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Analysis of technical efficiency of small-scale soybean farmers in Mpongwe District, Zambia: a Stochastic Frontier Analysis

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Abstract: *The study analyses the technical efficiency and its determinants in soybean production, applying a Cobb-Douglas stochastic frontier production model on survey data collected from 79 soybean growing households in Mpongwe district of Zambia. The result indicate presence of inefficiencies in soybean production in the area. The efficiency ranged from 5.82% to 85.7% with a mean of 50.3%. This implies that a chance exists for improving soybean output by 49.7% from using existing resources and technology in the study area.*

The inefficiency model results show that level of education, household size, extension contact, and market distance tend to increase technical inefficiency level among the soybean farmers. On the other hand, herbicide usage has significant negative effects on technical inefficiency of smallholder soybean production in the study area. This study recommends that government needs to enhance access to extension services, herbicides and improved seed, and improve feeder roads, to help farmers improve their technical efficiency in the study area.

Keywords: *Technical efficiency, Stochastic Frontier Analysis, Cobb-Douglas Production Function, Soybean, smallholder, Zambia*

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I. Introduction

Soya bean is an important legume crop in Zambia. It is a good source of plant protein and is used in preparation of foods and feed and a raw material in the processing of edible oils. Zambia has experienced tremendous growth in soya beans production in the last decade driven mainly by the livestock industry and human consumption including edible oils. Soya bean production is dominated by large commercial farmers who account for the larger share (>60%) of soya beans production. However, small scale farmers have increased their production of soya beans and as of 2017 their share was 45% of total production. The domestic soya bean requirement is estimated at 230,000 MT and in recent years Zambia has become self-sufficient in soya bean production. With the rising population and incomes among the Zambian households, demand for edible oils and livestock products and hence demand for soybeans is likely to remain high in the foreseeable future (Lubungu, et al., 2013) [1] and as such increased sustainable soybean production is essential for supporting the development of the oilseed processing sub-sector in the national economy.

The government, NGOs and private seed companies have been promoting soya bean production among smallholder farmers as part of the strategy for diversification of agriculture, reducing dependency on maize mono-cropping and for improving income generation and food security among smallholders. The promoted technologies include: use of improved seeds, inoculum, planting time, and herbicide use and crop management.

Production of soya bean increased from 55,000 metric tonnes (MT) in 2006 to 117,000 MT in 2010 and from 200,000 MT in 2012 to reach 351,000 MT in 2017. Associated with the increase in production has been the doubling in soya bean planted area in the period 2012-2017), from 99,000 ha in 2012 to around 200,000 ha in 2017. However, average soya bean yield decreased from 2.3 MT/ha in 2012 to 1.52 MT/ha in 2017. This indicates that the reported tremendous growth in soya bean production in Zambia in the last decade is attributed mainly to area expansion rather than yield or productivity improvement which actually has decreased. It is also important to note that the average yield obtained by smallholder farmers are lower than those of commercial farmers. For instance, the average yield in 2016 among small-scale farmers was 0.93 MT/ha and 2.87 MT/ha for commercial farmers (IAPRI, 2017) [2].

In spite of the various interventions, annual average soya bean yields in the country are still below the achievable/ potential yield of 3 MT/ha. This indicates that closing the yield gap presents a huge opportunity for improving soya bean production in Zambia in particular among smallholder farmers and this can be achieved through technical efficiency improvement. Technical efficiency improvement in soya bean production means that farmers can produce more without necessarily increasing the usage of resources (Etwire et al., 2013) [3]. Finding policy measures for improving soya bean technical efficiency calls for undertaking studies on productive efficiency. Literature search found few studies on productive efficiency of agriculture sector in Zambia and that the few studies had a bias towards maize than any other crop. The Zambian studies include: Chiona et al. (2014) [4] on maize, Kabwe (2012) [5] on cotton, and Musaba et al. (2014) [6] on maize. To the best of our knowledge, there was no known study that has addressed technical efficiency of soya bean farmers in Zambia including Mpongwe district. Therefore, the objective of this study was to analyze the technical efficiency and its determinants among soya bean farmers in Mpongwe district in Zambia using the stochastic frontier approach.

Measuring efficiency is vital because it is the first measure in practice that lead to considerable resource savings and has implications for policy formulation and farm management (Bravo-Ureta and Riegler, 1991) [7].

Efficiency refers to the ability of a producing unit to obtain maximum (optimal) output from a given amount of inputs. A technically efficient farm operates on the production frontier while a technically inefficient farm operates below the frontier. It could be efficient by increasing its output with same input level or using fewer inputs to produce the same level of output. As such the closer a farm gets to the frontier the more technically efficient it become (Rahman et al., 2005) [8].

Efficiency measurement has received significant attention from researchers in different fields of study. In agricultural economics, many studies on productive efficiency of crops and livestock production have been conducted using either the stochastic frontier approach or the Data envelopment Approach (DEA). The stochastic frontier analysis is a parametric method while the DEA is deterministic. The DEA uses mathematic programming methods, it circumvents the problem of misspecification of functional form and it can handle disaggregated inputs and multiple output technologies. However, being non-stochastic (deterministic), the DEA approach does not differentiate data noise and inefficiency, it attributes all deviations from production frontier to inefficiencies (Coelli and Battese, 1996) [9]. Thus DEA is very sensitive or likely to be subject to measurement errors. On the other hand, SFA takes into account measurement errors and other noise in the data. Thus, SFA is generally preferred in agricultural economics at farm level.

Various studies technical efficiency studies conducted in Africa on soybean farming included Etwire et al., (2013) [3], Avea et al., (2016) [10], Otitujo et al., (2014) [11], Amaza et al., (2007) [12] and Yegon et al., (2015) [13]. These studies found that soybean production was affected by technical inefficiencies which was associated with demographic, socio-economic, institutional and technical factors. The factors included: age, gender, education, membership of farmer group, extension visits, fertilizer use, improved seed use, credit and regional location of farmer among other factors. (Rahman et al., 2005)[8]. Several factors including socio-economic and demographic factors, farm plot level characteristics, environmental factor and non-physical factors are likely to affect the efficiency of smallholding farmers. Thus, most of the empirical studies show that socio-economic characteristics and farm characteristics are important sources of technical efficiency among farmers. This study, therefore, is an attempt aimed at measuring technical efficiency and identifying factors determining its magnitude in soybean production in Mpongwe district of Copperbelt province, Zambia using the stochastic frontier approach.

II. METHODS

Study area

This study was conducted in Mpongwe district, Copperbelt province, Zambia. The district is located approximately 95 kilometers south west of Ndola town and 65 kilometers south east of Luanshya town. The district and the province are found in agro-ecological region III of Zambia, which is a high rainfall zone, with 1000-1500mm of annual rainfall. There is tropical climate with two distinct seasons; the rainy season (late October- April) and the dry season (May to September). The region has good potential for the production of maize, soybeans, sweet potatoes, cassava, sorghum, beans and groundnuts and vegetables.

Sources and Type of Data

Data were collected from primary sources and secondary sources. The primary data were collected with the aid of a structured questionnaire designed to capture information on demographic and socio-economic characteristics of farmers (age, level of education, household size, experience), and farm characteristics (farm size area planted, crops grown, inputs, production cost, quantity of output), and participation in extension activities. The data were collected during the months of January and February of 2016.

Sampling Technique and Sample Size

Purposive and multistage sampling methods were used in selecting 120 farmers for the interview. First stage involved purposive selection of three blocks (Kashiba, Mpongwe east, Lukanga) from ten that make up the district. The second stage involved purposive selection of two agricultural camps in each block. In the third stage, 20 farmers were randomly selected from each camp with the help of extension workers and finally giving a total sample size of 120 soybean farmers.

Data Analysis

Descriptive statistics in terms of means, frequencies percentages and standard deviations were used to describe the socioeconomic and farm characteristics of soybean farmers in Mpongwe district. The estimation of technical efficiency of soybean farmers was achieved using the stochastic frontier approach.

Analytical framework: Stochastic Production Frontier Approach

The stochastic frontier production was adopted to measure the technical efficiency of smallholder soybean farmers in this study. The model was first proposed by Aigner et al. (1977) [14] and Meeusen and Van Den Brooeck (1977) [15]. The advantage of this approach is that the error term captures noise, measurement error and inefficiency component /exogenous shocks beyond the control of the farmer. The stochastic frontier production function required for estimating farm level technical efficiency is specified as:

$Y_i = f(X_i;\beta)\ exp\ (V_i - U_i)$ where i = 1, 2,…,n (1)

Here Y_i is the output of the i-th farm, X_i is denotes the actual input vector, β is vector of production elasticity coefficients and *Vi* denotes the random error not under the control of the famers, assumed to be independently and identically distributed as N $(0, \sigma_v^2)$, independent of U_i is one-sided error term that is independent of V_i and normally distributed as N $(0, \sigma_u^2)$, allowing the actual production to fall below the frontier without attributing all short falls in output from the frontier as inefficiency (Battese and Coelli, 1995) [16].

The technical efficiency of the i-th farm (TE_i) is defined in terms of the ratio of the observed output to the output of the best producing (frontier) firm using the same the technology and given the levels of inputs used by that firm (Battese, 1992) [17]. Thus, the technical efficiency of firm *i* in the context of the stochastic frontier production is specified as:

$TE_i = Y_i/Y_i^* = f(x_i, \beta)exp\ (V_i - U_i) / f(x_i, \beta)\ exp\ (V_i) = exp\ (-U_i)$ (2)

where $Y_i = f(x_i, \beta)exp\ (V_i - U_i)$ is the observed production with inefficiency and $Y_i^* = f(x_i, \beta)\ exp\ (V_i)$ is the frontier output quantity with no inefficiency.

The value of TE is bound between 0 and 1 such that $0 < TEi \leq 1$. When TE_i is 1, it indicates that a farmer is producing on the frontier with the available resources and technology and the farmers is said to be technically efficient. If TE_i is less than one, it implies that the farmer is producing on the production frontier for a given technology and resources. Such a farmer is said to be technically inefficient.

The determinants of technical efficiency can be considered by simultaneously estimating the production frontier and an equation for efficiency effects. Battese and Coelli (1995) [16], proposed a model in which the technical inefficiency effects in a stochastic production frontier are a function of other explanatory variables. The technical inefficiency model, *Ui* is defined as:

$$U_i = \delta_0 + \delta_i\ Z_{ij} \quad (3)$$

Where *Zi* represents the vector of explanatory variables that may influence the technical efficiency of a farm, δ_i is a vector of parameters to be estimated.

The unknown parameters for the stochastic frontier production function and the inefficiency effects model are obtained using the Maximum Likelihood Estimation (MLE) simultaneously. The likelihood estimates are presented as the variance parameters, $\delta^2 = \delta_v^2 + \delta_u^2$ and $\gamma = \delta_u^2 / \delta^2$, here gamma represents the proportion of error variance that can be attributed to technical inefficiency (Battese and Coelli, 1995) [16].

Empirical model: Stochastic frontier and inefficiency models

In order to determine technical efficiency and factors affecting efficiency of small scale soybean farmers in Mpongwe District on the Copperbelt Province in Zambia, a Cobb-Douglas production function was adopted. The empirical model of the Cobb-Douglas stochastic frontier production function was specified as follows:

$Ln\ Y_i = \beta_o + \beta_1 LnX_{1i} + \beta_2 LnX_{2i} + \beta_3 LnX_{3i} + V_i - U_i$ (4)

Where: Output (Y) is the total output of soya bean harvested in kilograms per hectare (kg/ha); X_1 is the seed quantity (kg/ha), X_2 is cost of agricultural chemicals (ZMW/ha); and X_3 is the total labour (man days/ha).

The inefficiency model based on Battese and Coelli (1995) [16] was specified as:

$$U_i = \delta_0 + \delta_1\ Z_1 + \delta_2\ Z_2 + \delta_3\ Z_3 + \cdots + \delta_8\ Z_{8i} \quad (5)$$

Where: Z_1= Age of farmer; Z_2 = Education (years); Z_3= Household size (persons); Z_4= Experience (years); Z_5= Crop area; Z_6= Herbicide used; Z_7= Distance to product market and Z_8= Extension visits.

The maximum likelihood estimates of the Cobb-Douglas stochastic frontier production function were estimated using the STATA software version 11. This software has the advantage of allowing simultaneous estimation of the production function and technical inefficiency model.
Diagnostic tests for multicollinearity using Variance Inflation Factor (VIF) and test for heteroscedasticity using Breusch Pagan tests were conducted before running the models. Since the estimated VIF mean value of 3.10 was below, it indicated absence of multicollinearity. The Chi-square value of 3.45 (df=1) for Breuch Pagan test was found to be insignificant at 5% probability level

III. Results and Discussion

Characteristics of soybean farmers

Table 1 presents a summary of variables used in the technical efficiency analysis. It shown that majority of the surveyed farmers were male (82%), indicating that soybean production was male-dominated. This confirms finding by Fisher and Qaim (2012) [18] that in African agriculture, males tend to dominate and control revenues from cash and export crops.-On average the small-scale soybean farmer was 45 years old, had 15 years farming experience, and household size of 7 people. The farmers has 9 years of formal education, which was equivalent to junior secondary education level. The farmer received one extension visit during the cropping season.

The average cultivated crop area was 4.5 ha, out of which 1.5 ha was planted to soybean and mean soybean output was 1,988 kg, which translated into an average yield of approximately 1,283 kg per ha for the 2015/16 season. This yield was below the average national yield of 1.700 kg/ha for soybean during 2015/16 (IAPRI 2017) [2]. This confirmed the fact that smallholder farmers in the study area were affected by low productivity.

The farmer used 152 kg of seed on 1.5 ha of planted area. Few farmers (25%) used certified soybean varieties and majority used recycled seed. For controlling weeds, most farmers (72%) used herbicides. The average cost of the agricultural chemicals i.e. herbicides and pesticides was ZMW 294 per farm. While average labour use per farm was 105 man days (person days). This captured labour use for all the operations namely: land preparation, planting, weeding, harvesting, and threshing.

Table 1: Summary statistics of the variables used in the soybean stochastic frontier production and inefficiency model

Variable	Units	Mean/Percent	Std. Dev.
Sex of farmer	1=male, 0=female	0.82	0.39
Age of farmer	years	45.34	12.01
Education	years	9.36	2.61
Household size	persons	7.24	3.29
Experience	years	15.57	11.10
Certified seed used	1=yes, 0=No	0.25	0.43
Herbicides used	1=yes, 0=No	0.72	0.45
Extension visits	number	1.39	1.65
Total Crop area	ha	4.89	3.29
Soybean area	ha	1.54	1.50
Soybean output	kg	1988.44	2291.71
Seed amount used	kg	152.36	144.04
Agrochemical cost	ZMW	294.24	334.79
Labour used	Man days	105.47	96.88

Production frontier

Table 2 shows the maximum likelihood estimates for parameters of the Cobb-Douglas stochastic production frontier and technical inefficiency effect models for smallholder soybean production in Mpongwe district. The results show statistically significant coefficient for sigma squared (σ^2). This indicated a good fit and correctness of the specified distributional assumptions of the composite error term. In addition, the estimated gamma (γ) of 0.91, means that 91% of the variation in actual output from maximum output (production frontier) among soybean farmers was due mainly to differences in farmers' practices. This implies that the production deviations from the frontier functions are practically due to technical inefficiency.

The coefficient of seed was found to be negative but not significant (P<0.01) in explaining farmers' inefficiency. It indicated that an increase in seed leads to an insignificant decrease in technical inefficiency. The insignificant effect of seed on production of soybean in Mpongwe district, could be attributed to the type of seed the farmers were using. This finding concurs with Yegon et al. (2012) [13].

The other outcome was that there is a positive and significant relationship (P<0.05) between agrochemicals and soybean output. The coefficient for agrochemicals at 0.26, suggests that a one percent increase in agrochemicals (i.e. fertilizer, herbicides and pesticides) will increase soybean output by 0.26%. This concurs with the findings of Yegon et al. (2015) [13] that an increase in fertilizer rate causes an increase in soybean output. Increased use of agrochemicals (fertilizers) would assist the smallholders compensate for the limiting land resource. However, this requires judicious and optimal usage for increased productivity and profitability (Yegon et al., 2015) [13].

The coefficient for labour (man-days) was found to be positively and significantly (P<0.01) associated with soybean output. The coefficient of 0.809 for labour variable is the largest among the coefficients for input variables used in the model. This implies that labour was the most significant input in the production of soybeans in the study area. This finding is not surprising given that soybean is a labour intensive crop and uses labour for important cultural practices such as planting, weeding, and harvesting which have to done timely in order to have a good harvest. A one percent increase in labour will lead to a 0.25% increase in soybean output.

Table 2: Maximum likelihood estimates of production frontier function for soybean farmers in Mpongwe,

Variable	Parameter	Coefficient	S.E	t-value	P>t
Stochastic Frontier					
Constant	B_0	3.738**	0.781	4.79	0.000
LNSeed	B_1	-0.283	0.192	-1.47	0.141
LNAgrochem	B_2	0.260**	0.117	2.23	0.026
LNmandays	B_3	0.809**	0.125	6.45	0.000
Inefficiency					
Constant	δ_0	-8.935	5.283	-1.69	0.091
Age	δ_1	-0.031	0.059	-0.53	0.596
Education	δ_2	0.513*	0.307	1.67	0.095
Household size	δ_3	0.413*	0.247	1.67	0.094
Crop Area	δ_4	0.27	0.178	1.51	0.130
Herbicides USED	δ_5	-3.871**	1.828	-2.12	0.034
Extension visits	δ_6	0.433**	0.195	2.22	0.027
Distance to market	δ_7	0.04*	0.02	1.87	0.061
Efficiency parameters					
Sigma squared	σ^2	1.278***	0.326	3.92	0.000
Lambda	λ	3.189***	0.272	11.71	0.000
Gamma	γ	0.91			
Log Likelihood		-70.761			
Wald Chi2(3)		55.07			0.000
Mean technical efficiency		0.503			

***Significant at 0.01 level; **Significant at 0.05 level; *Significant at 0.10 level.

Distribution of technical efficiency scores

Table 3, the mean technical efficiency (TE) in soybean production among sample farmers is 50.3%. Therefore, on average a farmer in the study area could increase soybean production by 50% from existing resources and technology by copying the best practicing farmers in the study area. The TE ranges between 5.82 and 85.7%, among the sample soybean farmers. Table also shows that over 45% of the sampled farmers attained technical efficiency levels below 0.50 and about 9% of famers had an efficiency score greater than 0.80. The variations in TE may arise from differences in socio-economic and institutional characteristics and the existing technologies among the sampled farmers. The estimated mean TE of 50.3% is consistent with findings of other studies in Africa including Etwire et al. (2013) [3] in Saboba and Chereponi districts of Ghana but slightly lower than the mean TE of 79% found by Amaza et al. (2007) [12] in Nigeria and 88% recorded by Avea et al. (2016) [10] in Ghana.

Table 3: Distribution of technical efficiency scores.

Efficiency score	Frequency	Percent
< 0.20	8	10.2
0.21 – 0.50	28	35.5
0.51 – 0.60	16	20.3
0.61 – 0.70	11	13.9
0.71 – 0.80	9	11.4
0.81 – 0.90	7	8.9
Sample size	79	100
Mean	0.5031	
minimum	0.0582	
maximum	0.8571	

Determinants of technical efficiency

The sources of technical inefficiency were examined using the estimated coefficients associated with the inefficiency variables specified in the inefficiency model. The variables used in the model included: age of the farmer, level of education, household size, crop area (farm size), extension contact and distance to the produce market. The results for the determinants of technical inefficiency are also presented in the lower section of Table 2. Out of the seven explanatory variables included in the inefficiency model five were significant and these presented below.

EDUCATION: Education plays a significant role in technology transfer and skills acquisition. It enhances ability of a farmer to acquire and process information, and make informed decisions on adoption of technology and better practices in farming and marketing. In this study a positive and statistically significant relationship is found between education level and technical inefficiency. This implies that farmers with high level of education tend to exhibit higher technical inefficiency than those with little education. This result is contrary to apriori expectation and is inconsistent with some past studies such as Yegon et al. (2015) [13] in Kenya and Oyewo et al. (2009) [19] in Oyo state of Nigeria.

HOUSEHOLD SIZE: Household size plays an important role in subsistence or smallholder farming in Zambia where farmers rely heavily on household members for the supply of farm labour requirement. In essence family size can be used as proxy for family labour availability. In this study, household size has a positive significant (p<0.10) effect on technical inefficiency, implying that larger households are less technically efficient than smaller households. The negative effect of household size on technical efficiency in the Mpongwe district implies that larger families have a higher number of dependents which reduces supply of farming labour and ultimately decrease efficiency in soybean farming. This finding concurs with (Mignouna et al. 2012) [20] but is inconsistent with finding of Saysay et al. (2016) [21] and Ogundari (2006) [22] who revealed a positive association and between family size and profit efficiency among rice producers.

HERBICIDE USE: The coefficient of the dummy variable for herbicide use (yes=1 or no=0) is significant (p<0.05) and negatively related to technical inefficiency of soybean production. This suggests that farmers who used herbicides to control weeds were more technically efficient than those who did not. This finding is consistent with the *apriori* expectation that application of yield enhancing technologies such as plant protection (herbicides and pesticides) improves production and productivity and hence reduces technical inefficiency of soybean production.

EXTENSION: Another outcome of the efficiency model was the positive and significant effect of extension service on technical inefficiency level. This result is contrary to empirical evidence shown by previous studies (Ajao et al. 2012 [23]; Binam et al. 2003 [24]; and Bocher et al. 2017 [25]; Chiona et al. 2014 [4]; Ugbabe et al, 2017) [26], that access to extension increases farmer's technical efficiency level or reduces inefficiency. The finding indicates that farmers with access to extension services were less technically efficient. This finding implies that farmers were not getting enough extension visits. In fact sampled farmers reported receiving on average one visit in the farming season. In addition, public extension service in Zambia due to underfunding is struggling to operate and deliver relevant messages and technologies to farmers which can help them increase their technical efficiency. The finding agrees with the study by Otitoju et al. (2014) [11] which showed extension contact to be positively related with technical inefficiency among soybean farmers in Benue State of Nigeria where the extension methods for disseminating newly introduced technologies were not good enough for the farmers to understand and improve technical efficiency.

DISTANCE: Given the poor state of most feeder roads in farming areas and long distances farmers travel to access produce markets, it not surprising to find that an increase of distance to the market significantly causes technical efficiency to decrease among soybean farmers. The coefficient of 0.0421 for distance variable means that a one kilometer distance from the local market is associated with 4.21% loss in technical efficiency. This finding is consistent with Bocher et al. (2017 [25] and Tan et al. (2010) [27]. An explanation is that there is increased cost of transport and less access to marketing and production technology for those who live in remote areas.

IV. Conclusion

The purpose of this study was to analyze the technical efficiency levels of smallholder soybean farmers. The Cobb-Douglas stochastic production frontier model used reveal that there was a wide variation in technical efficiency among sampled soybean farmers in Mpongwe District. The technical efficiency of the surveyed farms ranges from the minimum of 5.82% to a maximum of 87.5%, with a mean technical efficiency 50.3%, suggesting that a chance exists for improving soybean output by 49.7% from using existing resources and technology in the study area. Among the production inputs, seed had no significant influence on soybean output perhaps due to high usage of recycled seed by farmers in the area under study. Agrochemicals and labour, were the two inputs which had significant positive influence on soybean output among smallholder farmers of Mpongwe District.

The inefficiency model results show that level of education, household size, extension contact, and market distance tend to increase technical inefficiency level among the soybean farmers. On the other hand, herbicide usage has significant negative effect on technical inefficiency of smallholder soybean production in the study area. This implies that farmers who use herbicides to control weeds were more technically efficient than those who did not.

To improve productivity among smallholder soybean farmers in Mpongwe District, there is a need to address some important factors identified in this study which had significant influence on technical inefficiency. Since herbicide usage negatively and significantly influenced technical inefficiency, the government should consider providing incentives and accessibility to affordable herbicides and associated labor-saving technologies such as threshers and in view of the labor-intensive nature of smallholder soybean production.

In view of the finding that education level and extension contact cause a decrease in technical efficiency among soybean farmers, there is a need to design strategies to ensure that formal and informal educational programs and extension services are revamped and made to provide relevant training to farmers. This should emphasize delivering skills, knowledge and technologies that help farmers to improve efficiency through optimal use of productivity enhancing inputs in soybean farming.

Regarding the fact that an increase of distance to the market significantly causes technical efficiency to decrease among soybean farmers, there is need for government to improve feeder road conditions and encourage opening of agro-dealer shops in close proximity to farmers in the rural farming areas and thereby helping to reduce transport costs and other transaction costs hindering farmer's access to market and production technology.

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