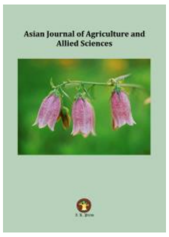

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Technical Efficiency among Smallholder Irrigators: Trends from Zimbabwe

Joseph Buteteh Chivizhe [a] and Norman Mupaso [b*]

[a] Department of Agricultural Practice, Midlands State University, Gweru, Zimbabwe.
[b] Department of Agricultural Economics and Development, Midlands State University, Gweru, Zimbabwe.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Smallholder irrigation productivity has been a topical issue among researchers and policy makers in developing countries. The level of productivity has raised questions on whether smallholder irrigation is the most suitable model for agricultural development. The study was conducted at HamaMavhaire and Ngondoma irrigation schemes in the Midlands Province of Zimbabwe. The aim of the study was to assess the level of technical efficiency and agricultural productivity in smallholder irrigated agriculture. The study used primary data collected from a randomly selected sample of 127 respondents. The sample comprised of 76 farmers from Ngondoma irrigation scheme and 51 farmers from HamaMavhaire irrigation scheme. The stochastic frontier production function was used to analyze the productivity and technical efficiency of the irrigation schemes. The study's findings show that the average technical efficiency for Ngondoma irrigation scheme was 69%. This implies that there is a potential of increasing agricultural productivity by 31% using the existing irrigation technology. The findings also show that for the efficiency model, the statistically significant variables are; manure (P<0.01), farm size and irrigation water (P<0.05). The results for HamaMavhaire irrigation scheme show an average technical efficiency of 65%. This implies that there is a potential to increase agricultural productivity by 35% using the existing technology. The

**Corresponding author: E-mail: mupaso2@yahoo.com; mupason@staff.msu.ac.zw;*

use of pesticides was statistically significant (P<0.01). The inefficiency model suggested that the statistically significant variables influencing agricultural productivity are years of schooling (P<0.01) and agricultural extension (P<0.05). The study concluded that there were potential gains to be realized by the farmers if technical efficiency of the smallholder irrigation schemes were to be improved.

Keywords: Agricultural productivity; technical efficiency; inefficiency model; ngondoma; hamamavhaire; smallholder irrigation scheme; technology.

1. INTRODUCTION

Irrigated agriculture is globally viewed as an important technology in transforming and boosting the contribution of the agricultural sector to the overall economy. The irrigation sector uses about 70% of the world's fresh water withdrawals [1]. The irrigated area accounts for 18% of cultivated area in developing countries and produces 40% of the value of agricultural output [2]. The sector contributes significantly in provision of food for the world's population which is projected to be 10 billion by 2050 [3]. Most of the projected growth will occur in developing countries where smallholder farming which is associated with low yields dominates [4]. Globally there are approximately 2.5 billion people involved in smallholder agriculture managing an estimated 550 million small farms [5].

Worldwide, the area under irrigation increased six times in the twentieth century, much of the expansion occurred in the 1950s with the development of industrialized agriculture process [6]. Most of the irrigated area expansion took place in developing countries [6]. At the global scale, 2.79 million km^2 (689 million acres) of agricultural land was equipped with irrigation infrastructure around the year 2000, with about 68% of the equipped area located in Asia, 17% in America, 9% in Europe, 5% in Africa and 1% in Oceania [1].

While, agriculture serves both as a source of income and a means of reducing poverty, 1.4 billion people still live in extreme poverty globally, with 75% of them living in rural areas of Sub-Saharan Africa (SSA) and southern Asia [7,8]. According to the FAO [9] food production forecasts (1995 – 2050), food production from irrigated agricultural lands should grow by at least 40% in the same period in order to meet a 33% population increase and satisfy the needs for improved nutrition worldwide. Although the development of smallholder irrigated agriculture would be expected to solve the problems of food insecurity and poverty, the results to date are disappointing, especially in SSA. For example, a study conducted by Mutambara and Munodawafa [10] in Zimbabwe found that irrigated maize had a yield range of 916kg/ha to 2540 kg/ha; beans 885kg/ha to 1716kg/ha and tomatoes 1460kg/ha to 5520kg/ha. The contribution of smallholder irrigated agriculture to the agricultural sector has been unsatisfactory in the sense that expectations such as increase in labour productivity, crop yields and annual incomes have not been met [10]. In Africa, several studies conducted on smallholder contribution to the economy show disappointing results [11-15].

Intensification of irrigation coupled with expansion of related agribusiness will continue to bring various benefits to human beings. Irrigation increases crop yields due to the availability of water to meet crop needs [16]. Irrigation also makes possible the production of a broad range of crops, many of which are considered specialty crops (that is, crops that are generally not viable under rain-fed agriculture) [17]. Crop yields are more stable and reliable under irrigation, thus significantly reducing insurance and other related costs.

In Zimbabwe, the Fast-Track Land Reform Program (FTLRP) left the smallholder irrigation sector (communal and old resettlement) representing 23% of total irrigated area [18]. The large-scale commercial irrigation sector has been reduced to 8 000 hectares, representing 27% of the irrigated area in the country [18]. The Ministry of Lands Agriculture and Water Development [19] estimated the irrigation potential in Zimbabwe based on available water resources at 240 000 hectares. At present, the smallholder irrigation is the largest sector following the reduction of the large-scale commercial sector from 98 000ha to 8 000 ha through vandalisation at the inception of the FTLRP [19]. According to the current legislation some of the vandalized schemes, once rehabilitated, will add to the smallholder's 11 000 ha [20]. Thus, making the smallholder irrigation sector to command the largest area at national level. The focus on irrigated agriculture has moved from large scale irrigation to smallholder irrigation [18]. Tremendous efforts have been made by the Government, the private sector and donor community to develop more smallholder irrigation schemes in Zimbabwe.

The performance of smallholder irrigation in Zimbabwe is poor. Land holdings are small and vary from 0.1ha to 1 ha in size [10]. Large crop yield gaps prevail between low and high producing farmers within the irrigation schemes [10,14]. The smallholder irrigated farms are considered to be non- viable and a drain on the national budget. Several authors commented on this issue worldwide. For example. Tijani [21] argue that efficiency and agricultural productivity are interconnected, as the former is critical to productivity growth. In resource-constrained economies and environments, inefficiency studies illustrate the feasibility of raising productivity through the improvement of efficiency without necessarily increasing the resource base or promoting new technology. Furthermore, Spate Irrigation Network [22] reported that the Aquacrop, a crop water model emphasises that with rising competition for finite water resources, uncertainty linked to climate change and a steady rise in demand for agricultural commodities, increasing water productivity is essential to achieving water and food security. According to Salman et al. [23] the policy guide to improve productivity in small-scale agriculture states that agriculture contributes to enhancing food crop production while, at the same reducing employed resources, that is producing more with less.

The World Bank [3] indicates that irrigated agriculture represent 20% of total cultivated land, supplying 40% of food produced worldwide. According to Froebrich et al. [24] the EAU4 Food project noted that food insecurity is expected to worsen globally because of population growth and climate change. In many African countries, population is expected to double by 2050; with the continent reaching 2.5 billion inhabitants [3]. Most population growth will be in the poorest SSA, hard hit by hunger and malnutrition and most vulnerable to climate change and variability [24]. The EAU4 Food project recommended a transdisciplinary approach in the design of future innovations involving actors outside the academic field in order to increase productivity in agriculture development projects.

The objective of this study was to assess the factors that influence technical efficiency and production in smallholder irrigated agriculture. The null hypothesis was that factors of production are allocated efficiently across all irrigated plots and that there are no differences in productivity on irrigated plots having similar crops and managed by different individuals. The study questions whether smallholder irrigation farmers are efficient and poor and in particular whether the farmers are efficient.

2. METHODOLOGY

2.1 The Study Area

The study was conducted at HamaMavhaire and Ngondoma smallholder irrigation schemes located in the Midlands Province of Zimbabwe. The Midlands province has eight administrative districts (see Fig. 1). The two irrigation schemes were purposively selected based on aspects of resource limitation, accessibility and type of irrigation in operation. HamaMavhaire irrigation scheme (located 190 42’ 20” south latitude and 300 32’ 20” east longitude) has an overhead irrigation system with one-hectare plots which are bigger than the “comma hectare schemes” found in the majority of the smallholder schemes nationwide. Ngondoma irrigation scheme (located 180 25’ 19.16” south latitude and 290 25’03.57” east longitude) has a variety of plot sizes ranging from 0.1ha to 1 hectare all under the surface irrigation system. Crops grown in both schemes include sugar beans green mealies, wheat and tomatoes and a variety of other minor crops like okra and chillies.

2.2 Sampling Procedure

The Cochran’s (1977) sample size formula for continuous data was used to calculate the sample size. Equation 1 shows the formula and calculation conducted.

$$n_0 = \frac{t^2 s^2}{d^2} \quad (1)$$

$$= \frac{1.96^2 1.167^2}{0.21^2} = 118$$

Where;

t = value for selected alpha level 0.025 in each tail = 1.96
s = estimate of standard deviation in the population= 1.167 (that is 7/6)
d = acceptable margin of error (0.03) for mean being estimated = 0.21

Fig. 1. Administrative districts of the Midlands Province
Source: DoID (2013)

In cases where the sample size exceeds 5% of population, which was the case in this study, the Cochran's (1977) correction formula is used to correct for final sample size. The correction formula is shown by equation 2.

$$n = \frac{n_0}{1+\left(n_0/_{population}\right)} \quad (2)$$

$= \frac{118}{1+(118/_{201})}$ = 74.89 = 75 farmers for Ngondoma irrigation scheme,

$= \frac{118}{1+(118/_{96})}$ = 52.93 = 53 farmers for HamaMavhaire irrigation scheme.

2.3 Data Collection

Primary data were collected from HamaMavhaire and Ngondoma irrigation schemes located in Chirumhanzu and Kwekwe districts respectively. A structured questionnaire was administered to 127 respondents (76 farmers at Ngondoma and 51 farmers at HamaMavhaire irrigation schemes). The researchers were assisted by three trained enumerators. The questionnaires were administered using the local language of Shona. The questionnaire sought to gather information on the level of agricultural productivity, incomes and income inequality as well as poverty prevalence. In addition, the questionnaire included questions on cropping area, level of inputs and output prices, as well as crop quantities produced, sold and consumed domestically, grain quantities in store and produce received or given in-kind, other sources of income, aspects of water resource, sources of water for irrigation, type of irrigation system, irrigation practices and utilization, access to sources of irrigation water and details of water and pumping costs.

2.4 Measuring Technical Efficiency and Its Determinants

Technical efficiency is defined as the amount by which the level of production for the farm is less than the frontier output [25]. The Stochastic frontier analysis measures technical efficiency as the amount by which the level of farm production is less than the frontier output [25]. The stochastic frontier analysis was formulated by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The study used the Frontier version 4.1c software to estimate technical efficiency. The model enabled the researchers to measure both technical efficiency sources and the impact of measurement errors or random variables constituting technical inefficiency. The random variables are not directly related to the production process and are factors that are beyond the control of the farmer. Parameters that are statistically significant in both the efficient and inefficient models are discussed in terms of their influence on productivity. Production data was based on primary information collected from the farmers. The production function used was specified as shown in equation 3: The model specification was also tested for multicollinearity and heteroscedasticity.

$$\ln yield = \beta_0 + \beta_1 \ln farm\ size + \beta_2 \ln fert + \beta_3 \ln seed + \beta_4 \ln irrig\ water + \beta_5 \ln manure + \beta_6 \ln pestcide + \ln labour + \alpha D' + \varepsilon_1 (V_1 - U_1) \quad (3)$$

Where; βo…. β6 are the parameters to be estimated; farm size is the extent of farm in hectares;

Fert is the quantity of fertilizer applied (kg/ha); seed is the quantity of seed used (kg/ha);

irrig water is the cost of irrigation water used (US$); manure is the quantity of manure used (kg/ha); pesticide is the quantity of pesticide used (kg/ha); labour is the quantity of labour employed (labour days/ha, hired and family);

D' is a vector for dummy variables
ε_1 is the error term equal to: ($V_1 - U_1$);
V_1 is a two-sided random error component outside the control of the farmer; and
U_1 is a one –sided inefficiency component.

3. RESULTS

The productivity of the smallholder irrigation efficiency was estimated using the Stochastic Frontier translog Production Function. The aggregated Maximum Likelihood results for Hama Mavhaire and Ngondoma irrigation schemes are shown in Table 1. The mean technical efficiency was 89.1% with a range of between 11.7% and 97.4%. This indicates that there is a 10.9% potential for increasing agricultural production given the existing inputs and state of technology. Two variables namely; manure and labour were found to have positive and statistically significant relationship with output (P<0.05 and P<0.01, respectively). The findings concur with those of a study conducted by the Malaysian Productivity Cooperation (MPC) [26]. The inefficiency model results indicate that age, education and agricultural extension had a negative and statistically significant relationship with productivity in the study area (P<0.1; P<0.01 and P<0.05 respectively).

3.1 Disaggregated Technical Efficiency Determinants for Ngondoma Irrigation Scheme

The disaggregated Maximum likelihood results for Ngondoma irrigation scheme show a mean technical efficiency of 69% and ranges between 11.1% and 93% (see Table 2). This implies that there is a potential to increase agricultural production by 31% using the existing inputs and technology. The results show that farm size and manure have a positive and statistically significant relationship with productivity (P<0.05 and P<0.01 respectively). In addition, irrigation water was found to have a negative and significant relationship with productivity (P<0.05).

Farm size was found to have a positive and significant relationship with productivity (P<0.05). This finding is contrary to those of studies conducted by Ladvenjcova and Miklovicova [27] in Slovakia and Ali and Deininger [28] in Rwanda, that found an inverse relationship between farm size and productivity. Irrigation water had a negative and significant relationship with productivity (P<0.05). The findings were similar to those of a study conducted by Irmak and Rathje [29] in Gothenburg Nebraska, USA. Botts [30] also noted that too much water was as harmful to plants as not getting enough water. The inefficiency model results indicate that gender and credit had a statistically significant relationship with productivity (P<0.05) (see Table 2). Similar findings were obtained by Dinye [31] in a study conducted at Tono irrigation scheme in Northern Ghana.

3.2 Disaggregated Technical Efficiency Determinants for Hama Mavhaire Scheme

Table 3 show the results of the determinants of technical efficiency for HamaMavhaire irrigation scheme. The quantity of pesticide was found to have a negative and statistically significant relationship with productivity (P<0.01). The findings are similar to outcomes by Sinha and Biswas [32] who observed that pest induced losses were on the increase despite increasing use of pesticide in Indian agriculture, particularly where synthetic pesticides are used. The inefficient model results show that education and extension have a negative and statistically significant relationship with productivity (P<0.1 and P<0.05 respectively).

Table 1. Pooled results of maximum likelihood estimation of the stochastic frontier production model

Variable	Coefficient	Std Error	t-ratios
Stochastic Production Frontier			
Efficiency Model			
Constant	1.319	0.958	1.377
Ln_Farm size	0.031	0.149	0.210
Ln_Fertilizer Applied	0.153	0.175	0.875
Ln_Quantity of Seed used	0.049	0.0510	0.835
Ln_Quantity of irrigated Water used	-0.120	0.091	-1.323
Ln_Quantity of manure used	0.206	0.090	2.279**
Ln_Quantity of Pesticides used	0. 054	0.046	1.170
Ln_Labour	0.317	0.112	2.838***
Inefficiency model			
Income of the farmer	0.056	0.223	0.253
Age (Years)	-0.493	0.249	-1.971*
Gender (1= Male, 0 otherwise)	0.013	0.079	0.163
Education (years of schooling)	-0.126	0.047	-2.675***
Credit (1=received, 0 otherwise)	-0.115	0.143	-0.805
Agric. Extension (1= received, 0 otherwise)	-0.016	0.0653	-2.251**
Sigma-squared	0.682	0.288	2.367**
Gamma	0.070	0.602	0.117
Log Likelihood Function	-110.11		
Mean technical efficiency	0.891		

; **; * means significant at 10%; 5% and 1% levels respectively*

Table 2. Results of Maximum likelihood estimation of the SFP model; Ngondoma

Variables	Coefficient	Std-error	t-ratio
Stochastic Production Frontier			
Efficiency model			
Constant	7.904	1.201	6.571
Farm size	0.401**	0.175	2.276
Fertilizer Applied	0.105	0.174	0.604
Quantity of Seed used	-0.117	0.087	-1.337
Quantity of irrigated Water used	-0.113**	0.043	-2.608
Quantity of manure used	0.074***	0.027	2.741
Quantity of Pesticides used	0.063	0.056	1.135
Inefficiency model			
Income of the farmer	0.220	0.315	0.700
Age (Years)	-0.081	0.139	-0.581
Gender (1= Male, 0 otherwise)	0.641**	0.242	2.65
Education (years of schooling)	0.044	0.039	1.137
Credit (1=received, 0 otherwise)	-0.128**	0.056	-2.269
Agric. Extension (1= received, 0 otherwise)	0.010	0.049	0.215
Income of the farmer	-0.050	0.096	-0.528
Sigma-squared	1.08	0.105	0.10.34
Gamma	0.999	0.00002	48412.215
Log likelihood function	-79.08		
Mean Technical efficiency	0.695		

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

3.3 Summary of the Findings

Table 4 shows that the technical efficiency for Ngondoma irrigation scheme was 69.5% and for HamaMavhaire irrigation scheme was 65.3%. The findings imply that there is potential for the farmers to increase crop productivity at the irrigation schemes, utilizing the existing irrigation technologies. The study findings are similar to those of a studies conducted by Essilfie et al. [25] and Bahtay et al. [15].

Table 3. Results of maximum likelihood estimation of the SFP model for hamamavhaire

Variables	Coefficient	Std- error	t-ratios
Stochastic Production Frontier			
Efficiency model			
Constant	11.342	1.382	8.205
Farm size	0.033	0.122	0.273
Fertilizer Applied	-0.091	0.245	-0.372
Quantity of Seed used	0.0456	0.140	0.326
Quantity of irrigated Water used	-0.222	0.292	-0.755
Quantity of manure used	13.957	0.098	0.014
Quantity of Pesticides used	-0.247***	0.090	-2. 738
Labour	-0.383	0.056	-0.068
Inefficiency model			
Income of the farmer	0.329	0.050	6.592
Age (Years)	-0.353	0.055	6.386
Gender (1= Male, 0 otherwise)	0.104	0.068	1.539
Education (years of schooling)	-0.572*	0.334	1.715
Credit (1=received, 0 otherwise)	-0.047	0.054	-0.869
Agric. Extension (1= received, 0 otherwise)	-0.331**	0.1543	-2.145
Sigma Square	0.815	0.219	3.719
Gamma	0.060	0.216	0.278
Log likelihood function	-42.126		
Mean Technical efficiency	0.65		

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

Table 4. Summary of technical efficiency (TE) for the two study areas

Standard measure of TE	Pooled	Ngondoma	HamaMavhaire
Number of respondents	127	76	51
Mean TE	0.891	0.695	0.653
Maximum TE	0.974	0.930	0.974
Minimum TE	0.117	0.111	0.122

Source: Own calculations

4. DISCUSSION

The objective of the study was to assess the factors that influence technical efficiency n smallholder irrigation agriculture. The study was motivated by the criticisms and outcries from researchers, practitioners and government officials that smallholder irrigation was failing to meet its intended objectives [11-15]. Governments of most SSA countries are failing to provide sufficient funding to support agriculture as agreed in the Maputo declaration [33]. The estimates of technical efficiency (TE) in this study imply that smallholder irrigation schemes were inefficient and operating below their full potential at the existing level of technology. There are potential gains to be realized by the farmers if technical efficiency of the irrigation systems were to be improved.

Availability of credit significantly influences production efficiency ($P<0.05$). However, the results show that 96% of the respondents were not accessing credit. This contributes to inefficiency as farmers find it difficult to access required inputs and produce at expected levels. Inadequate access to credit is mainly due to the existing land tenure system for smallholder irrigation schemes that does not allow land to be used as collateral by the banking institutions as the farmers do not have title to the land. Thus, smallholder irrigation farmers often engage in “Group Lending”, where a group of farmers get together and draft a constitution for credit application to a banking institution. Group members can only get a loan when every member pays up his/her arrears and group sanction is the operating instrument for ensuring that members pay up their loans. The GoZ has however, not taken a move to make its tenure system operate for the benefit of the smallholder farmers and the nation as a whole.

Manure was also found to be statistically significant. Soil fertility influences technical efficiency through improved crop yields. In most cases, the size of livestock herd affects the quantity of manure a farmer is able to harvest each year. Farmers are also encouraged to make compost from their crop waste near their plots to augment limited livestock manure. The excessive watering of crops was also a statistically significant variable. The misuse of irrigation water is a major concern at Ngondoma irrigation scheme which uses the flood irrigation system. However, farmers have no incentive to save water as they do not have individual water meters to gauge consumption, thus, over-watering negatively affects crop yields. The study found a negative and statistically significant relationship between farm size and productivity. This means that small plots are associated with higher levels of productivity. The farmers' efficiency increases if they commit themselves to small irrigation plots.

5. CONCLUSION

The results show that the farmers at Ngondoma and HamaMavhaire irrigation schemes have potential to increase productivity by 31% and 35% respectively using the current technology. This can be achieved through strengthening the current extension mechanism and paying particular attention to factors such as availability of manure and labour. The statistically significant determinants of production efficiency were pesticide use, farm size, use of manure and excessive watering. Schultz's (1964) hypothesis that the smallholder farmers are efficient but poor was rejected by the study. The findings show that the farmers were inefficient and poor as they were not able to produce on the frontier. The farmers should avoid excess watering of crops, inefficient pesticide application and ensure adequate use of farm manure to improve crop output.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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