to obtain maximum output from their given quantum of inputs, and increase their farm incomes, thereby reducing poverty (Asogwa et al., 2011). However, the mean of TEs indicates that if the average farmer of the sample could achieve the TE level of his most efficient counterpart, then average farmers of the sample could increase their output by 27% approximately through better use of available production resources given the current state of technology (that is, 1-(0.67/0.92)*100).

There is considerable room to increase agricultural output where farmers cultivate vegetables without additional inputs, given the existing technology in the regions studied. Identification of farm-specific factors contributing to technical inefficiencies is very useful and important for policy formation. Because farm size is directly related to technical efficiency, there is a need to enhance existing cluster farming practices and strengthen farmers' associations among smallholders to encourage knowledge sharing and thus improve technical efficiency. Vegetable cultivation is a labor-intensive, year-round activity. To attract more people to engage in farm labor, it is necessary to have better incentives such as competitive pay packages based on market prices, or by linking national employment programmes with farming activities in the study region. There is a need to improve farm management skills in all the regions studied to promote efficient use of resources and increase economic development.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Dr. Jackie Hughes for her valuable comments and suggestions on the various draft of this paper. We are also grateful to Ms. Maureen Mecozzi for her excellent editing of this paper. Finally, the authors wish to acknowledge the funding support from the Good Seed Initiative project through Irish Aid for this study.

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Last Saved By: Daniel
Total Editing Time: 202 Minutes
Last Printed On: 2/19/2015 12:36:00 PM
As of Last Complete Printing
Number of Pages: 8
Number of Words: 4,651 (approx.)
Number of Characters: 26,517 (approx.)