

*Full Length Research Paper*

# A stochastic frontier analysis on farm level technical efficiency in Zimbabwe: A case of Marirangwe smallholder dairy farmers

Stein Masunda\* and Amanda Rudo Chiweshe

Department of Agriculture Economics and Development, Midlands State University, Gweru, Zimbabwe.

Received 31 December, 2014; Accepted 12 May, 2015

**This study empirically investigates farm level technical efficiency of production and its associated determinants for Marirangwe smallholder dairy farmers, in Manyame district, Mashonaland east province in Zimbabwe. Using a stochastic production frontier model and a two step estimation approach, results for a sample of 27 smallholder farmers indicates that for the agricultural season 2013/2014, the average efficiency level was 54.9% particularly suggesting that dairy farmers are operating far below their production potentials. In particular, age, veterinary and extension, gender, farming experience and market performance were found to be significant factors affecting technical efficiency of the dairy farmers. The results of the study reveal that market performance, farming experience and gender positively affect the efficiency of dairy farmers. The results on gender implies that male farmers are more inefficient in dairy farming when compare to their female counterparts. On the other hand, age and veterinary and extension services was found to be positively associated technical inefficiency.**

**Key words:** Technical efficiency, dairy farmers, stochastic frontier analysis, marirangwe, smallholder, two step approach.

## INTRODUCTION

The agricultural sector is a key sector in Zimbabwe. The sector contributes on average 20% of gross domestic product (GDP) per year and has crucial backward and forward linkages as for instance, it acts as a major input provider for the manufacturing sector contributing about 60% of its raw materials and a market for the manufacturing sector. In terms of export earnings, the agricultural sector contributes more than 40% of total

export earnings with the key export earner being tobacco. Generally, the agriculture sector is a source of livelihood for about 70% of the total population.

Livestock production as a constituent sub sector of the agriculture sector has proven a crucial system in Zimbabwe as it provides food, traction and manure, and performs other social and economic functions such as customary rituals for the household participation in the

\*Corresponding author. E-mail: [smasundah@yahoo.ca](mailto:smasundah@yahoo.ca)

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

production systems albeit an increase in revenue leading to an increase in the general standard of living of the rural population. Livestock production in Zimbabwe is undertaken at both large scale and smallholder level. Smallholder dairy production, is encouraged since it helps communal farmers to spread risk by diversifying (Government of Zimbabwe, 2010).

Smallholder dairy farming was supported and promoted by the government with the goal of reducing income disparities and particularly addressing problems facing the smallholder dairy farmers. Thus, the Zimbabwean Government under the Ministry of Agriculture (MoA) introduced a program aimed at influencing the participation smallholder dairy farmers through the Dairy Marketing Board (DMB) to encourage smallholder farmers to take part in milk production. The board created a program known as the Peasant Sector Development Program, which later became the Dairy Development Program (DDP) with the help of NORAD, DANIDA, Africa Now and Heifer International. The DDP projects which was managed by Agricultural Development Authority (ADA) focused on commercial farmers with the aim of improving the technology base used in dairy production. The key purpose of the program was to improve milk production and marketing strategies in the sector thus the participation of smallholder farmers (Government of Zimbabwe; 2004).

Prior to independence, the smallholder dairy production was characterized by subsistence farmers. The composition of the breeds was dominated by indigenous breeds among small scale farmers. Since heralding of the program, 10 dairy projects across the country has been established through the use of financial, technical and informative aid (Government of Zimbabwe, 2004). Nonetheless, even with these diverse efforts, production level within the established projects still remains as low as 3% of total milk output (Hanyani et al., 1998; SNV, (2012).

Among the ten dairy projects are Marirangwe smallholder farmers who benefited under the Dairy development scheme. Marirangwe farming area falls in natural farming region 2b and ventures intensely in both crop production and dairy farming and is participating in the project of the DDP and thirty smallholder farmers are participating in dairy production. The area receives on average 700 mm of rainfall per year making it ideal for dairy farming. However, despite the concerted efforts to boost smallholder production by both the donor community and the government, growth of the smallholder farmers measured in terms of production is not motivating and as such this study seeks to establish the factors affecting their inefficiency levels. For instance, milk production is said to have plummeted from the high of 2.7 million litres in 1990 to 1.13 million litres in 2011. Despite having acquired and adopted the best technologies in milk production, MSDP has not significantly improved their output levels and as such a

study that tries to identify the key and significant factors for boosting milk production. Studies by Mupunga and Dube (undated), Ngongoni et al. (2006) and SNV (2012) focused on establishing the factors affecting the general operations and output of the smallholder farmers in Zimbabwe. No effort was directed towards determining the efficiency levels of the farmers under the different programs.

## **MARIRANGWE SMALLHOLDER DAIRY PROGRAMME: AN OVERVIEW**

Marirangwe smallholder dairy programme was established in 1983 following the initiatives of the government and the donor community. Like other dairy development programs, Marirangwe dairy project is governed by the Dairy act of 1977. It has a membership of 31 smallholder farmers and since the year 2010, the project has immensely benefitted from new market linkages with Keffalos, which is an established dairy processing entity and also form a heifer loan from the EU Stabex/NADF programme (SNV, 2012).

Marirangwe smallholder dairy project, (hereafter MSDP) is one of the best performing smallholder dairy schemes with a milk delivery to the milk collection centre of 900 L per day. However, it is argued that two members contribute more than 60% of this milk output (SNV, 2012). MSDP, flourished during its early years producing more than 250 000 L of milk per year. The harsh economic conditions of 2000 – 2009, which culminated into the hyperinflation of 2008, negatively affected the project. Production decreased to a low of 100000 litres of milk in 2003/2004 season.

Suggested as reasons for this noticeable decline were import pressures, low farm level productivity, poor commercialization, weak institutional support, low herd sizes and viability constraints. Ngongoni et al. (2006) also identified unavailability of costly protein rich concentration, feed sources and water sources as factors affecting milk production among smallholder dairy farmers.

## **MEASUREMENT OF TECHNICAL EFFICIENCY: THEORETICAL FRAMEWORK FOR STOCHASTIC FRONTIER MODEL**

The measurement of technical efficiency was provoked by Farrell (1957). Since then there has been a proliferation of refinements to the mechanics of measuring technical efficiency. Technical efficiency can be defined from the output oriented and input oriented approaches. In the input oriented approach, technical efficiency is measured as the ability of a decision making unit to increase its output levels given the same level of inputs. The input oriented approach asserts that a

decision making unit is technically efficient if it can produce the same level of output given a reduced input bundle (Coelli et al., 1998). Parametric and non-parametric methods have been developed to measure efficiency. The common used measures from the theoretical perspective are the data envelopment analysis (DEA) and the stochastic frontier analysis (SFA). The stochastic frontier approach uses econometric methods of estimation and the data envelopment analysis uses mathematical programming methods (Coelli, 1995).

**The stochastic frontier model**

The stochastic frontier model was suggested independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977). The model has been used by many different scholars involving cross-sectional data in the measure of efficiency with early empirical work employing a two stage formulation. Recent empirical work uses the one step approach to the estimation of efficiency. According to the stochastic frontier model, technical efficiency can be modelled as:

$$y = f(x; \beta)e^{\varepsilon_i} \quad \text{and} \quad \varepsilon = v_i - \mu_i \tag{1}$$

Where,  $y$  is maximum potential output on the frontier,  $x$  is the vector of the levels of inputs used,  $\beta$  are the unknown parameters and  $\varepsilon_i$  is the stochastic composed error. The two components of the composed error term are assumed to be independently and identically distributed. The component  $v$  is a symmetric normally distributed error term capturing output variation due to factors beyond the control of the farmer and  $\mu$  is a one sided error term capturing inefficiency of the decision making unit.

Technical efficiency is algebraically measured as follows:

$$TE = \exp(x_i\beta + v_i - \mu_i) \backslash \exp(x_i\beta + v_i) \tag{2}$$

$$TE = \exp(-\mu_i) \tag{3}$$

If  $\mu_i = 0$ , the farm is assumed to be efficient implying that the actual output is equal to the possible output. The farm will be lying on the production function hence technically efficient. The parametric model is estimated in terms of the variance parameters;

$$\delta^2 = \delta_v^2 + \delta_u^2 \tag{4}$$

and

$$\gamma = \frac{\delta_u^2}{\delta^2} \tag{5}$$

Where  $0 \leq \gamma \leq 1$  and is a variance measure fundamental in determining whether a stochastic frontier model is best over the traditional average production function. In the case of cross-sectional data, the technical inefficiency model can only be estimated if the inefficiency effects for  $\mu_i$ 's are stochastic. The maximum likelihood estimator approach which involves specification of the distribution of the error terms used in the model is surely the most common approach used in the estimation of stochastic frontiers (Battese and Tessema, 1997).

The stochastic frontier approach to econometric modelling of technical efficiency can be done in either the one step approach or the two step approach. The one step approach treats all variables as firm specific incorporating them into the maximum likelihood estimate. However, there are certain factors that are not firm specific which the firm cannot have due influence on. As such modelling these factors incorporating them into the maximum likelihood estimate might compromise the measure of technical efficiency. The two step approach which first estimates the production function and generating the levels of efficiency that are then regressed against another set of variables which are not firm specific is criticized on the potential of inducing a persistence bias that will be carried forward to the second stage thus affecting the estimates of efficiency (Wang and Schmidt, 2002). This study adopts the two step approach of measuring technical efficiency using the stochastic frontier modelling technique. The stochastic frontier modelling technique is adopted because it captures stochastic effects independent of the decision making unit.

**AN ECONOMETRIC STRATEGY OF ESTIMATING TECHNICAL EFFICIENCY**

The data used in this study was collected from 27 participating smallholder dairy farmers. The data analyses the production behaviour of the farmers for the season 2013/2014. MSDP has 31 smallholder farmers with 27 actively participating. Thus, all the participating smallholder dairy farmers were incorporated into this study. To measure efficiency for the farmers we adopt the Battese and Coelli (1995) technical inefficiency model using cross sectional data. The model is specified as follows:

$$y_i = \exp(x_i\beta + v_i - u_i) = \exp(x_i\beta + v_i) \exp(-u_i) \tag{6}$$

Where;  $y_i$  is the output for the farmer  $i$ ,  $x_i$  represents a  $(1 \times K)$  vector whose values are functions of inputs and other explanatory variables for the sample farm,  $\beta$  represents a  $(K \times 1)$  vector of parameters to be estimated,  $v_i$  represents independent and identically distributed random errors with a mean of zero and variance  $\delta^2$ ,  $u_i$  is assumed to be non-negative unobservable random variables associated with the technical inefficiency of production.

Since the approach adopted in this study is a two-step approach, a stochastic production function is estimated in a log linear form and this is given as follows:

$$\text{Log output}_i = \beta_0 + \beta_1 \text{Capital}_i + \beta_2 \text{labor}_i + (v_i - \mu_i) \quad (7)$$

Where  $\log \text{output}$  is the logarithm of output measured in liters and capital is proxied by herd size and labour is measured as the sum of family and hired labour during the 2012/2013 farming season. A priori,  $\beta_1 > 0, \beta_2 > 0$ .  $i$  represent the  $i^{\text{th}}$  dairy farmer,  $v_i$  is a stochastic error term and  $\mu_i$  is a one sided error term measuring inefficiency.

The residuals generated from equation two are then modelled as technical inefficiency in a model generally proposed as follows:

$$\mu_i = \delta_0 + \delta_1 Z_i \quad (8)$$

Where  $Z_i$  represents  $(1 \times M)$  vector of explanatory variables associated with the technical inefficiency effects in the sample farm.  $\delta$  is an  $(M \times 1)$  vector of unknown parameters to be estimated in the model.

Equation 8 estimating technical inefficiency in this particular case is estimated as follows:

$$\log \text{efficiency} = \alpha_0 + \alpha_1 \text{Age} + \alpha_2 \text{Gender} + \alpha_3 \text{Fexp} + \alpha_4 \text{Mperf} + \alpha_5 \text{Vetex} + w_i \quad (9)$$

$\log \text{efficiency}$  is the logarithm of technical inefficiency, age is measures as the number of years since birth of the responded, gender is a dummy variable for the sex of the responded and  $\text{Fexp}$  is farming experience measured as the number of years the responded has been involved in dairy farming,  $\text{Mperf}$  is market performance and measures the perception of the farmer on the performance of the market and  $\text{Vetex}$  is veterinary and extension services measuring the quality and availability of the extension services to the farmer.

## RESULTS AND DISCUSSION

### Definitions and summary statistics of farm and non-farm specific variables

A detailed summary of the output and input variables involved in the stochastic frontier production and inefficiency models for different farms in Marirangwe showing the sample means and standard deviations as well as the definitions of the variables used in the study are shown in [Table 1](#). The dependant variable for the stochastic production frontier model is the output which was measured in terms of milk units produced by each farmer in the 2012/2013 farming season. The independent socio-economic variables that were used as factors affecting the production of output and the levels of inefficiency are also summarized in [Table 1](#).

Approximately 87% of the farms are headed by males while the other 13% are headed by females. Age was captured grouped in ranges in which 1 represented the age group of less than 25 years, 2 represented the age group of 25 to 40 years and 3 represented the age group of 40 years and above. The mean age group was that of 25 to 40 years with a standard deviation of 0.61 implying that the majority of the farmers are in their middle ages.

Farming experience was measured in terms of the number of years the respondent have been engaged in agriculture. The overall mean for the farming experience of the respondents was at 15.23 years and this had a standard deviation of 0.43. This indicates that the majority of the farmers has vast knowledge in dairy farming. The herd size was captured as a measure of the number of cows the respondent have at the time of the data collection period. A mean of 9 was recorded on herd size with a standard deviation of 5.05. Labour was measured in terms of the number of hours used per week and the mean labour unit was 198.5 with a standard deviation of 320.25 and this is the variable with the greatest level of variability as compared to all the other variables. It means that farmers devote too much time looking after dairy cattle per week. Market performance had a mean of 0.67 and a standard deviation of 0.48, veterinary and extension services had a mean of 0.37 and a standard deviation of 0.49.

### Stochastic production frontier model estimation results

Maximum likelihood estimates of the Stochastic Frontier production function are given in [Table 2](#) and are obtained using Stata 11. The signs of the estimated parameters are as expected a priori except for labour which has a negative effect on output. Though the coefficient is negative and statistically significant its contribution to output of milk is quite negligible. In addition, another suspect is that the labour is uneducated in the field of dairy farming. With respect to herd size, the more cattle the farmer has the more output is likely to increase holding other things constant confirming the expected positive relationship between herd size and output.

Since assumptions are to be made on the distribution of the inefficiency term, the stochastic production frontier models as in many studies was estimated with an inefficiency term assumed to have a half normal distribution. Results of the model are presented in [Table 2](#). The likelihood ratio is 3.22 with a p-value of 0.036. The significance of the likelihood ratio test confirms the presence of the one sided error term in the composite error term. In that regards the diagnostic checks confirms the relevance of the stochastic parameter production function and the use of the maximum likelihood estimation as an estimation technique for both one sided error term distribution assumption. Simply put, these results indicates the presence of technical inefficiencies in production.

### Determinants of technical efficiency

In the determination of the factors affecting inefficiency, the predicted technical inefficiency terms was modeled

**Table 1.** Definitions and summary statistics.

Variable	Definition of variable	Mean	std. dev	Min	Max
Gender	dummy for the sex of respondent (0=female; 1= male)	0.87	0.35	0	1
Age	age in years (1= < 25; 2 =25 to 40; 3= >40)	2.33	0.61	1	3
farming experience	farming experience (in number of years)	15.23	14.22	5	40
herd size	herd size (number of cows)	9.03	5.05	3	23
Output	yield in unit of milk (measured in liters)	17387.4	25451.3	1800	118800
market performance	market performance (0="poor"; 1= "fair")	0.67	0.48	0	1
veterinary and extension	veterinary and extension services performance (0="poor"; 1= "good")	0.37	0.49	0	1
Labor	labor (measured in terms hours of hired and family labour per week)	198.5	320.25	56	1825
Sample Size		27			

**Table 2.** Maximum likelihood estimates of the stochastic frontier production function.

Logout put	Half normal
Herd size	0.156 <sup>***</sup> (8.01)
Labor	-0.000880 <sup>***</sup> (-2.67)
_cons	8.755 <sup>***</sup> (38.84)
Insig2v _cons	-2.868 <sup>***</sup> (-3.45)
Insig2u _cons	-0.153 (-0.39)
N	27

*t* statistics in parentheses, \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

against a vector of variables including age, gender, farming experience, market performance and access to veterinary and extension services. Results are presented in [Table 3](#).

The estimated coefficient of age (middle age and old age) are positive and statistically significant indicating that as the farmer gets older the less efficient they tend to become. This suggest that young dairy farmers are more efficient than older farmers. These results are consistent with the results by Mugeru and Featherstone (2008) and Pitt and Lee (1981). More so, the results are consistent with the findings of Abdulai and Huffman (1998) which

**Table 3.** Determinants of technical efficiency.

Login efficiency	
Middle age	0.606 <sup>***</sup> (4.33)
Old age	0.910 <sup>***</sup> (7.29)
Gender	-0.330 <sup>*</sup> (-1.90)
Experience	-0.0312 <sup>**</sup> (-2.55)
Market performance	-0.416 <sup>*</sup> (-2.03)
Veterinary and extension services performance	0.380 <sup>**</sup> (2.71)
Constant	-0.575 <sup>*</sup> (-1.90)
Observations	27
$R^2$	0.534

*t* statistics in parentheses, \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

states that older rice farmers in Northern Ghana were less efficient than young farmers.

Gender measured as a dummy states that males are more efficient than females. Veterinary and extension contact also measured as a dummy suggest that more veterinary and extension contact leads to more

technical inefficiency. The results could be explained on the basis of a poor program design on the part of the extension department or a lack of a participatory approach and bureaucratic inefficiencies in delivering extension to dairy farmers. Market performance and farming experience positively contributes to improved technical efficiency.

## CONCLUSION AND POLICY IMPLICATIONS

The study investigates the farm level technical efficiency of production and its determinants in Zimbabwe dairy farming using the case of Marirangwe smallholder dairy farmers in Seke district of Mashonaland East province. The study was undertaken on a sample of 27 smallholder dairy farmers in the farming season 2012/2013. The mean technical efficiency was estimated to be 54.9% for the sampled data indicating gross inefficiencies on the part of dairy farmers. Using a stochastic frontier production function, the empirical evidence suggests the critical factor in explaining output is herd size. In establishing the factors affecting farm level technical efficiency: farming experience, gender, age, market performance and veterinary and extension services are particularly important determinants.

In particular, the findings suggest that to stimulate efficiency, aged people should be enrolled into dairy training programmes to improve their efficiency levels. More so, in terms of supporting activities, empirical evidence suggests that males are more technically efficient as compared to females and as such for policy purposes more males should be trained about dairy farming as this will improve production efficiency. Furthermore, for veterinary and extension services, results suggest that the services need to be placed on constant check with the programs clearly designed and being participatory in nature. Also, the performance of the market is a critical determinant in determining efficiency levels of the farmers. If the prices in the market are poor there is no motivation for the farmers to become efficient. Therefore, if the prices are regulated then they need to be gazetted at prices that will motivate farmers to increase their efficiency levels. Otherwise letting the forces of demand and supply determine the prices will help farmers to be more efficient.

Thus, technical efficiency can be improved by dovetailing dairy farming training programs to the middle aged and old aged farmers, propagate and expedite veterinary and extension services in a participatory approach and encouraging more men to participate in dairy farming.

## Conflict of Interest

The authors have not declared any conflict of interest.

## REFERENCES

- Abdulai A, Huffman WE (1998). An examination of profit inefficiency of rice farmers in Northern Ghana. Staff Paper, Swiss Federal Institute of Technology, Department of Agricultural Economics. <http://ageconsearch.umn.edu/bitstream/18271/1/isu296.pdf>
- Aigner D, Lovell CAK, Schmidt P (1977). Formulation and estimation of stochastic frontier production function models. *J. Economet.* P. 28.
- Battese GE, Tessema G (1997). Estimation of Stochastic production function with time varying parameters and tech efficiency using panel data for Indian villages. *Agric. Econ.* 9:313-333.
- Battese G, Coelli T (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empir. Econ.* 20:325-332.
- Coelli TJ (1995). Estimators and hypothesis tests for a stochastic frontier function: a case of Monte Carlo Analysis. *J. Prod. Anal.* pp. 247-268.
- Coelli TJ (1977). Recent Developments in Frontier Modelling and Efficiency Measurement. *J. Agric. Econ.* P. 3.
- Coelli T, Rao P, Battese G (1998). *An Introduction to Efficiency and Productivity Analysis.* Boston: Kluwer Academic Publishers.
- Farrell M (1957). "The Measurement of Productivity Efficiency". *J. Royal Stat. Soc.* A120.
- Government of Zimbabwe (2004). *Review of Dairy Development in Zimbabwe.*
- Hanyani BT, Sibanda S, Ostergaard D (1998). Socio economic aspects of dairy development in Zimbabwe. 10:2.
- Meeusen KJ, Broeck V (1977). Efficiency estimation from Cobb-Douglas Production Functions with composed error. *Int. Econ. Rev.* P. 18.
- Mugera AW, Featherstone AM (2008). Backyard Hog Production Efficiency. Evidence from the Philippines. *Asian Econ. J.* 22(3):267-287.
- Mupunga EG, Dube DM (Undated). Smallholder dairy development programme in resettled and communal areas in Zimbabwe. FAO
- Ngongoni NT, Mapiye C, Mwale M, Mupeta B (2006). Factors affecting milk production in smallholder dairy sector of Zimbabwe. *Livest. Res. Rural Dev.* 18:5.
- Pitt M, Lee L (1981). The Measurement and Sources of Technical Inefficiency in the Indonesian Weaving Industry. *J. Dev. Econ.* 9:43-64.
- SNV (2012). *Evaluation of Smallholder Dairy programmes in Zimbabwe: Final Report.*
- Wang HJ, Schmidt P (2002). One-Step and two-step estimation of the effects of exogenous variables on technical efficiency levels. *J. Prod. Anal.* 18:282-284.