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Article

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Research Article

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Impacts of Improved Seed Maize Technology Adoption on Productivity and Technical Efficiency in Northern Ghana

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Abstract: Improved seed is one of the crucial ingredients for promoting agricultural productivity, farmers' livelihood, and global food security. The present study uses an endogenous treatment regression model (ETRM) to evaluate the impacts of improved seed maize technology (ISMT) adoption on technical efficiency and productivity using data from maize farmers in northern Ghana. The findings show that ISMT adoption impacts positively on technical efficiency. Adoption of ISMT enhanced technical efficiency by 16.1% and increased maize productivity by 33.8%. The study recommends dissemination of improved maize seeds to farmers and other interventions such as provision of fertilizer to enhance farmers' technical efficiency and productivity.

Keywords: adoption; stochastic frontier analysis; technical efficiency; endogenous treatment-regression model; Tolon District.

JEL Classification: C21; D24; Q12

1 Introduction

Improved technology adoption is critical for agricultural productivity and livelihoods of small-scale farmers in developing countries. Promoting agricultural productivity and global food security requires improved seeds (Almekinders et al., 2019). Improved seeds are high-yielding, disease-resistant and drought-tolerant, which also respond well to inorganic fertilizer (Lee, 2020; Simtowe et al., 2019), whereas traditional seeds tend to have lower yields but are more adaptable to the local environment (Anang, 2019). Several efforts have been made toward crop varietal improvements in many less-developed countries, including Ghana in recent times (Anang, 2019; Danso-Abbeam et al., 2017; Ogada et al., 2014) but the rates of adoption have been below expectations (Spielman and Smale, 2017). Studies on adoption of modern and high-yielding seeds in sub-Saharan Africa exist in the literature (Eriksson et al., 2018; Walker and Alwang, 2015; Alene et al., 2009; Krishna and Quarm, 2008). Some of the studies argue that adoption of improved seed varieties remains low particularly among smallholder producers (Alene et al., 2009; Krishna and Quarm, 2008), and that even where improved seeds are perceived to be available, affordable, and profitable, most smallholder farmers find it difficult to invest in these technologies (Hoogendoorn et al., 2018). Growing body of literature on the adoption of agricultural technology has therefore suggested the rethinking of the way improved seed technology is generated, designed and disseminated to farmers, while finding ways to improve demand for and uptake of improved seed technologies by the

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end-users (Eriksson et al., 2018; Rajendran et al., 2017). Understanding the drivers of adoption will help in redesigning and disseminating improved seed technologies to producers to enhance productivity and farm income.

Adoption of improved seed technology and technical efficiency (TE) of smallholder farmers are interlinked. One strategy of enhancing the productivity of smallholders is to enhance the efficient use of scarce production resources, which reduces technical inefficiency (Anang et al., 2020a). When producers utilize resources efficiently, inputs and improved technologies could further enhance the level of productivity. Where sub-optimal resource allocation exists, there is the need to enhance resource use efficiency. Estimating TE is a key step to diagnosing inefficiencies in resource utilization so as to find ways to improve resource use and ultimately productivity level. Also, success at enhancing uptake of improved seed technology by farmers is expected to translate into higher TE and productivity as well as higher income from farming and improvement in household food security (Anang et al., 2020a).

Some empirical studies have focused on TE of maize farmers in general (Awunyo-Vitor et al. 2016; Addai and Owusu, 2014; Sienso et al., 2013). Other studies have also investigated the impact of improved maize technology on TE (Abdulai et al., 2018a; Ahmed et al., 2017; Obayelu et al., 2016; Owusu, 2016). For instance, the study by Owusu (2016) indicated that adoption of improved maize technology increased producers' TE in Ghana. Abdulai et al. (2018b) also found out that adoption of improved rice technologies enhanced TE among Ghanaian smallholders. Obayelu et al. (2016) reported significantly higher mean TE for farmers who adopted an improved maize variety in Nigeria. Ahmed et al. (2017) reported a 4.42% increase in TE for farmers who adopted improved maize variety in East Hararghe Zone of Ethiopia. What is clear from these studies is that not much attention has been given to analyzing the influence of ISMT adoption on TE and productivity of maize farmers.

The present paper seeks to answer the following research questions. What factors influence the adoption of ISMT in northern Ghana? What factors affect the technical inefficiency of producers adopting ISMT in northern Ghana? What is the direct impact of adopting ISMT on TE and productivity of farmers? The present study is relevant and makes the following contributions. Firstly, the study expands the extant literature by analyzing the influence of adoption of ISMT on TE. Secondly, combining stochastic production frontier analysis and an endogenous treatment-regression model (ETRM) is an innovative empirical estimation strategy. Thirdly, the ETRM addresses self-selection bias, and jointly estimates the factors which influence adoption of ISMT adoption and factors which influence technical inefficiency.

The rest of the paper is organized as follows. Section 2 gives an overview of ISMT adoption in Ghana. Section 3 elaborates on the methodology used, section 4 presents the main findings while section 5 presents the discussion of the results and the implications. Section 6 is devoted to the conclusion and policy recommendations.

2 Overview of ISMT adoption in Ghana

The post-Green Revolution era has seen an increase in investment in agricultural research culminating in crop varietal development and dissemination to farmers globally, and Ghana is no exception. Traditional crop varieties have long been recognized to give lower yields hence, in the face of increasing population growth and declining farm output, attention has been given to developing and disseminating improved varieties that are high-yielding. Many smallholder farmers in developing countries however have long history of cultivating traditional varieties and have become adapted to such varieties over time. Wiredu et al. (2010) observed that farmers preferred local varieties for their palatability and adaptability to the local environmental conditions. In the quest to overcome low crop yields, food insecurity, and declining farm incomes, national agricultural institutions in most developing countries have put in place mechanisms to come out with modern planting materials to producers to replace low-yielding traditional varieties.

In Ghana, institutions like the Savanna Agricultural Research Institute (SARI) and the Crops Research Institute (CRI) have been working for several years to develop and disseminate ISMT to farmers. Currently, there are many improved seed maize varieties made available to farmers. SARI is situated in the northern savanna of the country and plays a major role in crop varietal improvement for the savanna ecological area where this study was conducted (Ragasa et al., 2013; Wiredu et al., 2010). SARI and CRI have rolled out improved seed maize varieties intended to increase farmers' yield and income while boosting food security (Ragasa et al., 2013). Despite the effort by institutions like SARI and CRI to come out with modern seed maize to producers, adoption rates of these improved technologies remain low. For example, low or non-adoption of ISMTs has been blamed for low yield of maize in Ghana (Lobell et al., 2009; Horna

and Nagarajan, 2010; Ragasa et al., 2013). As noted by Alhassan et al. (2016), Ghana is far from self-sufficiency in maize production as a result of current low yield levels. Ghana's maize yield currently averages 1.73 metric tons per hectare (Andam et al., 2017). However, achievable yield of maize from on-farm trials indicates economically attainable yields of approximately 5.5 metric tons per hectare (MoFA, 2015). While the research system in Ghana is actively engaged in developing and disseminating improved seed maize varieties, adoption of same by farmers has not been encouraging. Ragasa et al. (2013) noted that there was no increase in adoption of modern maize varieties by Ghanaian farmers since a 1997 study on adoption.

Currently in Ghana, the improved seed maize distribution system comprises the following. Breeding and varietal development is carried out by the national research institutions, mainly SARI and CRI (Ragasa et al., 2013). These institutes work in close collaboration with regional and international bodies such as CIMMYT whose work involves improving crop genetics. SARI and CRI are responsible for the production of foundation seeds from breeder seeds to maintain genetic quality. Registered seed growers across the country then produce certified seed maize from foundation seeds and distribute the harvest through licensed seed distributors to farmers. Farmers cultivate these certified seeds for a year or two and revert to the seed distributors to acquire fresh certified improved seed maize to avoid planting contaminated seed.

3 Materials and Methods

3.1 Study area, sampling and data collection

This research was conducted in Tolon District of Ghana in 2018 and covered activities for the 2017/2018 farming season. Tolon district is located between latitudes 9° 15' and 10° 0 02' North and longitudes 0° 53' and 1° 25' West. Tolon district is situated in the savanna ecological zone and experiences a unimodal rainfall regime with day temperatures in the range of 33°C and 39°C compared to 20°C and 26°C for night temperatures and rainfall of about 100mm per annum. The vegetation cover is mostly grassland interspersed with short trees and shrubs. Due to the long dry season, which lasts between October to April, the loss of soil organic matter is high leading to depleting soil fertility.

Multi-stage random sampling was employed in the study. Firstly, the district was chosen for its maize production potential and exposure of farmers to improved technologies especially improved maize seed by the Savanna Agricultural Research Institute (SARI), which is involved in crop varietal development and dissemination to farmers especially in northern Ghana. Evidence shows that despite the district's maize production potential, adoption of ISMT has been low, resulting in relatively lower than expected yields (Anang et al., 2020a). Secondly, eight (8) communities were randomly selected. Thirdly, twenty (20) farmers were selected at random from each of the eight selected communities to give a total sample of 180 respondents. The selected farmers were interviewed with a semi-structured questionnaire. The survey solicited information on household, farm, and institutional characteristics. Specifically, we collected data on input and output quantities, age, gender, and farming experience of the farmer, soil fertility status, frequency of weeding, access to credit and agricultural extension.

3.2 The stochastic production frontier model

Following Battese and Coelli (1995), the stochastic production frontier (SPF) used to estimate the technical efficiency was specified as:

$$Y_i = f(X_i\beta)\exp(V_i - U_i) \quad (1)$$

where Y_i denotes maize output, U_i defines a nonnegative error term representing technical inefficiency and V_i indicates the effects of pure random factors on production. The technical efficiency was derived as the ratio of observed output (Y_i) to the frontier output (Y_i^*) as in (2):

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(X_i\beta)\exp(V_i-U_i)}{f(X_i\beta)\exp(V_i)} = \exp(-U_i); \quad \text{where } 0 \leq TE_i \leq 1 \quad (2)$$

The empirical Cobb-Douglas model specified after performing functional form test was¹:

$$\ln Y_i = \beta_0 + \sum_{j=1}^6 \beta_j \ln X_{ji} + V_i - U_i \quad (3)$$

where X_{ji} is a vector of factor inputs including farm size (ha), labor (man-days), seed (kg), fertilizer (kg), pesticide (litres) and capital (Ghana cedis).

3.3 Endogenous treatment-regression model (ETRM)

The study applies the ETRM in the empirical analysis (Trivedi, 2005; Wooldridge, 2010). The advantages of ETRM are that apart from accounting for selection bias due to the non-random assignment of treatment (adopter versus non-adopter), the model could jointly estimate the factors which influence adoption of ISMT and the factors which influence TE or productivity, as well as the impact of ISMT adoption on TE or productivity. We specify the outcome and the treatment equations as:

$$TE_i = w_i\pi + \varphi L_i + v_i \quad (4)$$

$$L_i^* = w_i\gamma + u_i \quad (5)$$

$$\text{where } L_i = \begin{cases} 1, & \text{if } L_i^* > 0 \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

where TE_i denotes the predicted technical efficiency scores after estimating the stochastic frontier model in equation (3) or the productivity of the maize farmers, L_i denotes the variable representing observed adoption of ISMT. w_i is a vector of explanatory variables, L_i^* measures the probability of adoption. β and γ are vectors of unknown parameters, u_i and v_i are random error terms. The error terms follow the bivariate normal distribution with mean 0 and a covariance matrix given as:

$$\begin{bmatrix} \delta^2 & \rho\sigma \\ \rho\sigma & 1 \end{bmatrix} \quad (7)$$

The vector of explanatory variables includes household, farm and institutional characteristics (see Anang et al., 2017; Anang et al., 2016; Owusu, 2016; Asante et al., 2014; Watkins et al., 2014). The household characteristics are age, education, household size and number of cattle (herd size) of the farmer. The farm characteristics are farm size and soil fertility status. The institutional characteristics are extension contacts and credit access. Age is anticipated to have an indeterminate effect on adoption while number of household members, farm size, herd size, and extension contacts are expected to enhance adoption of ISMT. Also, farmers with fertile agricultural land are expected to have higher adoption. When farmers perceive their soils to be infertile and do not have the financial resources to purchase chemical fertilizers, they are more likely to depend on local varieties that have higher adaptability to the local environmental conditions

¹ The generalized likelihood-ratio (LR) was used in the functional form hypothesis test, $\lambda = -2\{\ln[L(H_0)/L(H_1)]\}$, where $L(H_0)$ denotes the value of the likelihood function under the null (H_0), $L(H_1)$ the denotes value under the alternate (H_1) hypothesis and λ has a chi-squared or mixed chi-squared distribution.

and can provide security against total crop failure (Wiredu et al., 2010). Technical efficiency is expected to increase with education (Baruwa & Oke, 2012), herd size (Anang et al., 2017), access to credit (Nkegbe, 2018; Abdallah, 2015) and extension contacts (Abdallah, 2015). Education improves the human capital and facilitates access to information leading to better farm performance. In the same vein, access to extension promotes technology adoption and access to information and services that promote efficiency and productivity. Farm credit enables acquisition of essential inputs to optimize output levels, thus enhancing productivity and TE.

4 Results

4.1 Characteristics of the sampled farmers

The descriptive statistics of the sampled farmers are provided in Table 1. We find that adopters of ISMT had larger farms and used more labor and fertilizer in production compared to non-adopters. The findings agree with expectation since improved seeds typically require more chemical fertilizer and labor input for optimum yield. Consistent with *a priori* expectation, adopters had higher maize output. This shows that adopters are taking advantage of the high-yielding potential of improved seeds to enhance farm output. Furthermore, 36% of the farmers adopted ISMT. The adoption of ISMT is therefore low among the smallholders which is of concern to policy-makers who seek to boost adoption of improved technologies by smallholders to enhance crop yields and farm income. Factors accounting for farmers' adherence to traditional varieties require further investigation in order to find ways to address the problem of low adoption of improved seeds. In addition, adopters had a statistically higher frequency of weeding than non-adopters.

As already indicated, the present study employed the stochastic frontier model (SFM) to estimate the TEs of the farmers. The Cobb-Douglas specification was used in the estimation of the TEs after functional form test (test statistic = 29.68; critical value = 32.67) led to a rejection of the translog specification in favor of the Cobb-Douglas functional form. We present the distributions of the technical efficiencies of the adopters and non-adopters of ISMT with kernel density curves as shown in Figure 1. The figure shows higher kernel distributions of technical efficiencies for adopters and non-adopters of ISMT on the right-tails of the distributions. However, the distribution of technical efficiencies of adopters of ISMT tend to be relatively higher at the peak (TE = 0.8) than the non-adopters of ISMT.

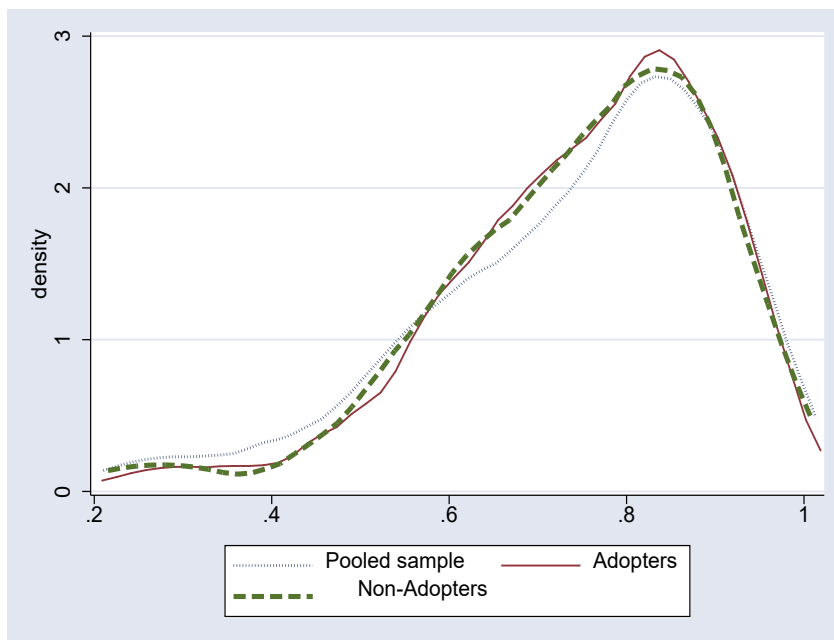


Figure 1: Distribution of technical efficiencies of adopters and non-adopters of ISMT.

Table 1: Characteristics of the farmers.

Variable	Definition of variables	Adopters (n = 64)	Non-adopters (n = 116)	Mean Difference
		Mean (SD)	Mean (SD)	
<i>Outcome</i>				
Efficiency	Technical efficiency	0.748 (0.147)	0.728 (0.014)	0.020
Maize productivity	Output per hectare	742.7 (25.43)	705.2 (17.75)	37.51
<i>Factor inputs</i>				
Farm size	Farm size in hectares	2.324 (0.192)	1.936 (0.100)	0.388**
Labor	Quantity of both family and hired labor in man-days	101.0 (58.41)	84.54 (42.64)	16.46**
Seed	Quantity of seed in kilograms	28.66 (18.06)	25.32 (14.47)	3.34
Fertilizer	Quantity of fertilizer in kilograms	686.3 (452.2)	499.4 (283.2)	186.9***
Pesticides	Quantity of pesticides in liters	5.094 (3.481)	4.379 (3.134)	0.715
Capital	Farm capital in Ghana Cedis	164.0 (99.59)	176.8 (99.12)	-12.8
<i>Household characteristics</i>				
Age	Age of farmer (in years)	35.88 (7.685)	33.66 (10.32)	2.22
Farming experience	Years of maize farming	20.06 (1.022)	19.01 (0.967)	1.054
Educational status	Dummy: 1 if educated; 0 otherwise	0.375 (0.488)	0.267 (0.444)	0.108
Household size	Number of household members	9.672 (5.512)	10.88 (5.115)	-1.208
Herd size	Number of cattle owned	4.063 (5.626)	3.638 (5.875)	-1.812
<i>Farm characteristics</i>				
Fertile soil	Dummy = 1 if soil is fertile; 0 otherwise	0.141 (0.044)	0.103 (0.028)	0.038
Moderately fertile soil	Dummy = 1 if soil is moderately fertile; 0 otherwise	0.781 (0.052)	0.716 (0.042)	0.065
Infertile soil	Dummy = 1 if soil is infertile; 0 otherwise	0.078 (0.034)	0.181 (0.036)	-0.103*
<i>Institutional characteristics</i>				
Extension visits	Dummy = 1 if farmer accessed extension service; 0 otherwise	0.156 (0.623)	0.138 (0.526)	-0.37
Access to credit	Dummy = 1 if farmer accessed credit; 0 otherwise	0.703 (0.460)	0.621 (0.487)	0.082

***, ** and * signify significance at 1%, 5% and 10%, respectively.

Figures in parentheses are standard deviation (SD).

Exchange Rate: 1 US\$ = GH¢ 4.5 in 2018.

Table 2: Estimates from the endogenous treatment regression model (ETRM).

Variable	(1)		(2)	
	Selection	Technical efficiency	Selection	Productivity
<i>Household characteristics</i>				
Age	0.049** (0.024)	0.003 (0.002)	0.049** (0.023)	0.006 (0.005)
Education	0.462** (0.230)	- 0.061** (0.026)	0.479** (0.230)	-0.112** (0.051)
Household size	- 0.055** (0.023)	- 0.001 (0.002)	-0.052** (0.023)	0.003 (0.005)
Farming experience	0.040 (0.041)	- 0.006 (0.004)	0.045 (0.039)	-0.009 (0.008)
Farming experience squared	- 0.002** (0.001)	0.000 (0.000)	-0.002*** (0.001)	-0.0001 (0.0001)
Herd size	- 0.004 (0.021)	0.008*** (0.002)	-0.004 (0.021)	0.013*** (0.004)
<i>Farm characteristics</i>				
Farm size	0.247** (0.106)	- 0.031*** (0.011)	0.100** (0.042)	-0.016* (0.009)
Moderately fertile soil	- 0.387 (0.319)	- 0.078** (0.035)	-0.340 (0.321)	-0.166** (0.071)
Infertile soil	- 1.039** (0.447)	- 0.231*** (0.047)	-0.965** (0.440)	-0.482*** (0.092)
<i>Institutional characteristics</i>				
Extension visits	0.355* (0.206)	0.001 (0.021)	0.362* (0.200)	0.006 (0.042)
Credit access	0.278 (0.221)	- 0.029 (0.023)	0.257 (0.217)	-0.052 (0.047)
Constant	- 1.991*** (0.005)	0.865*** (0.071)	-2.098*** (0.712)	6.678*** (0.146)
<i>Treatment effect (ATT)</i>				
Adoption of ISMT		0.161** (0.068)		0.338*** (0.102)
<i>Statistics</i>				
athrho		- 0.918** (0.412)		-0.933*** (0.294)
Insigma		- 1.978*** (0.128)		1.252*** (0.100)
Wald test of independent equations ($\rho = 0$)		$\chi(1)=4.96^{**}$		$\chi(1)=10.05^{***}$

***, ** and * signify significance at 1%, 5% and 10% levels respectively.

The reference dummy for fertility status is fertile soil

Figures in parentheses are standard errors

4.2 Empirical Estimates of the ETRM

The empirical estimates of the ETRM are shown in Table 2. As indicated, the ETRM model provides estimates of factors influencing technical efficiency or productivity, and factors influencing ISMT adoption.

4.2.1 Factors influencing adoption of ISMT

The selection models in Table 2 show the estimates of factors influencing ISMT adoption. We find that adoption of ISMT increased with producer's age at 5% level. The study further reveals that farming experience is positively correlated with adoption but the result is not significant. However, the quadratic term of the farming experience variable is significant and exhibits an inverse relationship with adoption at 5% level. Adoption therefore seems to increase at a decreasing rate with farming experience. Educated farmers had higher adoption in comparison to the uneducated at 5% level, which is in line with expectation. The probability of ISMT adoption decreased with household size at 5% level. Adoption of ISMT increased with farm size at 5% level implying that respondents with larger farms have a higher likelihood to embrace improved seeds to enhance productivity. As expected, adoption increased with extension contact, even though this was only at the 10% level. The findings further highlight the importance of farmers' perception of soil fertility status on improved variety adoption. Farmers who perceived their soils to be infertile had a lower likelihood to adopt ISMT at 5% level.

4.2.2 Determinants of technical efficiency

Table 2 also shows the factors affecting TE. Contrary to *a priori* expectation, TE decreased with education (at 5% level). This suggests that educated farmers were less technically efficient in production. TE also decreased with farm size (at 1% level). This suggests that as farm size increases, farmers become less technically capable of maximizing output from the input combinations. The study also revealed that herd size positively influenced efficiency (at 1% level). Farmers' perceptions of their soil fertility status significantly influenced TE. Farmers who perceived their fields to be infertile were less technical efficient compared to those who had fertile farmlands. Similarly, farmers who perceived their soils to be moderately fertile were less technically efficient in production in comparison to those who had fertile lands.

4.2.3 Determinants of Productivity

The determinants of productivity include herd size, suggesting that farmers who own farm animals are more productive. In line with expectation, farmers with soils lower in fertility had lower productivity. Furthermore, productivity decreased with farm size, signifying that smallholders become less productive when their acreages increase. Contrary to expectations, educated farmers were less productive than non-educated farmers.

4.2.4 Impacts of ISMT adoption on technical efficiency and productivity

Also indicated in Table 2 are the average treatment effects (ATT) which shows the impacts of adoption of ISMT on TE and productivity. The results show that adopting ISMT leads to 16.1% increase in TE of maize farmers. We also find that adoption of ISMT is associated with 33.8% increase in maize productivity, which goes to support the need to encourage smallholder farmers to plant improved seeds to optimize farm yields.

5 Discussions

5.1 Characteristics of the sample according to adoption status

In line with expectations, adopters of ISMT used more of the production inputs namely land, labor and chemical fertilizer. Improved varieties usually require more application of production inputs to give optimum yield. It is therefore expected that farmers' access to production inputs will affect their decision to adopt ISMT. Making these production inputs accessible and affordable to farmer is therefore essential to promote adoption and level of productivity. Adopters produced more maize than non-adopters, justifying the high-yielding potential of improved seeds. The higher output of adopters could also be attributed to the use of higher levels of production inputs such as chemical fertilizer and land. Encouraging smallholder farmers to plant improved seeds is therefore essential to improve farmers' output level. The results further reveal low adoption of ISMT among the respondents. Only 35.5% of respondents planted improved seeds, suggesting that producers still rely on traditional seeds. Measures to improve ISMT adoption should therefore include assessment of the factors that encourage the use of traditional varieties by farmers, and improving the desirability of improved seeds to enhance adoption. Understanding the socio-cultural setting and practices of rural people is essential to ensure that smallholders embrace new technologies.

5.2 Factors influencing adoption of ISMT

Adoption of improved seeds has gained the attention of researchers and policymakers for a long time. There is sufficient evidence showing that improved seeds provide better yields, and may also have other desirable characteristics such as early maturing and ability to withstand diseases. Despite these well-known technological benefits, adoption of improved seeds by farmers is not always guaranteed. Farmer-specific factors, characteristics of the technology, the ease of adoption or otherwise, and other socio-economic and institutional factors interplay to shape farmers' adoption decision. The influence of age on adoption decisions is somehow indeterminate. It has been argued that older farmers by virtue of years of farming experience, have higher adoption decision. However, older farmers may also have large families and greater responsibilities which may reduce their ability to patronize improved seeds. Also, older farmers may have bad experiences with adoption in the past that may shape their future adoption decisions. On the other hand, it has been argued that younger farmers may be more enterprising and adventurous, hence more likely to adopt improved technologies such as improved seeds. The result of this study however points to a positive influence of age on farmers' adoption decision. Older farmers are more knowledgeable and understand the benefits of modern technologies. The finding is corroborated by Islam et al. (2012) in their study in Bangladesh but at variance with that of Danso-Abbeam et al. (2017) on farmers' adoption decisions in Ghana.

A key determinant of technology adoption in the existing literature is farmers' level of education (Diirro et al., 2015; Gebresilassie and Bekele, 2015). Educated farmers tend to have higher adoption compared to the non- or less-educated, which is supported by the finding of this study. The result is corroborated by Danso-Abbeam et al. (2017) who investigated improved maize adoption decisions of smallholder farmers in Ghana. As indicated by Diirro et al. (2015) and Gebresilassie and Bekele (2015), educated farmers can process and assimilate information much better than the uneducated resulting in higher likelihood of adopting fertilizer and improved wheat variety, respectively.

Farm size plays a critical role in farmers' adoption decision. When viewed as a business, a large farm size signifies a larger business, which all things being equal, should be in demand for improved inputs such as improved seeds to maximize production. Large-scale farmers may be regarded as progressive with more entrepreneurial ability, hence more likely to use more external inputs in production. On the other hand, farmers with smaller farms may be landless and less resource-endowed which may hinder technology adoption. As indicated by the finding of this study, ISMT adoption correlates positively with farm size. The finding is similar to that of Ogada et al. (2014) on uptake of chemical fertilizer and improved maize varieties in Kenya.

A major determinant of farmers' adoption decision is access to agricultural extension (Anang et al., 2020b), which is corroborated by the result of this study. Extension agents help producers to access information on productivity-enhancing technologies and link farmers to service providers and input markets. Through extension agents, farmers

are able to learn about modern technologies and their potential benefits, thus increasing the likelihood of adoption. This is confirmed by Anang et al. (2020b) who observed that access to agricultural extension enhanced technology adoption by peasant farmers in Ghana.

One of the justifications for smallholder farmers planting traditional seeds is that such seeds can give some minimal yield even under adverse conditions such as low soil fertility, as compared to improved seeds which require more favorable conditions to give good yields. Hence, adoption is expected to be lower where farmers perceive their soils to be low in fertility, and do not have the means to acquire the inputs required to increase the fertility level. It is therefore not surprising that farmers who perceive their soils to be very infertile had lower adoption of ISMT. The result is plausible since improved maize varieties do not give good yields when soil fertility is low. Risk-averse producers who perceive their farmlands to be infertile are therefore more likely to choose traditional varieties that are adapted to the local environment but may be low-yielding.

Adoption decision is very much related to labor availability, since improved technologies usually require greater input use. Smallholder farmers are labor-intensive in production and therefore rely heavily on household labor. Hence, it is anticipated that adoption decision will positively correlate with household size, and invariable labor availability. The result, which indicates an inverse relation between household size and IMT adoption, is contrary to expectation. However, it may be argued that larger households face greater financial obligations, which may make it difficult to purchase improved seeds. The result leans towards that of Danso-Abbeam et al. (2017) in their maize adoption study in Ghana.

An important determinant of adoption decision in the extant literature is farmers' years of farming experience. Generally, more experienced farmers are expected to have higher adoption due to their improved knowledge of the benefits of improved technologies and years of experimentation. This is corroborated by findings indicating higher adoption by experienced farmers (Ahmed and Anang, 2019; Danso-Abbeam et al., 2017). The current study, although pointing to a positive influence of experience on adoption, did not show statistical significance as expected. The quadratic term however indicates that more experience farmers tend to adopt less. What the result suggests is that the adoption decision somehow increases at a decreasing rate with farming experience.

5.3 Determinants of technical efficiency

Education is a major determinant of efficiency level of farmers, with several studies reporting a positive effect of education on TE. However, there are other studies which have reported lower TE for educated farmers. Reasons for this could be that educated farmers who are more employable, may be involved in other non-farm employment, thus reducing their involvement in farm activities. The result aligns with that of Anang et al. (2017) in their study involving Ghanaian smallholder rice farmers. The positive influence of herd size on TE is an expected result mainly because of the interrelation between crop and livestock farming in smallholder agriculture. The result attests to the fact that farm animals play a useful role in smallholder agricultural production where they are used to perform farm operations such as carting of inputs to the farm, thus saving time and reducing drudgery. Manure from farm animals also enhances soil fertility status, thus enhancing farm yields. The result aligns with that of Anang et al. (2017), which showed that TE of Ghanaian rice producers increased with herd ownership. An ongoing debate is the farm size – productivity relationship in smallholder agriculture. While some authors argue that large-scale farmers are more productive, others hold the view that smaller farmers are more productive. This study shows that farmers with large farms have lower TE in production. The result aligns with that of Anang et al. (2016) on scale efficiency of rice producers in Ghana. Watkins et al. (2014) also support this finding. Generally, smallholders tend to lack the technological know-how to manage large farms, so when their acreage increases, this introduces more sources of inefficiency in production. The study further highlighted the importance of soil fertility status on farmers' efficiency level. Farmers' perception of their soil fertility status is expected to influence their decision making in terms of resource allocation. For example, farmers who perceive their soils to be infertile may be less likely to adopt ISMT due to the higher nutrient requirements of improved varieties. Under such situation, farmers may cultivate traditional varieties which may give lower yield but which may be more suited to the prevailing environmental conditions.

5.4 Determinants of productivity

In smallholder agriculture, farm animals are usually used by many farmers for farm activities such as traction and transportation of farm inputs thereby reducing drudgery and thus enhancing farm yield. It has also been argued that farmers in developing countries with small farms are more productive than those with large farms. This study supports the assertion that farm size and productivity are inversely related. The result could suggest that smallholders may not have the managerial ability to operate bigger farms. Furthermore, as alluded to by other authors (Anang et al., 2017), educated farmers may be less productive in farming if they are engaged in other non-farm activities that compete with their time for on-farm activities.

5.5 Impacts of ISMT adoption on technical efficiency and productivity

The main objective of the study was to evaluate the impact of ISMT adoption on TE and productivity. The finding of the study agrees with a priori expectation, which suggests that improved technologies enhance efficiency of production and level of productivity. ISMT is high-yielding and when combined with the right quantities of other inputs such as inorganic fertilizer, can give optimum yield levels. Other results support the positive impact of improved seeds on TE of maize farmers. The result agrees with the finding of Owusu (2016) which indicated that adopters were 6 – 8 percent more technically efficient in comparison to those who did not adopt. Thus, Ghanaian smallholder maize farmers who planted improved varieties made significant efficiency gains as compared to those who relied on traditional seeds. Reasons for farmers' reliance on traditional seeds, despite the high-yielding potential of improved seeds, include the high input demands for improved seeds, inability to purchase improved seeds, and farmers' fear of total crop failure in the event of erratic rainfall and change in climatic factors. Farmers perceive traditional seeds to outperform improved seeds when weather and agronomic conditions are less favorable since traditional seeds are more adapted to the environment (Wiredu et al., 2010). Hence, efforts aimed at improving adoption of ISMT (to enhance TE and productivity levels) should include the provision of subsidized inputs and credit facilities to farmers to promote adoption.

5.6 Implications for Practice

Adoption of ISMT is a critical factor that promotes technical efficiency and productivity of smallholder farmers. Despite this realization, many smallholder farmers still cultivate traditional varieties that are relatively low-yielding but have the ability to withstand environmental shocks. Hence, farmers' adoption decision is influenced by other factors such as livelihood security and the risk aversion of producers. Furthermore, concerns such as palatability and adaptability of the crop variety play a vital role in smallholders' decision to adopt. It is therefore important to factor in these considerations when designing packages for smallholder farmers.

The cost of adopting improved varieties remains at the core of farmers inability to adopt improved varieties. Farmers in dire financial needs are unlikely to be able to meet the cost of complementary inputs like chemical fertilizers and herbicides required to achieve optimum yield in the case of improved varieties. Increasing smallholder farmers' access to input subsidies is therefore critical to promote adoption. Currently, there is in place an input subsidy policy in Ghana which has improved fertilizer application rates among farmers. However, concerns remain about several smallholder farmers not being able to access the subsidy.

The study also highlighted the influence of soil fertility status on adoption decisions, technical efficiency and farm productivity. Farmers' perceptions of low fertility of their soils correlated with lower adoption, lower efficiency and lower productivity. Hence, the drive to promote ISMT adoption requires that soil fertility management is put in the forefront of such efforts. Extension agents must be adequately resourced to train farmers on soil fertility management.

6 Conclusion and Policy Recommendations

The study evaluated the influence of ISMT adoption on TE and productivity of smallholders in northern Ghana. An ETRM was applied to assess the impact of adoption on TE and productivity. The results revealed that TE improved with ISMT adoption. Adoption of ISMT increased TE by 16.1%, justifying the need to facilitate improved seed technology development and dissemination to smallholders to enhance TE of producers which is necessary to improve productivity, food and income security. Adoption of ISMT increased productivity by 33.8%. From a policy perspective, it is further suggested that producers should be motivated and supported to improve soil fertility as this correlated negatively with TE. Farming on soils that are low in fertility is a disincentive to ISMT adoption, hence the need to promote and train farmers on soil fertility management. Improving smallholders' access to subsidized chemical fertilizer and improved seeds under the Planting for Food and Jobs (PFJs) initiative is another way to promote adoption and TE of maize producers.

6.1 Limitations of the Study and Suggestions for Further Research

One limitation of this study is that it relied on a relatively small sample size. The sample size was limited due to resource constraints and lack of funding. Hence, it is suggested that future research should consider using an expanded sample size that covers a wider geographical area. Future study covering different ecological zones of the country is suggested to shed more light on adoption decisions and farmers' efficiency and productivity level. Also, from a methodological point of view, this study used the ETRM to control for sample selection bias. While this approach is innovative and intuitively appealing, its application in the context of efficiency analysis has been minimal. Hence, further research could consider more popular approaches such as the procedure proposed by Greene (2010) to address sample selection bias in efficiency analysis. The research's other limitations include the reliance on farmers' self-reported information, with the potential for common method bias. This is particularly important where respondents attempt to impress the interviewer by providing falsified responses. Aware of such possibilities, measures to control measurement bias were introduced by the interviewers. The measures included the use of triangulation (asking the same question in different ways), pre-testing the questionnaire to remove or rephrase sentences that introduce bias, and the use of random sampling and one-on-one interviews. Another concern is that most smallholders do not keep farm records, hence soliciting production information necessarily requires the use of farmers' self-reported information. To reduce biasedness and improve reliability of the data, the data was collected within the shortest possible time after the farming season had ended. Timely data collection soon after the farming season helps farmers to recollect with less bias.

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Appendix 1

Table 4: Estimates of technical efficiency model for maize production in Tolon District.

Variable	Coefficient	Standard Error	P> z
Farm size	0.733***	0.121	0.000
Labor	0.027	0.073	0.713
Seed quantity	0.126	0.098	0.200
Fertilizer	0.156***	0.060	0.009
Pesticide	0.010	0.015	0.525
Capital	0.071*	0.043	0.097
Constant	0.308***	0.029	0.000
/lnsig2v	- 4.192***	0.382	0.000
/lnsig2u	- 1.668***	0.172	0.000
Returns to scale	1.122		

*** and * imply significance at 1% and 10% level, respectively.