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Allocative efficiency of smallholder common bean producers in Uganda: A stochastic frontier and Tobit model approach

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Abstract

The study evaluated allocative efficiency levels of common bean farms in Eastern Uganda and the factors influencing allocative efficiencies of these farms. To achieve this objective, a sample of 480 households was randomly selected in Busia, Mbale, Budaka and Tororo districts in Eastern Uganda. Data was collected using a personally administered structured questionnaire with a focus on household decision makers; whereas a stochastic frontier model and a two-limit Tobit regression model were employed in the analysis. It was established that the mean allocative efficiency was 29.37% and it was significantly influenced by farm size, off-farm income, asset value and distance to the market. Therefore the study suggested the need for policies to discourage land fragmentation and promote road and market infrastructure development in the rural areas. The study also revealed the need for farmers to be trained on entrepreneurial skills so that they can invest their farm profits into more income generating activities that will harness more farming capital.

Keywords: Allocative efficiency, Stochastic frontier approach, Common bean, Uganda

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1. Introduction

Agriculture is the pillar of Uganda's economy and employs about 70.8% of the population. At the rural household level, the proportion of the population directly involved in agricultural activities is even higher with crop production accounting for more than 70% of the employment within the sector itself. However, about 68.1% depend on agriculture for subsistence, while the rest practice farming for commercial purposes (FAO, 2009). In general, the sector accounts for 25% of the Gross Domestic Product (GDP), (UBOS, 2010). Since 80% of the Ugandan population live in rural areas and depend almost entirely on Agriculture for their livelihoods, the sector serves as a basic source and provider of food self-sufficiency and security for majority of the population.

Specifically, common bean is an important legume grown in virtually all parts of Uganda. Apart from being considered as low status food or the 'meat of the poor', due to its low cost relative to animal products, bean provides a rich combination of carbohydrates (60-65%), proteins (21-25%), fats (less than 2%), vitamins and minerals (Ensminger *et al.*, 1994). In fact with increasing health concerns, most people especially the urban population are reducing consumption of animal proteins and instead they are turning to pulses such as dry bean due to their low fat content. Hence, the rationale for emphasis in more bean research is self-evident.

Bean is also an important source of income for many Ugandan farmers and traders due to the increasing demand both in the domestic and export markets. According to FAO statistics (2009), the value of bean output was USD 244.02 (million), while the agricultural GDP was USD 4,010.75 (million), indicating that bean accounted for 6.1% of the total national agricultural GDP. The crop ranked fifth behind banana, cassava, indigenous cattle meat and cattle milk in terms of value of output. Similarly, the estimated economic value of total bean output, when valued at 2009 market prices, was higher than total earnings from coffee, which is Uganda's chief export commodity (FAO, 2009). This implies that harnessing the bean yield potential through increased investment in bean research could lead to significant improvements in the health and wellbeing of many Ugandans (Harvest plus, 2006).

Uganda has witnessed upward trends in bean output for several years since 1997 (FAO, 2011) mainly attributed to the high uptake of improved bean varieties and expansion in the area under cultivation in the same period. However, the potential productivity level of the crop is yet to be achieved. The average bean yield has been recorded as 0.6-0.8 Mt Ha^{-1}, compared to the potential yields of 1.5-2.0 Mt Ha^{-1} which can be realized with improved varieties and good crop husbandry (Kalyebara, 2008). This creates a knowledge gap in explaining the reasons for these sub-optimal yields in the country.

Past studies on common bean in Uganda have mainly been focused on agronomic aspects of productivity improvement, while none has been done on the socio-economic perspectives of the problem such as allocative efficiency. This is based on the reality that efficiency of production is directly related to the overall productivity in the common bean sub-sector in Uganda. Therefore, the objective of this study was to investigate whether there is allocative inefficiency resulting from sub-optimal use of available resources; as a way to determine if smallholder bean farmers are getting maximum profits from the enterprise.

Production theory states that under competitive conditions, a firm is said to be allocatively efficient if it equates the marginal returns from production inputs to the market price of the input (Fan, 1999). A similar definition was given by Ali and Byerlee (1991), that allocative inefficiency is failure to meet the marginal conditions of profit maximization. Akinwumi and Djato (1997) in their study of the relative efficiency of women farm managers in Ivory Coast defined allocative efficiency as the extent to which farmers make efficient decisions; by using inputs to the point where their marginal contribution to the value of production is equal to the marginal factor costs. Therefore in this study allocative efficiency is defined as the ability of a bean farmer (decision maker) to use farm inputs up to the level where marginal value of production is equal to their factor price.

2. Materials and methods

2.1. Study area

This study covered the Eastern region of Uganda which is generally suitable for common bean production; hence it was appropriate for this study. Specifically, the study focused on four representative districts namely: Mbale, Tororo, Busia and Budaka because bean production is high in these areas (over 80%). In addition, farmers in these districts have been greatly sensitized by the government of Uganda and NGOs (such as CIAT and partners) to adopt new bean varieties and intensify their application of soil enhancing inputs and technologies, as a way to upscale agricultural productivity and livelihoods. The study area covered two agro-ecological zones (AEZs): The Montane AEZ, in which Mbale falls, is found at higher elevations between 1500-1700 metres above sea level and receives high and effective rainfall. In addition, the soils in this zone are majorly volcanic with medium to high productivity (Mwebaze, 1999).

On the other hand, the Banana-millet-cotton AEZ covers Tororo, Busia and Budaka Districts and it is found at lower elevations, receiving less evenly distributed rainfall ranging between 1000-1500mm per annum. The soils in the Banana-millet-cotton AEZ are a mixture of volcanic and alluvial with low to medium productivity. The major staple crops grown in the four districts include: bananas, sweet potatoes, cassava, Irish potatoes and beans. Other crops grown are coffee, wheat, barley, maize, millet, peas, simsim, sunflower, cotton, rice, onions, and carrots (Mwebaze, 1999).

The population in the districts is also very high (the lowest being Busia at 287,800 and the highest being Tororo at 493,300). In addition, population growth in the districts is high ranging between 2.5-3.5% per year (CIA World Fact book, 2011). However, the total land area in Uganda is 241,548 Km^2 of which 75% is available for cultivation. Therefore the capacity of this land resource to sustain the livelihoods of Ugandans given this rapidly increasing population largely depends on how well edaphic, climatic and biotic factors can be managed to increase and sustain its productivity.

2.2. Data

The population of interest constituted smallholder common bean producers in Eastern Uganda, while the sampling unit was the farm household. For sampling purposes a multistage sampling technique was employed involving purposive sampling of four districts in Eastern Uganda; after which a simple random sampling procedure was used at the County, sub-county, parish and village levels for each district. Then a representative sample of 480 households was randomly selected using a list of farmers in the village for purposes of the study. The sample size was then proportionately disaggregated as follows for the four districts, based on the intensity of overall bean production: Busia (285), Mbale (93), Tororo (70) and Budaka (32). Primary data was collected for the 2012 season using personally administered structured questionnaires and through observation method.

The data included information on common bean farming operations such as: quantities of seeds, planting and topdressing fertilizer, pesticides, herbicides, fungicides, manure, land area and labour man-days. Corresponding information on average input prices was also collected from the farmers. The land area under beans (in hectares) was then used to standardize the rest of the inputs, so that each input was considered in terms of the quantities per ha. Additional data focused on household socio-economic and institutional characteristics such as the farmer's age, gender, years of schooling, farming experience, primary occupation, household size, the income and asset profiles, distance to the market, agricultural extension contacts, group membership and the amount of credit received.

2.3. Stochastic frontier model

The history of stochastic models began with Aigneir and Chu (1968) who suggested a composite error term, and since their work much effort has been exerted to finding an appropriate model to measure efficiency. This resulted in the development of a stochastic frontier model. The model improved the deterministic model by introducing 'v' into the deterministic model to form a composite error term model (stochastic frontier). The error term in the stochastic frontier model is assumed to have two additive components namely: a symmetric component which represents the effect of statistical noise; and another error component which captures systematic influences typically unexplained by the production function and are attributed to the effect of inefficiency (Tijani, 2006). The model is as specified below:

$$Y = f(x, \beta)e^{(\nu - \mu)} \quad \text{.......} \quad (1)$$

Where $f(x, \beta)$ represents the production frontier function and $\nu - \mu$ is the error term. The $V_i's$ are random variables which are assumed to be independent and identically distributed (iid) as N(0,δV^2). The $V_i's$ are independent of the U_i's which are non-negative random variables assumed to account for inefficiency in production and are also assumed to be iid N(0, δu^2). From equation 1 it is possible to derive the technically efficient input quantities (X_{it}) for a given level of output Y^*. Assuming that equation 1 is of a Cobb-Douglas form (self-dual) then the dual cost frontier can be expressed as in equation 2:

$$C_i = g(P_i;\alpha)e^{(v+\mu)} \quad (2)$$

Where C_i is the minimum cost incurred by the i[th] farmer to produce output *Y*; *g* is a suitable function (C-D); P_i represents a vector of input prices employed by the i[th] farm in bean production; α is the parameter to be estimated; $V_i^{'}s$ and $U_i^{'}s$ are as specified above. We then apply Shepherd's Lemma in partially differentiating the cost frontier with respect to each input price to obtain the system of minimum cost input demand equations as in equation 3:

$$\frac{\partial c}{\partial p_i} = X_{di} = f(P_i Y_i;\varphi) \quad (3)$$

In equation 3, φ is a vector of parameters to be estimated. We can then obtain the economically efficient input quantities (X_{ie}) from input demand equations, by substituting the farmers' input prices *P* and output quantity *Y** into equation 3. Further, it is now possible to calculate the cost of the actual or observed input bundle as $\sum(X_i * P_i)$ while the costs of technically and economically efficient input combinations associated with the farmers' observed output are given by $\sum(X_{it} * P_i)$ and $\sum(X_{ie} * P_i)$ respectively.

Following Farrell (1957) methodology for measuring technical, economic, and allocative efficiency, it is assumed that economic efficiency is a product of technical and allocative efficiency. Hence we calculate allocative efficiency estimates based on these cost measures as in equation 4:

$$AE_i = \sum(X_{ie} * P_i) \Big/ \sum(X_{it} * P_i) \quad (4)$$

However, it is further assumed that the average level of allocative efficiency, predicted as AE_i in equation (4) is a function of socio-economic and institutional factors. In this study, the factors influencing efficiency were determined using a two-limit Tobit model since the allocative efficiency scores range between 0 and 1, depicting the upper and lower limits. The approach has been applied by other authors such as Nyagaka *et al.* (2009) and Obare *et al.* (2009).

2.4. Tobit model

The structural equation of the Tobit model is given as shown in equation 5:

$$y_i^* = x_i\beta + \varepsilon_i \quad (5)$$

Where y_i^* is a latent variable for the i[th] bean farmer that is observed for values greater than τ and censored for value less than or equal to τ (equation 6). The Tobit model can be generalized to take account of censoring both from below and from above. The X is a vector of independent variables postulated to influence efficiency. The $\beta's$ are parameters associated with the independent variables to be estimated. The ε is the independently distributed error term assumed to be normally distributed with a mean of zero and a constant variance. The observed y is defined by the following generic measurement equation (6):

$$y_i = y^* if \;\; y^* > \tau$$
$$y_i = \tau_y \; if \;\; y^* \le \tau \quad (6)$$

Typically, the Tobit model assumes that τ = 0 which means the data is censored at zero. However, farm-specific efficiency scores for the bean farms range between 0-1. Thus we substitute τ in equation 6 as shown in equation 7:

$$y_i = y^* \text{ if } 0 < y^* < 1$$
$$y_i = 0 \text{ if } y^* \le 0$$
$$y_i = 1 \text{ if } y^* \ge 1 \quad (7)$$

Therefore the model assumes that there is an underlying stochastic index equal to $\left(X_i\beta + \varepsilon_i\right)$ which is observed only when it is some number between 0 and 1; otherwise y_i^* qualifies as an unobserved latent (hidden) variable. The dependent variable is not normally distributed since its values range between 0 and 1. Therefore, the empirical Tobit model for the factors influencing allocative efficiency takes the form in equation 8:

$$y_i^* = \beta_0 + \sum_{n=1}^{11} \beta_n Z_i + \varepsilon_i \quad (8)$$

Where: Z_1 = age of the farmer (years); Z_2 = farming experience (years); Z_3 = education (years of schooling); Z_4 = gender of household head (1= if female and 0= otherwise); Z_5 = off-farm income ('000' of UGX); Z_6 = market access (Km); Z_7 = credit access (UGX); Z_8 = group membership (1= if yes and 0= if no); Z_9= assets owned ('000' of UGX); Z_{10}= main occupation of the farmer (1= if farming and 0= otherwise); and Z_{11}= farm size (hectares).

It is important to mention that estimating the model using OLS would produce both inconsistent and biased estimates (Gujarati, 2004). This is because OLS underestimates the true effect of the parameters by reducing the slope (Goetz, 1995). Therefore, the maximum likelihood estimation is recommended for Tobit analysis.

3. Results and discussion

3.1. Household characteristics

The selected sample for this study consisted of soil conservation technology adopters (56.5%) and 43.5% non- adopters. As tabulated in Appendix 1 below, the results show that over 69% of sampled households were male headed while 31% were female headed. In addition, 92% of them were fulltime farmers; 4.3% were business persons and 4% were salaried employees. In addition, the mean age of all farmers was 43 years, with the mean age for adopters and non- adopters being 45 and 41 years, respectively. Thus, based on t-test results, adopters had a significantly higher mean age than non-adopters. The mean level of formal education was 8 years which shows that the majority of sampled farmers had attained at least the primary level of education. Adopters also had a significantly higher mean schooling of 8 years compared to non-adopters who had a mean of 7 years. In terms of farming experience, the overall mean was 20 years while adopters and non-adopters had a mean of 20 and 19 years, respectively.

3.2. Farm-specific allocative efficiency scores

According to the results in Table 1, the mean allocative efficiency score among the sampled farmers in the study area was 29.37%. This score is quite low as it indicates that beans farmers in the area were 70.63% allocativelly inefficient. The mean allocative efficiency score for conservation technology adopters was higher than the overall at 29.95%, while the mean for non-adopters was lower than the overall at 28.61%. However, the mean difference between adopters and non-adopters was not statistically significant.

Table 1. Farmer-specific allocative efficiency scores

Allocative efficiency	**Adopters**		**Non-adopters**	
Class	Frequency	%	Frequency	%
0-24	102	37.58	81	38.84
25-49	131	48.41	108	52.07
50-74	38	14.01	19	9.09
Total	271	100.00	208	100.00
Mean		29.95		28.61
Std deviation		18.32		16.62
Maximum		73.81		65.80
Minimum		0.25		0.16
t-ratio				0.636
Sig.				0.525
Overall mean				29.37

The most allocatively efficient farmer was 73.81% efficient, whereas the least allocatively efficient farmer was 0.16% efficient. Thus, if the average bean farmers in Eastern Uganda were to achieve the level of allocative efficiency shown by the most efficient farmer, then they would realize a cost saving of 60.21%[1] holding resource availability constant. It was further shown that only about 14.01% of the adopters and 9.09% of non-adopters had allocative efficiency scores exceeding the 50% limit. These results generally imply that majority of the farmers were not able to apply the right combinations of available inputs in such a manner that could minimize their overall production costs and improve farm profitability.

Table 2. Farmer-specific efficiency scores across districts

Districts	Busia	Mbale	Budaka	Tororo
Mean (%)	29.65	28.87	25.28	30.81
S.D	17.29	19.71	16.80	16.46
ANOVA: F-ratio	0.175			
Sig	0.913			

Across the districts focused in the study, the ANOVA results (in Table 2) revealed that allocative efficiency levels did not differ significantly from district to another. However, mean results indicate that, bean farmers in Tororo district had the highest average allocative efficiency levels (30.81%), followed by farmers in Busia and Mbale districts with means of 29.65% and 28.87% respectively. Bean producers in Budaka were the least allocatively efficient with a mean of 25.28%. Allocative efficiency is concerned with costs of production; therefore, the fact that bean farms in Tororo district were located closer to the input markets than all the other districts may have been responsible for the relatively higher levels of allocative efficiency in Tororo (Appendix 2).

3.3. Determinants of allocative efficiency

The results in Table 3 show the estimates from the two-limit Tobit regression of selected socio-economic and institutional-support factors against farmers' allocative efficiency scores. The model is appropriately estimated with a pseudo R^2 of 19.3% and a model chi-square of 61.86 which was strongly significant at 1% level. Thus the explanatory variables chosen for the model were able to explain 19.3% of the variations in allocative efficiency levels. Among the selected variables, four turned out to be significant determinants of allocative efficiency namely: farm size, off-farm income, value of assets and distance to the input market.

The findings show that allocative efficiency was positively and significantly influenced by *farm size* at 10% level. According to the results, an increase in the farm size by a hectare increased the level of allocative efficiency by 3.2%. This is consistent as hypothesised and suggests that farmers with larger farms showed significantly higher levels of allocative efficiency. Similar results were found by Khai and Yabe (2007) among

[1] 60.21% is given as [(1-**(**29.37/ 73.81**)**) x 100]

soybean producers in Vietnam. The results reflect that larger bean farmers in Eastern Uganda exhibit economies of scale in production, which makes them more efficient in allocating resources.

Allocative efficiency level was also positively and significantly influenced by *off-farm income*. According to the results, a unit increase in off-farm income increased the level of allocative efficiency by 3.3%. This is attributed to the fact that off-farm earnings enable farmers to acquire the required farm inputs to improve their productivity. Similar findings were reported by Lopez (2008) among farms in the USA. In her findings, she observed that farmers with higher off-farm income also showed higher levels of allocative efficiency. However, Kibaara (2005) found a negative effect of off-farm income on farm efficiency among maize farmers in Kenya. This may be the case if the off-farm income generating activity deprives farmers' time to attend to their farms, making them incur more costs to hire labour.

Table 3. Tobit regression estimates of factors influencing allocative efficiency

Allocative Efficiency	Coefficient	t-value	P>|t|
Sex (1=Female)	-0.002	-0.030	0.972
Age (years)	-0.003	-1.570	0.118
Schooling (years)	0.005	0.800	0.426
Occupation(1=Farmer)	-0.001	-1.210	0.227
Farming (years)	0.000	-0.140	0.889
Farm size (hectares)	0.032	1.890	0.060*
Off-farm Income (UGX)	0.033	1.660	0.099*
Asset value (UGX)	0.079	5.000	0.000***
Distance to mkt.(km)	-0.013	-2.050	0.042**
Extension service	0.075	1.560	0.120
Group membership	0.210	1.370	0.173
Credit (UGX)	0.003	0.840	0.399
Constant	-0.464	-1.720	0.088*
Log likelihood = -129.539		LR chi²(12) =61.860	
Pseudo R^2 = 0.193		Prob > chi² = 0.000	

, **, * is significant at 10%, 5% and 1% respectively*

The *value of assets* owned also showed a positive effect on the level of allocative efficiency. This was consistent as hypothesised and the coefficient was also strongly significant at 1% level. According to the results, a unit increase in the value of assets lead to a 7.9% increase in farmers' allocative efficiency. Assets owned by farmers assisted them directly or indirectly in reducing costs of production and made them more allocatively efficient. These results are similar to those by Tchale (2009) among smallholder farmers in Malawi, who observed that asset ownership was a tool through which the farm's liquidity position was improved; hence increasing farm productivity through higher input access.

Further findings indicate that *distance to the input market* showed a negative effect on allocative efficiency as earlier expected and it was significant at 5% level. It was found that an increase in the distance to the market by one kilometre; led to a decrease in the level of allocative efficiency by 1.3%. Thus farmers whose households were located nearer to the factor markets showed higher allocative efficiency than those located in remote areas. This is because a farmer located far from the market incurs more costs to transport farm inputs from the market all the way to the farm. As such, nearness to the market improved allocative efficiency among bean producers in the study area. Similar results were reported by Bagamba *et al*. (2007) among smallholder banana producers in Uganda. The authors attributed their findings to the fact that the nearness to the factor markets increased farmers' access to credit facilities and non-farm income generating activities that enable farmers to afford and apply inputs on time. It also reduces dependence on the farm which is responsible for persistent cycle of poverty in remote areas.

4. Conclusion and policy recommendations

The main objective dealt with in this study was to evaluate allocative efficiency levels and the factors influencing allocative efficiency among smallholder bean farmers in Eastern Uganda. It was established that the mean allocative efficiency was 29.37%; although there was a large discrepancy between the most efficient and the least efficient farms. Finally, the Tobit regression model estimation revealed that allocative efficiency was positively influenced by value of assets (at 1% level), farm size and off-farm income (at 10% level); and negatively influenced by distance to the factor market at the 5% level.

Therefore the government of Uganda needs to introduce policies and sensitize farmers against land fragmentation since this would help enhance allocative efficiency. There is also need for the government and non-governmental organizations in the Agricultural sector to train farmers on entrepreneurship, so that they can divest their farm profits into other income generating activities through which they will acquire the needed farming capital and better their productivity significantly. This initiative will also reduce over-dependence on farm produce and provide alternative employment to the young people in the area. Uganda's Ministry of transport and works should also develop better roads and market infrastructure in the rural areas to attract private investors, as a way to reduce the distance farmers have to cover to the market. In so doing, bean farmers in Eastern Uganda will become more allocatively efficient in production; and enhance bean productivity in the area.

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Appendices

Appendix 1. Characteristics of sampled households

		Count	**%**			**Count**	**%**
Sex of Head	Male	332	69.1	Occupation	Farming	440	91.7
	Female	148	30.9		Employed	19	4.0
					Business	21	4.3
		Aggregate		**Adopters**	**Non- adopters**	**t-ratio**	**Sig**
Age	Mean	43.28		44.73	41.31		
	Std. deviation	12.47		12.45	12.33	2.240**	0.024
Schooling	Mean	7.69		8.08	7.21		
	Std. deviation	3.47		3.47	3.43	2.009*	0.052
Experience	Mean	19.58		20.34	18.54		
	Std. deviation	12.01		12.24	11.71	1.206	0.228
Total Sample =480; Adopters = 271; Non- adopters = 208							

**, ** is significant at 10% and 5% levels respectively*

Appendix 2. Household characteristics by district

Variables	Busia		Mbale		Budaka		Tororo	
	Mean	S. deviation	Mean	S. deviation	Mean	S. deviation	Mean	S. deviation
Age	43.42	12.75	42.5	11.47	42.37	11.39	44.18	13.46
Schooling	8	3.78	7.29	2.71	7.73	2.34	7.08	3.55
Farming years	19.99	11.71	21.02	13.25	19.41	9.59	16	12.16
Farm size	1.98	1.85	0.93	0.68	1.43	1.16	1.64	1.37
Total income	511,069.50	836,968.53	449,527.80	626,421.30	237,579.00	503,722.07	605,238.00	673,408.93
On-farm income	300,868.20	482,636.09	354,018.50	478,191.10	193,526.30	459,604.46	374,363.00	517,639.59
Off-farm income	92,281.82	167,813.07	57,546.30	122,571.60	37,736.84	526,15.84	118,625.00	203,279.23
Value of assets	535,044.90	1,061,745.00	408,805.60	604,878.70	878,263.20	1,461,348.70	475,188.00	742,618.40
Distance to the input market	4.19	3.29	3.27	3.17	3.84	3.35	3.16	1.63
Price per kg of beans sold	3,025.54	2,906.98	3,124.89	2,370.50	4,271.78	1,872.78	3,502.59	2,193.28
Credit	85,697.74	42,656.53	77,288.00	39,742.30	71,360.20	42,344.84	75,866.30	32,544.41