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Full Length Research Paper

Improved rice variety adoption and its effects on farmers' output in Ghana

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Sub-Sahara Africa and for that matter Ghana, missed out of the first Green revolution. However, with the instrumentality of the former United Nations Secretary, Kofi Annan, through the Alliance for Green revolution in Africa (AGRA) and other bodies, the revolution is being introduced in some parts of Africa, including Ghana. The extent to which the new revolution would work depends on a careful study of the socioeconomic underpinnings of technology adoption. This study sought to investigate the factors that influence the adoption of improved rice varieties and its effects on rice output in Ghana. The method of analysis involved an estimation of treatment effect model comprising a Probit equation and a production function. The empirical results show that the adoption of improved rice variety had a positive effect on farm output. Other inputs that had significant and positive impact on output were farm size, labour and fertilizer. The probability of adopting improved rice variety was high for the following: farmers who had formal education; farmers who had bigger household sizes; and farmers who had smaller farms. Contrary to our a *priori* expectations, however, farmers who had access to extension services had lower probability of adoption. The authors recommend that farmers be supported with more fertilizer subsidization. Farmers should also form farmer groups to support one another on the field. Also, the fundamental problems of illiteracy among farmers must be addressed.

Key words: Ghana, improved rice seeds, technology adoption, treatment effect model.

INTRODUCTION

Agriculture has a direct influence on the attainment of at least five of the Millennium Development Goals (MDGs) (MoFA, 2010a). The first goal of eradicating poverty and extreme hunger can only be achieved through increased agricultural productivity.

Agriculture continues to play a pivotal role in Ghana's economy, contributing to about 30% of gross domestic product (GDP). The agricultural sector also provides employment to about 50.6% of the labour force and in 2010, it was the largest foreign exchange earner (MoFA, 2010a). The overall growth rate of the agricultural sector, vis-à-vis the current annual population growth rate of 2.6% is 2.8%. The small margin between these figures has serious implications for the attainment of food security, employment generation and improvement in rural incomes and national economy (NAPCDD, 2003).

In spite of the significant role agriculture plays in the provision of food, food shortage still persists among many households in Ghana (Carr Jr., 2001). Ghana depends largely on imported rice (400,000 tonnes/annum) to

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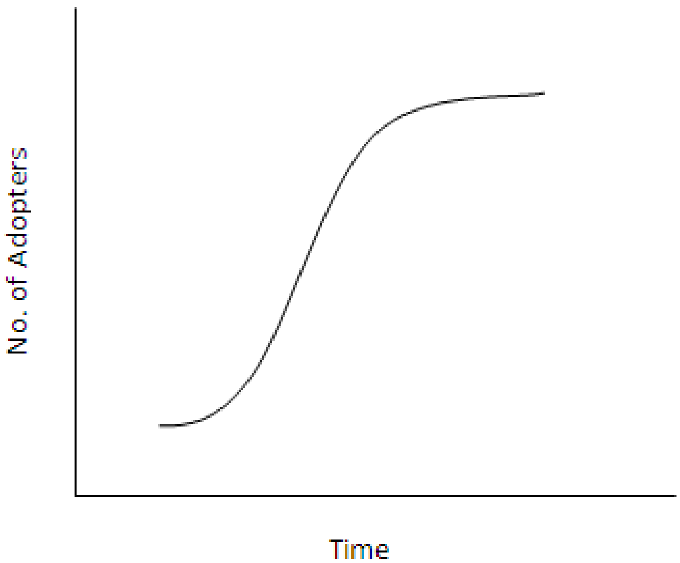

Figure 1. The s-shaped diffusion curve.

make up for the deficit in rice supply. The self-sufficiency ratio of rice in Ghana has declined from 38% in 1999 to 24% in 2006 (MoFA, 2010a).

The Government of Ghana in her drive to increase and promote the quality of locally produced rice in 2003, established and implemented the Nerica Rice Dissemination Project (NRDP). The main goal of the five year project was to contribute to poverty-reduction and food security through the adoption of high yielding NERICA upland rice varieties. Ten districts benefited from the implementation of the project which resulted in a cultivated area of 22,561.40 ha yielding about 56,400 metric tons of paddy Nerica rice (MoFA, 2010b). However, judging from the yields of farmers, there still appears a yawning gap between results of on-farm demonstration plots (6.5 Mt/Ha) and actual yields (2.4 Mt/ha) from the farmers' fields (MoFA, 2010b). Despite the prospects of improved varieties, adoption rates are still low. The objective of this study is to determine the socio-economic, farm characteristics as well as institutional factors that influence the adoption of improved varieties and the effects on rice output in Ghana.

MATERIALS AND METHODS

Literature review-diffusion of innovation

Rogers (1962) defined an innovation as an idea, practice or object that is perceived as new by an individual or other units of adoption. Also, he defined diffusion as the process by which an innovation is communicated through channels over time among members of the social system. The Innovation Diffusion Theory seeks to explain how, why and at what rate new ideas and technologies spread through cultures (Rogers, 1962). The origin of the theory is varied and spans over multiple disciplines. From the literature, the concept of diffusion was first studied by Gabriel Tarde in 1890 and then anthropologists Friedrich Ratzel and Leo Frobenius. Later on, Rogers made extensive studies and came up with four main elements that influence the spread of a new idea, namely; the innovation in question, the communication channels, time and the social system. These elements work in conjunction with one another. This means that for any technology to be adopted, it requires that first, the innovation should be communicated through a channel over a period of time, and this process takes place in a social system. The process relies heavily on human capital and the innovation must be widely adopted in order to be self-sustainable. Within the rate of adoption, there is a point where an innovation reaches mass saturation point; where the largest adoption rate is experienced. This is shown by a logistic curve with S shape as shown in Figure 1.

Rogers categorized the adopters as innovators, early adopters, early majority, late majority and laggards. As a new technology is introduced through a communication channel, innovators are normally the first to adopt the new technology, followed by the early adopters. These two categories are risk takers, who would adopt the technology despite the fact that they may not have full knowledge about its prospects. After some time when some positive benefits have been seen, the early majority joins and then the late majority. When the technology has proven to be good beyond every doubt, the laggards also join. However, despite some promising attributes of the technology, some people may not adopt it. The reasons are varying; some may not be aware of it, others may not have the means to access it, and some would still have some misgivings about the technology. Whatever, the reason, however, they would also have made a choice. It is important for socio-economists to intensify their research into the farmers' socio-economic, farm characteristics as well as some institutional factors that may encourage or discourage the adoption of agricultural innovations.

Rogers (1962) also identified five stages of accepting an innovation, namely; knowledge, persuasion, decision, implementation and confirmation. That is to say that when an innovation is introduced, the potential adopter needs to have knowledge about its benefits and limitations. After gaining the knowledge he/she needs to be persuaded that the benefits far outweigh the costs. If he/she is convinced he/she makes a decision to adopt the technology, otherwise he/she rejects it. Once a positive decision has been made, he/she implements it. Often times, this involves trying the technology on a small portion of the farmer's field. If it is successful, the technology is confirmed, and the farmer can increase the portion of his or her field in the next farming season.

Lastly, Rogers (1962) noted five attributes of a good technology as follows; simplicity, compatibility, trialability, relative advantage, and observability. That is to say that the innovation should not only be seen, it should be easy to understand and adopt. It should also be consistent with the farming practices already adopted by the farmer. Furthermore, the farmer should be able to experiment the new technology to know for him/herself its usefulness and viability.

Theoretical framework

Following Foltz's (2003) framework, technology adopters have a positive net willingness to pay for the technology or adaptation strategy. Farmers have what Foltz calls a reservation price $P_r = (w, k, \eta)$ for the technology that is greater than or equal to the actual market price P_m. He defined the reservation price as the amount that an individual would be willing to pay for the technology given his asset position w; other inputs he uses, k; and the parameter of his preference, η. According to him, P_m is the given price of the technology which is constant for all individual. Thus, for a given individual, the dependent variable A is defined as an index variable for whether or not he/she adopts the new technology. It takes on the value zero and one as follows:

$$A=1 \quad if \quad P_r(w,k,\eta)-P_m>0$$
$$A=0 \quad if \quad P_r(w,k,\eta)-P_m\leq 0 \tag{1}$$

where the variables are as defined. The function $P_r=(w,k,\eta)$ represents a shadow price for an individual adopting an adaptation strategy. The inference problem in terms of econometrics, according to Foltz, then becomes a question of parameterizing the equation that defines the net benefits of the technology to farmers. The standard model in the literature is the random utility model. Researchers are not able to observe the preference parameters of the utility function. It is however, assumed that they are known to decision makers.

Let these parameters be an unobserved variable so that the actual utilities of an individual can be written as:

$$U_i=P_{ri}(w,k,\eta)-P_m=z'\gamma+e_1 \tag{2}$$

where z is a set of characteristics of the decision maker observable to the econometrician, γ is a parameter vector and e_1 is the error term. Hence, $z'\gamma$ becomes an index function that allows us to estimate the probability of adoption $A=1$ in the following fashion:

$$\Pr ob\, P_r(w,k,\eta)-P_m>0=\Pr ob\,(z'\gamma+u_1>0) \tag{3}$$

Assuming that the disturbance term is normally distributed, this becomes a standard Probit model. By symmetry of the normal distribution, Equation 4 is obtained as follows:

$$\Pr ob\ (P_r-P_m>0)=\Pr ob\ (u_1<z'\gamma)=F(z'\gamma) \tag{4}$$

Where $F(\cdot)$ is the cumulative density function of the normal distribution.
This is then estimated using the maximum likelihood estimation, in which the likelihood function is as follows:

$$\ln L=\sum_{y_i=0}\ln(1-\Phi_i)+\sum_{y_i=1}\ln(\Phi_i) \tag{5}$$

Thus, in general the Probit model to be estimated to determine the factors influencing the adoption of improved rice varieties is of the form:

$$A^*=z'\gamma+u_1 \tag{6}$$

where A* can be viewed as an indicator for whether or not this latent variable is positive as depicted in Equation 7.

$$A=\begin{cases}1 & if\ A^*>0\ i.e\ -u_1<Z'\gamma\\ 0 & otherwise\end{cases} \tag{7}$$

The rest of the variables are as defined.

Sample selection bias

According to Barnow et al. (1980), sample selection bias arises when in program evaluations, the treatment (or control) status of the subjects is related to unmeasured characteristics that themselves are related to the program outcome under study. In this case, they define the term bias as the potential mis-estimate of the impact of the treatment (or programme) on the outcome. In this present study, selection bias can arise when improved rice adoption is related to unmeasured characteristics like farmers' innate ability which are also related to their rice output. Sample selection has been well expounded in Heckman (1979) and Smit (2003). One common version of sample selection which is related to this present study is where information on the dependent variable is available for all respondents, but the distribution of respondents over categories of the independent variable of interest has occurred in a selective way.

For example, in this present study, the main objective is to determine the effects of improved rice adoption on output. Thus, there are two main categories of respondents, namely adopters and non-adopters of improved rice varieties. If adoption (normally specified as a dummy variable) is simply regressed on output, the estimate of the adoption effect may be biased because the distribution of respondents over the categories of adopters and non-adopters was not random. Adopters may differ in several (measured and unmeasured) ways from non-adopters. If these characteristics are related to output, the coefficient of the adoption variable may catch up these effects and be biased because of this. In other words, supposed an output equation was estimated and it was found that adopters on a whole had a greater output level than non-adopters, how sure would the researchers be that adopters' relatively high level of output was as a result of the adoption of improved variety and not other positive innate characteristics that adopters possess? The idea behind Heckman's sample selection procedure is to estimate a selection equation (the Probit model in this study) and use the predicted values to form a selection control factor (λ) equivalent to the Inverse Mills Ratio (IMR) which will serve as an additional regressor in the substantive equation. In this case, the pure effect of adoption on output was measured. Besides, the other determinants of output are freed from the effects of the unmeasured characteristics and therefore the coefficients are unbiased (Smit, 2003).

Thus, given a substantive equation of the form:

$$Y_i=X_i'\beta+e_2 \tag{8}$$

Where Y_i is output, X_i is a vector of farm inputs, β is a vector of parameters to be estimated, e_2 is the two sided error term also with mean zero and constant variance.
Equation 6 is estimated and the predicted values of adoption used to construct λ equivalent to the IMR, which is included in equation 8 as an additional regressor. According to Heckman (1979) when this is done the pure effects of adoption can be evaluated and also, the other explanatory variables in equation 8 are freed from the unmeasured characteristics, such as the farmer's innate ability.

Treatment effect model

Treatment effect model is similar to the Heckman's two stage sample selection model. The main difference between the two

Table 1. Definition of variables used in the study.

Variable	Definition	Expected sign
Age	Age of the farmer in years	+/-
Education	Number of years of formal education	+
Household size	Number of people in farmer's house eating in the same bowl	+/-
Farm size	Size of farmer's yam plot in acres	+
Extension	Dummy; 1 if farmer had access to extension service during farm season in question formal education; 0 if otherwise	+
Adoption	Dummy; 1 if farmer adopted improved rice seed; 0 if otherwise	+
y_1	Natural Logarithm of rice output in kilograms	+
x_1	Natural Logarithm of farm size in acres	+
x_2	Natural Logarithm of labour cost in Cedis	+
x_3	Natural Logarithm of seeds in kilograms	+
x_4	Natural Logarithm of fertilizer cost in Cedis	+

however, is that in the case of the former, the treatment condition (adoption in this case) enters the substantive equation to measure the direct effect on output (Maddala, 1983). Thus, the regression equation becomes:

$$Y_i = X_i^{'}\beta + A_i\delta + u_2 \quad (9)$$

Where δ measures the effect of adoption on output and A_i is as defined earlier. Adding the IMR translates into:

$$\ln Y_i = \beta'(\Phi_i \ln X_i) + \delta'(\Phi_i A_i) + \sigma\phi_i + u_3 \quad (10)$$

(Maddala, 1983)

where ϕ_i and Φ_i are the probability density function (PDF) and the cumulative density function (CDF) respectively of the standard normal distribution, and $\Phi_i \equiv \Phi(w_i^{'}\gamma)$. u_3 is two sided error term with $N(0, \sigma_v^2)$. The rest are as defined earlier.

EMPIRICAL MODEL

The empirical models of the study are as follows:

$$A = \gamma_0 + \gamma_1 Age + \gamma_2 Agesqd + \lambda_3 Education + \gamma_4 Extensio \quad (11)$$

(Adoption Model)

$$y_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \delta_1 A + u_2$$

(Output model)
The variables are as defined in Table 1.

Data and study area

The data for this study come from the Statistical, Research and Information Directorate (SRID) of the Ministry of Food and Agriculture (MoFA) in conjunction with the Ghana Strategy Support Program (GSSP) of the International Food Policy Research Institute (IFPRI). It must be mentioned that the data was collected as a pilot study and as such the sample size for rice producers was only 414 from rice producing communities in thirteen selected districts in Ghana as follows: Gushiegu and Yendi districts of the Northern region, Bawku municipality and Kassena Nankana East in the Upper East region, Lawra and Sisala East in the Upper West of Ghana, North Tongu in the Volta, Sekyere Afram Plains in Ashanti, Assin North in the Central, Atiwa in the Eastern and Ga East and Ga West both in the Greater Accra Region of Ghana. The final data was sorted to select 406 because 8 of the farmers did not have all the information that are needed.

Definition of variables used in the study

Table 1 shows the definition of variables used in the estimation of the model and their expected signs. From the literature, the effect of the farmer's age is ambiguous; it can be positive or negative depending on the study. The argument is that older farmers may have more experience, resources, or authority that may give them more possibilities for trying a new technology. On the other hand, younger farmers have been found to be more knowledgeable about new practices and may be more willing to bear risk and adopt new technology because of their longer planning horizons. Education is also expected to have a positive effect on adoption because it increases knowledge thereby enhancing the ability to derive, decode and evaluate useful information for technology adoption.

Household size has been identified to have either positive or negative influence on adoption. Larger family size is generally associated with a greater labour force for the timely operation of farm activities. The negative relationship of the variable with adoption has been linked to increased consumption pressure associated with large family which does not permit them to have the means to invest in new technologies for their farms. Normally, farming households with bigger landholdings are supposed to have an enhanced ability to afford improved technologies and a greater capacity to cope with losses if the technologies fail. Furthermore, access to extension gives famers the opportunity to gain knowledge and also obtain some encouragement with respect to the adoption of technologies. Lastly, from neoclassical production economics output is a positive function of land (farm size), labour and capital (seeds and fertilizer) (Koutsoyannis, 1979).

RESULTS AND DISCUSSION

The results and analyses of the model estimation are presented in this section. The descriptive statistics of the variables used in the study are first discussed.

Descriptive statistics of the variables used in the study

Majority of the respondents were males constituting 75.4% of the sampled population. Also, the percentages of respondents who used improved seeds and traditional seeds were 49 and 51, respectively while 54.5% had access to extension services. Furthermore, from Table 2 the mean age of the farmers was 48.3. This age falls within the adult population in Ghana. One of the challenges facing agriculture in Ghana is the ageing population of the farmers. The farming profession appears unattractive to the youth. The average years spent in school by the farmers was 2.15. In Ghana, six years is spent in primary school while an additional three years is spent in the Junior High School (JHS) to complete basic education. The 2.15 average years spent in school by the sample farmers attests to the fact that there was low level of education among the farmers. Specifically, 76.2% of the farmers had no formal education, while 10.9% each finished basic and secondary education. Only 2.5% made it to the tertiary level. The mean farm size of 4.92 compares with the national average of 5 acres. In Ghana, small-scale farmers are about 92% of the farming population (MoFA, 2010c). On the average, it took Gh⊄ 11.01 and Gh⊄ 6.50 of labour and fertilizer costs respectively to cultivate 4.92 acres of rice plot. The average quantity of seeds for the same plot size was 24.41 kg.

Determinants of improved rice variety adoption

From the results in Table 3, all the variables, except age and age squared were significant. However, household size and education had a positive effect on the probability of adoption, farm size and extension service had a negative effect on adoption. Our findings are consistent with that of Foltz in (2003) who argued that formal education helps farmers to understand the information about a technology which in turn facilitates the adoption of a technology. Similarly, education gives farmers the ability to perceive, interpret and respond to new information much faster (Uaiene et al., 2009; Nzomoi et al., 2007; Salasya et al., 1996). Also, the significance of the household size variable can be attributed to the fact that the large household size served as labor for their farm plot. However, the negative sign of the coefficients of extension service and farm size variables did not meet our *a priori* expectations. Normally, the extension contact should lead to increased probability of adoption, since farmers who have contacts with extension staff have the opportunity of learning about improved varieties. Also, normally, farmers who have large farms size tend to have a higher probability of adoption because they are able to allocate some portions of their field to cultivating the improved seed as a trial, pending their full acceptance of the new technology. In this present study, the negative coefficient means that rather farmers with smaller farms as well as those who did not receive extension services had high probability of adopting improved rice varieties.

The effects of adoption on output

The main objective of this study was to investigate the effects of improved seed adoption on rice output. In other words, the study sought to find out whether the adoption of improved rice seeds leads to increased output as opposed to the adoption of traditional varieties, other things being constant. From Table 4, not only was the adoption significant but it maintained its expected positive sign confirming our *a priori* expectation that the adoption of improved rice seeds leads to increased output. This is consistent with the findings of Wiredu et al. (2010), Uaiene et al. (2009) and Sserunkuuma (2005).

It can also be observed from the table that apart from seeds, all the other variables were significant and maintained their positive sign. The sum of the coefficient of the conventional input is 0.76, implying that there was decreasing returns to scale. A 100% increase in land led to a 26% increase in output while a 100% increase in labour led to a 21% increase in output. Also, while a 100% increase in seeds led to a 5% increase in output, a 100% increase in fertilizer led to a 24% increase in output.

The significance of lambda (λ) in Table 1 implies that selectivity bias was present in the model and that if it was not correct, the estimated coefficients, including the adoption variable, would have been bias, meaning that the pure effects of the explanatory variables on output could not be measured. Thus, the pure effects of the explanatory variables on output would not have been measured. However, the correction of the selectivity problem ensured that the estimated coefficients were freed from the effects of unobserved factors that correlated with the adoption variable.

Policy implication

As indicated earlier, the findings of this study are consistent with that of many studies that evaluated the effects of the Asian Green revolution that took place in the early 1960s (Johnson et al., 2003; Janvry and Sadoulet, 2002; Evenson and Gollin, 2000; Hazell and

Table 2. Descriptive statistics of the variables used in the study.

Variable	Mean	Standard Dev.	Minimum	Maximum
Age	48.63	16.44	4.00	90.00
Education	2.15	4.16	0	15.00
Household size	7.47	5.88	1.00	40.00
Farm size	4.92	5.32	0.50	42.00
Labour cost	110.11	251.24	2.00	2876.00
Seed	24.41	40.62	2.00	250.00
Fertilizer cost	60.56	93.92	0	850.00

Note that the amounts quoted here are in old Ghana Cedis. The equivalence is as follows: 2,000 Old Ghana Cedis=2 New Ghana Cedis=1 US Dollar.

Table 3. Maximum likelihood estimates for the parameters of the Probit adoption model.

Variable	Coefficient	Standard error	Z	P > |Z|	[95% Conf. Interval]	
Adoption						
Age	0.026	0.029	0.90	0.367	-0.031	0.083
Age²	-0.000	0.003	-0.74	0.460	-0.001	0.000
Education	0.518	0.225	2.30	0.021**	0.077	0.959
Extension	-0.330	0.189	-1.74	0.082*	-0.700	0.042
Farm size	-0.031	0.175	-1.79	0.074*	-0.065	0.003
HH size	0.666	0.017	3.96	0.000***	0.034	0.995
Constant	-0.966	0.693	-1.39	0.163	-2.325	0.393
λ	-0.585	0.338	-1.73	0.084*	-1.248	0.780
Rho	-0.461					

Source: Field Survey *** Significant at 1%, ** significant at 5%. Note: Dependent variable: Adoption of improved seeds. Number of observation = 406. Wald chi² (5) = 66.27 and pro > chi² = 0.000.

Table 4. Maximum Likelihood Estimates of treatment effect model-two step estimates.

Variable	Coefficient	Standard error	Z	P > |Z|	[95% Conf. Interval]	
Output						
Farm size	0.255	0.122	2.09	0.036*	0.016	0.494
Labor	0.212	0.628	3.38	0.001***	0.892	0.335
Seeds	0.550	0.801	0.69	0.492	-0.102	0.212
Fertilizer	0.240	0.055	4.38	0.000***	0.132	0.347
Adoption	1.419	0.535	2.65	0.008***	0.370	2.467
Constant	3.237	0.431	7.50	0.000***	2.392	4.083

Source: Field survey ***, significant at 1%, ** significant at 5%, * significant at 10%. Note: Number of observation = 406, Wald chi² (5) = 66.27, Prob > chi² = 0.000.

Ramasamy, 1991). These studies found that with complementary inputs like fertilizer, irrigation and insecticides, the improved varieties of rice and maize did far better than the traditional seeds. The net effects of the Green revolution was that many countries that were hitherto net rice importers became net exporters leading to overall increased world output. Proponents of the Green revolution argued further that with expanded market as a result of exports, farmers had the opportunity to increase their output, leading to increased income, and for that matter poverty reduction.

On the other hand, critics argued that the Green revolution led to income inequalities in favour of large-scale farmers who had access to the complementary inputs. They stressed that since the high yielding varieties of rice and maize could not do well without the complementary inputs, little or no access on the part of poor small-scale farmers meant that they were often out-competed and marginalized by their well-to-do counterparts, leading to a further widening of the gap between them (Cleaver, 1972; Gadgil and Guha, 1995; Todaro and Smith, 2003). The implication then is that for the former to also benefit from the adoption of improved seeds, there should be conscious and affirmative efforts to support them in accessing the complementary inputs.

As indicated earlier, SSA and for that matter, Ghana, missed out of the initial Green revolution. However, with support from AGRA through the instrumentality of Kofi Annan, a former UN Secretary-General, the revolution has been re-introduced into the country. For the revolution to succeed this time, there is the need to correct the mistakes associated with the first one. Currently in Ghana, the fertilizer subsidy programme that was removed some years back has been restored. However, not only is the price of the input the same for all farmers, the mode of sale is such that large-scale farmers can have greater access to the disadvantage of small scale farmers. In the long run, if this is not checked the consequence would be that some small scale-farmers may buy the input at a higher price. Fortunately, in this study the probability of adoption was greater for small-scale farmers. Since they constitute over 90% of the farming population (MoFA, 2010c), they need to be supported. However, the fact that output increased with farm size means that large-scale farmers cannot be relegated to the background. Generally, both groups of farmers must be supported but there should be a conscious effort to ensure that large-scale farmers do not enjoy at the detriment of small scale farmers.

Conflict of Interests

The authors have not declared any conflict of interests.

List of acronyms: AGRA, Alliance for a Green revolution in Africa; CDF, cumulative density function; GDP, gross domestic product; GSSP, Ghana strategy support program; IFPRI, international food policy research institute; IMR, inverse mills ratio; JHS, Junior High School; MDGs, millennium development goals; MoFA, ministry of food and agriculture; NERICA, new rice for Africa; NRDP, rice dissemination project; PDF, probability density function; SRID, statistical, research and information directorate; SSA, Sub Saharan Africa; UN, United Nations.

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Impact of the adoption of semi-mechanized technologies of shea processing on rural women's income in Northern Benin (West Africa)

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In Benin, the shea sector is one of the most promoted sectors in government's attempt to diversify sources of farm income. The objective of this study is to evaluate the impact of the adoption of the semi-mechanized shea processing on the income of rural women in northern Benin. In total, a random sample of 200 women processing shea was investigated. A probit model was firstly run to analyze the factors determining the adoption of the semi-mechanization. Then, a multiple regression model was used to assess the impact of adoption on women's income. The results highlighted that, the adoption of semi-mechanization was determined by availability of electricity, availability of a market, contact with extension services and shea processing as main activity for woman. Moreover, the adoption of semi-mechanization has induced a positive and significant increase of rural women's income up to 103 914 Francs CFA. As a result, it is important that agricultural policy reinforce the promotion of modern agricultural processing technologies to improve the added value and to reduce poverty in rural areas. As well, electricity and market access, women's level of education and contact with extension need to be improved.

Key words: Adoption, impact, shea processing, semi-mechanization, income, Benin.

INTRODUCTION

In Benin, cotton is the main cash crop which contributes over 75% to the export earnings (DSCRP, 2007). The crisis in the sector has made the Government to promote new export sectors such as shea processing. Traditionally, the nuts mainly transformed in shea butter are manually crushed in mortar and then ground to stone. This laborious work is very difficult and requires a high amount of man-power. However, following the diagnostic survey of the processing of food products in Benin, the mechanization of certain stages of shea processing

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(semi-mechanization) has been identified as priority need that can reduce drudgery in the sector (Kruit and Godjo, 1998). As well, Ahouansou and Singbo (2005) showed that, in shea processing, grinding and milling operations are most restrictive. In addition to these operations, women's exposure to heat and smoke for hours during the roasting process and low yield (10 kg of roasted product per and per person on average) are constraints weighing down on shea processing in Benin (Yabi et al., 2009).

For improving the processing conditions, several tools are developed by manufacturers among which stand the Benin Cooperative of Agricultural Equipment (COBEMAB[1]). Through the Agricultural Program and Food Technology (PTAA[2]), the National Agricultural research System (INRAB[3]) supports this initiative, and from 2002 to 2003, an adaptation test of motorized equipment was conducted by the Program in the areas of N'Dali, Banikoara, Djougou, and Natitingou. The results showed that, the complex equipment made up a mill of BCAE and a corn mill motor is effective in enabling women processing shea to save up to 75% of their initial working time (Singbo and Ahouansou, 2005).

Nowadays in Benin, equipment such as the grinder or crusher, the shea grinder, the complex made up grinder and shea mill, and the churn are introduced and made available for women processing shea. Despite their performance in terms of saving time, it is relevant to check out whether the introduction of these technologies for semi-mechanized shea processing has increased the income of rural women, contributing to reduce rural poverty. Moreover, since the introduction of these technologies in shea parks of northern Benin, evaluation studies of their economic impact on adopting women have not been conducted yet. Thus, this study aims at assessing the impact of the semi-mechanization of shea processing on the income of rural women in shea parks in northern Benin.

Theoretical background

Talking about impact assessment, the major problem is to isolate the effects of a project, a program or an innovation on the target group. To deal with this problem, several frameworks or approaches are available. The common ones are the “before-after” approach, the “with-without” approach, the so-called "naive" approach, the experimental approach, and the non-experimental approach (Yabi, 2008). The 'before-after' approach compares the performance of key variables after the introduction of technology with the one before its introduction. But this comparison of situations "before” and “after" the introduction of a given innovation does not isolate the effects related to exogenous factors (inflation, rainfall, natural disasters, economic and agricultural policies for instance) that may arise during the adoption process and that could determine the adoption rate as well as the impact on individual. Moreover, this approach imposes a baseline study before the introduction.

Otherwise, data of the conditions “before” are not available.

In comparison with the "before and after" approach, the “with-without” one seems clearer an easier (Scherr and Muller, 1991). It divides the potential target group into two subgroups. One subgroup has received the technology (beneficiary or treatment group) and the other which has not (non beneficiary or control group). In this approach, one compares the two subgroups. The problem while using this approach is to find out respondents that are similar enough so that only the adoption or not of the technology sets out the difference between them.

The “naïve” approach consists in taking a random sample of adopters and non-adopters of a given technology and using the simple difference in mean scores observed in both groups as the impact estimation. While this estimation method is commonly used in the literature (Adekambi, 2005), the estimator is potentially biased (Heckman, 1990; Diagne, 2003) and does not take into account the socio-economic characteristics of operators. The experimental approach consists in setting up a group of people having the same rights and agreeing to participate in the experiment. The selected people are randomly divided within two subgroups: one group of those who receive the intervention (treatment group) and the second group of those who do not receive (control group). Participants in this experiment are randomly selected and any difference with non-participants is only due to treatment. This experimental approach is considered to be the most reliable (unbiased estimates) and gives results easier to interpret (Cochrane and Rubin, 1973; Bassi, 1984). However, this type of evaluation is difficult to apply in practice because of ethical problems arising in the case of social phenomena (Diagne, 2003). In addition people adopting are likely to be willing to participate in the experiment and one might come up with zero non-adopters.

Economists widely use non-experimental approach based on economic theory and econometric analysis to guide and minimize potential errors in the impact estimation (Diagne, 2003). Non-experimental approaches are used when it is not possible to select a control group. In this framework, it is possible to compare program participants with non-participants by using statistical methods to control the observed differences between the two groups that could influence the impact indicator regardless to the program participation. Indeed, it is possible, using regression analysis, to obtain a "control" of age, income, gender and other characteristics of the participants. This assessment approach is relatively inexpensive and easy to apply, but the results interpretation is not straightforward and the results

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themselves may be less reliable (Diagne, 2003), if the researcher was not aware of econometrics methods.

In this study, we consider three main technologies aiming at semi-mechanized shea processing and introduced in northern Benin: the grinder, the shea mill, and the entire complex (grinder + mill). Since the technologies under consideration are already introduced, we apply an ex-post evaluation. Regarding the strengths and weaknesses of the different impact assessment frameworks, we used a non-experimental approach. This approach is based upon principles of the "with-without" approached improved with econometrics methods. Finally, following the problem statement of this study, we mainly focus on income as impact estimator.

MATERIALS AND METHODS

Study area and database

The study area includes the 3 shea parks (Parakou, Bembèrèkè, and Kandi) in northern Benin situated between 09° 20' and 12° 30' North latitude and 0°45' and 3°20' East longitude. Thus, it is located in a Savannah area with a Sudano-Guinean climate characterized by a wet season (mid April to late October to early November). The annual rainfall varies between 900 and 1200 mm. This climate is very suitable to the shea production, making the study environment an area of high production and consumption of shea butter in Benin.

In the study area, 20 villages well known in shea production and processing were selected with the support of agricultural extension officers. The respondents were women performing activities related to shea processing. The sampling was conducted randomly (based upon a list of women processing shea per village) and included an initial number of 200 women producers of shea butter (10 per village). Regarding the assessment approach adopted, the sampled women were set into two subgroups: one group using at least one of the three main technologies of semi-mechanization and the second control group using the traditional method for shea processing.

Primary quantitative and qualitative data such as women's characteristics, technologies adopted and the production of shea butter were collected through a survey method by using an individual questionnaire. As well, the triangulation of data was done through semi-structured interviews, focus group discussions and interviews with key informants.

Modeling the impact of adoption on income

We aim at determining the effect of technological change on an outcome indicator defined by y (income). Let us call y_1 the income level for an individual i if he uses the new technology and y_o the level if he does not use the new technology. Then, we consider Wi as is a binary variable taking the value 1 when the technology is adopted and 0, if not. The causal effect of technology adoption for that individual i is the difference between y_1 and y_o:

$$\Delta y = y_1 - y_0 \tag{1}$$

The main problem while estimating Δy is that, for a given individual, the income is observed either following the adoption or before the adoption, but never both at once. Then, let us quote by P the probability of technology adoption. Having this, Δy is due to a change ΔP. Thus we might consider that:

$$\Delta y / \Delta P = \beta \tag{2}$$

By moving to an infinitesimal change (d instead of Δ), we come up with:

$$dy / dP = \beta \tag{3}$$

From equation [3], y can be expressed as a function of P and other factors Z. It comes out that:

$$y = F(P, Z, e) \tag{4}$$

Where, Z stands for exogenous factors other than P and e for the error term assumed to have a normal distribution with mean 0 and constant standard deviation. Since P is by hypothesis determined by some characteristics C specific to the individual adopting the technology, we have:

$$P = G(C, v) \tag{5}$$

Where, C stands for exogenous factors (education level, gender, contact with a project officer for instance) determining the probability of adoption, and v for the error terms assumed to be normally distributed with average 0 and constant standard deviation.

With such specification, we come up with two models: the adoption model (Equation 4) and the impact model (Equation 5). Wooldridge (2002) suggests estimating initially, the adoption model. Then, in a second step, the model impact by integrating an estimated probability Ĝ such as:

$$y = F(\hat{G}, Z, e) \tag{6}$$

In case the estimated coefficient of Ĝ is significant, Rosenbaum and Rubin (1983) demonstrated that, we could identify an average causal effect of technological change within a population. Their idea is to pinpoint the difference between the average level of the indicator of beneficiaries and non beneficiaries of the technology. This gives the average treatment effect (ATE) which is defined by the difference between the estimated income $\overline{y1}$ when the estimated probability is 1 and the estimated income $\overline{y0}$ when the same probability is 0. Mathematically, we have:

$$ATE = [(\overline{y1}/\hat{G} = 1) - (\overline{y0}/\hat{G} = 0)] \tag{7}$$

This indicator which measures the impact of the technology on an individual selected at random from the population is also equal to the average impact of technology on the entire population (Heckman, 1997; Wooldridge, 2002). Empirically, the logit or probit models was based upon the Maximum Likelihood method are widely used for estimating the adoption model (Equation 5). According to Heckman (1997), both logit and probit models do often generate similar results, and choosing one of them depends on the skill in data analysis. Thus, we used the probit model to estimate Equation 5. Thus, we get the following empirical equations:

$$G_i = \alpha_0 + \alpha_1 ELECTI_i + \alpha_2 EXPE_i + \alpha_3 CONTVUL_i + \alpha_4 MARCHE_i + \alpha_5 ACTPBEUR_i + \alpha_6 EDUCFT_i + v_i \tag{8}$$

and

$$y_i = \beta_0 + \beta_1 \hat{G}_i + \beta_2 LEFTH_i + \beta_3 AUTREV_i + \beta_4 EXPE_i + \beta_5 ACTPBEUR_i + \beta_6 LDMARCHE_i + \beta_7 EDUCFT_i + \beta_8 ABLEFTHJi + \beta_9 ABAUTREVi + \beta_{10} ABLDMARCHEi + e_i \tag{9}$$

Table 1. Descriptive statistics of women's characteristics.

Quantitative	Mean	Standard deviation
Experience in shea processing (years)	15.10	10.63
Qualitative	**Yes (%)**	**No (%)**
Adoption of semi-mechanized technology (G)	55.7	44.3
Availability of electricity in the village	45.75	56.25
Contact with extension	23.4	76.6
Availability of market in the village	52.08	47.92
Shea butter is the main activity of the respondent	73.96	26.04
The respondent received a formal education	4.69	95.31

Source: Authors' calculations.

Where, G stands for the distribution function of technology adoption and $\hat{G}_i$ for its value estimated from Equation 8. Similarly, y_i is the net annual income coming from shea processing of the i^{th} woman. This income is obtained by subtracting from the total revenues the total costs related to processing. The coefficients α and β were estimated by using the Maximum Likelihoods (ML) and ordinary least squares (OLS) methods respectively.

Exogenous variables and hypotheses to be tested

The selection of the prospective exogenous or explanatory variables was grounded in the literature and in our field observations:

a) Availability of electricity in a village (ELECT): Most of the new processing technologies use electric power. Therefore, the availability of electricity in the village is a prerequisite for adoption of these new technologies.
b) Years of experience in shea processing (EXPE): Following Huffman (1977) and Kokoye et al. (2013), learning from experience reduces allocative errors. Thus, we hypothesize that women having long experience of the traditional way of shea processing will be less likely to adopt new technologies.
c) Contact with extension (CONTVUL): According to Maddison (2006), people enjoying free extension advice are likely to adapt. In this line, we expect a positive correlation between the contact with extension and the adoption of new processing technologies.
d) Availability of market in the village (MARKET): The shea processing is a market oriented activity in northern Benin. Thus, the market access is an incentive for women processing shea. Stating this, we hypothesize that the market availability is positively correlated with the adoption of new technologies.
e) Shea processing as main activity of the respondent (ACTPBEUR): We assume that women invest more time and money in their main activity. Therefore, we expect a positive correlation between having shea processing as main activity and adoption of new processing technologies.
f) The respondent's formal education status (EDUCF): Educated farmers are more likely to respond to environmental changes by adapting (Maddison, 2006). They might also be likely to understand easily the advantage of new processing technologies (time saving and health benefits for instance). Therefore, the education level is expected to have a positive effect on the adoption of technologies.
g) Quantity of family labor available for processing (LEFTHJ): Here we make the assumption that when the family labor is available women are less willing to invest in new technologies. Then the quantity of family labor available for processing is expected to have a negative impact on the adoption processing of new technologies.
h) Income from other activities of women (AUTREV): The availability of income sources can make women able to afford investments related to new technologies use. Thus, we expect a positive correlation between income from other activities and adoption of new processing technologies.

Interaction between adoption and amount of family labor available (ABLEFTHJ), interaction between adoption and income from other activities (ABAUTREV) and interaction between adoption and distance from the village to the nearest market (ABLDMARCHE) were defined to measure the impact of the interaction between the adoption of semi-mechanized shea processing and amount of family labor available (LEFTHJ), income from other activities (AUTREV), and distance from the village to the nearest market (LDMARCHE) respectively. They enable to isolate composite impacts on the income of women adopting the new technologies. These variables were obtained by multiplying the estimated probability $\hat{G}_i$ by the three variables LEFTHJ, AUTREV and LDMARCHE respectively. EXPE, ACTPBEUR, and EDUCFT are assumed to determine indirectly women's income. Therefore, they are introduced in both adoption and impact models.

RESULTS

Women's characteristics

Descriptive statistics of women's characteristics are presented in Table 1. These results indicate that, 56% of the respondents adopt new shea processing technologies. Women have a consistent experience in shea processing (median 15 years), but few (23%) of them have contact with extension services. The level of education very low (5%).

Estimation of the adoption probability

The results of the adoption model indicate that, the model is highly significant at 1% (Table 2). The coefficients of all explanatory variables, except the years of experience, positively influence the adoption of the semi-mechanized shea processing. Electricity availability, contact with extension, and market availability are significant at 1%

Table 2. Results of econometric estimation of the adoption model.

Variable	Coefficients	Standard error	p-value
Availability of electricity in the village	1.250 ***	0.2082	0.000
Experience in shea processing	-0.124	0.119	0.299
Contact with extension	0.858***	0.276	0.002
Availability of market in the village	0.771 ***	0.212	0.000
Shea processing as main activity	0.622**	0.248	0.012
Respondent received a formal education	0.090	0.511	0.860
Constant	-1.072 ***	0.366	0.003
Dependent variable	Adoption probability (G)		
Pseudo R^2	0.233		
Log pseudo-likelihood = -101.086	Wald χ^2 (6) = 58.54***		
Number of observations = 192	Prob = 0.000		

Note: *** and **: Significant at 1 and 5%, respectively. Source: Authors' estimations.

while having shea processing as main activity is significant at 5%. The formal education status is not significant in the model. Subsequently, the determinants of the adoption of at least one type of technology are the availability of electricity or market in the locality, the contact with extension services, and the shea processing as main economic activity.

As expected, although the coefficient of the years of experience in processing is not significant, the more women are experienced, the more they are more likely to use traditional methods for shea processing. The level of formal education should have a significant positive impact on adoption, but the small proportion of women who received this education (5%) made its impact positive but not significant.

Impact of adoption on the income of women

To estimate the impact of adoption on women's income, other variables were used in addition to the estimated probability of adoption as described in the empirical model. The descriptive statistics of these variables are presented in Table 3. On average, women interviewed did earn 173,218 Francs CFA as income from shea processing. Women adopting processing technologies have higher incomes than they fellow women who did not adopt. This difference in incomes that could come from the difference in technology between the two groups will be tested by the impact model.

Women who are not adopting travel a longer distance (0.899 km) than the ones adopting (0.478 km) in order to access market. This result could be explained by the fact that, most of women adopting processing technologies belong to village-groups and deal their products in group to traders who use to collect the butter in the village. The amount of available man-power within the household, the income from other activities, the experience in processing and the formal education status are more or less the same between women adopting and they fellow who did not adopt. Finally, a high proportion of women adopting the processing technology (90%) have shea processing as their main economic activity.

Table 4 presents the econometric results of the impact model. The Fisher F statistic indicates that, the model is highly significant at 1%. The over-identification test of Hansen used to test the independence between the instruments and the error term is not significant (p = 0.110). The significance of the interaction terms was tested by the Wald test. The value of this test is 74.29, and is significant at 1%. Thus, the null hypothesis which states that, all interaction terms are zero cannot be accepted.

The coefficient of the adoption probability $\hat{G}$ estimated from the adoption model is positive and significant at 1%. Therefore, there is a positive correlation between income and adoption. Put into a simplistic way, adopting the new shea processing technologies ensure an increase of the annual income. Furthermore, the average impact of the adoption of the semi mechanization of shea processing on the annual income of women is 103,914.1 Francs CFA/year.

In addition to the adoption, the family labor available, the shea processing as main activity and the income from other activities have positive and significant coefficients at 1 and 5%, respectively on the women income generated by shea processing. Indeed, women processing shea and having many children, so more workers, have higher incomes. The shea processing as main activity is the key to improving income. This result is not surprising because women having shea butter processing as main activity spend most of their time in doing the activity. Finally, revenue from other activities did promote capital accumulation for a better investment in shea processing. As a result, these revenues have a positive impact on income.

Considering the interactions between adoption and the three target variables, it comes out that, revenues from

Table 3. Descriptive statistics of explanatory variables used in the impact model.

Variables	Adopting	Not adopting	Total
Quantitative: Means (Standard deviation)			
Annual income from shea processing	225 175 (30 002)	121 261 (52 100)	173 218 (60121)
Estimated probability of adoption	0.96 (0.14)	0	0 0.57 (0.14)
Amount of family labor available	4.903 (0.758)	4.972 (0.828)	4.93 (1.12)
Income from other activities	117218 (94008)	101421 (54653)	109 319 (108 740)
Experience in processing	2.473 (0.830)	2.339 (0.864)	2.41 (1.20)
Distance from the village to nearest market	0.478 (0.708)	0.899 (0.950)	0.690 (1.18)
Interaction between adoption and amount of family labor available	-0.030 (0.758)	0	-0.030 (0.758)
Interaction between adoption and income from other activities	6993.69 (94008.3)	0	6993.69 (94008.3)
Interaction between adoption and distance from the village to the nearest market	-0.186 (0.708)	0	-0.186 (0.708)
Qualitative: Relative frequencies (%)			
Shea processing as main activity	90.4	57.6	74
Formal education	94.2	96.4	95.3

Source: Authors' calculations.

other activities and the distance from the nearest market have a positive impact on income generated by the processing activity. However, the interaction between adoption and amount of labor has a negative impact on the income of women adopting new technologies. As we hypothesize, this is simply due to the fact that women having higher labor available are already less willing to adopt new technologies of processing.

DISCUSSION

Three factors are identified as determinants of the adoption of semi-mechanized processing of shea nuts. It is about the availability of electricity or market in the locality, the contact with extension services and the shea processing as main activity for women. These finding confirm the theoretical hypotheses of the study. As well, several authors highlighted the key role of variables such as extension services in the adoption of new technologies (Bravo-Ureta et al. 2005; Glèlè et al. 2008).

By adopting the technologies of shea processing, the results pinpointed that women could improve their incomes. This supports the general hypothesis stating that adoption of agricultural innovations lead to improvement of incomes. Glèlè et al. (2008) found out that, adopters of improved cassava varieties derive more income per hectare than non-adopters and they earn on average 140,358 Francs CFA per hectare against 46,984 Francs CFA per hectare for their fellow non-adopters. Similar studies were also conducted in other African countries and the results are consistent with those found out in Benin.

According to Benin et al. (2011), the technologies adopted by farmers in Uganda, through the National Program for agricultural extension services, have a positive impact on incomes. The direct and indirect impacts of adopters are estimated between 37 and 95% higher in comparison with non-adopters. Benin et al. (2011) also reported that, this positive impact increases over time. For instance, between 2004 and 2007, it increased from 27% to 55% per capita. In the same vein, Kato et al. (2011) showed that in the Nile Basin in Ethiopia, technologies for soil and water conservation have a positive impact on agricultural output. Because the performance of agriculture determines the level of income, these technologies have a positive impact on income.

According to Hassan and Thurlow (2010), the water management strategy adopted by the South African producers had as impact, an improved domestic production by 0.4% annually from 1994 to 2007; implicitly improving producers' income over the same period. Bellemare (2010) found out in Madagascar that, the adoption of technologies promoted by extension agents improves productivity and results indicated that, the elasticity of performance in relation with the number of visits is between 1.3 and 1.7. In Kenya, the adoption of technologies (such as systems of rotation with green fertilizers) of the International Center for the Improvement of Maize and Wheat Improvement Center (ICIMWIC) allowed producers to improve their yields (De Groote et al., 2010). But, as several authors emphasized, the adoption of new technology can have a positive impact if the additional costs are offset by the additional production. As proof of this, LUCOP-TAN (2010) found out that the adoption of new technologies for the development of the valleys in the region of Tahoua in Niger had no impact on producers' income. Indeed, the costs associated with the development of the valleys are very high and the additional production value obtained does not cover the aforesaid costs.

Subsequently, the impact of adopting a new agricultural technology supports the economic theory of the producer's balance. The adoption becomes economically profitable from when the marginal revenue generated equal the marginal costs. In this case, the economic impact of the technology adoption is positive.

Conclusion

This study analyzed the impact of the adoption of semi-mechanized shea processing on income of rural women in northern Benin. The findings highlighted that, the adoption of shea processing technologies increases women's incomes. As policy implication, it is important to strengthen the promotion of new technologies in order to boost the agricultural development in general and the shea processing in particular. In this line, special emphasis should be put on modern technologies of processing agricultural products to create more value added, implying more wealth.

Moreover, electricity and market access, women's level of education and contact with extension need to be improved. This study focuses only on income. Future researches could address other variables such as education level of children and health.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Options to reduce poverty among agro-pastoral households of Ethiopia: A case study from Aysaita district of Afar national regional state

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This paper discusses the dimension and intensity of poverty among the agro-pastoral households and development options based on survey data collected in 2011 from 180 randomly selected agro-pastoral households of Aysaita district. The study used the Foster, Greer and Thorbecke (FGT) index to examine the incidence of poverty, the poverty gap and severity of poverty. It also employed the Tobit regression model to analyse the determinants of intensity of poverty in the study area. Results show that about 52.8% of the sampled households have been living below poverty line with poverty gap and poverty severity indices of 0.16 and 0.07, respectively. The Gini coefficient is about 0.31. Some of the key determinants of intensity of poverty among agro-pastoral households are found to be diversification of livestock holding, and access to irrigated land, improved forage and market centers. The paper concludes by indicating that development interventions need to engage in diversifying herd per household, improving access to irrigation, regulating credit diversion and promoting off-farm employment to reduce poverty among the agro-pastoral households.

Key words: Agro-pastoral, poverty dimension, Gini coefficient, Tobit model, Foster, Greer and Thorbecke (FGT) index.

INTRODUCTION

Poverty in general and food insecurity in particular remains one of the challenges of developing countries in achieving their national development goals (MoARD, 2010). For instance, in Ethiopia it is estimated that about one third of the population are living in extreme poverty (DFID, 2011). About 87% of the population faces multiple deprivations while additional 6.8% of the population is at verge of falling under multiple deprivations. The intensity of deprivation of multidimensional poverty, which is the average percentage of deprivation experienced by people in multidimensional poverty, is estimated to be 64.6%. Population in severe poverty is 71.1% (UNDP, 2013). Historically, food aid and commercial food imports have been the main instruments to satisfy domestic food

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insecurity in the country (Little, 2008). Prior studies suggest that Ethiopia should address the relatively slow progress in the pastoralist and agro-pastoralist areas to meet its national development goals (Bevan and Pankhurst, 2008; PFE, 2007). For instance, about 92% of the population in Afar is food insecure in terms of calorie intake, and about 56% of the total population of the region is classified as poor (PFE, 2009). This is the region with large share of regional population living in poverty (MoFED, 2008). Specifically, the food insecurity and acute child malnutrition problems are increasing from time to time in Aysaita district, which is one of the largest districts in the region and focus of this study (FEWS NET, 2011). The number of people depending on relief assistance has increased in 2012 as compared to the late 2011 (FAO and WFP, 2012). it seems that, although various development interventions have been implemented in the area, little has been achieved.

There are ongoing policy debates among professionals and policy-makers on feasible strategies and possible intervention areas which will accelerate poverty reduction among the pastoral and agro-pastoral areas of the country. Hence, this paper assesses development options to reduce poverty among agro-pastoral households of Ethiopia. Specifically, it discusses the poverty gap and its severity among agro-pastoral households, and factors that determine the intensity of poverty in the area. The paper is organized as follows. Next, we present the research methodology such as sampling techniques, methods of data analysis, and description of the study area. Then we discuss the main results of the study. The findings show that the intensity of poverty among agro-pastoralists is determined by household assets holdings such as livestock and irrigable land; access to agricultural technologies, for instance, improved forage; and access basic institutional services such as market, extension and veterinary services. Finally, the study concludes by providing short term and long term development intervention options to reduce poverty among agro-pastoralists.

RESEARCH METHODOLOGY

Description of the study area

The study was conducted in Aysaita district of *Awsi* zone[1] in Afar National Regional State. Aysaita is one of the largest districts in the region and located in eastern part of Afar National Regional State. It has a total area of 138,800 ha and thirteen *kebeles*; of which two urban, six pastoral and five agro-pastoral *kebeles*. Naturally, it is plain in terms of topography. The mean annual temperature is between 30 and 45°C. The total population of Aysaita is estimated at 47,210 persons, of which about 66% classified as rural and 98.1% of these rural residents are Muslims (FDRE-PCC, 2008). In the district, pastoral and agro-pastoral system of livestock production is the dominant livelihood strategy. The livestock population in the district is estimated to be 71,383 cattle, 16,943 sheep, 23,086 goats, 3,277 camel and 482 donkeys (APARDB, 2009). The sedentary part of local people produces various maize, vegetable and oil crops. Cotton is also grown as a major crop by private investors along the Awash River where irrigation is possible. Due to long dry seasons and frequent recurrent drought, the quantity and quality of natural pasture is largely degraded thereby livelihood of pastoralists and agro-pastoralists are seriously affected.

[1] According to the Ethiopian Federal Democratic Republic administrative hierarchy, the regional states are divided into zones, districts and *Kebeles* (local administrative units), in that order.

Sampling and data collection methods

The study employed a multi-stage sampling procedure to collect primary data. Firstly, Aysaita district was chosen purposively because of its representativeness and high food insecurity among five *Awsi* zone districts. In the second stage, three agro-pastoral *kebeles* were selected randomly out of the five agro-pastoral *kebeles* in the district. Thirdly, 66, 60, and 54 agro-pastoral households were selected from three *kebeles* namely: Hinele, Kerbuda and Berga, respectively, applying probability proportionate to size (PPS) technique to have a total of 180 agro-pastoral households. Data was collected using pre-tested survey questionnaire. The survey questionnaire constitutes different parts which respondents were asked about their socio-demographic and economic profiles and characteristics. The survey was administered using experienced enumerators who speak the local language *Afara'f* fluently. Besides, Focus Group Discussions (FGD) were held with selected key informants (village elders, clan leaders and local administrators), and community members to supplement information we collected through survey. In addition, published and unpublished research reports from various governmental and non-governmental organizations were also reviewed.

Poverty indices estimation techniques

The primary step in poverty index computation is to determine suitable poverty line that serves as a point of reference. In this study, cost of basic need (CBN) method is used to set poverty lines. Accordingly, a seven-day recall method was used for the food items served for the household within that week. In setting a poverty line, the minimum daily energy intake requirement per adult equivalent of 2,200 kcal is used (MoFED, 2008). A reference food basket was constructed based on a typical diet for the poorest half of the sample households in the nominal consumption. The quantity of the food basket is determined in such a way that it meets the predetermined level of minimum caloric requirement. This basket is valued at local prices to arrive at a consistent food poverty line. Then, a specific allowance for a non-food component is added to the food poverty line. To account for the non-food expenditure, the food poverty line is divided by the food share of the poorest half of the sample households. Finally, this method gives a representative poverty line that provides a monetary value of a poverty line and accounts for the food and non-food components. Secondly, one has to choose the appropriate poverty measurement index. Despite various poverty measurement indices such as equally-distributed-equivalent-Foster-Greer-Thorbecke (EDE-FGT) poverty index, FGT poverty index, Watts poverty index, and Sen-Shorroks-Thon poverty index (Araar and Duclos, 2009), the three most commonly used poverty measures are the head count index (HI), the poverty gap index (PG), and severity index (Foster et al., 1984) which can be defined in terms of the well-known Foster-Greer-Thorbecke (FGT) index.

The mathematical expression of the FGT poverty index is:

$$P_\alpha = \frac{1}{n}\sum_{i=1}^{q}\left(\frac{\pi - C_i}{\pi}\right)^\alpha \qquad (1)$$

Where P_α = poverty measure; π = poverty line; C_i = household consumption expenditure per AE; n = the number of households under consideration; q = the number of poor households; i = household index; $\pi - C_i$ = poverty gap. If $C_i < \pi$ the household was counted as poor, when $C_i \geq \pi$ the household was considered as non poor; α = measure of sensitivity of the index to poverty or the weight attached to the severity of the poor.These measures are defined for $\alpha \geq 0$, the commonly used values of α are zero, one and two. When α equals to zero (all poor are given equal weight), so Equation 1 is reduced to the headcount ratio, which measures the incidence of poverty or the percentage of people falling below the poverty line:

$$\alpha = 0 \rightarrow P_0 = \frac{q}{n} \tag{2}$$

When α is equal to one, we obtain P_1 or the poverty gap index which estimates the average distance separating the poor from the poverty line or the average level of deprivation among the poor:

$$\alpha = 1 \rightarrow P_1 = \frac{1}{n\pi} \sum_{i=1}^{q} (\pi - C_i) \tag{3}$$

Setting α equal to two gives the severity of poverty or squared poverty gap index (Equation 4). This poverty index measures the severity of poverty. It depicts the severity of poverty by assigning each household a weight equal to its distance from the poverty line. Thus, it takes into account not only the distance separating the poor from the poverty line (the poverty gap) but also the inequality among the poor. Squared poverty gap index gives larger weight to the poorest of the poor by squaring the gap, as it is more sensitive to redistribution among the poor:

$$\alpha = 2 \rightarrow P_2 = \frac{1}{n\pi^2} \sum_{i=1}^{q} (\pi - C_i)^2 \tag{4}$$

The Gini-coefficient was also estimated. The procedure involved ranking the households on the basis of some quality of interest in our case consumption expenditure and then estimating cumulative proportions. It shows the distribution of expenditure above the poverty line. The closer the distribution indicates the existence of more pronounced poverty in the study area while the more dispersed the distribution depicts the contrary. Both the FGT and Gini index were computed by employing the specialized ".ado" program DASP 2.1 (Araar and Duclos, 2009) which is compatible with the Stata statistical software.

Econometric model

In recognition of the fact that a strictly dichotomous regression model is not sufficient to examine the intensity of poverty because it assumes uniform intensity of poverty, a Tobit model is used for econometric analysis as it handles both the probability and intensity of poverty at the same time (Greene, 2003; Maddala, 1983). Thus, a Tobit regression model was used to draw inferences on the covariates of agro-pastoral household poverty intensity. The full model, which was developed by Tobin (1958) is expressed as:

$$y_i^* = \beta_i X_i + u_i$$

Where i = 1, 2, 3… n.

And

$$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases} \tag{5}$$

Where y_i = The observed dependent variable; y_i^* = latent variable, which in this study is referred as the intensity of poverty; X_i = factors explaining intensity of poverty; β_i = parameters to be estimated; u_i = error terms; where, $u_i \sim \text{NID}(0, \sigma^2)$.

The limited dependent variable y_i^* is defined as:

$$y_i^* = \left(\frac{\pi - C_i}{\pi} \right) \tag{6}$$

Where π = Poverty line, C_i = household consumption expenditure per adult equivalent (AE).
The expected value of the poverty intensity (poverty gap ratio) in poor households can be estimated:

$$E(y_i / y_i^* > 0) = X\beta + \sigma \frac{f(z)}{F(z)} \tag{7}$$

Where σ = The standard deviation of the error term, *z* is denoted by $\frac{\beta_i X_i}{\sigma}$ = the z-score for the area under normal curve; F(z) = the cumulative normal distribution of z, and f(z) = the value of the derivative of the normal curve at a given point.

Following McDonald and Moffitt (1980), the Tobit model can be further decomposed to determine the effect of a change in value of the k^{th} variable on change in the expected depth of the poverty. Thus, the change in the intensity of poverty with respect to a change in explanatory variables among the poor households is:

$$\frac{\partial E(y_i / y_i^* > 0)}{\partial X_k} = \beta_k \left[1 - Z \frac{f(z)}{F(z)} - \left(\frac{f(z)}{F(z)} \right)^2 \right] \tag{8}$$

If parameter estimates of the entire population are required, it will be necessary to compute the derivatives of the estimated Tobit model to predict the effects of changes in the explanatory variables. Accordingly, the adjusted estimate which is the marginal effect of an explanatory variable on the expected value of the dependent variable is estimated as follows:

$$\frac{\partial \text{E}(y_i)}{\partial X_i} = F(\text{z})\beta_i \tag{9}$$

Based on prior studies household demographic characteristics, access to resource and attributes of the resource are identified as factors that explain the intensity of poverty at the household level (the dependent variable). Summary descriptions and expected signs of explanatory variables are presented in Table 1.

Table 1. Description and expected sign of explanatory variables.

Dependent variable	Description of the variables	Expected sign
Intensity of poverty	It refers to the poverty gap ratio such that the non-poor group was given a value 0 whereas the poor group was assessed in the continuous range	
Explanatory variable		
SEX	Dummy variable which takes a value of 1 if the household head is male; 0 otherwise.	-
EDU	Dummy variable that takes a value 1 if household head and/or spouse are literate; 0 otherwise	-
FASZ_AE	Refers to the size of agro-pastoralist household members who live together under the same roof expressed in AE.	+
DPR	Dependency ratio, it is the ratio of number of non-productive age group in family members (< 15 years and > 65 years) to the number of productive age group.	+
OXEN	Considered as dummy variable 1 if own ox/oxen; 0, otherwise.	-
IRGFARSZ_AE	Refers to the total cultivated land (in ha) under irrigation owned by household per AE.	-
TLU_AE	The total number of livestock holding measured in tropical livestock units (TLU) per AE.	-
DDSTLU_AE	Number of animals lost due to outbreak of diseases and drought in TLU per AE.	+
ASPROD	Dummy variable taking a value of 1 if the household has involved in improved forage production; 0 otherwise.	-
FARIN_AE	Refers to total annual earnings of the family from sale of agricultural produce per AE.	-
EXPEAGPA	The time (in years) since sampled household started to practice agro-pastoral mode of life rather than pastoral	-
DMOTLU	The number of dead animals during mobility in TLU	+
HERDIV	Dummy variable valued 1 for agro-pastoralists who shifted herd composition from grazers (cattle and sheep) to browsers (camels and goats) following the recent drought; 0 otherwise	-
EXTCON	The variable was considered as dummy taking 1 for households visited by extension agents; 0 if not visited	
CREDIT	Takes a value 1 if the agro-pastoral households have used the available source of credit, 0 otherwise	-
MKTDIS	This is a continuous variable used as proximity to the market center measured in kilometer.	+

RESULTS AND DISCUSSION

Dimensions of poverty among agro-pastoral households

The overall poverty indices computation using the FGT measures based on total poverty line[2] of 176.78 USD per adult per year shows that the head count index is 0.5278 while the poverty gap and poverty severity indices are

[2] The poverty line based on a typical diet for the poorest half of the sample households was ETB 2145.46 per annum (Annex Table 2A) or USD128.34[2] taking the rate during the survey period, 1 USD = 16.72 Birr. The total poverty line was obtained after adjusting for non-food expenditure using the average food share of the poorest 50% agro-pastoral households. The share of food expenditure of the poorest 50% households was 72.60%. Dividing the food poverty line of ETB 2145.46 by 0.726 gives the total poverty line of ETB 2955.29 per adult per year (which is around USD 176.78 per adult per year). This is approximately ETB 8 per adult per day; equivalent to half a US dollar per day.

Table 2. Poverty incidence, severity and inequality.

Kebele	Head count index (P_0)	Poverty gap index (P_1)	FGT poverty index (P_2)	Gini coefficient of consumption expenditure
Berga	0.6852	0.1481	0.0481	0.2937
Hinele	0.4697	0.1353	0.0448	0.2786
Kerbuda	0.4500	0.2040	0.1133	0.3392
Overall	0.5278	0.1621	0.0686	0.3131

Source: Own survey data (2011).

0.1621 and 0.0686, respectively (Table 2). The head count index (P_0) indicates 53% of the sampled agro-pastoral households are poor. This index indicates the percentage of the population whose consumption expenditure was less than the poverty line. The comparison of poverty incidence across the *kebeles* shows that the proportion of agro-pastoral households living in poverty is markedly the highest in Berga *kebeles*. Poverty gap index (depth of poverty) estimates the total resources needed to bring all the poor to the level of the poverty line and also captures the extent to which individual expenditure falls below poverty line. According to the household survey results, the depth of poverty is higher in Kerbuda, followed by Berga and Hinele *kebeles*, implying that more resources are required to bring the poor households out of poverty in Kerbuda than Berga and Hinele taking into account the number of people who reside in the respective *kebeles*. The overall poverty depth of 0.1621 means that if resources are mobilized equal to 16.21% of the poverty line and distributed to the poor in the amount needed so as to bring each individual up to the poverty line, then at least in theory, poverty could be eliminated. In the same way from poverty severity index, a 7% falls below the threshold line implies severe inequality. Thus, it can be inferred that there is a high degree of inequality among the poorest agro-pastoralist population. The results also show the existence of sever inequality in Kerbuda *kebele* even if there is less prevalence of poverty relatively. The indices we found differ from prior values reported in poverty profile reports, which are a head count index of 0.429, poverty gap index of 0.078, poverty severity index of 0.021 and poverty line of ETB 1075.03 in 2004/2005 in rural areas of Afar region (MoFED, 2008). Our report shows that higher percentage of the population in the area is living in poverty. This might be due to high inflation in food and non-food items prices in the year 2011.

In March 2011, the country level food inflation and non-food inflation rate was 27 and 25%, respectively as compared to the same month of the previous year (WFP, 2012). Secondly, it might consolidate the finding of Bevan and Pankhurst (2008) which stated that poverty incidence measures for Somali and Afar are generally unreliable but are likely to be high. Demeke et al. (2003) also indicated the data problems in the government reports especially in the poverty figures of rural areas. Result of the analysis in Table 2 shows that the Gini coefficient of consumption expenditure of sample respondents in Hinelee *kebele* is about 0.28 while the figure is slightly higher for samples from Berga and Kerbuda *kebeles*, which is 0.29 and 0.34, respectively. The combined Gini index for the total sample is about 0.31. Moreover, the Gini coefficent reported in this study is higher than the figure reported by the Ministry of Finance and Economic Development for the rural area of Afar National Regional State for the year 2004/2005, which is 0.28 (MoFED, 2008). This shows worsening of inequality in consumption among the population in Afar region.

The relative high Gini coefficient of expenditure distribution in Kerbuda *kebele* indicates that unequal distribution of consumption expenditure prevails among agro-pastoralists who reside in Kerbuda while the distribution is better among respondents living in Berga and Hinelee *kebeles*.

Determinants of poverty and intensity of poverty

Among a total of sixteen explanatory variables hypothesized to determine intensity of poverty, most of them turned out to be significant. The Tobit model output is presented in Table 3 shows that the family size in adult equivalent (FASZ_AE), number of livestock per adult equivalent (TLU_AE), improved practice of pasture production (PASPROD), credit utilization (CREDIT), and distance to market place (MKTDIS) have statistically significant influence on intensity poverty among agro-pastoralists at $P<0.01$ while oxen ownership (OXEN), irrigable plot size per adult equivalent (IRGFARSZ_AE), and extension contact (EXTCON) are statistically significant at $P<0.05$ and some of the remaining variables such as sex of the household head (SEX), number of dead animals due to disease outbreak and drought per adult equivalent (DDSTLU_AE) and herd diversification (HERDIV) are significant at $P<0.1$. Annex Table 1A presents summary statistics of the explanatory variables. Before fitting the Tobit model, the multicollinearity problem was tested using variance inflation factor (VIF) and contingency coefficient. We also checked for non-normality using Jarque-Bera technique, heteroscedasticity and endogeneity problems using

Table 3. Maximum likelihood estimates of Tobit model and marginal effects.

Variable	Estimated coefficient	$\frac{\partial E(y_i / y_i^* > 0)}{\partial X_k}$	$\frac{\partial E(y_i)}{\partial X_k}$
Constant	0.411 (0.374)		
SEX	-0.076* (0.039)	-0.0324 (0.018)	-0.0458 (0.025)
EDU	-0.041 (0.059)	-0.0169 (0.025)	-0.0239 (0.036)
FASZ_AE	0.040*** (0.014)	0.0156 (0.006)	0.0220 (0.008)
DPR	0.011 (0.025)	0.0044 (0.010)	0.0061 (0.014)
OXEN	-0.092** (0.036)	-0.0373 (0.015)	-0.0524 (0.021)
IRGFARSZ_AE	-0.176** (0.088)	-0.0693 (0.034)	-0.0975 (0.048)
TLU_AE	-0.032*** (0.008)	-0.0125 (0.003)	-0.0176 (0.004)
DDSTLU_AE	0.104* (0.06)	0.0410 (0.023)	0.0577 (0.033)
PASPROD	-0.168*** (0.043)	-0.0754 (0.022)	-0.1059 (0.030)
Log FARIN_AE	-0.052 (0.044)	-0.0203 (0.018)	-0.0286 (0.025)
EXPEAGPA	-0.003 (0.003)	-0.0013 (0.001)	-0.0018 (0.002)
DMOTLU	0.013 (0.009)	0.0049 (0.004)	0.0069 (0.005)
HERDIV	-0.060* (0.035)	-0.0237 (0.014)	-0.0332 (0.020)
EXTCON	-0.100** (0.046)	-0.0439 (0.022)	-0.0623 (0.031)
CREDIT	0.136*** (0.038)	0.0580 (0.018)	0.0816 (0.024)
MKTDIS	0.043*** (0.01)	0.0169 (0.004)	0.0238 (0.006)
Sigma	0.185*** (0.014)		

Source: Own survey data (2011). ***, ** and * indicate statistical significance at 1, 5 and 10% probability level, respectively. LR chi^2 (16) = 176.39***. Figures in the parentheses refer to the standard errors.

White's general heteroscedasticity and Hausman specification test, respectively. The results of the tests show that there is no serious econometric problem that could lead to biasness of the research findings. The log likelihood ratio (LR) test also depicts that the model explained significant non-zero variations in factors influencing poverty intensity and that the model displays a good fit. Similarly, the ratio of the maximum likelihood estimates of the Tobit regression to the sigma value (σ = 0.185, t = 13.11 and p = 0.000) verified that the model has a good fit to the data because it has closer figure to the corresponding probit estimators (Greene, 2003).

As stated in Johnston and DiNardo (1997), there is no direct and simple way of presenting interpretation of parameter estimates in the Tobit model. Rather a more interesting interpretation can be made using marginal effect of explanatory variable by adopting McDonald and Moffitt (1980) decomposition procedure. Therefore, the effect of changes in the explanatory variables on intensity of poverty is discussed based on the marginal effect part of the Tobit model output. The negative and significant association between the variable SEX and intensity of poverty among agro-pastoralists shows that male-headed households in the area were less vulnerable to poverty than female-headed households. Thus, having male-headed household poverty intensity of poor households reduces by 3.24%, ceteris paribus. In addition, poverty intensity of the entire sample decreases by 4.58%. The possible justification is related to resource entitlement and workload on women. Similarly, Geda et al. (2008) and Etim and Patrick (2010) reported that male headed households are associated with lesser poverty depth in Ethiopia and in Akwa Ibom State, Nigeria, respectively. There is also a positive and highly significant association between family size and intensity of poverty. On average, one unit increase in family size (in AE) among poor households increases the intensity of poverty by 1.56 %, if all other variables are held at their mean value. While the poverty intensity of the entire sample increases by 2.2%. The likely explanation is that in the study area households depend on degraded rangelands, less productive livestock, and low-input and low-output agriculture. Thus, increasing household size results in an increase in food demand. In most cases, this demand cannot be matched with the existing food supply so ultimately end up with food insecurity and poverty. Similarly, Etim and Solomon (2010) reported that households who have large family size are associated with greater poverty depth in Uyo, Nigeria.

It has been reported in various studies that livestock holding tends to reduce the intensity of poverty among pastoralists and agro-pastoralist communities (Enquobahrie, 2004; MoFED, 2008). Similarly, our findings show that a unit increase in livestock holding (in TLU per AE) tends to decrease the intensity of poverty of poor households by 1.25%, holding all other variables at their mean value. Meanwhile the poverty intensity of the entire sample decreases by 1.76%. The underlining reason is that livestock is used as source of direct consumption, live asset (bank), source of cash income, means of purchasing power, social security and means of coping. Household with own oxen have a 3.73% intensity of poverty compared to households without oxen, keeping other things constant. At the same time, the intensity of poverty of the entire sample decreases by 5.24%. The implication is that households with oxen were able to undertake farm activities timely, properly and produce better to secure family food requirement. Similarly, keeping other variables at their mean values, a 1 ha increases in irrigable land per AE would lower intensity of poverty of poor households by 6.93%. In addition, the entire sample poverty intensity decreases by 9.75%. Nevertheless, land size is limited resource so it could not be increased as the household wishes in order to increase energy intake of the household. Thus, it only highlights the importance of irrigation schemes to intensify pastoral agriculture production and reduce poverty status of agro-pastoral households.

Bogale (2011) also reported that households who have access to irrigable land are associated with lower poverty prevalence in eastern Hararghe highlands of Ethiopia. Besides, IFPRI (2012) indicated the importance of expanding irrigation in pastoral areas to tackle poverty. The number of dead livestock due to animal diseases affects the intensity of poverty positively (Hilina, 2005; Kefelegn, 2007). An increase in death of livestock due to diseases by one TLU per AE increases poverty intensity of poor households and the entire sample by 4.1 and 5.77%, respectively, holding all other variables at their mean value. This is perhaps due to loss of live asset because of seasonal drought and diseases. Moreover, the results of the study show that as the households diversify their herd in response to recurrent drought, poverty intensity of poor households decrease by 2.37% since they can raise better disposable income from herd, throughout the year, ceteris paribus. At the same time, the poverty intensity of the entire sample decreases by 3.32%. Bhasin (2011) and Boku (2008) also found that herd diversification could be used as one of the strategies to minimize impact of climate change among agro-pastoral communities, improve resilience after recurrent drought and in turn reduce poverty. Poverty intensity of poor households reduces by 4.39% if the sample respondents have contact with development agents. In the same way, poverty intensity of the entire sample decreases by 6.23%. The implication is that more emphasis should be given to upgrade the knowledge of extension agents to improve agro-pastoralists wellbeing (Etim and Solomon, 2010). The marginal effect analysis also showed that agro-pastoral households who involve in improved pasture production were less likely to be susceptible to poverty. As the household participate in improved pasture production, the intensity of the poor households' poverty decreases by 7.54%, ceteris paribus. The poverty intensity of the entire sample decreases by 10.59%. This is because production of improved forage minimizes the livestock feeds shortage and also uses as source of cash income [in the study area, 1 kg Blue Panic (*Panicum antidotale*) seeds is sold for ETB 100].

On the other hand, quite remarkably, credit utilization showed positive relation with the intensity of poverty. This is, perhaps, because of the fact that even though the credit scheme in the area is considered pro-poor, it has not been able to list the households above the poverty line. This might be due to credit diversion problem which is common among pastoralists and agro-pastoralists in the area to use finance obtained through credit for direct consumption instead of spending on production. Although, credit is supposed to be used to purchase agricultural inputs (agricultural technologies), agro-pastoralists in the study area usually obtain agricultural inputs such as improved varieties, agricultural hand tools and implements for free from the regional government, research institutes and NGOs.

Thus, agro-pastoralists use credit to solve their immediate food shortage and social obligations rather than to purchase agricultural inputs. As a result, it is common among agro-pastoralists to sell their asset such as livestock to settle their debit which may in turn reduce their resource endowment and increase poverty. It is important also to note that the most of sampled respondents (about 48%) had accessed credit from their friends and neighbors while about 35% of the samples got credit from their relatives. Merchants are also important sources of credit for considerable sample agro-pastoral households (about 15.4%). This reveals how important the role of informal credit sources among the pastoralist and agro-pastoralist households (Annex Table 3A). Nevertheless, in most cases, credit services are in kind unless it is obtained from the formal sources such as commercial bank.

The variable distance to market place is found to be associated positively with the intensity of poverty of sample agro-pastoralist households. Specifically, with a kilometer increase in market distance from agro-pastoral household residence, the poverty intensity tends to increase by about 1.69% for the poor sample households and by 2.38% for the total samples, keeping other things constant at their mean value. It appears that agro-pastoralists living far from market place might find it difficult to escape from poverty. This is in line with the earlier research findings by Kebede et al. (2005) and Bigsten et al. (2003).

Policy implications

Findings of this study shows that the intensity of poverty among agro-pastoralists is determined, among other things, by household assets holdings such as livestock and irrigable land; access to agricultural technologies for instance improved forage; and access basic institutional services such as market, extension and veterinary services. The study reveals that it is worth considering development interventions like developing irrigable rangelands, strengthening improved forage production to be used for both herbage and seed production in order to reduce poverty among the agro-pastoralists. Moreover, herd diversification such as development of browser animals mainly camel and goat need to be part of the livestock restocking program to develop resilience after diseases and drought induced loss of productive assets, and creating job opportunities to minimize disguised unemployment also remain important options to reduce intensity of poverty.

It appears that empowering women to improve their access to and control over resource through better institutional set up, and legal and administration system could contribute a lot in reducing the intensity of poverty among agro-pastoralists. The development programs also need to work towards improving the frequency of contact of development agents with agro-pastoralists. This can be achieved by arranging field days and continues trainings. Of course, increasing number and capacity of extension agents in the area also something that needs to be addressed.

The unexpected positive association between credit use and poverty intensity indicated that credit provisions have not been meeting their purposes of reducing poverty. Although, the underlying reasons require further empirical study, in general, credit diversion to consumption appears to be a main problem. Thus, targeted safety net program such as food transfer programs need to be tied to productive activities. Better provision of credit service (interest free credit in areas where religion bans paying and taking interest on credit) through formal institutions such as cooperatives, and pastoral and agro-pastoral research extension groups seems also an option.

In considering results of this study, what becomes clear is the importance of reducing distance of agro-pastoralist to market centers to reduce poverty. This can be achieved through development of subsidiary market places in selected sites of the rural villages and with establishment of marketing cooperatives along with other development interventions. In sum, the high poverty incidence in the study area denotes that agro-pastoralists need to receive due attention to achieve national development goals. This calls for policy measures to be geared towards promoting long-term sustainable livelihood and resilience to disaster among agro-pastoralists. In the meantime, it is necessary to implement development interventions that support immediate needs of the agro-pastoralists.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Annex

Table 1A. Summary statistics of explanatory variables.

Variable	Dummy variables	Continuous variables			
	% of 1 responses	Mean	Standard deviation	Minimum	Maximum
SEX	77.8				
EDU	17.8				
FASZ_AE		4.94	1.63	1	10.75
DPR		1.02	0.71	0	5
EXPEAGPA		13.26	5.76	2	26
TLU_AE		5.49	4.38	0.7	29.75
IRGFARSZ_AE		0.42	0.35	0	1.59
DDSTLU_AE		0.39	0.34	0	1.59
DMOTLU		1.87	1.86	0	7.16
FARIN_AE		7.76	0.51	6.2	8.70
OXEN	56.1				
HERDIV	48.9				
EXTCON	81.7				
PASPROD	72.8				
CREDIT	34.4				
MKTDIS		7.58	1.81	3	15

Source: Own survey data (2011).

Table 2A. Diet of the poorest half of the sample households and value of food poverty line.

Food group	Gram consumption per day/AE	Mean$^{\Psi}$ kcal per kg/lt	Kcal needed to get 2200 kcal	Kcal share (%)	Mean price per kg/lt	Value of food poverty/year
Cereal	315.28	3470	1198.87	54.49	2.50	287.70
Milk	450.48	860	413.39	18.79	10.00	1644.24
Edible oil	4.33	8120	280.49	12.75	21.65	34.20
Meat	1.19	1970	61.87	2.81	32.00	13.92
Vegetables	12.86	370	15.94	0.72	1.70	7.98
Fruits	0.22	520	15.83	0.72	6.00	0.48
Spices	1.80	2970	95.09	4.32	36.00	23.66
Coffee and tea leaf	6.45	1190	43.63	1.98	35.50	83.52
Salt and sugar	11.86	1780	74.89	3.40	11.50	49.76
Total			2200	100		2145.46

Source: Own survey data (2011) and $^{\Psi}$adopted from MoFED (2002).

Table 3A. Share of agro-pastoralist major sources of credit.

Sources	Number of respondents	Percentage
Friends and neighbors	30	48
Relatives	22	35
Merchants	9	15
Commercial bank	1	2
Total	62	100.00

Source: Own survey data (2011).

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Assessment of technical efficiency and its determinants in beef cattle production in Kenya

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The stochastic metafrontier method is applied to estimate technical efficiency levels in beef cattle production in Kenya. Subsequently, a Tobit model is used to assess factors that might influence efficiency. Results show that the average efficiency level is 0.69, suggesting that there is considerable scope to improve beef production in Kenya. Considering the importance of the livestock enterprise to rural livelihoods and its potential role in poverty reduction, there is need for appropriate development strategies for enhanced efficiency. In particular, livestock development policies should focus on provision of technology-related services. For instance, promoting use of controlled cattle crossbreeding methods would enhance productivity gains. Effective institutional support is also necessary in order to improve efficiency, including improved access to market contracts, better farm management skills and off-farm income opportunities.

Key words: Beef production, technical efficiency determinants, metafrontier, Kenya.

INTRODUCTION

Measurement of technical efficiency (TE) provides useful information on competitiveness of farms and potential to improve productivity, with the existing resources and level of technology (Abdulai and Tietje, 2007). Moreover, investigating factors that influence TE offers important insights on key variables that might be worthy of consideration in policy-making, in order to ensure optimal resource utilisation. There is extensive literature on TE of crops, dairy and mixed crop-livestock farms, but that on beef cattle enterprises is limited (Barnes, 2008; Ceyhan and Hazneci, 2010; Featherstone et al., 1997; Fleming et al., 2010; Hadley, 2006; Iraizoz et al., 2005; Rakipova et al., 2003 are exceptions). In Kenya, 70% of all households are engaged in crop and livestock farming; about 84% of them depend on livestock for livelihoods in rural areas (KIPPRA, 2009). However, past studies on efficiency mainly focus on crops (Nyagaka et al., 2010) and dairy (Kavoi et al., 2010); no study has analysed the TE of beef cattle farms in Kenya.

The present study investigates TE and its determinants in beef cattle production in Kenya. There are three main beef cattle production systems in Kenya: nomadic pastoralism, agro-pastoralism and ranches. Nomadic pastoralism and agro-pastoralism contribute about 65%

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of total beef output in Kenya, while the rest is obtained from ranches and a small proportion from culled dairy cattle (Omiti and Irungu, 2002). Further, it is estimated that over 60% of livestock in Kenya is kept by pastoralists in the arid and semi-arid lands (which constitute about 80% of Kenya's landmass) providing employment to about 90% of the population in those areas and contributing nearly 95% of their income (KIPPRA, 2009). However, more than 50% of pastoralists in Kenya live below the poverty line, that is, they survive on less than USD$1 per day (Thornton et al., 2007). As noted by Larsen et al. (2009), improving the efficiency and productivity of crop and livestock enterprises is important for enhancing economic growth and reducing poverty in agriculture-dependent developing countries such as Kenya.

Livestock contribute about 42% of agricultural output in Kenya; 35% of this is derived from beef cattle. Generally, beef production is considerably less than estimated consumption (FAO, 2005; MoA and KIPPRA, 2009). However, development of the livestock sub-sector is relatively neglected by policy. For instance, public funds allocated to livestock development are low (less than 10% of the annual national development expenditure) (Mugunieri et al., 2011; Otieno, 2008). Consequently, most farmers have limited access to better farm technologies, requisite skills and market services. Further, weak linkages between research-extension service providers and farmers are considered to contribute to low and/or inappropriate use of inputs by farmers. As a result, agricultural productivity and growth are relatively low; yet the agricultural sector is expected to play an important role as the engine of national economic development (Mugunieri and Omiti, 2007; Oluoch-Kosura, 2010).

Investigating the determinants of TE in beef cattle, production should provide analytical insights to enhance beef supply in the domestic market, and possibly enable Kenya to export, for example, to the European Union (EU) where it has preferential access. Moreover, as land becomes scarce and enterprise competitiveness change in developing countries such as Kenya, it is important to streamline development policy to prioritize resource allocation on cattle production systems that offer commensurate returns to investments. The analysis of determinants of TE would provide insights to address this information need. For example, in Uganda, similar analytical insights have been used to advocate for policies that encourage sedentarization of nomads by promoting investment on requisite inputs such as water and pasture development, and provision of basic infrastructure (Wurzinger et al., 2009).

In this study, we use the stochastic metafrontier-Tobit (henceforth referred to as SM-Tobit) method. This involves first, estimating TE through a metafrontier approach (O'Donnell et al., 2008), and subsequently using a Tobit model (Tobin, 1958) to investigate determinants of the TE. The SM-Tobit method is preferred to a one-step stochastic frontier approach (SFA) (Aigner et al., 1977; Meeusen and van den Broeck, 1977) because although a one-step SFA reduces bias in estimation, the metafrontier framework improves analysis by accounting for technology gaps and allows comparison of TEs across heterogeneous groups (O'Donnell et al., 2008; Villano et al., 2010) such as production systems. For completeness of analysis of efficiency determinants, a one-step SFA (Battese and Coelli, 1995) is applied alongside the SM-tobit model. The use of ordinary least squares (OLS) regression to estimate determinants of TE (see for example, Dadzie and Dasmani, 2010) is considered unsuitable because it might lead to biased estimates, given that TE scores are bounded between 0 and 1. Further, use of SFA with dummies for study sites or production systems is not recommended in capturing technology differences. Specifically, such dummy variables were found to be highly correlated with farm characteristics and did not improve the model fit; their inclusion led to statistical insignificance of most parameters.

Generally, the Tobit model can be applied to investigate determinants of efficiency in any of the following two formats:

(a) Stochastic frontier-Tobit, for example in Nyagaka et al. (2010). However, this approach does not account for technology differences and cannot accommodate many explanatory variables, without loss of parsimony;
(b) SM-Tobit, which allows hypothesis tests on the nature of inefficiency, and accounts for technology differences.

In addition, this approach is suitable for modelling a continuous censored dependent variable (such as TE, which is bounded between 0 and 1) (Bravo-Ureta and Pinheiro, 1997; Wooldridge, 2002). However, there is a dearth of empirical literature on application of the SM-Tobit method, Chen and Song (2008) being an exception. The present study contributes to the literature by applying this approach to investigate TE and its determinants in beef cattle production in Kenya.

ANALYTICAL FRAMEWORK

Estimation of the SM-Tobit involves three stages. First, the SFA (Aigner et al., 1977; Meeusen and van den Broeck, 1977) is used to investigate TEs across the production systems. In the second stage, a metafrontier (O'Donnell et al., 2008) is estimated to adjust the TE scores from SFA, taking into account any technology differences. Finally, a Tobit model is applied to assess variations in the TE scores obtained from the metafrontier estimation. Assume there are *k* groups or production systems in the cattle industry. The stochastic production frontier is specified as:

$$Q_n = f(X, \beta) + \varepsilon^* \tag{1}$$

where Q_n is the output of the n^{th} farm; X is the vector of inputs used by the n^{th} farm; β is a vector of production parameters to be estimated; ε^* is the composite disturbance term given by:

$$\varepsilon^* = v - u \quad (2)$$

where v represents statistical noise assumed to be independently and identically distributed (IID) as a normal random variable with zero mean and variance given by σ_v^2, that is, $v\sim N(0,\sigma_v^2)$ (Aigner et al., 1977). Farm-specific technical inefficiency in production is typically assumed to be captured by u, which is a non-negative random variable.

The u is assumed to be IID half-normal, that is, $u\sim |N(0,\sigma_u^2)|$. Although u can also assume exponential or other distributions, the half-normal distribution is preferred for parsimony because it entails less computational complexity (Coelli et al., 2005). The u is independent of the v-term and it measures the TE relative to the stochastic frontier. When data are in logarithm terms, u is a measure of the percentage by which a particular observation or farm fails to achieve the frontier, ideal production rate (Greene, 2003). Following Battese and Corra (1977), the variation of output from the frontier due to technical inefficiency is defined by a parameter (γ) given by:

$$\gamma = \frac{\sigma_u^2}{\sigma^2} \text{ such that } 0 \le \gamma \le 1 \quad (3)$$

where $\sigma^2 = \sigma_u^2+\sigma_v^2$.

Taking account of various determinants of TE, we can specify the stochastic frontier production function in (1), for each production system as (O'Donnell et al., 2008):

$$Q_{nk} = f(X_{nk}, \beta_k)\exp(v_{nk} - Z_{nk}\delta) \quad (4)$$

where Q_{nk} denotes the output for the n^{th} farm in the k^{th} production system; $f(.)$ is the functional form used, for example the Cobb-Douglas or translog specification; β_k is a vector of input parameters to be estimated for the k^{th} production system; Z is a vector of factors that influence the technical inefficiency of farms, while δ is a vector of inefficiency parameters to be estimated.

The TE can be measured as the ratio of actual output observed (Equation 4) to that expected maximum level from the use of available inputs (assuming any deviation is pure noise) (Boshrabadi et al., 2008):

$$TE_{nk} = \frac{f(X_{nk}, \beta_k)\exp(v_{nk} - Z_{nk}\delta)}{f(X_{nk}, \beta_k)\exp(v_{nk})} = -Z_{nk}\delta \quad (5)$$

Each frontier measures individual farmers' performance relative to the dominant technology in a particular production system. However, the model in (5) is inappropriate for comparing the performance of farms across different groups of farms that are not identical technology-wise (O'Donnell et al., 2008). In order to capture variations in technology within and between production systems, Battese et al. (2004) suggest the use of a meta-frontier production function to measure efficiency and technology gaps of firms producing in different technological environments. The meta-frontier is considered as a smooth function that envelops the explained (deterministic) components of the group stochastic frontier functions (e.g., for different production systems). It explains deviations between observed outputs and the maximum possible explained output levels in the group frontiers. The meta-frontier equation can be expressed as:

$$Q^* = f(X_n, \beta^*) \quad n = 1,2,\ldots N \quad (6)$$

where $f(.)$ is a specified functional form; Q^* is the meta-frontier output; and β^* denotes the vector of meta-frontier parameters satisfying the constraints:

$$f(X_n, \beta^*) \ge f(X_n, \beta_k), \text{ for all } k = 1,2,\ldots K \quad (7)$$

In order to satisfy the condition in (7), an optimization problem is solved where the sum of absolute deviations (or squared deviations) of the meta-frontier values from the values of the group frontiers are minimized:

$$\min \sum_{n=1}^{N} |\ln f(X_n, \beta^*) - \ln f(X_n, \beta_k)| \quad (8)$$
$$s.t. \ln f(X_n, \beta^*) \ge \ln f(X_n, \beta_k)$$

In terms of the meta-frontier, the observed output for the n^{th} farm in the k^{th} production system (measured by the stochastic frontier in (4)) can be expressed as:

$$Q^*_{nk} = \exp(-Z_{nk}\delta) * \frac{f(X_n, \beta_k)}{f(X_n, \beta^*)} * f(X_n, \beta^*)\exp(v_{nk}) \quad (9)$$

where (recall from (5) that, $-Z_{nk}\delta = TE_{nk}$) the middle term in Equation (9) represents the technology gap ratio (TGR):

$$TGR_n = \frac{f(X_n, \beta_k)}{f(X_n, \beta^*)} \quad (10)$$

The TGR measures the ratio of the output for the frontier production function for the k^{th} group or production system relative to the potential output defined by the metafrontier, given the observed inputs (Battese et al., 2004). Values of TGR closer to 1 imply that a farm in a given production system is producing nearer to the maximum potential output given the technology available for the whole industry. The TGR is subsequently referred to as meta-technology ratio (MTR) to account for the wider environment in which production takes place and other factors that might influence the potential productivity gains from a given technology. The TE of the n^{th} farmer relative to the meta-frontier (TE^*_n) is the ratio of the observed output for the n^{th} farm relative to the meta-frontier output:

$$TE_n^* = \frac{Q_{nk}}{f(X_n, \beta^*)\exp(v_{nk})} \quad (11)$$

Following (5), (9), and (10), TE^*_n can be expressed as the product of the TE relative to the stochastic frontier of a given production system and the MTR:

$$TE_n^* = TE_{nk}.MTR_n \quad (12)$$

After estimating the metafrontier TE scores, determinants of efficiency are investigated using a two-limit Tobit model, given that efficiency scores are bounded between 0 and 1 (Bravo-Ureta and Pinheiro, 1997; Wooldridge, 2002). The two-limit Tobit model is specified as:

$$\theta^{k*} = Z\delta + e$$
$$\theta^{k*} = \{(0 \text{ if } \theta^{k*} < 0); (\theta^{k*} if\, 0 < \theta^{k*} < 1); (1 \text{ if } \theta^{k*} > 1)\} \quad (13)$$

where θ^{k*} and θ^{k} are the latent and observed values of the metafrontier TE scores, respectively; Z denotes the vector of socio-demographic and other independent variables assumed to influence efficiency; and *e* is the random term.

Data and estimation

Sampling and data collection

The study was conducted in four districts (Kajiado, Kilifi, Makueni and Taita Taveta), which are representative of the main beef cattle production systems in Kenya: nomadic pastoralism, agro-pastoralism and ranches. Nomads are usually found in climatically marginalised environments; they are less sedentary and migrate seasonally with cattle and other livestock in search of pasture and water (Fratkin, 2001). They are less commercialised, but derive a relatively large share of their livelihood from cattle and other livestock. Generally, nomads are considered to maintain cattle principally as a capital and cultural asset, and sell only when absolutely necessary (Thornton et al., 2007). In contrast, the agro-pastoralists are sedentary; they keep cattle and other livestock, besides cultivating various crops, and are fairly commercialised. Finally, ranches are purely commercial livestock enterprises, but may also grow a few crops for use as on-farm fodder or for sale. The ranches mainly use controlled grazing on their private land, and purchased supplementary feeds. However, both the nomads and agro-pastoralists generally depend on open grazing, with limited use of purchased feeds (except during dry periods).

The areas sampled in the study are contiguous, hence logistically more accessible. A multi-stage cluster (area) sampling approach (Horppila and Peltonen, 1992) was used. Within the four districts, smaller administrative units (divisions) were randomly selected from lists of all divisions in these districts, taking into account the general distribution of cattle in the study area. Subsequent stages involved a random selection of a sample of locations, from which a number of smaller units (sub-locations) were selected. The primary sampling units for the survey were 40 sub-locations. Systematic random sampling was used to select individual respondents for interview during the survey.

A structured questionnaire was applied for data collection. The main variables captured in the data included: relative importance of cattle and other enterprises to household income; cattle inventory in the past twelve months; production inputs such as feeds, labour, veterinary supplies and advisory services, and fixed inputs; cattle breeding method; access to extension and market services; and household socio-demographic characteristics. With the assistance of local experienced interviewers who were adequately trained prior to the surveys, the questionnaire was pre-tested, edited and then administered through face-to-face interviews of farmers between July and December 2009. A random route procedure (for example first left, next right, and so on) was followed by the interviewers to select every fifth or tenth farmer, in sparsely or densely populated sub-locations, respectively (Lohr, 2007). In total, 313 farmers including 66 ranchers, 110 nomads and 137 agro-pastoralists were interviewed.

Some of the farm characteristics from the survey are shown in Table 1. On average, ranchers have larger herds and farms than the nomads and agro-pastoralists. Both nomads and ranchers tend to keep indigenous (local) cattle breeds such as the east African *Zebu* and *Boran*, which are relatively more adapted to dry and hot areas (e.g., Kajiado and Kilifi) where most farmers in both systems live. In contrast, the agro-pastoralists have a majority of crossbreeds and pure exotic breeds. The ranchers have significantly higher average monthly household incomes than nomads and agro-pastoralists. In common with the nomads, they depend more heavily on cattle as the main source of income. Only a quarter of farmers in the three systems depend on off-farm income. This is consistent with the observation that a few pastoralists near Peri-urban areas are gradually diversifying their activities into wage labour or small businesses, due to rapid population growth and the concomitant pressure on resources, such as water and grazing land (Thornton et al., 2007). Further, one-third of the farmers (although a smaller proportion of ranchers) depend on both crops and other livestock such as sheep and goats (shoats), besides cattle enterprises.

The ranchers use most of their land to grow fodder. Most agro-pastoralists and nomads have individual land ownership with relatively secure tenure (possess either a title deed or allotment letter). About 40% of ranchers however, have group-owned land without secure tenure. Most of these farms were previously large-scale government or private landholdings that have only been sub-divided recently, either to address group ranch management problems or to provide long-term access to younger members (Thornton et al., 2007). However, as noted by Lengoiboni et al. (2010), the existing land laws and property rights in land administration in Kenya tend to focus on ownership and control of land, but are inadequate in serving pastoralists' temporal and spatial access rights. Generally, improved land tenure and access rights (e.g., through land registration) are considered as important prerequisites for long-term and ecologically beneficial land-related investments, technology adoption and productivity enhancement (Deininger, 2010; Kabubo-Mariara et al., 2010; Oluoch-Kosura, 2010).

Over 60% of all farmers, including more than three-quarters of the nomads are found in rural areas. More than half of farmers in all the production types are male, with ranchers having less than a quarter of females. There is no significant difference in the average age of agro-pastoralists and ranchers, but generally farmers in both categories are slightly older than the nomads. Across the three production systems, the level of formal education (secondary and above) is consistently lower than 40%.

Currently, ranchers benefit from relatively better access to livestock extension and veterinary advisory services, and most of them have farm managers. A higher proportion of agro-pastoralists use controlled cattle breeding. This is consistent with the observation that the more commercially-oriented farmers (that is, ranchers and agro-pastoralists) prefer cattle breeding strategies that target market and/or profitability requirements, e.g., faster growth and higher gains in live weight, while the relatively less-commercialised nomads mainly focus on cattle survival traits such as drought resistance, hardiness and disease tolerance (Gamba, 2006). Generally, more than half of farmers sell cattle to abattoirs, e.g., the Kenya Meat Commission (KMC), while the rest sell to other outlets such as open-air markets. Only one third of farmers (mostly ranchers) have access to prior market information and sell on contract. As noted by Omiti et al. (2009) and Shilpi and Umali-Deininger (2008), improving market infrastructure (e.g., provision of appropriate market information and contract opportunities) and enabling farmers to access the markets are important for enhanced commercialisation, and would possibly improve their incomes and livelihoods.

Empirical estimation

The main production variables for the beef cattle enterprise are summarised in Table 2. On average, ranchers use more inputs and produce the highest output. Nomads and agro-pastoralists use significantly lower amount of feeds and invest less in professional veterinary services. Farmers (especially the nomads) in remote areas of Kenya with limited access to professional veterinary services prefer community-based and /or self-administered herbal animal health services (Irungu et al., 2006). The agro-pastoralists have the highest unpaid labour component, perhaps to reduce costs due to greater enterprise diversification compared to the other farm types. Consistent with their less-sedentary nature, the nomads use the least amount of on-farm feeds (which might be from

Table 1. Sample characteristics from the survey, 2008 to 2009.

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Average cattle herd size	53.1[b]	11.4[c]	150.9[a]	55.5
Main cattle breed is indigenous (% of farmers)	68.2[a]	27.0[c]	54.5[b]	47.3
Monthly income above Kshs 20,000 (% of farmers)*	22.7[b]	15.3[b]	84.8[a]	32.6
Percentage of farmers who derive more than half of income from cattle (specialisation)**	78.2[b]	36.5[c]	93.9[a]	63.3
Dependence on both crops and other livestock (% of farmers)	31.8[a]	38.7[a]	7.6[b]	29.7
Dependence on off-farm income (% of farmers)	25.5[a]	24.8[a]	24.2[a]	24.9
Average farm size (acres)	84.1[b]	9.5[b]	426.5[a]	123.6
Land ownership with title deed/allotment letter (% of farmers)	78.2[a]	77.4[a]	54.5[b]	72.8
Individual land ownership and not communal (% of farmers)	96.4[a]	96.4[a]	65.2[b]	89.8
Rural location (% of farmers)	83.6[a]	65.7[b]	72.7[b]	73.5
Gender (% of male farmers)	66.4[b]	67.2[b]	87.9[a]	71.2
Average age of respondent (years)	38.6[b]	42.4[a]	42.1[a]	41.0
Secondary education and above (% of farmers)	30.0[a]	38.7[a]	34.8[a]	34.8
Access to livestock extension services in the past year (% of farmers)	49.1[b]	35.8[c]	77.3[a]	49.2
Access to veterinary advisory services in the past year (% of farmers)	50.0[b]	51.8[b]	87.9[a]	58.8
Percentage of farms with manager	8.2[b]	7.3[b]	75.8[a]	22.0
Use of controlled cattle breeding method (% of farmers)	58.2[b]	79.6[a]	68.2[b]	69.6
Main market is abattoir e.g., KMC (% of farmers)	49.1[c]	64.2[b]	77.3[a]	61.7
Access to prior market information in the past year (% of farmers)	26.4[b]	19.7[b]	68.2[a]	32.3
Sale of cattle on contract (% of farmers)	16.4[b]	24.8[b]	53.0[a]	27.8
Experience in cattle production (years)	15.5[a]	13.2[a]	13.7[a]	14.1

[a,b,c] differences in the subscripts denote significant differences (10% level or better) across the production systems. * 75 Kenyan shillings (Kshs) were equivalent to USD$1 at the time of the survey. ** Other studies e.g., Hadley (2006) also defined specialisation as the proportion of household income derived from a particular enterprise. Further, based on the distribution of income in the present study, the 50% criterion is used in order to maintain a reasonable sample in each category.

naturally-growing pasture in their temporary abodes or possibly donations from sedentary farmers; there is no evidence to indicate that nomads invest in fodder cultivation). Generally, both nomads and agro-pastoralists use poor livestock feeding regimes (Oluoch-Kosura, 2010); this might entail infrequent feeding schedules and inadequate and/or low quality feeds. However, nomads have higher depreciation costs than agro-pastoralists, because almost all of them possess portable cattle equipment such as dip sprayer, chaff cutter, dehorning and castration equipment (Table 2).

In order to ensure consistent estimates of inefficiency effects in the SFA, the one-stage model proposed by Battese and Coelli (1995) was preferred over the alternative two-stage analytical process. A likelihood ratio (LR) test showed that the Cobb-Douglas functional form provided a better fit to the pooled and individual-group survey data than a translog model. The LR test failed to reject the null hypothesis that Cobb-Douglas model was a better specification of sample data, with for example LR statistic of 3.58 compared to the chi-square critical value of 18.31 at 5% and 10 degrees of freedom in the case of the pooled sample. All parameters in the stochastic frontier and model for technical inefficiency effects were simultaneously estimated in one equation as:

$$\ln Q_{n(k)} = \beta_{0(k)} + \sum_{i=1}^{4} \beta_{i(k)} \ln X_{ni(k)} - Z_n \delta_{(k)} + v_{n(k)} \quad (14)$$

where $Q_{n(k)}$ is the annual value of beef cattle output (measured following the approach in Hadley, 2006, assuming one price in each site); X_{ni} represents a vector of inputs where X_{n1} is beef herd size, X_{n2} denotes total feed equivalents, and X_{n3} is the cost of veterinary services, while X_{n4} is a *Divisia* index calculated as (Boshrabadi et al., 2008):

Table 2. Average annual output and inputs, 2008 to 2009.

Variable	Nomads (n = 110)	Agro-pastoralists (n = 137)	Ranchers (n = 66)	Pooled sample (n = 313)
Value of beef cattle output (Kshs)	135,961[b]	37,807[c]	579,155[a]	186,452
Beef cattle equivalents (herd size)	36[b]	8[c]	112[a]	40
Depreciation costs (Kshs)	7,278[b]	2,535[c]	228,042[a]	51,753
Veterinary costs (Kshs)	17,256[b]	14,911[b]	145,036[a]	43,174
Paid labour costs (Kshs)	33,547[b]	10,648[c]	128,512[a]	43,549
Opportunity cost of unpaid labour (Kshs)	37,219[b]	47,752[a]	35,286[b]	41,422
Purchased feed equivalents (Kg)	5,848[b]	3,331[c]	14,162[a]	6,500
On-farm feed equivalents (Kg)	219[c]	4,005[b]	18,442[a]	5,718
Cost of other inputs, e.g., market services, branding etc. (Kshs)	17,943[b]	5,339[c]	189,863[a]	48,678

[a,b,c] differences in the superscripts denote significant differences (at 10% level or better) across the production systems. Total labour costs and feed equivalents comprise both paid and unpaid labour, and purchased and on-farm feeds, respectively.

$$X_{n4(k)} = \prod_{i=1}^{3} C_{ni(k)}^{\alpha_{ni}} \tag{15}$$

Where $\alpha_{ni(k)}$ represents the share of the i^{th} input in the total cost for the n^{th} farm in the k^{th} production system; $C_{n1(k)}$ = depreciation, insurance and taxes on farm buildings, machinery and equipment (Kshs); $C_{n2(k)}$ = total cost of labour (Kshs); $C_{n3(k)}$ = other costs, e.g. fuel, electricity, market services, hire/maintenance of machinery, purchase of ropes, branding etc. (Kshs).

Inputs were measured as follows. The beef cattle herd size was computed as the average number of cattle kept in the past twelve months, adjusted with the relevant conversion factors. Following insights from focused group discussions with key informants in the livestock sector in Kenya, the conversion factors were calculated as the ratio of average slaughter weight of different cattle types to the average slaughter weight of a mature beef bull. The average slaughter weight of mature bull, considered to be suitable for beef in Kenya, is 159 kg (FAO, 2005). The estimated conversion factors were: 0.2, 0.6, 0.75, 0.8 and 1, for calves, heifers, cows, steers and bulls, respectively.

In order to capture the approximate share of feeds from different sources in each production system, the quantities of purchased and non-purchased (or on-farm) feeds were first adjusted with the average annual number of dry and wet months, respectively, in each district. Assuming one price in a given locality (Chavas and Aliber, 1993), average feed prices were computed using prices from district annual reports and recent surveys (Lukuyu et al., 2009), after validation with research staff at the Kenya Agricultural Research Institute (KARI). Both purchased and non-purchased feeds were then converted to improved feed equivalents by multiplying the respective feed quantities by the ratio of their prices (or opportunity costs) to the average per unit price of improved fodder. Depreciation costs on fixed inputs were based on the straight line method, assuming a 10% salvage value. The depreciable value of an asset was based on the proportion of time that it was used in the cattle enterprise. Labour costs comprise both paid and unpaid labour; the latter valued using the average minimum farm wage in a particular district. The labour costs were adjusted with the share of cattle income in household income. Similar adjustments were applied to other incidental variable costs, such as fuel and electricity bills.

Intuitively, a negative sign of an element of the δ vector in Equation (14) implies that the variable has a positive influence on TE or decreases inefficiency (Brummer and Loy, 2000). The log likelihood for the half-normal model can be expressed following Greene (2003). The parameters of the stochastic frontiers were obtained by maximising the likelihood function using FRONTIER version 4.1c software (Coelli, 1996). The metafrontier in (5) was estimated through linear programming (LP) and standard errors obtained using the bootstrapping technique in SHAZAM version 10 software (Whistler et al., 2007). Finally, the Tobit model (13) was estimated using LIMDEP version 9.0/NLOGIT version 4.0 software (Greene, 2007), to investigate determinants of TE. The log-likelihood function for the two-limit Tobit model is expressed following Wooldridge (2002).

RESULTS AND DISCUSSION

The results reported in Table 3 show that relative to the metafrontier, nomads have a mean TE of 0.65, agro-pastoralists a mean of 0.70 and ranchers a mean of 0.76. The average pooled sample TE with respect to the metafrontier is 0.69, implying that there is scope to improve beef production in Kenya by up to 31% of the total potential (Table 3). The mean meta-technology ratio (MTR) in the pooled sample is 0.93, implying that, on average, beef farmers in Kenya produce 93% of the maximum potential output achievable from the available technology.

In addition, the study showed that 98% of farmers across the three production systems have MTR estimates below 1, indicating that they use the available technology (e.g., crossbreed cattle) sub-optimally. Perhaps this can be explained by the view of Diagne (2010) that low rates of adoption or poor use of agricultural technologies in sub-Saharan Africa is largely due to lack of awareness on the technologies and/or how to use them. The average MTR is highest in ranches (0.96) and lowest in the agro-pastoralist system (0.91). This is consistent with the differences in relative levels of investments in the cattle enterprise by farmers in the three production systems

Table 3. Technical efficiency and meta-technology ratios.

Model		Nomads	Agro-pastoralists	Ranchers	Total
TE w.r.t. the pooled frontier*					
	Mean	0.711[b]	0.749[a]	0.774[a]	0.741
	Min	0.328	0.275	0.442	0.275
	Max	0.972	0.945	0.954	0.972
	SD	0.141	0.133	0.121	0.135
TE w.r.t. production system frontiers*					
	Mean	0.681[b]	0.767[a]	0.792[a]	0.738
	Min	0.302	0.313	0.499	0.302
	Max	0.998	0.936	0.938	0.998
	SD	0.172	0.119	0.101	0.143
TE w.r.t. the metafrontier					
	Mean	0.647[c]	0.696[b]	0.763[a]	0.693
	Min	0.278	0.267	0.481	0.267
	Max	0.943	0.909	0.944	0.944
	SD	0.162	0.112	0.099	0.136
Meta-technology ratio					
	Mean	0.942[b]	0.907[c]	0.963[a]	0.931
	Min	0.905	0.806	0.892	0.806
	Max	1.000	1.000	1.000	1.000
	SD	0.020	0.044	0.025	0.040

Notes: * these TE scores are only shown for completeness of analysis. However, comparisons are based on metafrontier and meta-technology ratios due to differences in technology across the production systems. [a,b,c] Differences in the superscripts denote significant differences (at 10% level or better) across the production systems.

(for instance, see higher depreciation costs for ranchers in Table 2). Further, that the MTR is higher for nomads than for agro-pastoralists can perhaps be explained by the notion of 'catching-up or convergence to best practice' (Rao and Coelli, 1998). This stipulates that, on average, farmers who conventionally operate below the technology frontier might be expected to adopt technologies at a relatively faster rate than those who produce near the frontier.

Ranchers and nomads have relatively low variation in MTRs (SD is 0.020 and 0.025), perhaps because both groups keep indigenous breeds or their crosses, while the agro-pastoralists have more crossbreeds of indigenous and exotic cattle. Compared to the exotic breeds, indigenous breeds generally adapt well to drier conditions where most beef cattle are reared in Kenya. The maximum estimated MTR is 1 in all three production systems, which means that the group frontiers are tangent to the metafrontier (Battese et al., 2004); it was found that 2% of farmers in the sample (at least one farm from each production system) produce on the metafrontier. This suggests that in order to achieve further productivity gains (for the small proportion of technology-optimal farmers) it is important to provide a relatively better technology (cattle breed). When MTRs are higher than meta-technical efficiency scores, it implies that individuals are better at using available technologies, but their efficiency measures remain relatively low due to other non-technology factors.

Besides estimating TE scores, another key objective of TE analysis is to explain possible sources of inefficiency, commonly referred to in the literature as inefficiency effects (Coelli et al., 2005). In this study, possible determinants of TE were investigated by inclusion of various socio-economic and technology-related variables in the estimation. The selection of variables for the inefficiency model started with a review of literature on relevant policy variables followed by a test of multicollinearity through computation of variance inflation factors (VIF) for each of the descriptive variables (Table 1). This involved estimation of 'artificial' OLS regressions between each of the farm characteristics as the 'dependent' variable with the rest as independent variables:

VIF for each regression is calculated as:

$$VIF_i = \frac{1}{1 - R_i^2} \quad (16)$$

Table 4. Production function estimates and determinants of technical efficiency.

Variable	Pooled Stochastic frontier (n = 313)	Metafrontier-Tobit (n = 313)
Production input parameters		
Constant (β_0)	7.62***(0.146)	8.28***(0.0016)
Beef herd size (β_1)	0.89***(0.016)	0.90***(0.0001)
Improved feed equivalents (β_2)	0.04***(0.013)	0.03***(0.0001)
Veterinary cost (β_3)	0.08***(0.015)	0.06***(0.00004)
Divisia index for other costs (β_4)	0.02***(0.007)	0.02(0.0133)
Inefficiency effects		
Constant (δ_0)	-0.30(0.407)	0.62***(0.031)
Indigenous breed (δ_1)	-0.26(0.178)	0.01(0.016)
Controlled breeding method (δ_2)	-0.65***(0.256)	0.06***(0.018)
Access to market contract (δ_3)	-0.62***(0.240)	0.04**(0.017)
Farm size (δ_4)	0.0006**(0.0003)	-0.00002(0.00002)
Specialisation (δ_5)	0.84***(0.281)	-0.04**(0.016)
Peri-urban location (δ_6)	0.84***(0.284)	-0.01(0.017)
Presence of farm manager (δ_7)	-1.27**(0.527)	0.05**(0.022)
Age of farmer (δ_8)	-0.01*(0.007)	0.0007(0.001)
Off-farm income (δ_9)	-0.92***(0.367)	0.03*(0.017)
Beef herd size (δ_{10})	-	0.003***(0.0001)
Income-education (δ_{11})	-	-0.04**(0.018)
σ^2	0.30***(0.093)	-
γ	0.86***(0.050)	-
Log likelihood function	-32.36	206.06

Notes: statistical significance levels: ***1%; **5%; *10%. Corresponding standard errors are shown in parentheses. The log likelihood of a Tobit model with continuous dependent variable (censored between 0 and 1, in this case) can be positive or negative because it represents the log likelihood of a density or cumulative density function, unlike in discrete distributions where the log likelihood is of a probability and always negative or zero (Greene, 1990).

where R_i^2 is the R^2 of the artificial regression with the i^{th} independent variable as a 'dependent' variable.

Since all the independent variables exhibited $VIF_i<5$, it was concluded that there was no multicollinearity and therefore all these variables were eligible for inclusion in the model estimation (Maddala, 2000). The next stage involved estimation of a pooled stochastic frontier where all the descriptive variables were included as possible determinants of inefficiency. From this, variables that were insignificant and did not improve the overall model fit were dropped. Subsequent re-estimations were undertaken to obtain better results in terms of significance.

Results from the pooled stochastic frontier and metafrontier are shown in Table 4. Positive input parameters imply that increased usage of these inputs would yield more output as postulated by theory, assuming that producers are rational (Coelli et al., 2005). The metafrontier results show that an increase in the use of any of the three inputs (beef herd size, improved feed equivalents, veterinary expenditure) would lead to significant improvement in output. The sum of elasticities generally equals one, indicating that on average the constant returns to scale property of the Cobb-Douglas specification fits the data. The sum of input elasticities were slightly below one, for nomads (0.98) and agro-pastoralists' frontiers (0.97), and marginally exceeded one (1.02) for ranchers. Necessary regularity conditions are fulfilled. All marginal physical products were found to be positive at the sample mean and for all observations (that is, there is monotonicity). Further, concavity test is fulfilled as the second order derivatives of production parameters were negative in all production systems. Perhaps, the only violation occurs for second derivative of herd size, which though negative is insignificant.

In a one-step stochastic frontier estimation, the parameter for inefficiency level usually enters the model as the dependent variable in the inefficiency effects component of the model; therefore a negative sign of a variable in the *Z-vector* implies that the corresponding variable would reduce inefficiency (or increase efficiency). On the contrary, a positive *Z-variable* is interpreted as potentially having a negative influence on efficiency (Brummer and Loy, 2000; Coelli et al., 2005). In the two-stage Tobit estimation however, conventional interpretation of regression parameters is applicable because the TE measure obtained from the optimisation process in the metafrontier estimation is used as the dependent variable in the subsequent Tobit model (Chen and Song, 2008). Thus, positive signs of variables in the metafrontier-Tobit model imply that such variables would increase efficiency.

The significance of σ^2 confirms that the frontier model is stochastic (rather than deterministic). Moreover, the value of γ implies that 86% of the discrepancies between the observed value of beef output and the frontier output can be attributed to failures within the farmers' control. Results on the estimated inefficiency effects from both the stochastic frontier and the metafrontier-Tobit models show that use of controlled breeding method, access to market contract, presence of farm manager and off-farm income would significantly improve efficiency, while specialisation (higher dependence on beef cattle for income) would reduce efficiency (see lower part of Table 4). Farm size, farmer's age and Peri-urban location were found to be significant in the pooled stochastic frontier, but not in the metafrontier-Tobit model. The finding on farm size contradicts that of Sharma et al. (1999) who showed that large farms in the relatively industrialized state Hawaii (compared to less industrialized Kenya) were more efficient than small ones, due to relatively lower labour use and feed cost, per unit of output, in the large farms.

Perhaps the unexpected influence of farm size on efficiency might be attributed to lack of long-term investments on land by most Kenyan pastoralists. Moreover, although some farmers have relatively secure land tenure, as noted earlier (Table 1), Fenske (2011) observed that social and cultural constraints often prevent Kenyan pastoralists from using land as collateral in order to acquire other requisite farm inputs; hence most of the land is fallow. As a consequence, the fallow land acts as an indirect cost, for example in the form of high opportunity cost of feeds and labour to oversee grazing elsewhere. Results show that older farmers are likely to be more efficient, perhaps because they are likely to have more experience (Rakipova et al., 2003). Further, Peri-urban location was shown to contribute significantly to inefficiency. This does not support the observation of Stifel and Minten (2008), that remoteness increases inefficiency in rice production in Madagascar through limited access to technology and infrastructure. In the present study, however, it is worthwhile to note that main grazing areas and water sources for most cattle farmers are located away from the urban centres.

Given the statistical differences in the production systems, the pooled stochastic frontier might be considered inappropriate for policy application and are only presented for completeness of the analysis (Battese et al., 2004). Hence, the subsequent discussion focuses on variables that are significant in the metafrontier-Tobit estimation. Controlled cattle breeding might be expected to increase efficiency by improving genetic quality, enhancing adaptation of cattle to environmental conditions and ensuring optimal stocking (Wollny, 2003). Further, Kavoi et al. (2010) note that, given proper management, planned crossbreeding of exotic and indigenous cattle can improve potential for higher output in relatively dry areas of Kenya. Results show that use of market contracts also significantly improves TE. This is consistent with the view of MacDonald et al. (2004) that sales contracts are important in enabling farmers to obtain steady and increased income through an assured market, and reduced input and output price risks. Well-functioning contractual arrangements might also provide improved access to better inputs and more efficient production methods (Oluoch-Kosura, 2010). In addition, provision of better contracts and improving other market infrastructure (e.g., information services) are deemed important for increased agricultural commercialisation and possibly better incomes and livelihoods to farmers (Omiti et al., 2009; Shilpi and Umali-Deininger, 2008).

Moreover, availability of a manager with appropriate managerial capacity is considered to be a useful asset in the organisation of inputs and overall decision-making in the farm (Nuthall, 2009). Therefore, availability of a professional farm manager might be expected, as shown in this study, to enhance co-ordination of farm operations and ensure better utilisation of resources. On the contrary, lack of proper management might lead to accumulation of less productive resources and their less intensive use, consequently resulting in lower efficiency (Meon and Weill, 2005).

The significance of off-farm income suggests that, as noted by Alene et al. (2008), there might be considerable re-investment of such earnings in various farm operations by some cattle keepers in Kenya. The finding on specialisation seems to contradict the suggestion by Rakipova et al. (2003) that farmers who depend heavily on cattle production for their livelihoods might be more efficient. However, this result supports Featherstone et al. (1997), Hadley (2006), Hallam and Machado (1996) and Iraizoz et al. (2005), that specialised farmers are relatively less efficient due to lack of flexibility to adapt to changes in market and policy environments.

Compared to the stochastic frontier, the metafrontier-Tobit model offers an improvement in the ability to explain TE; two additional variables, that is, beef herd size and an interaction term (for education and income), are found to be significant. These two variables were dropped from the pooled stochastic frontier results in Table 4 because their inclusive led to wrong signs and statistical insignificance of other parameters due to correlation with input parameters in the one-step SFA estimation. The metafrontier-Tobit approach eliminates the correlation and yields more parsimonious results with these two variables included. Beef herd size is shown to have a positive effect on efficiency, which implies that economies of scale are important in improving efficiency (Featherstone et al., 1997). There is a general expectation in the literature that education of a household head or main decision maker in the farm should contribute to improved efficiency. More so, the returns to formal education are considered to be higher in modernised agricultural systems, where most operations are knowledge-based (Phillips, 1994).

In the present study, income and formal education did not individually improve the model fit, but inclusion of the interaction variable shows that farmers with formal education and higher income are relatively less efficient. Perhaps this suggests that such farmers (especially the agro-pastoralists) are likely to invest more in, and/or pay greater attention to, enterprises that are more profitable than beef cattle. Indeed, cross tabulations show that 52% of cattle farmers with formal education and higher income also keep shoats (sheep and goats). Shoats might be considered as substitutes to cattle; this suggests that some farmers could be shifting resources away from, and possibly lowering efficiency in, beef cattle enterprises. Generally, shoats are often regarded as an important alternative to cattle in pastoral areas, because they are more resilient to droughts, have faster reproduction rates (allowing quick herd replacement) and can be easily sold to reduce losses in severe droughts (Lebbie, 2004; Huho et al., 2011).

Moreover, weak linkage between formal training systems and local farmers' information needs is often considered to contribute to inappropriate and/or low use of inputs and technologies in sub-Saharan Africa (Diagne, 2010; Oluoch-Kosura, 2010); hence lower efficiency. Generally, this appears consistent with the 'traditional vs. modernised system' hypothesis suggested by Phillips (1994); inability to adapt formal skills to local conditions in traditional systems results in less than optimal returns from education. This is consistent with Allam et al. (2011) who also found a negative significant influence of formal education on TE due to the tendency by highly educated people to practice less professional farming because they consider agriculture to be relatively less rewarding than other economic sectors.

Conclusions

This study applied the stochastic metafrontier-Tobit model to investigate TE and factors that might influence efficiency in beef cattle production systems in Kenya. Results show that the majority of farmers use available technology sub-optimally and produce less than the potential output; average MTR is 0.93 and TE is 0.69. Further, it was found that controlled cattle breeding method, access to market contract, availability of a professional farm manager, off-farm income, herd size and farmers' age all contribute positively to efficiency. On the contrary, farm size, income and formal education did not have a favourable influence on efficiency. These findings may have important implications on policies aimed at improving beef production efficiency in Kenya.

It appears reasonable to provide relevant livestock extension and other support services that would facilitate better use of available technology by the majority of farmers who currently produce sub-optimally. Necessary interventions, for instance, would include improving farmers' access to appropriate knowledge on cattle feeding methods and disease monitoring. Moreover, provision of relatively better technology (e.g., locally adaptable and affordable cattle breeds and breeding programmes) would enable relatively efficient farmers to achieve further productivity gains.

In order to improve resilience to droughts and to enhance livelihood opportunities, farmers should be encouraged to keep optimal herds of cattle and shoats (sheep and goats), and promote synergies between both enterprises (e.g., through balanced re-investments), rather than shifting resources away from cattle enterprises. Further, it is necessary to improve farmers' access to requisite market services, including contract opportunities. In addition, it is important to provide appropriate training services that enhance farmers' management practices, and/or encourage them to employ skilled farm managers. Policies that promote diversification of enterprises, including creation of off-farm income opportunities would also contribute to improving efficiency among Kenyan beef farmers. Future research could offer more insights by investigating requisite institutional arrangements, market infrastructure, regulations and farm investment incentives that would promote better use of farm technology and efficient production in cattle enterprises.

Conflict of Interests

The authors have not declared any conflict of interests.

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