UNIVERSITY OF CAPE COAST

EFFECT OF FARM SIZE ON EFFICIENCY, PLOUGHING TECHNOLOGY AND FOOD SECURITY AMONG MAIZE FARMERS IN THE NORTHERN REGION OF GHANA

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Signature:………………………….. Date…………………

Name: Francis Taale

Supervisors' Declaration

We hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis as laid down by the University of Cape Coast.

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ABSTRACT

Farm size has been identified as a significant determinant of resource use efficiency, household food security and choice of improved agricultural methods. However, empirical literature is replete with controversies concerning the exact nature of this relationship. This study examined the relationship between farm size, efficiency, ploughing technology and household food security among maize farmers in three districts of the Northern Region of Ghana by addressing some of the methodological weaknesses in existing studies with respect to the use of cross-sectional dataset and skewed preferences for the two-stage estimation procedure. Employing a three-year balanced panel dataset on 787 households, the study examined the relationship between farm size and efficiency. With the same sample, the study also investigated the relationship between farm size and choice of ploughing technology using the multinomial probit regression model, and the association between farm size and household food security using a probit regression model. Empirical results indicate that there is a significant positive relationship between farm size and efficiency. It was also established that farm size had a significant positive influence on choice of ploughing technology whereas there was no statistically significant relationship between farm size and household food security. Findings from this study have implications for designing land consolidation initiatives and public policies on improving household food security through the adoption of fertiliser and fostering participation in social network as well as livestock production.

KEYWORDS

Efficiency

Farm size

Household food security

Panel data

Ploughing technology

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DEDICATION

To my family and the late Love Kwaku Bedjo Tsifoko Quarshiegah

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LIST OF ACRONYMS

CRTS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DMUs	Decision-Making Units
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GLSS	Ghana Living Standards Survey
GPS	Global Position System
GSS	Ghana Statistical Service
IPA	Innovations for Poverty Action
ISSER	Institute of Statistical, Social and Economic Research
LHRT	Likelihood Ratio Test
MoFA	Ministry of Food and Agriculture
OLS	Ordinary Least Square
PAS	Presbyterian Agricultural Service
SFA	Stochastic Frontier Analysis
SNM	Savelugu-Nanton Municipality
SNMA	Savelugu-Nanton Municipal Assembly
TAM	Technology Acceptance Model
TLU	Tropical Livestock Unit
TMA	Tamale Metropolitan Assembly
VRTS	Variable Returns to Scale
WMD	West Mamprusi District
WMDA	West Mamprusi District Assembly

CHAPTER ONE

INTRODUCTION

Higher efficiency in agricultural production propelled by the adoption of improved farming technology is regarded as a necessary precondition for achieving economic growth and industrialisation while ensuring environmental sustainability (Todaro & Smith, 2015). It is also viewed as a critical determinant of rural welfare and an avenue through which the earnings of peasant households can be raised in order to boost the demand for manufactured consumer products. According to neo-classical economic theory, higher agricultural productivity brought about by the mechanisation of agricultural processes can promote economic growth and development by facilitating the transfer of surplus labour from the agricultural sector to other sectors of the economy (Lewis, 1955).

Currently, it is estimated that more than 60 percent of the people in Ghana depend on agriculture for a bulk of their livelihoods (Emmanuel, Owusu-Sekyere, Owusu, & Jordaan, 2016). This means that the transfer of surplus labour from the agricultural sector to industries fuelled by improvements in technical efficiency and the adoption of modern farming technologies has the potential to contribute more meaningfully to economic growth and development including ensuring household food security. There is the need, therefore, to fully understand the drivers of resource use efficiency, choice of ploughing technology and the food security situation of smallholder farmers in various agro-ecological zones of the country.

Farm size has been identified as a significant determinant of resource use efficiency, household food security and ploughing technology adoption

(Alem, 2013; Madau, 2011; Wongnaa, 2016). However, literature is replete with controversies concerning the exact nature of this relationship. Among other issues, the relationship between farm size, resource use efficiency, food security and ploughing technology among maize farmers in Ghana is not well known due to the scanty nature of empirical studies in this area.

The role of this thesis is to contribute to the debate regarding the relationship between farm size, technical efficiency, ploughing technology and household food security by addressing some of the methodological weaknesses in existing studies with respect to the use of cross-sectional dataset and skewed preferences for the two-stage estimation procedure. By combining the stochastic frontier analysis (SFA) and the data envelopment analysis (DEA), the study is able to examine whether the relationship between farm size and resource use efficiency is influenced by the choice of estimation technique as espoused by previous studies. Aided by a balanced panel dataset on 787 maize farmers, the study also investigates the effect of farm size, efficiency and ploughing technology on household food security, thus expanding the discourse on the effect of alternative ploughing technology on welfare.

In this first chapter, the background to the study, statement of the problem, objectives, the significance of the study, scope of the study, and the organisation of the study are discussed.

Background to the study

The importance of agricultural productivity growth fuelled by the adoption of improved farming technology in the development process of the advanced economies is well recognised and documented in the literature

(Lewis, 1955; Todaro & Smith, 2015). Evidence based on systematic reviews of development history highlight the fact that higher levels of agricultural productivity facilitated by the adoption of mechanised operations and heavy substitution of manual power with machines in the farming process played a major role in the development efforts of Europe, North America and Asia (Hayami & Ruttan, 1985).

Todaro and Smith (2015) have outlined the significant role that the interaction between technology and agriculture played in the growth and development processes of the advanced countries. These authors advanced that before economic growth and development could take place and become self-sustaining in today's advanced economies, it ultimately had to start in the rural areas in general and in the agricultural sector where a significant proportion of the population was initially employed. This was facilitated first by the introduction of more effective and reliable technology in the agricultural sector that led not only to the growth of output per agricultural worker but also to the transfer of surplus labour to other areas of the economy. The replacement of manual power with machines for most farming processes also led to the creation of strong forward and backward linkages between agriculture and industry.

To achieve high and sustained level of economic growth and development, Arthur Lewis, through what came to be known as the *dual sector theory of economic development*, argued that most advanced economies had to put in a number of measures that allowed them to break down barriers inhibiting the agricultural sector in general and food crop producers in particular. One of these measures was the widespread reduction of manual power in land tilling processes and introduction of machines which led to the expansion of agricultural output and led to the availability of cheap raw materials for the smooth and effective functioning of agro-based industries. Similarly, the introduction and subsequent widespread adoption of improved farming methods contributed to the creation of excess labour for agricultural production and to the transfer of surplus hands to industries (Lewis, 1955), all of which created the impetus for economic growth and development.

As advanced by Lewis (1955), the transition from a state of total reliance on the production of primary agricultural products employing outmoded and inefficient production technologies to a condition of dualism, with the coexistence of a strong technology-driven agricultural sector and a vibrant and highly commercialised industrial sector was a significant landmark and major precondition for the economic progress of today's advanced economies. This dual sector creates incentives which did not previously exist, and thus provides a new form of saving. In Lewis' view, profits create the relevant incentives for the owners of capital in the industrial sector to innovate by developing products and services needed by the agricultural sector whereas the possibility of acquiring assets in the industrial sector provides incentives to farmers and other workers in the agricultural sector. Implicitly, the *dual sector theory of economic development* assumes that growth of employment in the industrial sector is proportional to the rate of capital formation in both the industrial and agricultural sectors. In that regard, any innovation which increases the productivity of the subsistence sector has the potential to increase real wages in the industrial sector and contribute to industrial sector growth and advancement, thus reducing poverty and malnutrition.

Extending the *dual sector theory*, Thirlwall (2006) argued that because of the dominance of the agricultural sector in the economic structure of most developing countries, important factors like the physical attributes of land, the land tenure system, the ratio of labour to land and the extent of natural resource endowment are likely to affect the speed of economic growth and development by influencing the pace of agricultural production and modernisation. Thirlwall further opined that once agricultural producers emerge from a stagnatory subsistence state and begin to specialise and produce goods for export, and industry develops under the impact of growth in the agricultural sector, the two sectors of agriculture and industry will become much more interdependent and effective in contributing to economic growth and development.

According to Thirlwall (2006), higher agricultural productivity is good for both the agricultural sector and industrial sector because it increases the demand for goods produced by farmers and absorbing surplus labour created by the mechanisation of agricultural processes while the agricultural sector also provides a ready market for industrial goods arising out of higher real income for farmers and factor contribution to development through the release of resources for agro-based industries. In Thirlwall's view, agricultural productivity achieved by higher efficiency and adoption of modern ploughing technologies permits the release of surplus labour from agriculture to industry and the production of cheap raw materials for industrialisation; which in turn leads to increasing returns, rising income per capita and greater capital accumulation and improved welfare for all.

Hunt and Lipton (2011) reported that faster growth in agriculture facilitated by technology adoption was central to the economic growth and development processes of the advanced countries; and that adoption of modern farming technologies must take centre stage in low-income countries if any meaningful economic growth and development is to take place in these countries. Similarly, Schultz (1964) indicated that the low productivity of farm labour in traditional agriculture is due more to an absence or low application of specific factor inputs than to a shortage of reproducible capital. Further, Schultz maintained that the most practical and economical thing to do in order to achieve sizeable increase in agricultural productivity resides in enhancing the efficiency of existing agricultural producers through improvements in the quality of factor inputs they use, and by the application of advances in knowledge and modern technology on a broader front.

According to Schultz (1964), additional quantities of existing basic inputs will achieve no meaningful result in increasing agricultural efficiency without changing the mode of production currently being used by farmers in developing countries. Contrary to the conventional wisdom that a stagnant agricultural sector is the result of reluctance on the part of peasant producers to respond to price incentives, Schultz argued that low returns to agriculture caused by the dependence on primitive and outmoded technologies is the root cause of the antipathy to work and investment in the agricultural sector. In addition, Hayami and Ruttan (1985) advanced that the creation of a strong and resilient agricultural system backed by the application of modern processes and procedures for increasing food production played a fundamental role in the economic growth and development of many advanced countries and is the most reliable long-term strategy for overcoming poverty in low-income countries. Moreover, Mellor (1995) posited that an integral part of the modernisation of the economies of high income countries was the decline in the economic importance of subsistence farming based on traditional tools and a rise in skills and knowledge including the knowledge to adopt and make use of modern production technologies.

Krueger, Valdés and Schiff (1991) have documented that countries with high levels of productivity in other sectors of their economies and modest or no discrimination against their agricultural sectors have achieved high levels of industrialisation while countries with low levels of productivity and a strong bias against agriculture through trade and pricing policies have also failed in their bid to industrialise. Parente and Prescott (2000) posited that differences in per capita national income between the developed and developing countries are a result of differences in total factor productivity in key sectors including the agricultural sector; which in turn are the results of country-specific characteristics that cause constraints in work practices and technology adoption.

Higher levels of agricultural productivity brought about by the substitution of manual power with machine tools for farming also played and continue to play a leading role in the development efforts of many South American countries, particularly Argentina and Brazil (Spolador & Roe, 2013). The importance of an agricultural sector that embraces modern technology in contributing to economic advancement and food security has also been highlighted in the literature. For example, World Bank (2009) showed that a small increase in growth in agriculture caused by the adoption of improved farming technology is on average twice as effective in reducing poverty and hunger compared to growth in non-agricultural sectors of the economy.

Through its report, *Awakening Africa's Sleeping Giant*, World Bank (2009) asserted that reducing poverty in Africa over the next decade will depend largely on stimulating agricultural growth through widespread application of modern farming techniques and improvements in the efficiencies of existing producers. Wiebe, Soule and Schimmelpfennig (2001) also noted that for Sub-Saharan Africa to meet the food security needs of its citizens in the next decades, agricultural production in the region will need to grow by one to two percent greater than even the most optimistic projections. This inherently implies the replacement of the tools and methods currently being employed by agricultural producers in the region.

Kevin (1993) points out that economic growth of at least four percent per annum in the continent will require the agricultural sector in most countries to be mechanised and to grow by more than the forecasted Gross Domestic Product (GDP) growth rate of four percent. Dorward, Kydd, Morrison and Urey (2004) illustrate the complementary relationship between growth in agriculture and growth of industries on the one hand, and between growth-enhancing policies and welfare on the other hand. Dorward *et al.* argued that, in addition to largely benefitting poor people, short to medium term agricultural growth brought about by the adoption of improved ploughing technologies creates potential synergies between welfare support and nationwide economic growth and development efforts.

Boccanfuso and Kabore (2004) highlighted that growth in the agricultural sector in general, and in the food crop subsector in particular contributes more to poverty reduction than macroeconomic growth. Specifically, Boccanfuso and Kabore estimated that increasing the productivity of food crop farmers by motivating them to adopt improved ploughing methods will result in at least 80 percent reduction in poverty. This is so because many low-income households tend to have more of their household members employed in jobs with higher linkages to food crop production than to other sectors of the economy.

Applying a Ramsey framework, Irz and Roe (2005) demonstrated that a small increase in agricultural productivity has drastic implications for economic growth and poverty reduction than higher growth in non-agricultural sectors. Similarly, Todaro and Smith (2015) drew attention to the significance of agriculture and argue that it is in this sector where the battle for long-term economic growth and development in low-income countries will be won or lost. They highlight the forward and backward linkages that exist between agriculture and a spectre of economic outcomes including food security, poverty reduction and demand for industrial goods fostered by an active and resilient rural economy.

Corroborating the same view, Ogada and Nyangena (2015) articulated that, for most Sub-Saharan African countries, the adoption of sustainable agricultural practices that enhance agricultural productivity and improve environmental outcomes remains the most pragmatic option for achieving economic growth, food security and poverty alleviation. They also recognised the important role of agricultural research and technological improvements, and in particular research which focus on smallholder farmers, the environments within which they operate, and their most common crops.

Unfortunately, the historical regularity in which rapid economic growth and development is preceded by sustained agricultural growth resulting from the adoption of improved ploughing technology is yet to occur in many African countries (Abate, Rashid, Borzaga, & Getnet, 2016; Wiebe *et al*., 2001). Between 1966-1968 and 2006-2008, for example, farm output per person fell by 25 percent in Sub-Saharan Africa while it doubled in South Asia and tripled in East Asia (Hunt & Lipton, 2011).

In addition, land productivity in Sub-Saharan Africa's agriculture rose by an average of 1.9 percent per year between 1980 and the mid-1990s, while it increased by 3.4 percent and 2 percent per year in South Asia and Latin America and the Caribbean respectively (Zepeda, 2001). Over the same period, crop production in Sub-Saharan Africa grew by 2.7 percent per year, and food production rose by 2.4 percent per year. By contrast, labour productivity in agriculture in the region dropped by an average of one percent per year whereas it increased by 1.9 percent and 2.5 percent per year in South Asia and Latin America and the Caribbean. Further, food insecurity affected nearly one-third of the population in Africa between 2012 and 2013 (Zouhair, 2014). Moreover, it has been proven that while agriculture is central to Africa's economic growth and development, the performance of the agricultural sector in most African countries has seriously lagged behind (Kariuki, 2011; Kendie, 2002; Ojo, 2009).

Venkatesan and Kampen (1998) advanced that growth in agricultural production in Sub-Saharan Africa in the past was achieved by expanding the amount of land cultivated, but today there is little scope for using this route due to the declining per capita landholding and absence of unused fertile lands. According to Venkatesan and Kampen, the only defensible option left for increasing agricultural production amid land scarcity and rising population is the adoption of efficient labour-saving production techniques. Moreover, Wiebe *et al.* (2001) argued that though expected increase in agricultural output from improved technology and price policies are generally very difficult to quantify, such improvements are prerequisites to make possible the increases in productivity from the use of conventional inputs and research. Their study concluded that educating rural dwellers about the significance of modern farming technologies is imperative for the future prospects of agricultural productivity growth in Sub-Saharan Africa.

Compared to other regions of the world, Sub-Saharan Africa is the only place where yields of maize have remained typically low; measuring about one tonne per hectare (Food and Agricultural Organization [FAO], 2008), and where food security and livelihoods are deteriorating in real terms (Kendie, 2002; Todaro & Smith, 2015). Literature suggests that maize growing households in Sub-Saharan Africa have been lagging behind their counterparts in other countries with respect to the adoption of modern farming technologies (FAO, 2011; Krishnan & Patnam, 2014; Sheahan & Barrett, 2017; Takeshima, Pratt, & Diao, 2013). For example, Sheahan and Barrett indicate that the ownership of agricultural machinery and adoption of modern inputs of production remains very rare among farmers in Africa. Meanwhile, Takeshima *et al*. indicate that mechanised land preparation is currently used by only a handful of farmers in the continent.

According to FAO (2011) and FAO (2008), the number of tractors per 1000 hectares of arable land in Sub-Saharan Africa has declined from 2 in 1980 to 1.3 by 2003. Over the same period, however, the number of tractors per 1000 ha in Asia and Pacific rose from 7.8 to 14.9. Further, it has been proven that maize production in many countries in Africa is still characterised by the use of outmoded hand tools such as hoes and cutlasses, with hardly any conscious efforts being made to integrate the use of mechanised ploughing technologies (Mensah, 2005; Van der Meijden, 1998; Vissoh, Gbèhounou, Ahanchédé, Kuyper, & Röling, 2004).

According to Vissoh *et al*. (2004), hand weeding through the use of hoes, cutlasses and other traditional tools is still the major weed control practice on smallholder farms in Africa. Meanwhile, Chivinge (1990) and Mensah (2005) indicate that the use of simple hand tools for farming is slow, cumbersome and inefficient. Further, due to shortage of labour in the rural areas caused mostly by the out-migration of young adults to urban areas in search of better jobs and social amenities, land preparation and other on-farm processes are delayed thus hampering agricultural production and resource use efficiency (Alenoma, 2013; Mahama, 2013).

Like other developing countries, improvement in agricultural productivity facilitated by the adoption of improved farming technologies is important for the economic growth and development of Ghana. First, agriculture is still an important subsector of the Ghanaian economy, despite the rise of other sectors such as the services and extractive industries in recent times (Institute of Statistical, Social and Economic Research [ISSER], 2017; Ministry of Food and Agriculture [MoFA], 2011). For example, the agricultural sector contributed 30 percent of the country's GDP in 2010 and employed over 60 percent of the working population (MoFA, 2011). Until this time, the sector was the mainstay of the economy; dominating in terms of its contribution to GDP and employment.

Apart from providing the bulk of the food consumed domestically, the sector also helps in attracting foreign exchange revenue through the export of agricultural commodities (Mensah, 2014). Directly or indirectly, agriculture provides livelihoods to about 60 percent of Ghana's population, and employs 56.8 percent of female-headed and 73.1 percent of male-headed households in rural areas (Emmanuel *et al.*, 2016; Ghana Statistical Service [GSS], 2013a). Moreover, agriculture is also recognised as having a huge potential to the industrialisation efforts of the country, and improvements in the efficiency of existing farmers is estimated to be crucial if the country is to achieve any substantial economic growth and development (Dasmani, 2015; Peprah, 2011).

In recognition of the significance of agriculture to the total transformation of the economy and ensuring food security, the Akufo-Addo administration is vigorously pursuing the 'Planting for Food and Jobs' programme. As an illustration, the President made it abundantly clear in his speech at the launch of the programme at Gaoso in the Brong Ahafo Region that food was unnecessarily scarce and expensive in a country that has huge potentials for agricultural production. In his speech to commemorate the 2017 Farmers' Day celebrations, the President also indicated that creating a vibrant agricultural sector is imperative to increasing the income of farmers in order to make them better able to enjoy quality living standards and support their families and the industrialisation efforts of the country (Governement of Ghana, 2017).

Undoubtedly, the benefits of Planting for Food and Jobs and creation of a vibrant agricultural sector to support to household food security and economic growth are fairly obvious. But their achievement is inextricably linked to the efficiency of existing producers and particularly the ability of food crop farmers to adopt the relevant farming technologies needed to respond to the new demands outlined by the programme. Meanwhile, an important challenge currently confronting agricultural production in Ghana that deserves attention is the low adoption of mechanised ploughing technologies among farmers.

Moreover, evidence shows that similar ambitious programmes implemented in the past did not do anything much to transform agriculture in the country, except marginal increase in cocoa output and relatively small increase in the share of horticultural crops in the export portfolio of the country. For example, Diao, Cossar, Houssou and Kolavalli (2014) and Killick (2010) indicate that while Ghana has implemented series of programmes and policies since independence aimed at transforming the agricultural sector, the bias has been in favour of cocoa and other horticultural crops without much been achieved with respect to a holistic transformation and modernisation of the agricultural production. More emphatically, Diao *et al.* (p.169) argued that apart from cocoa, government intervention in agriculture has not done much to modernise the sector. In addition, Wolter (2009) shows that while Ghana faces stagnating production of important food staples needed by domestic consumers, such as maize, the export of horticultural crops has been increasing.

According to Akudugu, Guo and Dadzie (2012), low adoption of agricultural technologies among farmers in Ghana is the root cause of food production deficits and household food insecurity. Others are the preponderance of smallholder agriculture and small nature of agricultural landholdings which make it virtually unsuitable to employ certain scale-biased and indivisible but highly productive technologies such as tractors (Chamberlain, 2007). Moreover, the use of traditional farming tools such as hoes and cutlasses still dominate the country's maize production in terms of technologies, thus forestalling any chances of productivity growth and improvement in technical efficiency.

Maize is an important food staple and a major source of income for many households in Ghana including those in the Northern Region. It is used for a variety of dishes including tuozaafi, porridge, and cake. In addition, maize is a critical raw material for many agro-based industries, especially bakery and breweries. Its role as an important feed material for livestock production in different parts of the country has also been widely documented (Nurudeen, Larbi, & Hoeschle-Zeledon, 2015). Moreover, maize production is an important source of biomass energy and serves as one of the main cooking fuels for many poor households in Ghana. For most households in the Northern Region of Ghana, maize is consumed in one form or the other.

Currently, maize production accounts for about 27 percent of Ghana's total arable land and more than 50 percent of total land dedicated to cereal production (Ofori, Opare, Lartey, & Agyei-Ohemeng, 2015; Seini, 2002). Despite all these, the average yield of maize production in Ghana remains one of the lowest in the world, much lower than the average yield in Sub-Saharan Africa and yields obtained in countries with similar environmental conditions. In 2012, for example, maize yields in Ghana averaged 1.2-1.8 metric tons, far below the potential yield of 4 to 6 metric tons under similar conditions (MoFA, 2013; Ragasa, Chapoto, & Kolavalli, 2014).

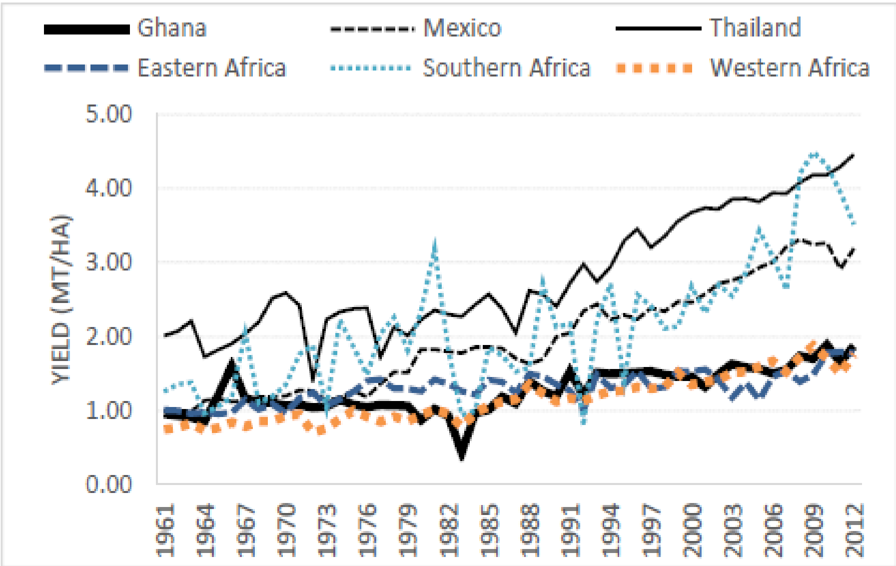

Figure 1: Comparison of maize yield in Ghana and other areas

Source: Ragasa *et al.* (2014).

Existing evidence points to the fact that average yield on most maize farms in Ghana is below achievable yield (MoFA, 2010), implying that a wide scope of opportunities exists for improvement in maize production through the adoption of improved technologies. As is evident from Table 1, the ratio of average yield to achievable yield for maize is 0.28, reflecting that about 72 percent of achievable yield is lost every year. Because maize production plays a crucial role in the diets of many households in the country, the consequences of the poor performance of this crop on poverty and household food insecurity are correspondingly high. For example, while Ghana can generally be regarded as a food secure nation compared to other developing countries, pockets of food insecurity still exist in areas regarded as major maize production hubs such as the Northern Region (Sagre & Haruna, 2016).

Table 1: *Average and achievable yield of selected crops in Ghana*

Crop	Average Yield	Achievable Yield	Yield Ratio
Cocoyam	6.7	8.0	0.84
Millet	1.3	2.0	0.65
Soybean	1.5	2.3	0.65
Groundnuts	1.5	2.5	0.60
Cowpea	1.3	2.6	0.50
Cashew	0.8	1.8	0.44
Cocoa	0.4	1.0	0.40
Rice	2.4	6.5	0.37
Yam	15.3	49.0	0.31
Maize	1.7	6.0	0.28

Source: MoFA (2010).

Wokabi (1998) identified the dependence on traditional farming practices as one of the major factors militating against maize production and indicates that widespread application of scientific methods is essential if maize cultivation will continue to play its role in the diets and welfare of farm households. Further, it is estimated that without increasing the resource use efficiency of existing maize producers, about 267000 metric tonnes of maize will have to be imported every year to meet domestic demand in Ghana (Angelucci, 2012). This suggests that improving the efficiency of existing maize producers in the country through the promotion and adoption of mechanisation and access to large farms, can contribute massively to reverse the poor yield performance and ensure household food security.

Like other food crops grown in Ghana, maize production is threatened by many inhibiting factors including the continued dependence on outmoded techniques of production that negatively affects not only the livelihoods of the farming population in Ghana but also the government objectives of creating a resilient economy backed by an agricultural sector which is capable of producing for food and jobs. Amanor-Boadu (2012) opines that though maize is a principal human food and livestock feed in Ghana, its production is performed essentially by smallholder farmers under traditional tillage and rain-fed conditions, thus preventing the crop for achieving its full potential in terms of contribution to food availability and raw materials for industrial processing. In particular, increasing access to land for maize production among agricultural households in the Northern Region of Ghana can contribute immensely to household food security, given that Northern Region accounts for a significantly high proportion of the over 2.1 million people in the country that were classified as food insecure in 2010 (MoFA, 2011).

Statement of the problem

Though the inverse relationship between farm size and efficiency has been regarded as a stylised fact of agricultural production in developing countries, a great deal of controversy has developed regarding this proposition. In particular, the ‘poor but efficient’ hypothesis advanced by Schultz (1964) and the ‘inverse farm size-productivity’ hypothesis proposed by Sen (1962) concerning agricultural production in developing countries have both been critiqued as outdated and deficient in terms of their empirical rigour and treatment of time-invariant household heterogeneities (Barbier, 1984; Rao & Chotigeat, 1981). Moreover, following recent trends of growth in average farm size and increase in farm output in market-oriented economies, the debate on the farm size-efficiency relationship has once more been re-kindled with a positive relationship expected between farm size and efficiency (Rao, 2014). Like efficiency, the relationships between farm size and ploughing technology and food security among agricultural households in developing countries have also become high on the policy agenda of governments, the international community and academic researchers.

Empirical studies investigating the relationship between farm size and efficiency, ploughing technology and household food security among farmers in Ghana are limited. In addition, as regards analytical techniques, previous studies on the relationship between farm size and these three issues have largely relied on cross-sectional dataset and the two-stage estimation procedure in which technical efficiency scores from the first stage production function are often regressed on other independent variables using either the Ordinary least Square (OLS) or Tobit estimation technique (Abatania, 2013; Abdulai & Huffman, 2000; Awuma, 2008). Nevertheless, this technique has been recognised to be biased and inconsistent due to its violation of key axiomatic conditions (Abdulai & Eberlin, 2001; Caudill & Ford, 1993; Wang & Schmidt, 2002). Further, the use of cross-sectional dataset in analysing resource use efficiency is regarded problematic due to the inability of dataset of this sort to address certain heterogeneities (Newey, 2007).

The search of the literature thus far suggests that no empirical research has been conducted on the farm size-technical efficiency relationship in

Ghana using panel data, much more explore the relationship between farm size and other important issues such as food security and ploughing technology among the same households for which efficiency scores are reported. For instance, Debrah (2015) reports results on the relationship between farm size and agricultural productivity, and suggested that the relationship between farm size and resource use efficiency is not consistently positive. But this study used the profit function approach which has been regarded as deficient in the sense that it has the potential to classify a large proportion of producers as inefficient (Aigner, Lovell, & Schmidt, 1977).

In addition, Asante, Villano and Battese (2014) found a strong positive relationship between technical efficiency and farm size among yam producers in three agroecological zones of Ghana when they used cross-sectional dataset and physical output as the dependent variable in the production frontier. In this regard, it is important to study the relationship between non-price adjusted measures of efficiency and farm size employing their technique and panel dataset to enhance the quality of academic discourse.

Besides testing the relationship between technical efficiency and farm size by combining both parametric and non-parametric estimation techniques, the relationship between farm size and choice of ploughing technology and household food security are also investigated in this study. This extends the frontier of knowledge on empirical studies on the link between farm size and productivity performance, household welfare and agricultural technology adoption in Ghana.

Purpose of study

The main purpose of this study is to investigate the effect of farm size on efficiency, ploughing technology choice and household food security from an objective perspective. The study seeks to contribute knowledge to extend the discourse on the inverse farm size-productivity hypothesis, the combined effect of farm size and technical efficiency on household food security, and to provide policy recommendations for safeguarding the welfare and technology adoption efforts of maize farmers in Ghana.

Objectives of the study

The broad objective of the study was to examine the relationship between farm size and efficiency. Specifically, the study also:

i. estimated the relationship between farm size and technical efficiency;
ii. estimated the relationship between farm size and scale efficiency;
iii. investigated the effect of farm size on choice of ploughing technology, and
iv. estimated the relationship between farm size and household food security.

Hypotheses of the study

The primary hypothesis of the study is that farm size does not have a significant positive impact on efficiency. Letting Ho to represent the null hypothesis and Ha to represent the alternative hypothesis, then the study states that:

(1) Ho: There is no significant positive relationship between farm size and technical efficiency.

Ha: There is a significant positive relationship between farm size and technical efficiency.

(2) Ho: There is no significant positive relationship between farm size and scale efficiency.

Ha: There is a significant positive relationship between farm size and scale efficiency.

(3) Ho: There is no significant positive relationship between farm size and choice of animal traction or tractor over hoe for ploughing.

Ha: There is a significant positive relationship between farm size and choice of animal traction or tractor over hoe for ploughing.

(4) Ho: There is no significant positive relationship between farm size and household food security.

Ha: There is a significant positive relationship between farm size and household food security.

Significance of the study

Higher agricultural productivity and improved ploughing technologies are important steps towards ensuring food security among households in Sub-Saharan Africa (Asfaw, Shiferaw, Simtowe, & Lipper, 2012). While various reasons and opinions have emerged and waned about the relationship between farm size and the technical performance of agricultural producers, those studies which have subjected the matter to rigorous empirical analysis have produced mixed evidence. The large variation in results is mainly due to differences in estimation methods and the reliance on cross-sectional dataset that fail to account for time-dependent and producer-specific heterogeneities.

To the best of my knowledge, all previous studies on the relationship between farm size and efficiency in Ghana used cross-sectional data and hence failed to control for time-dependent household heterogeneities that could be correlated negatively or positively with resource use efficiency scores. In addition, very few empirical studies, if any, have explored the relationship between farm size and other important management problems confronting the same households for which efficiency estimates are calculated or combined different estimation techniques to study resource use efficiency among the same households.

Apart from Abatania (2013) and Nkegbe (2011) who came very close to the issue by combining the DEA and SFA approaches, no study of this nature has examined the relationship between farm size and efficiency with panel dataset. Specifically, Abatania studied the relationship between farm size and efficiency using cross-sectional dataset on smallholder farmers in the Upper East Region of Ghana. Unfortunately, these studies did not use panel dataset and hence was unable to account for certain time-dependent household heterogeneities that may be correlated with efficiency. Further, they study did not investigate the relationship between farm size and other important issues that could affect the same households for which efficiency estimates were obtained, such as their food security situation and choice of ploughing technology. In this regard, more empirical studies on the relationship between farm size and these issues using other sources of data and estimation techniques are very relevant to inform agricultural policy and programmes on land resource utilisation. By addressing these flaws, this study contributes to the advancement of literature on farm households in Ghana.

Moreover, understanding the determinants of resource use efficiency and choice of ploughing technology is critical because of the importance of productivity growth in agriculture and farming technology adoption for overall economic growth and national food security. In Ghana, because of the importance of agriculture in overall employment and household food security, growth in the agricultural sector will continue to be a major tool in the fight against hunger and malnutrition. Improvements in technical efficiency constitute a major component of total factor productivity growth and are identified as particularly important for reducing food production deficits and increasing earnings in the rural areas of the country (Addai & Owusu, 2014; Evans, Mariwah, & Antwi, 2015). The use of improved techniques of production including the adoption of mechanised and intermediate ploughing techniques has also been identified as an important factor that can contribute to agricultural productivity growth and improvements in farmers' efficiencies (Akudugu *et al*., 2012), both of which can increase food availability and improve the quality of human life.

The nature of relationship between farm size and resource use efficiency, ploughing technology and food security among households in the Northern Region of Ghana is important because the region has a lot of potential for maize production, despite being located in an agro-ecological zone that can hardly be described as favourable (Sidibé, Williams, & Kolavalli, 2016). Knowledge on the farm size-productivity relationship has obvious importance for policy concerning land management as well as government regulations for the small-scale farm sector. It would advance understanding of the factors promoting or inhibiting agricultural production and provide a solid basis upon which policy can be formulated and implemented. In addition, if the factors underpinning variations in choice of ploughing technology and household food security are identified, they will assist in the determination of appropriate policies and programmes that will help to improve the technical performance of farmers and ensure household food security through the promotion of agricultural mechanisation.

This study is different from existing studies in the sense that it is one of the first studies to make use of panel dataset and combine both parametric and nonparametric approaches to estimate technical efficiency. It is also one of first of its kind to investigate the determinants of choice of ploughing technology using plot-level dataset. The benefits of using panel dataset against cross-sectional dataset, which is a typical problem of most past studies, are numerous. First, panel dataset makes it possible to control for individual effects that may be correlated with certain independent factors in the objective function (Newey, 2007). Second, due to the presence of multiple observations on the same unit, panel dataset makes it possible to consider heterogeneities that may exist beyond what is possible to control using a cross-sectional approach which lumps together individual effects and random errors (Hsiao, 2003).

According to Rashidghalam, Heshmati, Dashti and Pishbahar (2016), having information on the same decision-making units over time improves the reliability of estimated coefficients of explanatory parameters by allowing researchers to control for time-invariant heterogeneities, a situation which is not possible with cross-sectional data. In addition, strong assumptions about the distribution of error terms and differences in production technologies are not necessary for panel dataset. In cross-sectional data, especially for maximum likelihood estimations, distributional assumptions on error components are critical so as to distinguish inefficiency from statistical noise resulting from measurement errors. Maximum likelihood estimations also require inefficiencies to be independent of input variables. In practice, however, these assumptions are unrealistic. Panel dataset provides more observations on each producer than cross-sectional data and this makes it easier and possible to obtain accurate estimates of efficiency for each producer even if some or most of the assumptions of the maximum likelihood estimation are violated.

An additional value of the study lies in its ability to model the determinants of household food security and choice of ploughing technology, thus expanding the scope of knowledge on agricultural production and related issues in the country. Moreover, increasing the agricultural productivity levels through the adoption of modern farming technologies is regarded as vital to economic growth in poor countries where productivity growth and technology adoption has been lagging behind the rest of the world for a very long time. Thus, understanding the factors affecting the choice of ploughing technology among maize farmers in the Northern Region of Ghana will constitute a right step in this direction as it will help to keep agricultural policy formulators and implementers in the country abreast with the major variables that matter for hunger prevention and agricultural mechanisation.

Scope of the study

The study sought to examine the relationship among farm size, efficiency, ploughing technology and household food security among maize farmers in selected areas in the Northern Region of Ghana. The dataset used for the analysis came from a secondary household-level survey among maize farmers conducted by Innovations for Poverty Action (IPA) in association with Presbyterian Agricultural Services. The data collection was restricted to three administrative areas (Tamale Metropolis, Savelugu-Nanton Municipality, and West Mamprusi District) and covered the 2008/2009, 2009/2010, and 2010/2011 cropping seasons. To achieve the objectives outlined in the study, a balanced panel on 787 households was constructed from the original dataset subject to the condition that each household included in the final analysis had complete and accurate information on all the variables needed by the study for the three years.

Contributions of the study

While the overarching objective of this study was to provide evidence on the relationship between farm size and technical efficiency through the use of panel dataset and combination of different estimation strategies, others were to examine the influence of farm size on ploughing technology and household food security. The combination of different estimation methods for the analysis permits me to confidently claim that the findings are unique and generalisable because no previous study has analysed these three issues in tandem. The use of panel dataset allowed me to deal with unobserved time invariant heterogeneities that pose econometric problems when dealing with cross-sectional data. Moreover, the study's questions and methods set out to fill gaps in past research that ignore the influence of farm size on different dimensions of performance. Knowledge on the relationship between farm size and technical efficiency, ploughing technology and household food security based on panel dataset are relatively scarce.

Most empirical studies with respect to Ghana only investigate generic agricultural households with a single measure that capture performance. Of these three dimensions, the issue of ploughing technology is often overlooked. For example, technology adoption studies that examine the relationship between farm size and agricultural technology fail to adequately assess the association between size of agricultural landholding and the choice of ploughing technology at plot-specific level. This study charted a new territory by investigating the relationship between farmland size and the decision to adopt animal traction or tractor relative to hoe for land preparation employing plot-level information. This is also one of the first empirical studies to model the proportion of farmland ploughed by alternative technologies to hand hoe, and hence constitutes an advancement of knowledge and research on agricultural technology adoption in the country.

Delimitations of the study

Several issues could be investigated about maize farmers in the Northern Region of Ghana. However, three issues were covered in the current study. These were their technical and scale efficiencies, choice of ploughing technology and food security status. With respect to ploughing technology, the study focused on the main method employed in preparing farmland for sowing. The thesis further focused on self-reported food security status. Household food security status is defined by their response to the following question: *In the last 12 months did any member of your household miss meals because the household could not afford enough food*? Households which responded in the affirmative are considered to be food insecure while those who indicated the opposite are regarded to be food secure. The study focuses on maize farmers in only three administrative areas (Tamale Metropolis, Savelugu-Nanton Municipal, and West Mamprusi Districts) employing a panel design. The positivist philosophy guided the study with Sen's (1962) *inverse farm size-productivity theory* and the *farming system evolution theory* by Hayami and Ruttan (1985) providing the theoretical foundation.

Limitations of the study

Methodologically, the study has contributed to the academic discourse on efficiency and agricultural technology adoption in a number of ways. First, unlike previous studies, this study used panel dataset. Through this approach, the study provides estimates which can inform agricultural policies in a better fashion than otherwise. Second, the study also made a novel contribution by investigating the extent of food security and ploughing technology adoption of the same households for which the efficiency scores were obtained and discussed. This can be viewed as an improvement over previous studies which concentrated either only on efficiency or food security status while ignoring other important aspects closely linked to agricultural production. Nevertheless, there are a number of limitations associated with the study which need to be pointed out.

To begin with, the study employed data on households from only three administrative areas in the Northern Region and hence the results may not generalizable for the whole region. A comprehensive study covering all the districts in the region could have been more ideal and relevant. Furthermore, the study is based on a short panel, and hence may not have taken care of household heterogeneities which need a longer span of time to be completely addressed.

In addition, the study acknowledges the weakness of using purely quantitative estimation techniques in explaining social phenomenon and relying on limited sample size to draw universal conclusions about cause and effects. Moreover, it has been argued in the literature that intra-household food allocation dynamics can affect the food security status of different household members differently. Unfortunately, due to data limitation, this issue was not investigated in the present study.

Another limitation of the study which needs to be acknowledged is the self-reported nature of the data used for the analysis. It must be stressed that the dataset employed for the analysis were based on self-reported information regarding farm size dimensions and maize output. Much as information collected using this procedure remains an important source of data for empirical studies testing the farm size-productivity hypothesis, pressure is mounting from beneath for a change towards other methods such as the deployment of GPS for capturing farm size and involvement of trained experts in quantifying farm output. From this angle, therefore, the current study is limited because none of these measurement modes was used to obtain the dataset.

Organisation of the study

The study is organised into seven chapters. Chapter One covered the general introduction to the study and includes the background to the study, statement of the problem, objectives of the study, hypotheses to be tested, significance of the study, scope of the study, contribution of the study as well as the limitations of the study. It also outlines the organisation of the study. The second chapter presented review of related literature.

Chapter Three discussed the research methods. It also highlighted the sources of the data and the procedures used to clean the data for the selection of the households included in the study. The measurement of variables, summary statistics of the data, and reliability check of the dataset employed for the analysis are also provided in this chapter. Results on the efficiency estimates obtained from both parametric and nonparametric techniques as well as the factors explaining variations in the efficiency were presented and discussed in Chapter Four. Chapter Five provided empirical results and discussions on ploughing technology. This is followed by results on household food security in Chapter Six. Chapter Seven, which is the final chapter, summarised the findings and concluded the study.

CHAPTER TWO

LITERATURE REVIEW

Introduction

The focus of the study is to examine the relationship between farm size, resource use efficiency, and choice of ploughing technology and food security among maize growing households in the Northern Region of Ghana. Background issues and related matters were covered in the first chapter. This second chapter is dedicated to review related literature on the three broad issues set out in the thesis. It is organised into five sections. The first part looks at the various definitions of efficiency and examines the different estimation methods and their relative advantages and disadvantages. Related empirical studies on the determinants of resource use efficiency are covered in the second section. The third and fourth sections cover the review of empirical studies on agricultural technology and household food security respectively, closely followed with a summary of the main highlights on the various studies reviewed.

The concept of efficiency

Efficiency, like other economic concepts, has been conceptualised differently by different authors. For example, Førsund and Hjalmarsson (1974) define efficiency as a relative measure of performance because the performance of one decision-making unit must be compared with a standard which involves value judgment about the objectives of economic activities. According to Farrell (1957), efficiency signals the strength of one decision-making unit over others in the production of a maximum output of a good or service with a given set of inputs. More generally, Koopmans (1951) recommends that efficiency should be defined as the situation under which it is not possible to improve any input or output without necessarily worsening some other inputs or output. Koopmans reasoned that decision making units (DMUs) are considered efficient if it is impossible for them to produce more of any output without producing less of some other output or using more of some input.

With specific reference to agriculture, efficiency is defined as the ability of a farmer to produce the maximum amount of output with a given set of inputs subject to a chosen level of technology (Bravo-Ureta, 1986). Efficiency has also been defined as the ratio of mean production conditional on the levels of factor inputs and farmer effects to the corresponding mean production if all farmers utilised their inputs more efficiently (Battese & Coelli, 1992). Tubene (1997) and Latruffe (2010) discuss four types of efficiency namely: scale efficiency, pure technical efficiency, allocative efficiency, and overall efficiency. Scale efficiency refers to the ratio between technical efficiency score estimation under the assumption of constant returns to scale and the corresponding score under variable returns to scale. It gives insights into whether a farmer operates at an optimal or sub-optimal size. Farmers which are scale efficient operate under constant returns to scale and tend to have a scale elasticity of one while scale inefficient farmers on the other hand can improve upon their production by exploiting economies or diseconomies of scale. Pure technical efficiency, also sometimes termed technical efficiency, assumes variable returns to scale and indicates the extent to which a producer is able to attain the maximum output from available inputs. It is a physical notion and is thus not affected by input and output prices (Carlsson, 1972).

It has also been suggested that efficiency can be discussed in relation to input-orientation and output-orientation. Debreu (1951) defined input-oriented efficiency as the ability of a decision-making unit to use minimal inputs to produce a given set of outputs. Similarly, Farrell (1957) proposed that output-oriented efficiency capture the ability to obtain maximal output from a given set of inputs. By definition, the output vector is considered to be technically efficient if no equi-proportionate expansion of output is feasible without causing some other outputs to be reduced. Output-oriented efficiency is measured as the ratio of actual output to potential output. Except under constant returns to scale, both input-oriented and output-oriented measures of efficiency generate different scores (Färe & Lovell, 1978). Regardless of orientation, however, all measures of efficiency yield estimates which range between zero and one; with values closer to zero reflecting higher inefficiency and those closer to one indicating greater efficiency (Bhasin, 2009).

According to Yang (2014), a decision-making unit whose efficiency score is zero would be classified as fully inefficient while one with a value of one will be judged as fully efficient. Conversely, a producer would be described as fully efficient if its output coincides with the output of producers on the frontier whereas a producer whose output is less than the output of producers on the frontier would be considered inefficient even if its output is significantly greater than zero (Bhasin, 2002).

Another way to define efficiency is to resort to the methods by which it is estimated. Under this approach, two types of efficiencies have been identified in the literature. These are discussed next.

Parametric methods

Prior to the popularisation of parametric approaches, the Malmquist index numbers approach was employed for productivity analysis. This approach measured productivity change by calculating the geometric mean of the input distance and the output distance functions (Caves, Christensen & Diewert, 1982; Färe, Grosskopf, Norris, & Zhang, 1994). However, it did not allow for the identification of determinants of resource use efficiency which may be needed for policy purposes (Darku, Malla, & Tran, 2013; Tone, 2004). Consequently, the parametric approach where a non-negative one-sided error term capturing inefficiency in production is added to the symmetric error term in a typical production function, was jointly proposed by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977). By isolating the effects of statistical noise from inefficiency, productivity estimates obtain from the parametric methods allow hypotheses to be tested regarding the production structure and level of inefficiency. They are also seen to be more suitable than index numbers as well as the non-parametric methods for efficiency estimation in single-output production processes with multiple inputs or multi-outputs situations where outputs can be reasonably aggregated into one measure using prices (Otieno, 2011).

Although the parametric methods to efficiency estimation allow for the identification of policy variables, there are not without flaws. The first generation of parametric methods, particularly the SFA, was not designed to handle panel data (Battese & Coelli, 1988). Another weakness of these methods is that efficiency measures are sensitive to the functional form of the production frontier and the assumptions regarding the distribution of the one-sided error term (Croppenstedt & Muller, 2000). Secondly, parametric methods cannot provide estimates for efficiency when the DMUs being studied produce multiple outputs (Bhasin, 2009).

To a very large extent, a number of the limitations of the first generation parametric methods to efficiency analysis have been addressed to by the second generation versions (Battese & Coelli, 1988; Battese & Coelli, 1995; Brümmer, 2001; Koenker & Bassett, 1978). For instance, Koenker and Bassett proposed the quintile production frontier approach as an alternative to the traditional SFA. This new technique differs remarkably from the traditional SFA by not requiring the imposition of a particular form on the distribution of the inefficiency term. It estimates the production frontier via a quintile regression of high percentile that describes the production process (Darku *et al.*, 2013). Efficiency estimates of all decision-making units are derived by using the obtained coefficients from the regression and comparing each decision-making unit’s actual output with its potential output given the optimal technique.

An advantage of this new approach is that it is robust to the deviations from distributional assumptions regarding the error term since it imposes asymmetric distribution of the error term. Its major weakness is that it does not allow for the investigations of the determinants of efficiency which may be needed for policy purposes. Additionally, the choice of the upper quintile for the estimation of the production frontier is arbitrary since quintile differentiation is influenced by the sample size and the amount of information available about the upper tail.

As a further improvement of the SFA-type models, Battese and Coelli (1995) developed a one-stage estimation procedure where potentially influential variables on efficiency are considered simultaneously with input variables and added to the production function while Battese and Coelli (1988) augmented the approach to accommodate panel data. These new techniques are utilised in this thesis since they are recognised to be superior to the traditional approach of using cross-sectional data and the two-stage estimation technique (Caudill & Ford, 1993).

Non-parametric methods

Non-parametric methods are one of the newest techniques for efficiency analysis. In these methods, the efficiency frontier is empirically constructed by enveloping all available observations using graphical decomposition techniques. Unlike other methods, non-parametric methods do not require knowledge of the functional form of the production technology and the distribution of errors. Therefore, they can be used in situations where the relationship between inputs and outputs is unclear (Li, Chi, & Wang, 2016). In addition, non-parametric methods are less data demanding because they work well with relatively small data points (Farrell, 1957).

Within the non-parametric models, the efficiency score of each decision-making unit is measured relative to other decision-making units with the restriction that all decision-making units must fall on or below the efficient frontier (Uri, 2003). An additional strength of the non-parametric methods is that they can decompose the estimated efficiencies into different components (Annim, 2010). The DEA, pioneered by Banker, Charnes and Cooper (1984), is regarded the most common non-parametric method. The approach was developed based on studies by Debreu (1951) to overcome the challenges identified with existing methods for measuring efficiency at the time.

Like other non-parametric techniques, the DEA approach uses mathematical linear programming to estimate the efficient frontier for a group of decision-making units and can handle multiple inputs and outputs (Ohlan, 2013). By incorporating many inputs and outputs into the same estimation, the DEA approach provides a fairly simple way of estimating disparities in efficiency (Haji, 2007).

Despite all these merits, the DEA is not without limitations. First, it is a deterministic approach built on the assumption that all deviations between observed output and the frontier output is inefficiency. This assumption breaks down at the empirical level because the possibility that the observed output of a producer can differ from the potential because of stochastic shocks and measurement errors in the dataset are all ignored. Secondly, results of the DEA approach may be affected by sampling variation, implying that efficiency estimates are likely to be biased upward. Latruffe (2010) argues that when the most efficient decision-making unit within the population is not contained in available sample, the efficiency of the available decision-making units will be measured relative to the sample frontier instead of the true population frontier, thus biasing the calculated efficiency scores downward.

Although the actual values of efficiency estimates differ between alternative approaches of the parametric and nonparametric techniques, literature shows that there is a strong positive correlation between efficiency scores from the two methods. Consequently, many authors are advocating for the combination of both methods in order to produce reliable ranges within which the true efficiency scores may fall. For instance, Abatania (2013), Nkegbe (2011), Annim (2010), Kwon and Lee (2004) as well as Sharma, Leung and Zaleski (1997) are some of the studies that combined both methods. This lends support to the decision of the current study to employ both the SFA and DEA. Moreover, very few studies on the efficiency of farmers in Ghana in general, and Northern Region in particular, have used both methods on the same data. This thesis will bridge the gap in the literature to that effect and pave the way for more nuanced analysis. In addition, it has been revealed that the use of the parametric and non-parametric approaches does not yield significantly different results when applied in either the single output-multiple inputs or multiple output-multiple inputs framework (Martínez, 2016). Thus, each approach can act as robustness check on the alternative method, leading to reliable estimates.

Review of related empirical studies

Prior research has shown that efficiency, choice of ploughing technology and household food security are affected by a broad range of factors. For the purpose of this thesis, these factors are grouped into five categories namely agronomic, sociodemographic, technological, institutional, and infrastructural factors. Agronomic factors consist of farm size, land tenure security, and land fragmentation.

Sociodemographic factors cover variables such as age, sex, and household size, attainments in formal education, participation in off-farm work, risk aversion, and asset ownership. Institutional factors represent social, government and macroeconomic policies which can promote or inhibit efficiency, ploughing technology choice and the attainment of household food security. These include government subsidies on agriculture, trade policies, press freedom, political and civil liberties, and social cohesion. Membership in peasant associations is also considered an institutional factor. Infrastructural factors measure the extent of provision of social amenities such as roads, irrigation schemes, markets, and electricity which may not directly be needed for agricultural production but which improve the welfare of farmers by enabling them to attend to their farms more efficiently using modern technology and timely purchase of farm inputs due to the availability of income from off-farm activities. Finally, technological factors include but not limited to access to agricultural extension services and information.

Considering the objectives of the thesis, the review of related literature on factors affecting efficiency, ploughing technology and household food security is organised such that more attention is paid to studies which included farm size as an explanatory factor. It must also be emphasised that, the approach of basic review of literature is used in this study. Solaja (2017) maintains that basic review of literature depicts planned efforts to identify, appraise and synthesise leading available evidence on a specific issue in order to provide informative and evidence-based answers.

Factors affecting efficiency

Farm size has been identified as one of the most important agronomic factors that determine variations in efficiency among agricultural producers. But empirical findings with respect to this variable are diverse to the extent that no generalisation can be made about the nature of the exact relationship with respect to this variable and efficiency. Generally, however, the prediction of significant positive relationship between farm size and efficiency tend to be more pronounced among studies in developed countries compared to studies from developing countries.

A plethora of empirical studies conducted to identify the factors responsible for differences in efficiency among farmers in the United States of America have generally established that large farm operators are the more efficient group compared to their counterparts with small farms. For example, Mugera and Langemeier (2011) established that technical efficiency varies directly with farm size, with the mean technical efficiency being 0.4872 for very small farms, 0.5631 for small farms, 0.6678 for medium farms, and 0.7983 for large farms. In their study among farmers in Southern Minnesota, Olson and Vu (2009) also found that large farms are consistently associated with higher efficiency scores than smaller farms.

Bagi (1982) estimated technical efficiency of 193 famers in two counties of West Tennessee based on data collected in 1978. This study used the maximum likelihood method to estimate a Cobb-Douglas stochastic frontier function to obtain technical efficiency scores. Results show that the relationship between farm size and technical efficiency is sensitive to the choice of indicator for farm size. When farm size was based on acre of land cultivated, small and large farms achieved similar levels of efficiency. Contrarily, when farm size was based on the value of farm sales, large farms had higher efficiency than smaller farms.

Unfortunately, the studies by Mugera and Langemeier (2011), Olson and Vu (2009) and Bagi (1982) were based on the two-stage estimation procedure and the SFA approach, despite the recognition that the two-stage technique is inconsistent because of its violation of key axiomatic conditions regarding the treatment of error terms (Caudill & Ford, 1993). In addition, Mugera and Langemeier and Olson and Vu also failed to account for the influence of national policies despite wide recognition that the relationship between farm size and efficiency in developed countries is influenced by several national policies including state-sponsored subsidies for research and development (Aly, Belbase, Grabowski, & Kraft, 1987).

Kalaitzandonakes, Wu and Ma (1992) combined both the DEA and SFA approaches to investigate the relationship between farm size and technical efficiency among grain farms in Missouri and found that technical efficiency was positively related to farm size regardless of the estimation method. Even though the study by Kalaitzandonakes *et al.* can be viewed as an improvement over the previous American studies cited in this work due to their combination of parametric and non-parametric estimation methods, its weakness lies in the reliance on cross-sectional data instead of panel data, which is the focus of this thesis.

Paul, Nehring, Banker and Somwaru (2004) also combined the stochastic production frontier and deterministic data envelopment analysis models to compute and compare the scale and technical efficiencies of small family farms relative to large industrial farms using a panel data of farms in the corn belt of the United States of America. They found that large farms were more efficient than small farms. Using panel data for the period 2003 to 2007 and the stochastic frontier approach, Nehring, Gillespie, Sandretto and Hallahan (2009) also found that large conventional farms in the United States were more competitive and technically efficient than small and medium farms. Unfortunately, Paul *et al.* and Nehring *et al.* did not present results for the separate years of the panel, which may be needed to track the performance of certain independent variables over time. They did not also consider the influence of national policies as suggested by Aly *et al.* (1987), Serra, Zilberman and Gil (2008) as well as Samarajeewa, Hailu, Jeffrey and Bredahl (2012).

Serra *et al.* (2008) studied the impact of government payments on production inefficiencies among farmers in Kansas over the period 1998 to 2001 using SFA with Cobb-Douglas production function specification. Empirical results show that government transfers provided fewer incentives to farmers to efficiently work their farms compared to market prices. Indirectly, these findings implied an inverse relationship between farm size and efficiency since government subsidies tend to be biased in favour of large scale operators. On the contrary, Samarajeewa *et al.* (2012) found that government support had a significant positive relationship with technical, allocative and economic inefficiency among beef cattle farmers in Alberta, signaling that the production efficiency of farmers that received government support was lower than those who did not receive any support. Moreover, they also found a significant negative relationship between farm size and technical, allocative and economic inefficiency, and attributed it to the benefits associated with economies of scale on large farms.

Papadas and Dahl (1991) examined the relationship between farm size and technical efficiency in the United States. Using data from 31 states and the DEA estimation technique, they found that though some gains in efficiency appeared as farm size increases, the gains were not significantly large enough to warrant the drawing of conclusion that producers with large farms were more efficient than those with small farms. In addition, Wu, Devadoss and Lu (2003) posit that the relationship between farm size and technical efficiency is positive but insignificant whereas farm location had a significant negative impact on efficiency.

Peterson (1997) indicates that the advantages of large farms observed in most parts of the United States disappeared while there is evidence of diseconomies of scale as farm size increases when a number of biases in the data were corrected for. After accounting for various factors believed to be positively correlated with output and production cost, such as land quality, infrastructure, and off-farm employment, it was observed that small family and part-time farms were the more efficient category.

Empirical studies on agricultural production in Germany generally point to the role of national development policies in contributing to variations in technical efficiency between different farm categories. For example, Mathijs and Swinnen (2001) as well as Torben and Uwe (2013) indicate that the relative gains in technical efficiency on large farms can be linked to the transition from a traditional agricultural system to modern technology-based production structure with emphasis on mechanised farming techniques and structural changes in agricultural policies which favour large-scale farm producers over family farms in the allocation of subsidies and other governmental support to agricultural producers.

Amara, Traore, Landry and Remain (1999) applied the deterministic SFA with translog production function specification to estimate the technical efficiency of potato farmers in Canada and examine the influence of a number of factors suspected to affect resource use efficiency including soil conservation using cross-sectional data on 82 farms. The study used a logistic function technique to transform the technical efficiency scores so that the dependent variable in the second-stage estimation could be a binary outcome to allow for the application of the Tobit regression approach. Among other factors hypothesised to affect technical efficiency, the adoption of soil conservation practices was found to exert a significant positive influence on technical efficiency. The study also found a significant negative relationship between farm size and technical efficiency.

O'Neill and Mathews (2001) investigated the factors affecting variations in efficiency among farmers in Ireland and found that farming in the east of the country; larger household size and higher levels of borrowings were positively associated with higher efficiency while a significant negative relationship was found between farm size and efficiency, signaling the superiority of small farms over large farms.

Wilson, Hadley and Asby (2001) estimated the technical efficiency of wheat farms in Eastern England using the SFA approach and panel data for the period 1993 to 1997. Results from the second-stage regression estimation show that there is a significant positive between farm size and technical efficiency. Hadri and Whittaker (1999) used the stochastic frontier production analysis to investigate the relationship between farm size and technical efficiency. They employed panel data for the period 1987 to 1991 for farms in South West England and found a significant positive relationship between farm size and technical efficiency. However, they did not test whether the relationship between farm size and efficiency was sensitive to the choice of estimation method.

Bojnec and Fertő (2013) studied the factors accounting for variations in efficiency among farmers in Slovenia. Results show that the relationship between farm size and efficiency is positive and significant. Cloutier and Rowley (1993) applied the DEA approach to estimate and identify the determinants of technical efficiency among dairy farmers in Canada. The DEA model was estimated on the assumption of constant returns to scale. Their results indicate that large farms are more efficient than smaller ones. Contrarily, Sawers (1998) attributes the lack of inverse relation between farm size and efficiency in the Argentine interior to policy distortions and market imperfections in the allocation of agricultural inputs. The author notes significant disparities in access to critical farm inputs and information between small-scale and large-scale farmers and suggested that by deliberately making it difficult for small-scale farmers to access and use key modern inputs like fertiliser and farm credit, small farm operators are bound to be unproductive and inefficient. This put into perspective the argument raised by Sharif and Dar (1996) that technical efficiency is positively related to farm size because large farm owners tend to have greater access to public services than their counterparts with small farms.

Ünal (2008) examined the relationship between farm size and crop yields in Turkey. After controlling for location-specific heterogeneities suspected to affect the relationship between farm size and resource use efficiency, Ünal found a significant negative relationship between farm size and efficiency, and concluded that smallholder producers should not be undermined in policies geared towards increasing agricultural production and improving household welfare.

Tipi, Yildiz, Nargeleçekenler and Çetin (2009) investigated the impact of farm characteristics and sociodemographic factors on the technical efficiency of rice farmers in Turkey. An input-oriented data envelopment analysis was employed to estimate the technical efficiency scores whereas Tobit regression technique was used to identify the determinants of technical efficiency. The results of the study indicate that farm size had a significant positive impact on efficiency.

In a related study, Tipi and Rehber (2006) estimated technical efficiency and total factor productivity of farmers in the South Marmara Region of Turkey over the period 1993 to 2002 using the DEA and DEA-based Malmquist index. Their analysis indicates that technical efficiency is affected by a number of factors not related to the technological choices made by respondents. The main factors which significantly explained variations in technical efficiency were farm size, environmental conditions, location, size of the local economy, and availability of good transportation network. The results also indicate that institutional factors like extension services and government policies strongly and positively affected technical efficiency.

Giannakas, Tran and Tzouvelekas (2000) investigated the effect of input growth and technological change on the technical efficiency of olive farmers in Greece. A balanced panel data on 125 olive farms during the period 1987 to 1993 was used for the analysis. The study estimated a flexible modified translog stochastic production function with Box-Cox transformation of the independent variables. Results show that small farm sizes, high fragmentation of farms, and extensive protectionism of the olive farming sector were responsible for the low efficiency levels among the respondents.

Reddy (2002) investigated technical efficiency differences between tenant and owner operated sugarcane farms in Fiji using the SFA technique and found significant variation between the two groups of farms with respect to input usage and technical efficiency. Owner operated farms utilised higher amount of family labour and animal traction compared to tenant operated farms. It was also observed that for both classes of farms, technical efficiency was inversely related to farm size, although the relationship was not statistically significant.

Madau (2011) employed a three-year balanced panel data to study technical and scale efficiencies of citrus farmers in Italy and found that technical efficiency was positively affected by farm size. The policy implications of Madau's study is that improvement of technical efficiency strongly depends on citrus farms attaining an adequate size in order to allow their users to amply scale-biased techniques of production. Meanwhile, the number of farm plots was established to have a significant negative effect on technical efficiency, reflecting that technical efficiency of citrus production tends to decrease with land fragmentation. This underscores the importance of policies aimed at encouraging farmland consolidation.

Brock, Grazhdaninova, Lerman and Uzun (2008) examined the effect of farm organisation on technical efficiency in Russia. They made use of both SFA and DEA to estimate technical efficiencies scores. The efficiency ranking by both methods indicates that household plots were more efficient than corporate farms, which in turn were more efficient than peasant farms. The mean technical efficiency based on the SFA was 0.745 while the mean technical efficiency using the DEA was 0.357. In terms of farm types, household farms achieved an average technical efficiency of 0.472; corporate farms achieved 0.339 while peasant farms obtained 0.276.

Although the debate on the relationship between farm size and agricultural efficiency is largely inconclusive, empirical studies from a wide range of developing countries show that the relationship is negative, reflecting that small farm operators are the more efficient group. For instance, Schultz (1964) proposed the "poor but efficient" hypothesis after establishing a strong inverse relationship between farm size and allocative efficiency among peasant households within traditionally poor agricultural communities in Guatemala. Schultz advanced that the widely held doctrine that peasant farmers in poor countries are either indifferent or respond perversely to price incentives is blatantly false and lack any empirical foundation, and that policies based on this view always impair the efficiency of agriculture. His analysis shows that there is, in fact, considerable evidence to show that agricultural producers in developing countries in general, and particularly farmers in close proximity to large markets with good transportation network, respond very actively to price variations.

In a related study, Behrman (1968) concludes that peasant households in low-income countries respond significantly and substantially to economic incentives. Like Schultz (1964), Behrman focused on general allocative efficiency rather than farm-specific efficiency scores. But the analyses of both studies have has brought to the fore a number of key questions that need to be addressed by scholars who maintain that the supply behaviour of peasant households in low-income countries is inconsistent with classical economic theory. First, both studies have shown that contrary to conventional wisdom, peasant households respond to economic incentives by allocating their farm resources in a consistent and optimal manner. Moreover, both studies show that smallholder producers can achieve comparative levels of efficiency as large-size farm operators, such that on the grounds of efficiency alone there is no basis to discriminate between large and small farms in terms of access to productive capital.

Cornia (1985), in his investigation of agricultural systems in developing countries, discovered considerable evidence in favour of an inverse relationship between farm size and agricultural productivity, and attributed it to more intensive use of agricultural land and increased application of time-tested traditional farming practices by smallholder producers. Similarly, Prosterman and Riedinger (1987) found that 11 of the top 14 countries in terms of grain yields per hectare are countries in which small-scale farming is the dominant mode of production.

Drummond (1972) also indicates that small traditional farms and large mechanised farms exhibited no substantial differences in their efficiency of resource utilisation, and concluded that attempts to tag smallholder agricultural producers as technologically backward and technically inefficient as a justification for the promotion of capitalist farming lacks a solid scientific basis. In Drummond's view, small farms are the optimal size for output maximisation, labour absorption, and equity in the distribution of income. A study on the technical efficiency of traditional and non-traditional food crop production in Haiti also indicates that there is a strong inverse relationship between farm size and technical efficiency (Dolisca & Jolly, 2008).

Munroe (2001) indicate that despite decades of market transition, agriculture in Poland still exhibits low productivity with the inverse farm size-productivity hypothesis dominating in most agro-ecological zones. Similarly, Rosset (2000) argues against the commonly held notion that small farms are backward, unproductive and less efficient than large-scale corporate farms. Using evidence from both developed and developing countries, the author demonstrates that small farms are multi-functional, more productive, more efficient, and are able to contribute more to employment and economic growth and development than large farms. His analysis implies that the seemingly high output often observed on larger farms, as opposed to smaller farms, can be blamed on unfair trade and agricultural policies. In particular, Rosset points out that by deliberately making it difficult for small farm operators to access essential productive capital such as credit, technology, research information, subsidies, extension services, and other productivity enhancing infrastructure like improved road networks and modern crop varieties, agricultural policies can increase the cost of production for smallholder farmers and make it difficult for them to be efficient and competitive.

Latruffe, Balcombe, Davidova and Zawalinska (2004) investigated the determinants of technical efficiency among crop and livestock farms in Polland using both SFA and DEA approaches. The sample sizes of the study were 222 and 250 for crop farms and livestock farms respectively, with the corresponding mean technical efficiencies estimated to be 57 percent and 71 percent. This study revealed that, on average, livestock farmers are more technically efficient than crop farmers. For both specialisations, however, large farm owners were observed to be more efficient than small farm owners. Other significant findings of the study by Latruffe *et al.* are that efficiency is significantly and positively affected by the soil quality on crop farms and the share of land rented in by farm operators as well as the level of agricultural education. The most important policy conclusion from the study by Latruffe *et al.* is that measures that can promote increase in farm size might have beneficial effects on efficiency due to the positive link between farm size and efficiency. Similarly, the development of land leasing opportunities was regarded as significant for the crop farms sector due to the positive association between share of rented land and technical efficiency. Thus, agricultural policies that facilitate the development and efficient operation of land markets and assist smallholder farmers to move to non-agricultural employment could contribute to the improvement of technical efficiency in the long-run.

Jaime and Salazar (2011) also found that, among wheat farmers, large farm operators achieved higher efficiency scores than their counterparts with small farms, signaling that policies that contribute to farmland consolidation have the potential to increase agricultural production and economic growth. In India, the seminal paper by Sen (1962) laid the foundation for further empirical investigations on the relationship between farm size and technical performance. Using India's Farm Management Survey data, Sen established a strong inverse relationship between farm size and agricultural productivity measured by output per acre of land. However, Sen's study has been critiqued as old fashioned and inadequate in terms of its empirical rigour and treatment of time invariant household heterogeneities and failure to estimate farmer-specific efficiency scores (Barbier, 1984; Coelli & Battese, 1996; Ghose, 1979).

Barbier (1984) argues that the inverse relationship between farm size and agricultural productivity found in studies based on limited dataset in selected agro-ecological areas should not be taken as a *prima facie* evidence that this relationship holds over time and space. In particular, Barbier quashed the very existence of a functional relationship between farm size and agricultural productivity and indicated that Sen's (1962) inverse farm size-productivity thesis is spurious. Moreover, Ghose (1979) argues that a necessary condition for the existence of an inverse relationship between farm size and efficiency is technological backwardness. Ghose further suggests that advances in technology will erode most of the advantages enjoyed by smaller farms and contribute to the collapse of Sen's inverse farm size-productivity hypothesis and to the emergence of a significant positive relationship between farm size and productive efficiency. Like Sen, however, the studies by both Barbier and Ghose also used cross-sectional data and hence were not able to account for the influence of time and technology on the relationship between farm size and performance. Moreover, none of these studies estimated farm-specific efficiency, though they used indicators that can generally be accepted as fair approximations of efficiency.

Rao and Chotigeat (1981) studied the relationship between farm size and agricultural productivity. They estimated a translog production function to investigate the relation between output and inputs. Their study was conducted using farm level data from several states in South India over the period 1962 to 1970. Results show that there is no systematic inverse relationship between farm size and productivity. It was also observed that large capital infusion canceled out the negative effects of land area and led to a positive relationship between farm size and productivity. But this study did not estimate farm-specific resource use efficiency scores and thus cannot be regarded as superior to the study by Sen (1962).

Providing more nuanced analysis on the relationship between farm size and farmers' performance in India, Coelli and Battese (1996) used panel data from three villages with diverse agro-climatic conditions to estimate efficiency scores and investigate the relationship between farm size and efficiency. Results revealed a significant inverse relationship between farm size and level of technical inefficiency, suggesting that large farms are more technically efficient than smaller farms. Coelli and Battese used the one-stage estimation procedure and also accounted for year effects by including year dummies in both the production function and the technical inefficiency model. This makes their study more superior to other empirical studies on the relationship between farm size and efficiency.

Tadesse and Krishnamoorthy (1997) used the two-stage estimation technique based on the SFA approach to study the efficiency of rice producers across ecological zones and farm size groups in Tamil Nadu of India. The study shows that 90 percent of variation in output among farms was due to differences in technical efficiency. The study further indicates that farmers operating small and medium-sized farms achieved higher levels of efficiency than their counterparts with large farms. Unlike other previous studies, Tadesse and Krishnamoorthy tested for the effect of interaction between farm size and agro-ecological location on efficiency, and found that small and medium farms located in the southern and north-eastern zones were operating at higher levels of efficiency than farmers in other ecological areas. In addition, the study revealed that animal power was over utilised by farmers.

Employing panel data on rice farmers in the Philippines and the SFA approach with profit function formulation, Shively and Zelek (2003) found that producers with small farms were inefficient because they over applied labour and under applied fertilisers and pesticides. In addition, Huang, Tang and Bagi (1986) employed a stochastic profit approach to examine the economic efficiency of farms. Results of the study indicate that the mean economic efficiency for large farms was greater than for small farms. Although these studies were conducted in two different countries which make it difficult to compare their results, the use of profit functions for efficiency analysis is inconsistent and problematic in the sense that efficiency estimates based on profit functions are sensitive to prices and hence cannot be used as a yardstick for classifying farmers in developing countries.

According to Aigner *et al.* (1977), profit function models do not provide numerical measures of farm-specific efficiency scores, and hence are more likely to misclassify some category of producers as inefficient when indeed they are efficient. Aigner *et al.* favoured the use of physical quantities of output rather than profit since the former is more robust and less likely to be affected by price distortions. Corroborating the same view, Binswanger, Deininger and Feder (1993) expressed dissatisfaction about the methodological flaws in studies purporting to test the farm size-productivity hypothesis in developing countries, and asserted that the use of profit indicators to measure and explain agricultural productivity in traditional farming systems is fundamentally flawed since it does not take into account the peculiar situation of smallholder farmers.

Bakhsh (2007) employed the parametric technique with varying production functions to estimate the level and determinants of efficiency among farmers in Pakistan. On the basis of the log likelihood test, Bakhsh found that the translog specification was preferable over Cobb-Douglas model. Considering the relationship between efficiency and farm size, it was established that farm size had a significant inverse impact on efficiency.

In their study of rice production in Punjab District of Bangladesh, Abedullah and Mushtaq (2007) found a significant inverse relationship between farm size and efficiency, and suggested that this could be explained by the inability of large farms to meet labour requirements for effective production. Contrarily, Kabir, Musharraf, Haque and Khan (2016) found a significant positive relationship between farm size and efficiency in four districts of Bangladesh, and argued that this can be attributed to the better planning and innovativeness of large farm operators. Results of the study also indicate that efficiency increases with increasing years of formal schooling and off-farm income but reduces as the age of the family head increases.

More recently, Zulfiqar, Datta and Thapa (2017) investigated the relationship between farm size and resource use efficiency among cotton producers in the Punjab District of Pakistan. Factors affecting technical and economic efficiencies were identified using bootstrapped truncated regression. There was variation in technical efficiency and this was predicted to be positively influenced by farmers' education, farming experience, and drainage status, and negatively influenced by the number of household members involved in farming and the area under cotton. Moreover, economic efficiency was negatively affected by the number of household members involved in farming and the intensity of using crop management practices. Without doubts, this study broadened the literature on the determinants of resource use efficiency among agricultural producers and the causal relationship between farm size and technical efficiency. Like other previous studies, however, its major limitation lies in the use of cross-sectional dataset and utilisation of one estimation approach.

Xin, Zhang, Wang and Nuetah (2015) employed the stochastic meta-frontier approach to measure technical efficiency and to investigate the relationship between technical efficiency and farm size among broiler producers in China. Empirical evidence from this study shows a significant positive association between technical efficiency and farm size. Geographical location was also found to have a significant effect on technical efficiency. Efficiency in the southern region, which was dominated by yellow-feathered broilers, was found to be significantly lower than in the northern sector where white-feathered birds were the dominant species. Also, technical efficiency scores estimated from the meta-frontier model varied substantially across farm sizes in both locations.

Rios and Shively (2006) examined the relationship between farm size and technical efficiency using data on a sample of coffee farms in two districts of Vietnam. This study adopted the two-stage estimation procedure in which the DEA approach was used in the first stage to estimate the efficiency scores whereas the Tobit regression technique was used to investigate the effects of agronomic factors and sociodemographic characteristics on the estimated efficiencies. Empirical results show a significant positive relationship between farm size and efficiency, implying that large farms are more than small farms. However, Rios and Shively argued that the main factor which caused large farms to be more efficient than small farms was that large farm owners had more access to credit to invest in productivity enhancing technologies than small farm owners. This strengthens the arguments by Rosset (2000) that structural differences in access to productive resources can play a crucial role in deepening the disparities between large farm owners and small farm operators with respect to technical performance.

Dao (2013) employed the data envelopment analysis under the assumption of variable returns to scale to estimate the technical efficiency of crop farms in the Northern Region of Vietnam. The study also examined the determinants of technical efficiency. Empirical results furnished by the author reveal that technical efficiency varies directly with farm size, off-farm income while it varies inversely with land fragmentation and use of family labour.

Moreover, it was also observed that farms favouring market-oriented products such as annual industrial crops achieved greater technical efficiency scores compared to those focusing on staple crops like rice and maize. Krishna and Veettil (2014) also found a positive and significant relationship between farm size and technical efficiency in the northwest Indo-Gangetic Plains, and indicated that a one percent expansion in farm size will increase technical efficiency by about 0.5 percent. However, Bozoğlu and Ceyhan (2007) found strong negative relationship between farm size and technical efficiency and farm size among vegetable farmers, signaling the presence of the inverse farm size-productivity hypothesis.

Squires and Tabor (1991) studied the relationship between technical efficiency and farm size among mixed crop farms in Indonesia and found that smaller farms were much more technically efficient than large farms. This study shows that smaller farm owners had more control over their agronomic activities and exploited economically beneficial land cultivation patterns and resource allocation decisions.

Gilligan (1998) examined the relationship between farm size and efficiency among farmers in Honduras. Using the DEA approach, economic efficiency of each farm was estimated and disaggregated into measures of scale and technical efficiencies. Next, these measures were then used to determine how the relative share of each source of inefficiency differed by farm size. Results show that farm size is inversely related to both scale and technical efficiency. However, after controlling for the presence of decreasing returns to scale, producers with large farms were found to be more technically efficient than those with small farms. Further decomposition of efficiency measures into scale and technical efficiency indexes confirmed the econometric results, reflecting that diseconomies of scale dominated the relative technical efficiency of large farms. This implied that overall economic efficiency could be improved by reducing farm size. Unfortunately, this study did not use panel data neither did it compare results based on the nonparametric DEA approach to those of the SFA approach.

Rathore (1984) provides more nuanced analysis of the farm size-efficiency relation. He first estimated the productivity differential between small and large farms and then decomposed the observed differences into three contributing factors: neutral technological differences, non-neutral technological differences and input use differences. He finds that, on the average, small farms had higher level of output than large farms. Neutral technology was in favour of large farms while non-neutral technology was in favour of small farms. In terms of input use differences, small farms are also found to do better than large farms, thus signaling the occurrence of the inverse farm size-productivity hypothesis.

Rahman, Schmitz and Wronka (1999) examined the impact of farm-specific factors on the technical inefficiency of rice production in Bangladesh. Using cross-sectional data on 500 farmers and the SFA approach with Cobb-Douglas model, they found that the factors which had significant positive influence on annual rice output were extension services, farm size, bullock power, fertiliser utilisation, human labour, and irrigation cost. The model of technical inefficiency effect showed that farm size had a significant and positive impact on efficiency. Rahman *et al.* argued that the positive relationship between technical efficiency and farm size could be due to the fact that small farm operators had alternative sources of income and hence put less effort into farming compared to large farm owners.

Cimpoies and Lerman (2008) and Lerman and Sutton (2006) did a comparative analysis of the technical efficiency of small and large farms in Moldova based on cross-sectional data from three national farm surveys. In both studies, technical efficiency scores were estimated separately for the two categories of farms using the SFA approach. Their analysis shows convincingly that small farms achieved higher technical efficiency than large corporate farms. The average technical efficiency for small farms was estimated to be 0.70 while the average technical efficiency for corporate farms was 0.67. In contrast, Giannakas, Schoney and Tzouvelekas (2001) as well as Tzouvelekas, Pantzios and Fotopoulos (2001a) found an insignificant inverse relationship between farm size and technical efficiency.

Llewelyn and Williams (1996) found insignificant negative relationship between farm size and the technical efficiency of food crop production in the East Java zone of Indonesia while Mariyono (2014) reported a significant positive relationship between farm size and technical efficiency among rice producers. Meanwhile, Tzouvelekas, Pantzios and Fotopoulos (2001b), Curtiss (2000) and Morrison (2000) also found strong positive relationship between farm size and efficiency, and concluded that large farms are crucial for agricultural productivity growth and improvement in the welfare of agricultural households.

Ladvenicová and Miklovičová (2015) found strong inverse relationship between farm size and technical efficiency among food crop producers in Slovakia. Moreover, Koester and Striewe (1999) found evidence in favour of smaller farms in the case of transition countries and argued that these countries suffer from diseconomies of scale in a number of areas thus making smallholder farming the only plausible alternative. Unfortunately, this study failed to recognise the rapid developments taking place in these economies with respect to rapid integration into the world economic system and adoption of modern agricultural technology. They did not also examine the relationship between farm size and technology adoption as well as household food security.

Hadley (2006) studied the determinants of technical efficiency by applying the restricted Cobb-Douglas functional form on panel data of farm households in England and Wales for the period 1982- 2002. His analysis shows that the sampled farmers were generally efficient, with a large proportion of respondents observed to be operating close to the optimal production frontier. In addition, he discovered that the factors that significantly predicted variations in efficiency scores between the sampled farmers were farm size, debt-to-capital ratios, farmer age as well as levels of specialisation and ownership status.

Compared to other parts of the world, empirical studies on the relationship between farm size and efficiency in Africa are relatively few and inconclusive. While some studies found an inverse relationship between farm size and productivity; implying that the redistribution of land in favour of small farms has the potential to increase output, generate employment and contribute to poverty reduction and household food security, some studies also provide contrary evidence and argued that land consolidation holds the key to the socioeconomic transformation of the continent.

Larson, Otsuka, Matsumoto and Kilic (2014) used a model of endogenous technology choice to explore the relationship between farm yield and farm size using alternative data on African countries. Their analysis shows that the inverse farm size-productivity relationship holds across a broad platform of data. Larson *et al.* then recommended that researchers interested in testing the farm size-productivity relationship in Africa should endeavour to use surveys with narrow geographic reach in order to produce more reliable results even though results on the farm size-productivity hypothesis are better suited for policy decisions when they are based on data that are broadly representative. None the less, studies in individual countries continue to produce conflicting and inconclusive results regarding the relationship between farm size and efficiency.

In South Africa, for example, a number of empirical studies have been implemented to test the relationship between farm size and efficiency but results remain varied and inconclusive. Van Zyl, Binswanger and Thirtle (1995) indicate that the inverse relationship between farm size and technical efficiency of agricultural production in South Africa becomes stronger and more accentuated as policy distortions which favour large farms are removed. The authors conducted empirical analyses on farm-level data from official surveys for seven regions in various years and investigated the relationship between technical efficiency and farm size in commercial farms using the DEA approach.

Employing a similar approach as Van zyl *et al.* (1995), but accounting for differences in land quality, Chavas and Van Zyl (1993) established a highly significant negative relationship between farm size efficiencies and debt burden, and a significant positive relationship between managerial ability and efficiency. Their results show that the issue of scale efficiency is a complex one and is influenced by a range of factors. Similarly, von Bach and Van Zyl (1992) found a significant positive relationship between scale efficiency and managerial ability, and concluded that this explains why better managers have large farms. Meanwhile, Van Zyl (1995) indicates that despite a history of policies favouring relatively large mechanised farms, a significant inverse relationship exists between farm size and efficiency in the commercial farming sector of South Africa. Moreover, Hattingh (1986) shows that the relationship between farm size and efficiency in South African agriculture is mixed. For example, he found a significant positive relationship between farm size and efficiency in sheep farming in Karoo and in cattle ranching in the North-western Transvaal region of South Africa but a significant inverse relationship between farm size and efficiency on irrigated farms at Vaalharts and dryland grain farms in Free State.

Ngwenya, Battese and Fleming (1997) studied the determinants of technical efficiency among wheat farmers in the Eastern Free State, South Africa. Stochastic frontier production function was estimated in which technical inefficiency effects were modeled in terms of farm size and other explanatory variables. They found a significant inverse relationship between farm size and technical efficiency. In sharp contrast to the above results, Mango, Makate, Hanyani-Mlambo, Siziba and Lundy (2015) in their study of smallholder maize farms in Zimbabwe, and Bizimana, Nieuwoudt and Ferrer (2004) in their study of smallholder mixed crop farms in Rwanda found a significant positive relationship between farm size and efficiency, signaling that increases in farm size has the potential to increase agricultural production and create the necessary forward and backward linkages with other sectors of the economy.

A study by World Bank (1983) in Kenya indicates that output per hectare was 19 times higher on farms below 0.5 hectares than on farms measuring over 18 hectares. The study further indicates that a reduction in the average farm size by 10 percent could increase output by seven percent and employment by about eight percent. Lele and Agarwal (1989) compared the domestic resource costs for coffee and tea production between small-scale and large-scale farmers in Kenya. Their study revealed a strong comparative advantage in favour of smallholder production. Even after controlling for gender of household headship, wa Githinji, Konstantinidis and Barenberg (2011) found that the inverse relationship between land size and output per acre still held in Kenya. However, like the studies by World Bank and Lele and Agarwal, wa Githinji *et al.* did not estimate farm-specific efficiency scores neither dis she test for the impact of different estimation methods on the relationship between farm size and efficiency. Her analyses were also limited to productive performance while important issues confronting the same producers such as their food security status and state of farm mechanisation were unexplored.

Njeru (2010) applied the SFA to investigate the factors influencing the technical efficiency of wheat production in the Uasin Gishu District of Kenya. The frequency distribution of the levels of inefficiencies reveals that about 15 percent of large-scale farmers experienced inefficiency of over 20 percent compared with only 5 percent of small-scale farmers. The mean technical efficiency for large-scale farmers was 0.866 as against 0.882 for small-scale farmers. In a related study, Mburu, Ackello-Ogutu and Mulwa (2014) found a significant positive relationship between farm size and technical efficiency. Nonetheless, the efficiency scores of small-scale farmers was very high, thus compelling the authors to conclude that small-scale farming need not be disregarded in the agricultural change process. Similarly, Muyanga and Jayne (2014) found a positive relationship between technical efficiency and farm size, but indicated that there was a strong poverty reduction argument for investing in small-scale farms.

Brambilla and Guido (2009) employed cross-sectional survey data to examine the impact of marketing reforms and farm size on the efficiency of cotton farmers in Zambia. This study indicates that small farms are more efficient than large farms. In contrast, Chiona (2011) found that there exists a significant positive relationship between farm size and efficiency among maize farmers in Zambia, and called for the implementation of land consolidation policies. The DEA technique was used for the analysis in this study. Musaba and Bwacha (2014) also found significant positive relationship between farm size and efficiency among maize farmers in the Masaiti District of the Copperbelt Province of Zambia based on the SFA approach. Unfortunately, like other previous studies, the samples used in these studies were very limited in scope and hence do not allow drawing conclusions on the entire population.

Haji (2007) implemented a study to estimate technical, allocative and economic efficiency and their determinants in smallholder vegetable-dominated mixed farming systems in Eastern Ethiopia. Employing data on

150 respondents, he found that the DEA technical efficiency estimates were similar under the assumption of constant returns to scale and variable returns to scale. The mean technical, allocative and economic efficiencies were found to be 91 percent, 60 percent and 56 percent respectively, reflecting the existence of substantial allocative and economic inefficiency. Results from the second-stage regression show that asset ownership, off-farm income, farm size, extension visits, and household size significantly explained variations in technical efficiency. Asset ownership, crop diversification, consumption expenditures and farm size have significant impact on allocative and economic efficiencies. Haji also revealed that the excess cost due to inefficiency in the sample was 44 percent, and that this occurred mainly as a result of allocative inefficiency attributable to low asset ownership and farm size, high consumer spending as well as barriers to the flow of labour between farm and off-farm activities.

Simonyan, Umoren and Okoye (2011) studied the determinants of gender differentials in resource use efficiency among maize farmers in Essien Udim Local Government Area of Nigeria. This study applied the SFA approach based on the restrictive Cobb-Douglas functional form and also employed cross-sectional data. It also used the two-stage estimation technique in which efficiency scores from the first stage were regressed on a set of explanatory variables hypothesised to affect technical efficiency. Results indicate that technical efficiency obtained by male farmers was significantly and negatively related to farm size whereas the technical efficiency scores obtained by female farmers was significantly and positively explained by farm size. This implies that female farmers will do relatively better if they have access to more farmland than male producers, a result similar to those obtained by Bempomaa (2014) in her study on maize farmers in the Ejura Sekyedumase District of the Ashanti Region of Ghana.

Kadiri, Eze, Orebiyi, Lemchi, Ohajianya and Nwaiwu (2014) modeled the relationship between farm size and technical efficiency among agricultural households in Nigeria. Applying the SFA based on the Cobb-Douglas specification and cross-sectional data collected from interviews conducted among heads of farming households, they found a significant positive relationship between farm size and technical efficiency, suggesting that increases in farm size will lead to increased agricultural production and food availability. Invariably, the findings of this study underscore the crucial role of land consolidation and the significance of large-scale producers in agricultural productivity growth and industrialisation.

Paul, Adebola, Dare and Olubukola (2017) used the DEA approach to examine the factors accounting for variations in technical efficiency among farms operating under two different production systems. Results of the second-stage analysis based on the Tobit regression technique revealed that the factors which had significant impacts on technical efficiency were land constraints, education, access to extension services, and membership in cooperative societies. The study also found significant variations in technical efficiency across the sex of producers, with female farmers observed to be more technically efficient compared to their male counterparts.

Contrary to other studies in Nigeria, Popoola, Ogunsola and Salman (2015) and Awerije and Rahman (2014) found evidence in favour of a strong inverse relationship between farm size and technical efficiency whereas

Bamiro and Aloro (2013) found that farm size has no significant impact in explaining variations in efficiency. Moreover, Ibrahim, Shamsudin, Yacob and Radam (2014) report that the only significant determinants of technical efficiency among maize farmers in northern Nigeria are education, access to credit and type of agro ecological zone. This study also found most maize producers relied on hand tools as the main source of farm power, followed by animal traction with the least being tractor services. Consequently, farm mechanisation was predicted to be an insignificant determinant of technical efficiency, albeit positive.

Unfortunately, none of the studies discussed above examined the impact of the interaction between farm size and credit on efficiency, despite acknowledging that the farm size-efficiency relationship can be moderated by other factors including credit. The impact of the interaction between farm size and loan amount on efficiency is tested in this thesis, thus making it an improvement over the studies by Popoola *et al.* (2015) and others. Moreover, Kevane (1996) advanced that if investment in soil fertility management and other on-farm activities is important and farmers' access to credit and insurance is conditioned on the size of agricultural enterprise, then difficulties in accessing financial markets may lead to the emergence of a significant positive relationship between farm size and productivity.

Hazarika and Alwang (2003) applied the stochastic cost function to estimate efficiency among tobacco producers in Malawi. This study revealed that large farm operators are less cost efficient compared to with small farms. The study also revealed that access to credit retards the gains in cost efficiency from an increase in the acreage of farmland brought under tobacco production, which suggests that the methods of credit disbursement was faulty. Chirwa (2007) studied the determinants of technical efficiency among smallholder maize farmers in southern Malawi using the one-stage estimation procedure of the SFA approach and plot-level data. Results show a significant positive relationship between farm size and technical efficiency. The analysis also revealed that maize plots which were partly prepared with hired labour and planted with hybrid seeds were more technically efficient than plots prepared solely by family labour and plots on which non-hybrid seeds were used. Moreover, membership of the household head in a farmer-based organisation as well as interaction between the level of education and adoption of hybrid maize seeds were also found to significantly influence efficiency.

Owen (2003) examined the relationship between farm size and technical efficiency of among maize producing households in Malawi. Unlike other previous studies, Owen used a more nationally representative data and also divided the analysis into two to control for the effect of hybrid seed adoption. Empirical results show that there is a negative relationship between farm size and technical efficiency among producers of local maize varieties whereas a positive relationship between farm size and efficiency in the hybrid maize model. Other variables which were identified to have resulted in the negative relationship between farm size and productivity in the local maize model are plot area measurement errors, higher transport cost and differences in input quantity. In addition, Dorward (1999) investigated the farm size-productivity relation among smallholders, concentrating on two ecological zones in Malawi. The study found a significant positive relationship between farm size and productivity, not only when it examined national data, but also when it used data for each region separately. This raises important questions concerning the type of dataset suitable for testing the relationship between farm size and resource use efficiency (Larson *et al*., 2014).

Verschelde, D'Haese, Rayp and Vandamme (2013) used a nonparametric approach, with a Cobb-Douglas production function specification, to investigate the technical efficiency of mixed crop farms in two provinces of Burundi. Five production models each with different control variables were specified. Technical efficiency was found to be inversely related to farm size. Land fragmentation and perceived low soil quality also had significant inverse effect on technical efficiency. However, as returns to scale was dependent on farm scale, the study concluded that it is possible for large farms with low field fragmentation to exploit economies of scale. Furthermore, the study found a significant positive relationship between farm size and household food security and concluded that large-scale agriculture could contribute to poverty reduction and food security.

Like other African countries, empirical studies on the relationship between resource use efficiency and agronomic factors in Ghana have yielded mixed and inconclusive results. For instance, Abatania (2013) combined both parametric frontier and nonparametric models to investigate the factors accounting for variations in efficiency scores among farmers in the Upper East Region of Ghana. Using data from the fifth round of the Ghana Living Standards Survey (GLSS) and bootstrapping technique that allowed him to correct for sample selection bias, Abatania examined the relationship between technical and scale efficiency and various socioeconomic and agronomic factors. Empirical results show that a significant negative relationship exists between farm size and the two indicators of efficiency.

Asante *et al*. (2014) applied the SFA approach based on the translog function to estimate and investigate the relationship between farm size and the technical efficiency among yam producers in three agro-ecological zones of Ghana. Their analysis revealed significant positive relationship between farm size and efficiency. In addition, Adzawla, Fuseini and Donkoh (2013) and Dzene (2010) also found significant positive relationship between technical efficiency and farm size. Contrarily, Ahwireng (2014) and Etuah (2014) established a significant inverse relationship between farm size and technical efficiency, and suggested small-sied farm owners are more technically efficient compared to large farm owners due to managerial difficulties associated with the latter. Moreover, Abdul-Hanan, Ayamga and Donkoh (2014) showed that there is no statistically significant relationship between farm size and technical efficiency while Ansah, Oduro and Osae (2014) established a curvilinear relationship between the two variables.

More specific studies which investigate the relationship between farm size and efficiency among maize farmers in Ghana also continue to produce conflicting results regarding the nature of relationship between farm size and efficiency. For example, Dasmani (2015) applied the SFA approach based on the translog production function formulation and the metafrontier approach to investigate the determinants of efficiency among farmers across three agro-ecological zones of Ghana including the Northern Region. Results show mixed findings for the variable representing farm size. For instance, while farm size had a significant inverse impact on the technical efficiency of maize producers in the pooled sample and in the coastal and forest zones, there was no statistically significant relationship between farm size and efficiency among maize farmers in the Northern Region.

Wongnaa (2016) also found mixed results on the relationship between farm size and technical efficiency among maize farmers across the different agro-ecological zones of Ghana. The variable for farm size was positive and significant at 10 percent for maize farmers in the pooled sample, one percent for maize farmers in the northern savannah zone and in the transitional zone. Conversely, farm size was negatively related to technical inefficiency and significant at one percent and 5 percent for maize farmers in the forest and coastal savannah zones respectively.

In a related study, Wongnaa and Awunyo-Vitor (2017) studied the determinants of scale efficiency of maize farmers in four agro-ecological zones of Ghana. This study employed cross-sectional data on 576 maize farmers in the Guinea Savannah, Transition, Forest and Coastal Savannah zones of the country using structured questionnaires. Employing the likelihood ratio test, the authors rejected the Cobb-Douglas specification in favour of the translog functional form. In addition, they found that scale inefficiencies existed in maize farms across the four agro-ecological zones. Their results further showed that scale efficiency was explained by farm size, educational level, maize farming experience, access to good roads and ready markets, membership in association, utilisation of extension services, household size, land fragmentation, as well as use of fertiliser, pesticides and improved maize seeds. The significant inverse relationship between land fragmentation and scale efficiency reported by this study underscores the importance of land consolidation and farm size growth. Moreover, Demetriou (2013), Downing (1977) as well as Kalantari and Abdollahzadeh (2008) have documented that one of the critical factors militating against agricultural productivity growth and household welfare improvement in most countries is the preponderance of smallholder farming and the fragmented nature of landholdings brought in part by rapid urbanization and the continued treatment of agricultural land as a collective asset which must be subdivided among heirs on the demise of loved ones.

Although, Dasmani (2015), Wongnaa (2016) as well as Wongnaa and Awunyo-Vitor (2017) used different estimation techniques for which reason their results might not be directly comparable, the mixed evidence on the relationship between farm size and efficiency across the different agro-ecological zones gives credence to the arguments raised by Larson *et al.* (2014) that the relationship between farm size and agricultural productivity is better studied when the analysis is restricted to farmers growing the same crops and located in a more similar agro-ecological zone where distortions in agro-climatic conditions can be controlled for. This is achieved in this thesis since the dataset used for all empirical analysis was obtained from maize farmers located in the same agro ecological zone.

A significant proportion of existing studies testing the relationship between farm size and resource use efficiency among agricultural producers in both developed and developing countries tend to focus on a simple linear relationship. However, evidence is beginning to mount in favour of a nonlinear relationship between the two variables. For example, Bhatt and Bhat (2014) and Asefa (2012) reported that the relationship between farm size and technical efficiency is nonlinear. In addition, Strange (1988) provides theoretical justification why the relationship between farm size and technical efficiency may be nonlinear. He advanced that small farms can be inefficient because they are unable to make full use of expensive, scale-biased and indivisible farm tools while large farms could also be inefficient because they face inherent management and labour requirement problems. According to Strange, peak efficiency is likely achieved on medium sized farms that have one or two hired labourers.

Weersink, Turvey and Godah (1990) estimated the efficiency of dairy farms and disaggregated it into purely technical, congestion and scale efficiencies. They employed data on 105 farms in the Ontario region of Canada, for the year 1987, and DEA method to compute technical efficiency scores. The regression analysis of factors affecting overall technical efficiency levels revealed that there was a curvilinear relationship between farm size and technical efficiency, with technical efficiency first increasing with farm size and then falling when farm size exceeded 102 units.

Henderson (2015) used a nationally representative data from the Nicaraguan Living Standards Survey for the periods 1998, 2001 and 2005 to investigate the relationship between farm size and technical efficiency. He employed a four-stage empirical framework to simultaneously test competing explanations for the inverse relationship between farm size and agricultural productivity. The analysis of technical efficiency estimates was done with the parametric approach based on a Cobb-Douglas functional form specification. Empirical results of the study indicate that relationship between farm size and technical efficiency is nonlinear. The study also found that the ratio of owned to operated landholdings had a negative and statistically significant effect on technical efficiency for all samples, which suggests that increasing land tenure security could improve technical efficiency via relaxation of credit constraints.

Helfand and Levine (2004) observed that the relationship between farm size and technical efficiency among food crop farmers in the Brazilian Center-West is a quadratic parabola with technical efficiency decreasing with farm size up to about 500 ha and then increasing for farm size ranging from 10,000 to 20,000 ha. The study also indicates that access to institutions, extension services, credit, and modern inputs are key factors responsible for the differences in efficiency across farms and thus improvement in these factors could improve the technical efficiency of small and medium farms. Fandel (2003) provides evidence based on a study of corporate farms in Slovakia which points to a curvilinear relationship between efficiency and farm size. Using dataset on 1147 households and the DEA model, the study estimated a mean pure technical efficiency of 0.623. Regarding the relationship between farm size and technical efficiency, empirical results show that the best technical efficiency performance is achieved by farms of the size group below 100 hectares, and by farms above 1000 hectares.

Heltberg (1998) found a U-shaped relationship between farm size and farm productivity in Pakistan, after controlling for various factors suspected to be sources of market imperfections. Teryomenko (2008) applied a panel data set for the period 2001 to 2005 to study the effect of farm size on technical efficiency in Ukraine. The value of crop output per hectare and technical efficiency were used as measures of farm productivity. Technical efficiency was estimated with both SFA and DEA. The analysis of the determinants of technical efficiency indicates that the relationship between technical efficiency and farm size is nonlinear. Similarly, Mignouna, Manyong, Mutabazi, Senkondo and Oleke (2012) found an inverted U-Shaped relationship between farm size and technical efficiency among maize farmers in western Kenya with Imazapyrresistant maize for striga control.

Besides farm size, a broad range of sociodemographic factors have also been found to influence variations in resource use efficiency among farmers. One common sociodemographic factor which has been used in predicting technical efficiency is education. However, like agronomic factors, empirical findings on this variable are mixed and inconclusive. For example, whereas Asante *et al*. (2014) and Dasmani (2015) found significant positive relationship between formal education and efficiency and suggested that formal education increases the adoption capabilities of innovations and augments the managerial experience of farmers thus leading to higher productivity and technical efficiency, a number of empirical studies have also found evidence to the contrary. Yang (1997) concluded that higher level of formal education may not enhance labour productivity when it is reduced to performing basic and routine farm tasks.

Ansah *et al*. (2014) found a significant inverse relationship between formal education and profit efficiency in maize production in the Ejura Sekyedumase District in the Ashanti Region of Ghana, and indicated that highly educated farmers are more likely to allocate a greater proportion of their time to off-farm activities with little time left to manage their farms efficiently. Ansah *et al*. also noted that educated people are often too quick to apply modern agricultural techniques and inputs which may turn out to be costly and unsuitable to local agro-ecological conditions.

More recently, Paul *et al*. (2017) also found a significant negative relationship between formal education and efficiency among poultry farmers in Nigeria, and suggested that while more years of schooling might be good for some agricultural producers, it might not be good for others. Consequently, they advocated against to rash to policy regarding the importance of education to farmers. Kalaitzandonakes and Dunn (1995) stressed that the inconsistencies in results on the relationship between education and efficiency could be attributed to disparities in measurement. However, the study by Kalaitzandonakes and Dunn can be described as woefully inadequate because it failed to specify what an accurate measure of education should be. Moreover, much of the literature that the authors critiqued employed measures which can be regarded as fair approximations.

Empirical evidence on the relationship between household size and resource use efficiency are also varied and inconclusive. Some studies suggest that large household size imposes managerial constraints on agricultural producers and thus have a significant inverse impact on productive efficiency (Asante, Wiredu, Martey, Sarpong & Mensah-Bonsu, 2013; Mango *et al*., 2015; Okoye *et al*., 2016). On the other hand, household size has been found to exert significant positive influence on efficiency by serving as a cheap source of labour for most on-farm operations (Asante *et al*., 2014; Bhatt & Bhat, 2014). Household size is considered an alternative to commercial labour and hence is expected to positively explain variations in resource use efficiency among agricultural producers, especially in societies that do not have opportunities for labour hiring services (Ibrahim *et al.*, 2014).

Asante *et al*. (2013) found a significant inverse relationship between household size and technical efficiency, and explained that this could be attributed to the adverse effects of large family size on food and other financial resources that can be used to increase agricultural production. According to Asante *et al*., large household size increases the opportunity of shirking among some household members and this has the potential to reduce the amount of effort dedicated to farming. Meanwhile, Bhatt and Bhat (2014) found a significant positive relationship between household size and technical efficiency, and suggested that household size through its positive correlation with availability of family labour reduces labour constraints and results in more quality labour for carrying out farming activities in a timely manner. Adding to this complexity is the observation by Kabwe, Namonje and Chisanga (2016) and Mignouna *et al*. (2012) that household size affects technical efficiency in a nonlinear manner. These mixed findings imply that a consensus is yet to emerge regarding the exact relationship between household size and resource use efficiency among farmers, which could be due to the role of some moderating factors such as age composition and health status that remain untested by existing studies. These are tested in this thesis by including health shock as an additional explanatory variable.

Review of literature on agricultural technology adoption

Several theoretical and conceptual frameworks have been developed and used to explain decisions regarding agricultural technology adoption and choice of ploughing methods. But two of these theories have been proven to be more useful. These are: *the farming system evolution theory* proposed by Boserup (1965) and *the induced technology adoption theory* by Hayami and Ruttan (1985).

Farming system evolution theory

The central contribution of the farming system evolution theory is that agricultural technology in general and farm mechanisation in particular is endogenous rather than exogenous to the entire economic system. This theory has its basic tenets in the fact that the progress of agricultural technology is influenced by agro-ecological conditions and induced by the changing characteristics of the socio-economic environment in which farmers are found (Diao *et al*. 2014). According to the farming system evolution theory, the primary driving force behind the changing structure from traditional farm tools towards higher intensification methods are population density and market access. According to this theory, higher levels of population growth creates higher demand for food and increases the pressure on agricultural producers to expand production to meet growing demand, failure of which will result in shortage of agricultural products with its attendant negative consequences on health and calorie intake. Similarly, ready markets create the enabling environment for the uptake of agricultural technology facilitated by rising farm income resulting from the easy marketing of farm produce (Boserup, 1965).

Induced technology adoption theory

Following the recognition that the farming system evolution theory was inadequate in explaining differences in agricultural mechanisation adoption, particularly based on micro level data, Hayami and Ruttan (1985) formulated a model of induced technical change in which the development and application of new agricultural technologies is endogenous to the economic system which allows for the assessment of the emerging demand for farm mechanisation as a part of a technology adoption process.

The induced technology adoption theory conceptualises agricultural technology innovation and adoption as a continuous process which is often biased towards saving that factor of production regarded as scarce. Ruttan (2002) notes that alternative farming technologies are developed and adopted by farmers to facilitate the substitution of relatively abundant factors for scarce factors. In his view, mechanised technologies such as tractors and animal traction are labour saving and hence are adopted to substitute machinery for manpower whereas biological and chemical technology such as inorganic fertilisers, herbicides and weedicides are used to save land.

The induced technology adoption theory further argues that because changes in land and labour productivity are relatively independent, the adoption of labour saving technologies like tractors and animal drawn farm implements by farmers is not necessarily driven by the incentive to improve land productivity, which is the main focus of most biological and chemical technologies.

Empirical literature on agricultural technology adoption

Traditionally, most empirical studies on agricultural technology adoption or dis-adoption focused on imperfect information, risk, uncertainty, institutional constraints, human capital variables, input availability and infrastructure as important correlates for policy attention. More recently, social networks and learning has also gained recognition as a significant factor for adoption decisions. In the following paragraphs, some of the empirical studies linking these factors to agricultural technology adoption in general and choice of ploughing technology in particular are reviewed.

Among the numerous factors hypothesised to influence ploughing technology adoption, farm size, land ownership security, household size, and access to credit have been identified as the most important. For example, proponents of both the farming system evolution and induced technology theories posit a significant positive relationship between farm size and the decision to mechanise farm operations because larger farm owners tend to adopt new forms of mechanisation considerably faster and at lower comparative cost than smaller farms (Boserup, 1965; Hayami & Ruttan, 1985; Ruthenberg, 1980). The reason being that farm mechanisation becomes most profitable and contributes significantly to welfare when land is abundant and labour is scarce relative to land.

Binswanger (1986) highlights three reasons why a large farm size is needed before agricultural mechanisation can take place and have meaningful impacts on society as a whole and the livelihoods of agricultural households in particular. First, the opportunity cost of capital relative to labour is different among different farm size groups but is much higher on small farms which own few assets with collateral value and have abundant family labour. The second reason why mechanisation is suitable on bigger farms is that certain machine processes and tools operate well under genuine economies of scale which makes them easier to be used on bigger and favourably shaped plots of farmland compared to smaller and meandering farms (Maranan, 1985).

Binswanger (1986) argues that large scale owners are often the first group of agricultural producers to adopt mechanisation since they derive a lot of benefits from using modern machines and tools for their land preparation. On the other hand, Maranan (1985) pointed out that smaller farm sizes render the adoption of agricultural mechanisation uneconomical since most modern farming devices are indivisible and capital-intensive investments. Similarly, FAO (1981) reports that the exclusive use of scale-biased agricultural machinery such as standard tractors on farms less than 2 hectare in size is uneconomical, especially if the fields are fragmented and undulating.

Moreover, Mabuza, Sithole, Wale, Ortman and Arroch (2013) show that additional fixed costs associated with the use of most modern ploughing technologies impede adoption on smaller farms as lower levels of output on these farms lead to higher average fixed costs. Ahaneku, Oyelade and Faleye (2011) advanced that farm size, availability of labour and custom services, crop selection, and cultural practices all affect the selection of optimum equipment and, ultimately, the number of tractors necessary to carry out farming operation. Although demand for tractor power generally increases with farm size, the authors also noted that excess labour requirements may permit owners of one tractor to employ several operators to keep the machine running for extended periods of the day during high demand times leading to reduced performance and early breakdown.

Van der Meijden (1998) indicate that the first major constraint to agricultural mechanisation in West Africa is the size of the landholdings per farmer and the size of each field, which hampers the effective use of tractors and results in a high percentage of non-productive usage. Secondly, field clearing is a problem. Even when disc implements that can more easily overcome stumps and stones are used, fully cleared farm fields are rare. Steep slopes are also identified as another constraint. Lastly, Van der Meijden concluded that poor or non-existent access roads contribute to the high breakdown rates of machinery and adds to the list of factors causing the low rate of adoption among smallholder farmers.

Wongnaa (2016) studied the factors responsible for differences in agricultural technology adoption among maize farmers in three agro-ecological zones of Ghana. This study used three proxies (herbicides, fertiliser and planting in rows) to measure agricultural technology. Results show that the coefficients and marginal effects of farm size were significant and positive for all three types of technologies. Morris, Tripp and Dankyi (1999) found a significant positive relationship between farm size and the adoption of agricultural technology measured by improved maize seeds and chemical fertiliser, and explained that this could be due to the fact that farmers with large landholdings are better able to cover higher fixed implementation costs due to better access to capital and credit from financial institutions. None the less, a number of empirical studies have also found significant inverse relationship between farm size and the adoption of agricultural technology.

Nkonya, Schroeder and Norman (1997) found a significant negative relationship between farm size and agricultural mechanisation using chemical fertiliser application as a proxy, and explained that farmers use fertilisers more intensely per hectare on smaller farms whereas farmers who own bigger farms might only use a small quantity of fertiliser for experimental purposes and due to high associated cost. Employing the theory of farming system evolution and the theory of induced technology adoption by Hayami and Ruttan (1985), Diao *et al*. (2014) found that the demand for certain mechanised farming operations, particularly tractors and animal traction, has emerged even among small-size farm owners. In particular, Diao *et al.* indicate that the development of mechanised service hiring opportunities in which medium and large-scale farmers who are owners of tractors provide hiring-out services to small-scale represents a promising model for sustainable mechanisation.

According to Mendola (2007), subsistence-oriented smallholder farmers are more risk averse to adopt agricultural innovations due to limited holding and uncertain outcome of new technologies. Therefore, if small size operators are guaranteed of the positive performance of a certain agricultural technology and are also confident about the market potential and related risk of non-adoption, they are more likely to accept more advanced farming technologies. This puts into perspective Diao *et al*'s. (2014) proposition that market access is germane to the evolution of farming systems towards higher intensification and mechanisation.

Rauniyar (1998) examined the factors driving the adoption of technological practices among farmers in Nepal. Unlike previous studies that focused on a limited range of technology and crop farmers, Rauniyar developed indices of technology adoption out of 30 adoption practices among fishpond operators. An additional value of this study was that it departed from the traditional approach to regression by combining both structural equation modeling and multiple regression techniques to analyze the data. The study suggests that the education level of fishpond operators played an important role in increased adoption of management and technological practices. Ethnicity, geographical location, smaller fish farm size, access to inputs and cash reserves and proximity to market infrastructure also increase the probability of adoption of desirable management and technological practices. The study also found a strong inverse relationship between farm size and the amount of technological practices adopted; contradicting the commonly held belief that agricultural mechanisation is more regular among large farm holders and uncommon among people with small farms. Undoubtedly, even though this study has advanced knowledge on agricultural technology adoption by introducing a novel regression approach, the sample of respondents used for the analysis was very limited in scope and does not allow drawing conclusion on the entire population. Moreover, the study did not use panel data and hence was unable to address unobserved time dependent dynamics that can affect the relationship between farm size and agricultural technology adoption.

Sharma, Bailey and Fraser (2011) also found a significant positive relationship between farm size and the number of improved agricultural technologies adopted among cereal producers in the United Kingdom. Nevertheless, significant negative relationship between farm size and agricultural technology adoption has also been found by a number of empirical studies. For example, Sidibé (2005) argues that if the complementary inputs to an agricultural technology are scarce, smallholder farmers may adopt such a technology more easily whereas larger farm owners might not. In addition, Marra and Carlson (1987) found an inverted U-shaped relationship between agricultural technology and farm size, reflecting that as farm size grows, agricultural mechanisation may not increase proportionally. Idrisa, Ogunbameru and Amaza (2010) and Ebojei, Ayinde and Akogwu (2012) also found an inverse but insignificant relationship between farm size and agricultural technology adoption, signaling that smaller farm owners may be better placed to adopt new technologies compared to large farm owners.

Literature suggests that the system by which agricultural lands are held and used can determine the extent of production efficiency and choice of agricultural technology independent of environmental conditions and characteristics of producers (De Soto, 2000; Thirlwall, 2006). Moreover, significant link has been established between land tenure and agricultural mechanisation in a number of cross-sectional studies. For example, De Soto points out that the underdevelopment of formal land rights in developing countries in general and the limited share of land administered through statutory title documents in Sub-Saharan Africa in particular, has hindered agricultural development by maintaining very productive capital as “dead asset”. Compared with weak and insufficient property rights, land ownership security implemented through statutory land title registration is expected to increase productivity and encourage farm mechanisation by making resources available for investment.

Generally, three reasons have been advanced to support the prediction of a positive relationship between land tenure security and agricultural mechanisation. First, secured land rights are expected to provide a guarantee for farmers to undertake long-term investment and adopt modern farming technologies since there will be no fear of unlawful expropriation once land title contracts have been negotiated, agreed upon, and entered into with due compensation (Eskander & Barbier, 2017; Kendie & Enu-Kwesi, 2011).

Banerjee and Ghatak (2004) advanced that since the benefits of investment in new agricultural machinery are normally realised with at least one period lag, if tenants are evicted during this period because they lack secured access to land, they will enjoy only a small fraction of the expected benefits from their investments. This could cause tenants to supply a lower level of investment effort for the same crop share; a reason why land titling is thought to be a good predictor for higher investment. Moreover, it has been argued that secured land rights make it easier to use land as collateral to obtain loans from financial institutions to purchase or hire the services of agricultural machine owners which would otherwise not have been possible (Cossar, Houssou, & Asante-Addo, 2016). Secure land rights are also believed to reduce the incidence of land disputes through clearer definition and enforcement of rights, and hence should contribute significantly to the adoption of improved farming methods and mechanisation (Yaro & Ibn Zackaria, 2009).

Feder and Onchan (1987) found a significant positive relationship between land ownership security and investment in agricultural machinery and suggested that land ownership security is germane to increasing the rate of adoption of agricultural mechanisation. Similarly, Ruttan (1977) indicates that landowners were better off than tenants in the adoption of many technological packages rolled out during the Green revolution period, especially when it came to the adoption of mechanised operations and high-yielding crop varieties. The study also highlighted that certain determinants such as farm size and access to credit were significant only in the early stages of the adoption process.

Contrarily, Thirlwall (2006) posits that land tenure status may be a necessary condition for increased agricultural productivity and agricultural technology adoption, but it is clearly not a sufficient condition for this to take place. He argues that land reforms are not always successful, and that many countries have experienced increased agricultural productivity and farming system evolution towards intensification and agricultural mechanisation without having to change their land tenure systems greatly. Because conditions differ from one country to another, Thirlwall maintains that it is difficult to generalise about what type of land tenure system is good for the adoption of improved agricultural methods.

Apart from the binary indicators of land ownership security, the role of the length and stability of land ownership in influencing farm mechanisation has also been acknowledged in the literature. For instance, short leases combined with high investment costs have been found to deter tenants from adopting improved agricultural technologies (Doss, 2001; Morris *et al.*, 1999;

Sheikh, Rehman & Yates, 2003). According to Doss, tenants are often reluctant to adopt new agricultural technologies whenever there is a higher probability of losing their farms.

Moreover, Morris *et al.* (1999) established a significant relationship between agricultural technology adoption and land ownership security, with adoption found to be relatively high among land owners compared to tenants. Consequently, the author advanced that land owners keep the entire returns of benefits associated with technology adoption whereas renters or farmers under sharecropping systems must repay fees to land owners thus making the latter more risk averse. On the contrary, some studies have also found negative or no significant relationship between land ownership and adoption of agricultural technology. For example, Jacoby and Minten (2007) indicate that having a land title has no significant impact on investment and adoption decisions regarding agricultural mechanisation.

Fenske (2011) observes that although the risk of expropriation exists under the customary land tenure systems, it is too small quantitatively to have a measurable impact on investment behaviour and productivity. He maintains that under many indigenous systems of land tenure, producers are limited to usufruct rights over their plots but rights of use are generally free and secured for plots under cultivation. This may be sufficient to encourage land specific investments and increase technology adoption. Ntege-Nanyeenya, Mugisa-Mutetikka, Mwangi and Verkuijl (1997) reported that the use of modern agricultural products and processes is higher among tenants than among farmers who own land principally for profit maximisation purposes.

Anik and Salam (2015) also found that land ownership has no significant impact on agricultural technology adoption. With specific reference to animal traction, Mbata (2001) found no significant relationship between land ownership status and adoption among farmers in the Maseru District of Lesotho, and suggested that land ownership status is not a major barrier to agricultural mechanisation. Kleemann, Abdulai and Buss (2014) investigated the factors that affect farmers' decision to adopt agricultural technology and the return on investment from adoption using an endogenous switching regression model. The authors used multi-stage sampling procedure to select 386 from 75 villages in three regions of Ghana. Results from their equation show that younger, higher educated, wealthier, and more risk-averse farmers with larger farms but a lower share of own land tended to show preferences for organic certification. It was also found that although experience does not play a significant role in adoption decision, how it was acquired appears to be important.

Employing cross-sectional data on 215 farmers in Oyo State of Nigeria and the probit regression technique, Akinola (1987) found that farm size, ability to read and write, access to credit from informal sources, and regular attendance of society meetings had significant positive effect on the decision to hire tractor services. Conversely, age and the size of labour force had significant negative effect on the decision to hire tractor services. Though this study has advanced our knowledge on the relationship between farm size and mechanisation, it is restrictive in the sense it only focused on the use of tractors without addressing other intermediate mechanisations such as animal traction. Moreover, it also suffers the methodological flaws in existing studies regarding the use of binary indicators to measure mechanisation. These weaknesses are addressed in this thesis by analysing both the decision to adopt as well as the proportion of land allocated to animal traction and tractor services.

More recently, Amaza, Abass, Bachwenkizi and Towo (2016) investigated the factors influencing the adoption of mechanised technologies by rural households in the rural areas of Tanzania. Unlike other previous studies on agricultural technology adoption, this study utilised a double-hurdle model that allowed it to analyse the decision to adopt and the amount of capital investment on the new technology. The study revealed a positive correlation between farm size and rate of adoption. In addition, amount invested by households in the technology was found to be influenced by farm size and other variables such as the number of females in the household, the education level of the processors, farming experience, and the distance to the nearest product market.

Geographical location is also one of the most important agronomic factors that have been found to influence agricultural mechanisation. Population pressure, access to markets, and agro-ecological conditions which tend to vary from one geographical location to another have been identified as key drivers that cause farmers to find ways to increase productivity and adopt new technologies (Cossar, 2016). In particular, evidence shows that agro-ecological conditions such as topography, soil conditions, and rainfall availability and distribution determine the type mechanised technologies to adopt and the extent to which these technologies can be used. According to literature, farmers in certain agro-ecological zones are more likely to adopt improved agricultural technologies compared to others due to economies of scale and absence of certain critical social infrastructure. Unexpected climatic factors may make farmers hesitant in their decisions to use agricultural machinery.

Foster and Rosenzweig (1995) used a target-input model of new technology to investigate the determinants of agricultural technology adoption among smallholder farmers in India. Their model assumes that the best use of agricultural technology is what is unknown and stochastic. Applying this model to household panel data on the adoption of high yielding varieties among farmers in the rural areas of India, Foster and Rosenzweig established that farmers may initially not adopt a new technology due to imperfect knowledge about how it works; however, adoption eventually occurs due to own experiences and neighbours' experiences. This underscores the proposition by Feder and Rosenzweig (1995) that the process of technology adoption by farmers is not linear. According to Feder and Rosenzweig, agricultural producers become perfect adopters of new technologies through what they termed as learning by doing. Results by Cavatassi, Lipper and Narloch (2011) on the adoption of improved technologies showed that risk-factors coupled with access to markets and social capital drive farmers' decisions to adopt or not to adopt. Similarly, Challa (2013) posits that crop failures as a result of unexpected climatic factors may make farmers hesitant to adopt improved agricultural technologies.

Ulluwishewa (1987) applied a systems approach to study the effects of geographical location and household level factors driving the mechanisation of tillage operation among paddy rice farmers in Sri Lanka. The analysis of this study shows that both socioeconomic factors and agro-ecological conditions pertaining to dryness and hardness of soils collectively determine the extent of farm mechanisation.

Feder and Umali (1993) did a systematic review of the literature on the adoption of agricultural innovations and concluded that agro-climatic environment is the most significant determinant of locational differences in adoption rates. Sarkar *et al.* (2015) also found that the use of traditional agricultural tools was more prevalent among farmers in some districts in India than others, confirming the influence of location on agricultural machinery use and farm mechanisation. Kaliba, Verkuijl and Mwangi (2000) investigated the factors affecting the adoption of improved agricultural technologies among maize farmers in the intermediate and lowland zones of Tanzania and found that geographical location has a statistically significant effect on proportion of land allocated to improved agricultural technology.

Mbata (2001) maintained that animal traction is adopted faster in areas where draft animals and grazing land are easily available, as is the case in most districts in the Northern Region of Ghana. Cossar (2016) also modelled the determinants of agricultural mechanisation adoption in Ghana and found that geographical location has a significant impact on the use of agricultural machinery by farmers. Combining survey data with geospatial datasets, the empirical analysis of the study showed that population growth and travel time to the local urban centre explain a significant and large proportion of the variance in machinery use by farmers in Ghana.

Although the role of marital status in explaining farm technology adoption has generally been overlooked by previous studies, there is every reason to expect that marital status can affect decisions regarding farm mechanisation. Moreover, evidence based on studies in other fields of technology adoption supports the view that marital status plays a significant role in the decision to make use of time-saving technologies. For example, Cutler, Hendricks and Guyer (2003) reported that a widowed individual tended to reside in a household where technology use is low or non-existent compared to those who were married. Yin, Devaney and Stahura (2005) advanced that because of the greater number of family members, married households are more likely to demand and use modern production technologies in order to save time and increase productivity.

Umar, Musa and Kamsang (2014) found a significant positive relationship between marital status and the adoption of improved maize cultivars and argued that this could be attributed to the fact that marriage comes with more responsibilities to shoulder in terms of meeting the basic needs of family members. In their view, any agricultural technology that will increase the availability of food in order to ensure food security will be adopted by households with large family sizes. Korupp (2006) also provides similar evidence when he noted that the presence of children in a household could lead to greater technology adoption and use compared to households without children. However, a cautionary note needs to be entered here because none of the studies enumerated above investigated farm mechanisation. Moreover, marriage can have either a positive or negative effect on farm mechanisation depending on the socioeconomic conditions with which farmers are faced. For example, marriage can lead to an increase in food requirement at the household level and create incentives to expand agricultural production and thus increasing the likelihood of adopting mechanised farm processes. On the contrary, marriage can also lead to an increase in the availability of manual power for farm work and thus have a negative effect on agricultural mechanisation. In this regard, it can be concluded that the relationship between marital status and agricultural mechanisation is still an open race.

Education has been identified as an important factor that can encourage or deter the adoption of agricultural mechanisation, with literacy serving as an essential support tool in this regard. Doss and Morris (2001) show that the effect of education on agricultural technology adoption can be positive or negative depending on the type of agricultural technology being studied. For example, they found that while education had a significant positive influence on the adoption of improved maize seeds, an insignificant result was observed between this variable and fertiliser adoption. Musa, Idrisaa, Yahayab and Abdulsalamc (2012) argued that formal education equip farmers with more information searching skills and can easily lead agricultural producers to accept new farm technology more readily compared to those with little or no formal education. According to Umar *et al.* (2014), farmers who are able to read and write are always at a lead in perception and deduction of recommended technological packages. Thus, the likelihood of adoption of improved technologies increases with increase in years of formal schooling, as risk aversion decreases.

Ali and Behera (2016) examined the determinants of farm mechanisation, using the adoption of energy-based water pumping machines as a proxy for mechanisation, and found that educated, younger and wealthier farmers were more likely to adopt alternative water pumps for irrigation compared to the less educated farmers. Similarly, Alene and Manyong (2007) studied the effect of education on agricultural productivity under traditional and improved technology in northern Nigeria using an endogenous switching regression analysis, and found a significant positive relationship between formal education and technology adoption. According to Alene and Manyong, formal education increases the ability to assess, interpret, and process information about new technologies, and should generally have a positive impact on the decision to mechanise farm operations.

Employing a double-hurdle estimation strategy, Beshir, Emana, Kassa, and Haji (2012) established a significant positive relationship between level of education and adoption of modern agricultural technology among farmers in northern Ethiopia. Salasya, Mwangi, Mwabu and Diallo (2007) reported that the main attributes of agricultural technology that predict adoption among farmers are high yield whereas the important socio-economic factors are farm size, livestock ownership, education level of the farmer, and locality specific characteristics. Moser and Barrett (2003) also found a significant positive relationship between number of years of formal schooling and agricultural technology adoption, and argued that the result could be explained by the fact that respondents with more years of schooling might have better access to information which enabled them to understand and deal with technical elements of agricultural technologies compared to those with fewer or no years of schooling.

Ebojei *et al.* (2012) found that farmers who are educated are four times more likely to adopt improved agricultural technologies compared to their counterparts who were illiterates. Moreover, Gego (1986) and Akpoko (2007) advanced that the market penetration of agricultural mechanisation depends on the provision of instruction booklets and other after-sale services, signalling the importance of education on the part of users. Uneducated farmers may not be able to use such instruction booklets, and hence may refuse the associated technology altogether. Specifically, Lewis (1996) highlights that, apart from the financial capital required to invest in purchasing tractors, the amount of human capital present in a household determines the adoption of tractor for ploughing and other on-farm processes.

Alcon, de Miguel and Burton (2011) and Beyene and Kassie (2015) studied the factors affecting agricultural technology adoption. Unlike previous studies, these studies employed the duration analysis technique which allows the timing of an event to be explored in a dynamic framework, thus overcoming the barriers associated with static models. Reported results highlight the importance of education, technology trialability, credit availability, policy factors, and institutional factors such as information networks, and systematic effects that influence the adoption decision over the lifetime of the producer. With regard to agronomic factors, both studies show that farm size has no significant impact on adoption but Alcon *et al.* found a significant inverse relationship between adoption and age, signalling that younger farmers were faster to adopt new agricultural technologies whereas Beyene and Kassie established a strong positive relationship between age and adoption, reflecting that older respondents were more likely to adopt.

Ayandiji and Olofinsao (2015) found a negative but insignificant relationship between education and farm mechanisation; a result which contradicts the conventional wisdom view of a significant positive link between education and agricultural mechanisation. In addition, Uematsu and Mishra (2010) found a strong negative relationship between formal education and agricultural technology adoption using a more nationally representative survey data, and suggested that rather increasing agricultural technology adoption, formal education can be a barrier to technology adoption, especially for small-scale farmers who have higher tendency to work off-farm.

While a number of past studies posit that participation in off-farm activities relaxes credit constraints among farm households and increases investment in farm asset, evidence provided by Harris, Blank, Erickson and Hallahan (2010) rejects the claim that off-farm income drives investment in farm machinery. Rather, results of the study by Harris *et al.* confirmed that type of enterprise; farm size and location are the most significant drivers of farm investment compared to off-farm income. Similarly, Tura *et al.* (2010) found that high levels of formal education coupled with lack of land ownership had a significant negative impact on technology adoption as measured by improved maize seeds. Moreover, Musa *et al*. (2012) report that level of formal education has no significant impact on farm mechanisation.

Availability of credit has been recognised as vital for the modernisation of agriculture and crucial to increasing investment on new techniques of production. A vast body of literature shows that farmers who have access to credit, particularly from formal sources, are more likely to adopt improved technologies compared to their counterparts who do not receive credit. For instance, Doss, Mwangi, Verkuiji and de Groote (2003) and Maranan (1985) indicate that, in many instances, farmers cite lack of access to credit as the major factor militating against technology adoption. Generally, literature shows that the absence of formal credit makes it extremely difficult for farmers in developing countries to meet the initial investment costs and significantly delay the uptake of new technologies.

Beshir *et al.* (2012) documented that farmers who have access to credit from formal financial sources are more probable to adopt improved technologies compared to those who have no access to formal credit. Similarly, Zerbo (2014) reports that access to credit, regardless of the source from which it comes, is important when substantial investments are required to purchase indivisible technologies such as agricultural equipment. Even if farmers are not required to purchase their own agricultural machinery, credit availability is still crucial to allow them to take advantage of hired services from owners of for-hire machinery (Cossar *et al.*, 2016). A strong positive relationship between access to credit and agricultural technology adoption has also been acknowledged by Anik and Salam (2015), Saleem, Jan, Qureshi and Khattak (2011) as well as Feleke and Zegeye (2006). Nonetheless, Gregory and Sewando (2013) found a strong inverse relationship between access to credit and agricultural technology adoption, and suggested that this could be attributed to the fact that the credit was diverted into other purposes besides the reasons for which it was sought.

Literature shows that farmers' wealth can influence the adoption of improved agricultural technology. Like other economic concepts, wealth is very difficult to define and be measured precisely. Nonetheless, it has been conceptualised as the total value of assets by most of the empirical studies on agricultural technology adoption. For example, Zerbo (2014) considered wealth as the total value of assets owned by a household and highlighted that wealth conceptualised in this manner determines whether or not a farm household can afford to adopt new agricultural processes, and whether or not other sources of funding such as credit would be acquired to finance the cost associated with agricultural technology adoption. Zerbo also explains that because investing in new agricultural technologies could fail to generate the expected returns in case of negative shocks, the stock of wealth that agricultural households tend to own can act as leverage against this risk and consequently fuel adoption. In Zerbo's view, wealthy households are better able to absorb negative shocks and invest in new technologies compared to those who are poor or possess few assets.

Savadogo, Reardon and Pietola (1998) maintained that income obtained from the sale of household assets positively influences the adoption of animal traction technology. According to this study, income generated from the sale of household assets is used to purchase supporting technology in lieu of quasi-inexistent formal lending for animal traction technology. Ghimire and Huang (2015) as well as Langyintuo and Mungoma (2008) also found that adopters of agricultural technology tend to have above average wealth compared to non-adopters.

Contrarily, Kaliba *et al*. (2000) indicate that there can be a negative link between wealth and the adoption of input-intensive and indivisible agricultural technology. The authors explained that because agricultural households manage risk differently, poorer households may increase the intensity of technology adoption in order to increase the expected output whereas wealthier households may diversify their input sources in order to reduce production cost. Moreover, because agriculture may not be the primary source of income to wealthier households, such households may not deem it relevant to commit a significant proportion of their initial endowment to invest on farm assets and agricultural machinery, thus leading to a negative relationship between wealth and technology adoption.

Doss *et al*. (2003) pointed out that wealth was controlled for in almost all studies which investigated technological adoption among maize growing households in Eastern Africa. However, they maintained that some measures of wealth could have other impacts on the technology adoption process of farmers. In particular, they noted that livestock can be used as a direct agricultural input and might negatively impact the adoption of improved agricultural technology. But this view contradicts the empirical results of Mabuza *et al*. (2013) and Mottaleb, Krupnik and Erenstein (2016) who found that livestock possession increases agricultural mechanisation.

In his study among smallholder farmers in three districts of Tanzania, Kabbiri (2009) found farm size, crop yield, produce prices, fertiliser use, and unavailability of labour to be the most significant factors influencing the utilisation of animal traction. The study also found that the number of animals owned as well as the number of farm plots cultivated by respondents had a significant positive effect on the probability of adopting animal traction. The study further proved that animal traction use was more profitable if farmers used it together with other agricultural inputs such as improved seeds and fertiliser. The significant positive link between animal traction adoption and unavailability of labour as reported by this study underscores the relevance of family size in explaining agricultural mechanisation. Although the study did not specifically test the relationship between animal traction and household size, the establishment of a significant positive link between animal traction adoption and labour unavailability epitomises this fact.

Takeshima *et al*. (2013) employed cluster analysis to study the patterns of tractor adoption among agricultural households in Nigeria based on data from the Nigerian Living Standard Survey. The study distinguished between two categories of tractor services (self-ownership and hired services), and found that households in the country could be grouped into six clusters on the basis of their mechanisation. Within all six clusters, it was established that tractor users were wealthier in terms of farm size, livestock ownership and labour availability and expenditure on intermediate farm inputs. With respect to geographical location, the study found significant differences in tractor use patterns across agro-ecological zones, with tractor use among households in the South observed to be associated more with input-intensive crop production systems and highly concentrated among medium-scale producers than in the north where tractor use was associated with increased nonfarm income-earning activities rather than area expansion.

Abate *et al*. (2016) studied the effects of institutional financial services on farmers' adoption of agricultural technology in Ethiopia based on a propensity-score matching regression technique. Results based on a sample of 817 respondents suggest that access to institutional finance has a significant positive impact on both the adoption and extent of technology use. However, when the impacts were disaggregated by type of financial institution and farm size, significant heterogeneities were observed. In particular, services from financial cooperatives were observed to have greater impact on technology adoption than those from microfinance institutions, and the results also varied depending on farm size and types of inputs.

Akpoko (2007) studied the factors influencing the adoption of intermediate farm tools and equipment among farmers in the Semi-arid zones of Nigeria and found that a significant positive relationship exists between the adoption of intermediate tools and equipment and farm size, after-sale services, age of household head, and years of farming experience whereas a significant negative relationship was established between access to extension services as well as household size and the adoption of intermediate farm tools and equipment, signalling that farmers who did not make use of extension services as well those with smaller family sizes adopted intermediate farm tools and equipment more intensively than their counterparts.

Gurara and Larson (2013) investigated the determinants of agricultural technology adoption among farmers in Ethiopia, using chemical fertiliser as a proxy for modern agricultural technology. The results of regression analysis based on the probit regression technique show that high transport costs, illiteracy, adverse local climates, and limitation in risk and credit markets were the major constraints on the functioning of fertiliser markets, suggesting that government actions to close knowledge gaps and lower transportation costs could increase agricultural technology adoption use among farmers.

Patric, Bayeh and Tapela (2005) studied agricultural tractor ownership and utilisation among households in the Kgatleng District of Botswana, and found that tractor ownership was more prevalent among households headed by people with formal education compared to those headed by illiterate respondents. Moreover, households headed by people 41 years and above compared to their counterparts headed by people younger than 41 years were more likely to use tractors in preparing their farms for planting and other on-farm processes.

Cossar *et al*. (2016) studied the drivers of agricultural mechanisation in Ghana focusing on tractor adoption. Using the Ejura-Sekyedumase District as a case, this study examined the factors affecting smallholder farmers' participation in tractor service networks and the implications of the adoption of mechanical technology in agriculture for farmers and institutions based on perspectives that go beyond the suppliers and users of mechanisation services. Results show that, in addition to rising population density and favourable access to local and regional markets, the current pattern of use of tractors by farmers in the district emerged from favourable historical and institutional factors that served to increase the availability of tractors as well as the rate of adoption among farmers. Participation in tractor service networks was also found to be influenced by a host of factors including farmers' access to capital and knowledge, experience in farming, and social contacts. A significant positive association was also established between tractor adoption and farm size. In particular, the study shows that households who own or make use of tractor services cultivated more than 4 ha of land on average whereas non-users were found typically to cultivate smaller farms of around three hectares.

Akpeintuik (2003) investigated the factors affecting agricultural mechanisation among smallholder farmers in the Builsa District of the Upper East Region. He used animal traction adoption as a proxy for mechanisation. Empirical results provided by the study shows that there was no significant difference between adopters and non-adopters across a number of characteristics including family size, access to credit, and education of household head. However, significant variations were observed between adopters and non-adopters across farm size and livestock endowment, with adopters found to cultivate larger areas of land on average and also possessing more number of livestock compared to non-adopters.

Takeshima, Adhikari, Poudel and Kumar (2015) found that although tractor adoption in the Terai District of Nepal tended to be common among large farm owners compared to small farms, and among households headed by males compared to those headed by females, growth in tractor use in the study area was associated with input use intensification rather than expansion of the amount of farmland area under cultivation. While the studies by Cossar *et al*. (2016), Takeshima *et al*. and Akpeintuik (2003) have advanced our knowledge on the factors affecting agricultural mechanisation adoption among households in developing countries, they have certain weaknesses that are worth pointing out. First, all three studies are descriptive and without any empirical rigour. Second, these studies modelled one form of mechanisation technology or the other without addressing the possibility that households could use multiple mechanisation technologies on different plots, which is the focus of this study.

Mottaleb *et al*. (2016) investigated the determinants of agricultural mechanisation adoption among agricultural households in Bangladesh by focusing on the adoption of three types of small-scale agricultural machinery (irrigation pump, thresher, and power tiller) using a nationally representative household data. Employing a multinomial probit regression model with households without any of the machines serving as the reference category, it was revealed that machinery ownership was positive and significantly explained by livestock ownership, access to credit, connectivity to electricity, and access to paved roads. The authors also found a significant positive relationship between machinery ownership and size of landholdings. Sex of the household head was observed to play a role in the estimated functions for thresher and power tiller, though no significant differences were observed between households headed by females and those headed by males with respect to the ownership of water pumps.

Olsen and Lund (2009) examined how incentives and socioeconomic factors affect Danish farmers' decision to invest in agricultural machinery using a logistic regression model. Results show that younger farmers with a high production and high debt are more likely to invest in agricultural machinery than other farmers. The study also found that farmers paying the lower interest rates and investing in land were more likely to invest on machines in order to maintain the options for further expansion of production. Although this study did not specifically test the influence of access to credit, the significant relationship between investment on machinery and debt-to-output ratio and interest rate generally points to the role that access to credit plays in increasing agricultural mechanisation.

Mbata (2001) studied the socioeconomic factors responsible for the adoption of animal traction in the Maseru District of Lesotho. A probit model was employed to analyse the data, employing the maximum likelihood estimation technique, to quantify the effects of a selected variables on the animal traction adoption in the study area. Results show that the decision to adopt animal traction is equally sensitive to both sociological and economic factors, with the most significant factors in terms of statistical power being the number of draft animals owned by respondents and household farm income.

Adewuyi, Ashaolu, Ayinde and Ogundele (2006) implemented a study to identify the determinants of farm mechanisation among smallholder farmers in the Ibarapa Zone of Oyo State in Nigeria. The authors used farm machinery as a proxy for mechanisation and also examined the differences in productivity between users and non-users of farm machinery. One hundred and twenty five arable crop farmers were interviewed using two-stage stratified random sampling technique while information from 60 users and 40 non-users of farm machinery was used for the empirical estimation. Data collected were analysed using descriptive statistics, Logit regression analysis, budgetary analysis and test of mean differences. The study revealed that relative to non-users of farm machinery, the majority of the farmers using machinery were young, more educated, cultivated larger areas of farmland, and had more exposure to extension services. Moreover, household income and farming experiences were also found to be significant positive determinants of mechanisation. Further, the test of hypotheses revealed that users of mechanisation significantly made more profits than non-users. The study recommended that farmers should be encouraged to cultivate large farms through collective or cooperative efforts and that majority of the farmers should be enlightened to use farm machinery as an avenue for improved farm productivity.

Ghosh (2010) examined the determinants of farm mechanisation among agricultural households in the Burdan District of West Bengal in India based on a logistic regression model. Empirical results show that significant positive relationship exists between farm mechanisation and farm size, irrigation, experience in farming, government extension support services, and access to institutional credit. The author also found a strong inverse relationship between farm mechanisation and age of household head, and suggested that age-old customs act as hindrance to farm mechanisation among households headed by older people.

Rasouli, Sadighi and Minaei (2010) researched into the factors driving agricultural mechanisation among sunflower producers in Iran with the view to identifying the major factors hindering the implementation of a national agricultural mechanisation programme as well as to assess the agricultural mechanisation levels practiced by farmers. This study consisted of two phases. In the first phase, a Delphi technique was used to gather experts' opinions on variables affecting agricultural mechanisation in the country while the second phase involved a cross-sectional empirical study designed to investigate the agricultural mechanisation level practiced by farmers. Results from the expert interviews using the Delphi technique show that the main constraints on farm mechanisation were small farm size and fragmentation of landholdings. The findings of the second phase of this research indicated that agricultural mechanisation was practiced on an average of 0.5 ha of cultivated land. Multivariate linear regression of the study indicated that 46.9 percent of the variance in the level of agricultural mechanisation was explained by a wide range of variables including farm size and household income.

Debertin, Pagoulatos and Aoun (1982) used a derived demand function for mechanisation and cross-sectional data on farmers in Kentucky which allowed them to identify the significant determinants of farm mechanisation.

Their results revealed that farm size, labour availability, age and years of formal education are all significant determinants of agricultural mechanisation. In particular, a strong positive relationship was established between farm size and the level of agricultural mechanisation, signalling the importance of large size landholdings on farm mechanisation.

Using the number of groundwater pumps as a proxy for farm mechanisation, Smith and Urpelainen (2016) found that the net area of agricultural land under cultivation and agricultural assets have significant positive impacts on farm mechanisation. In addition to increasing the number of electric water pumps, Smith and Urpelainen also found that rural electrification greatly increases the number of diesel pumps possessed by framers. Their results suggest that if rural electrification increases the number of modern agricultural technologies and promotes irrigated agriculture, then the demand for diesel pumps will also grow because many farmers need reliable technologies that do not depend on electricity to run. This implies that without improvements in the supply of electricity through rational power sector reforms, developing countries my fail in their bid to mechanise agricultural production and sustainably transform their economies.

Min and Jiaying (2012) conducted a study to examine the extent of spatial disparities in agricultural mechanisation in the rural areas of China and the factors driving the spatial variations in agricultural mechanisation. Employing provincial-level data collected in 2009 and the method of exploratory spatial data analysis, the study found significant differences in agricultural mechanisation among the provinces included in the sample. Moreover, it was established that rural per capita net income, educated population, and per capita cultivated land had significant influence on the estimated disparities in agricultural mechanisation.

Moayad and Tong (2005) studied the extent of agricultural mechanisation in Sudan with the view to identifying the challenges facing mechanisation adoption among smallholder farmers in the country. Descriptive evidence reported by the study shows that agricultural production in Sudan is mainly practiced through three systems: small farming with traditional rain-fed system, rain-fed mechanised system and irrigated farming system, each producing specific crops using different levels of mechanisation. In addition, hand tools and animal traction were found to be dominant in the traditional rain-fed system, with mechanical power and sophisticated implements such as tractors, combined harvesters and power tillers commonly used in irrigated and rain-fed mechanised systems. It was also observed that the country benefits from wind and solar energy to some extent, especially in rural areas, thus enabling it to solve the problems of electricity and petroleum shortage for irrigation pumps and other agricultural activities.

Makanga and Singh (1997) found low levels of agricultural mechanisation in Kenya. The study also noted that the use of hand tools was very common among small-scale farmers, the majority of whom were poor and uneducated. Among the numerous constraints inhibiting the adoption of agricultural mechanisation technologies, land ownership insecurity, land fragmentation, lack of capital and technological adaptability, high product pricing structure and low marketing, extension and adult education, problems related to transition to animal power, soil and water erosion, machinery operation and maintenance and lack of required infrastructure were identified as the most important.

Literature on food security

This section presents the review of related literature on the determinants of household food security. The review is organised into two parts. The first part gives a general overview of the concept of food security by pointing out some operational definitions. The second part presents empirical studies on the determinants of food security. Like other sections on literature review, the empirical review in this section is structured on the extent of coverage and factors used, with more attention paid to studies which included farm size as one of the explanatory factors. This is followed by a synthesis of the main highlights from the literature on the three issues being explored by the study.

The concept of food security

Strictly speaking, food security has no precise definition. Nearly three decades ago, Maxwell (1996) enumerated over 200 definitions in published writings and argued that rather than being an analytical weakness, the wide variety of definitions depicts the diversity in people's experiences and description of the problem. Consequently, Maxwell advanced that understanding food security and responding to it requires an explicit recognition of the complexity and diversity in the term. While not discounting the complexity of food security as underscored by Maxwell (1996), the definition proposed at the world food summit in 1996 has been proven to be more useful (FAO, 2002). In that regards, this study conceptualises household food security as the situation in which people at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life.

Other useful definitions of food security include those offered by Bajagai (2013), Maharjan and Khatri-Chhetri (2006) as well as Phillips and Taylor (1998). According to Bajagai, a household is food secure when it has access to the food needed for a healthy life for all its members (adequate in terms of quality, quantity, and safety and culturally acceptable) and when it is not at undue risk of losing such access. In addition, Maharjan and Khatri-Chhetri advanced that food insecurity is the inability of households or individuals to meet their daily required food consumption levels in the face of fluctuating production, food prices and income. Meanwhile, Phillips and Taylor hold the view that food insecurity exists when all memebers of a household have an inadequate diet for part or all of the year or face the possibility of an inadequate diet in the future. Simply put, food insecurity is the absence of food security and applies to a wide range of issues ranging from famine (Sen, 1981), periodic hunger (Carman & Zamarro, 2016) to uncertain food supply (Demi & Kuwornu, 2013).

Given that there is no single definition or indicator that best measures household food insecurity, the concentration in this study will be on transitory food insecurity since this is the major problem in Ghana (Alem, 2013; Atuoye & Luginaah, 2017; Sagre & Haruna, 2016).

Dimensions of food security

Four dimensions of food security are identified in the literature. These include: food availability, food access, food utilization, and food stability. Availability captures physical existence of food. It addresses the supply side of food security by empasing sufficient quantities of quality and nutritious food from domestic agricultural production and import. At the national level, food availability is a combination of domestic food production, commercial food imports and exports, food aid and domestic food stocks whereas at the household level it could be from own production or purchases from local marketing outlets (Bajagai, 2013).

Food access refers to the ability to obtain sufficient and balanced diets to meet the nutritional requirement of all who need food (FAO, 2002). As a dimension of food security, food access encompasses income, expenditure and the purchasing ability of households or individuals. Generally, the focus on food access as a dimension of food security begun with Sen (1981) who argued that food insecurity occurs as a result of absence of entilement over food but not as an otcome of there not being enough food. According to Sen, food access is guaranteed when households or individuals exercises control over enough resources which can allow them to obtain food in sufficient quantity and quality for a healthy life. In Sen's view, any variations in this dimension can seriously disrupt production strategies and threaten the welfare of the affected populations.

Another dimension of food security reported in the literature is food utilization. This dimension addresses not only the volume offood consumsed by households or individuals but also what, how and when they eat. Other issues covered by this dimension include food preparation, intra-household food distribution, water and sanitation, and safety practices. In otherwords, it measures the ability of food consumers to derive the optimal benefits from the food they eat (Kuwornu, Suleyman, & Ditchfield, 2013). Finally, stability measures the temporal conditions of food and nutrition security (Bajagai, 2013). The attainment of this dimension implies assurance about the conituation of food availability, access and effective use of food resources.

Factors affecting household food security

As a multifaceted construct, household food security is affected by a range of factors but farm size has been hypothesised as the most important of all determinants impacting on household food security. Undoubtedly, farm size determines the extent of control that agricultural households can have including the types of crops to grow; the techniques to employ in growing such crops, and the quantity and quality of food to produce and consume. Hence a significant positive relationship could exist between farm size and household food security.

Most research on food insecurity take as a starting point the fact that people experience food insecurity when their resources are so seriously below those commanded by the average household. For example, as far back as 1981, Amartya Sen had predicted a significant link between deprivation and resource endowment, thus providing a sound basis for the expectation of a significant positive impact of farm size on deprivation as a broad social construct and food insecurity as a subset of this construct (Sen, 1981).

Sen (1981) argues that every household is endowed with a bundle of resources (including farm land) that can either be exchanged directly for food or used to produce the quantity of food that is adequate to keep its members from being chronically starved and deprived. Thus, if the initial entitlement set of a household does not include food and cannot be exchanged for a commodity bundle with an adequate amount of food, then members of that household are bound to become hungry and food insecure, even if food availability increases for society as a whole. Nonetheless, Sen's work was largely theoretical and thus cannot be taken as *primie facie* evidence of a universally verified positive relationship between farm size and household food security. Moreover, while some empirical studies have established significant positive link between farm assets and household food security, others have also found either significant inverse or insignificant association between the two variables, which suggests that debate about the influence of farm size on household food security is far from being settled.

Yami *et al*. (2013) advanced that the amount of arable land that peasant households in Ethiopia tend to own and operate has serious implications on their productivity and food security status. Because most agricultural households often engage in subsistence farming, the size of farmland they own and use has a significant contribution towards their production and food security situation. Yami *et al*. maintained that, as both producers and consumers, peasant households have to maximise production from available resources to meet the food requirements of their members and to accumulate household assets through minimal sale of surplus produce. This makes farm size an important factor to household food security.

Feleke, Kilmer and Gladwin (2005) argued that the likelihood of agricultural households experiencing food insecurity is explained more by supply-side side factors such as farm size, land ownership and access to inputs. The major policy implication of this study is that food security in developing countries in general and among poor households in particular originates more from physical food production and distribution. Thus, expanding the capacities of poor households in developing countries to access food, preferably from production from their own plots, could contribute to significant reduction in the probability of being food insecure and poor.

Harris-Fry *et al.* (2015) examined the determinants of food security and women's dietary diversity among households in the rural areas of Bangladesh. They employed cross-sectional data on households drawn from nine unions in three districts and the multinomial logistic analysis. They stated that land ownership, adjusted relative risk ratio, livestock ownership, women's literacy measured by ability to read, and access to media all significantly reduced the risk of food insecurity while household size significantly and positively increased it. Moreover, households with vegetable gardens, higher household income, and literate women were significantly more likely to have better dietary scores compared to the counterparts without such capitals.

Barrett and Sahn (2001) argued that in rural areas with low-income agricultural economies, the chronically food insecure are usually landless or causal labourers in intermediate industries. Similarly, Maharjan and Joshi (2011) report that household food insecurity is significantly related to being poor or occupying a lower occupational caste, having a larger family size, higher dependency ratio, living in a female-headed household, being landlessness, non-participation in social organisations, and dwelling in a less favourable agro-ecological zone.

Abdul-Jalil (2015) investigated the relationship between access to credit and household food security in the Karaga District of the Northern Region and found that access to credit from both formal and informal sources had a strong positive effect on household food security and increased the probability of food security by about 18 percent. Other factors which were found to have significant positive impact on food security are household size, level of education of household head, geographical location, and possession of a motorbike while having a male household head had a significant negative effect. Although not significant, farm size and access to extension services had positive effects.

Mannaf and Uddin (2012) studied the factors responsible for variations in food security among maize growing households in selected areas in the Bogra District of Bangladesh. Results show that age of household head, household size, monthly agricultural income and food expenditure significantly influenced household food security status. They also found a positive relationship between farm size and household food security. In contrast, Warr (2014) argues that endowments in land resources do not necessarily leads to food security at the household level, although it may be positively correlated with farm output. This makes it generally impossible to conclude that a significant positive relationship exists between farm size and household food security.

Kidane, Alemu and Kundhlande (2005) probed the determinants of households' food security of peasant households in Koredegaga in the Oromia

Region of Ethiopia using a logistic regression procedure. The model was initially fitted with eleven factors, of which six factors (farm size, oxen ownership, and fertiliser application, educational level of household heads, household size, and per capita food production) were found to be significant. Apart from household size which had a negative effect on food security, the rest of the significant variables had positive effects. Analysis of the partial effects revealed that improvement in educational levels of the household heads and fertiliser application led to relatively greater probability of food security. The study also found significant positive relationship between farm size and being food secure.

Seid (2007) reports that, in the Amhara Region of Ethiopia, household food insecurity varies inversely with male headship, educational attainment of household head, agricultural productivity of the household, participation in off-farm activities, gifts and remittances, livestock ownership, and share of food in total household expenditure, but positively with household size, and age of the household head. In particular, the study notes that a one percent increase in the number of years of education of the household head and number of livestock results in 0.661 and 0.002 percent reduction in the odds of being food insecure while a one percent increase in the household size and age of the household head caused 0.123 and 0.001 increases in the chance of being food insecure.

Like Seid (2007), Christiaensen (2000) reports results showing a strong positive relationship between non-food gifts and average household food consumption during the hunger period based on a model which includes gifts and temporary out migration as instruments in household food security.

Contrarily, Ibok, Bassey, Atairet and Obot (2014) and Hofferth (2004) observed that the higher the age of a household head, the more stable the economy and food security status of the household. Both studies argued that because older people tend to have relatively richer experiences of the social and physical environments as well as greater experiences of farming, they are better position to contribute to household food security than young and inexperienced household heads. Additionally, older household heads have better access to land than relatively younger and inexperience heads in the sense that younger men and women either have to wait for a land distribution or have to share land with other siblings (Bempomaa, 2014).

Abo and Kuma (2015) studied the determinants of food security in the Wolaita Sodo Town of Ethiopia. Unlike other studies, they focused on only female-headed households in urban areas and used the logit model. Results show that food security is statistically significantly related to the age and level of education of the household head, health status of the household head, household size, ownership of consumer durable and productive assets (including farmland), number of active household members, and backyard gardening. Unfortunately, access to credit, total number of livestock owned, employment status of the household head, and ownership of a savings account, remittances, and sum of monthly income of all household members were not significant in predicting food security.

Alem (2013) applied a probit regression technique to examine the demand and supply side factors affecting food security status of households in the north western Ethiopia. He also investigated the coping strategies used by households to manage food security. Results show that both demand and supply side factors significantly affect household food security. From the demand side, household size, livestock ownership and access to markets determined households' food security whereas on the supply technology adoption and farm size were identified as the most significant factors. In addition, the study found that the major coping strategies were reducing the amount of household food consumption and number of meals per day.

Kassie, Ndiritu and Stage (2014) studied the determinants of gender inequality and household food security in Kenya. Using an exogenous switching treatment regression technique which enabled them to account for heterogeneities in male-headed and female-headed households, they observed that there exists important gender-specific factors that make female-headed households to be less food secure compared to male-headed households even though both groups have similar observed characteristics. Results concerning the determinants of female-headed households' food security suggest that female-headed households' food security increases with land quality, farm size, social network size, membership in farmers' association, use of improved seeds, fertiliser adoption, location in a favourable agro-ecological zone, family size, savings, household and farm assets, and age of the household head, while livestock size, distance to major market centre, off-farm income, distance to water source, and distance to agricultural extension office had negative effects on food security.

Dzanku and Sarpong (2011) found that household food security has a significant inverse relationship with dependency ratio, access to credit, distance to market, ownership of large domestic animals, and share of total farm land under non-staple crops; a significant positive relationship with ownership of small livestock (poultry, sheep and goats), share of farmland on staple crops, physical assets, remittances, non-farm income, and social capital; and a curvilinear relationship with age of household head. Moreover, the study also found that while sex of household head had no statistically significant effect, female-headed households were more likely to experience food insecurity compared to male-headed households. A plausible explanation for this could be due to difference in agricultural assets endowment which tends to be skewed in favour of older males than females (Bempomaa, 2014).

Gebre (2012) observes that food insecurity is related to larger family size, lack of assets (including livestock and farmland), lack of access to employment, old age of household head, living in a female-headed household, living in a household in which the main breadwinner is poorly educated as well as living in a household with no access to credit services. Raboloko (2016) also found that the incidence of food insecurity among urban households in Botswana increased with household size and increase in age of the household head. In addition, Garrett and Ruel (1999) suggest that a household's ability to be food secure depends on whether or not it has enough income to purchase food at the prevailing market prices; sufficient land to grow its own food or many livestock to engage in barter with net food sellers.

Faridi and Wadood (2010) probed the determinants of food security among households in Bangladesh using a nationally representative dataset. Among other factors (access to electricity, quality of housing, employment status, education, family composition, age of household head, and prices), farm size was found to be a significant positive determinant of household food security. The marginal effect of farm size was estimated to be 0.047, reflecting that increasing farm size by one extra acre could lead to about 4.7 percent increase in the likelihood of being food secure. Gebrehiwot and van der Veen (2014) provide estimated empirical evidence which shows that food security among farming households in the rural areas of Ethiopia is significantly explained by size of farm land, household size, livestock ownership, frequency of extension services, and proximity to basic infrastructures. Moreover, the study also shows that households relied largely on consumption-based coping strategies when faced with food shortages.

Hesselberg and Yaro (2006) applied the livelihood vulnerability framework to investigate the determinants of food insecurity among smallholder households in the Upper East Region of Ghana. Using data on 598 households from three communities in the Kassena-Nankani District, the study reports that the odds of belonging to a fragile food group increases with increase in household size and ill health but reduces as educational level of household head, size of farmland, proportion of irrigation land, and livestock size increases. The study also shows that multiple income sources including off-farm activities are necessary to reduce food insecurity among the households. This calls for concerted efforts and policies to be put in place in to increase the availability and utilisation of opportunities related with off-farm activities. According to Adu, Dramani and Oteng-Abayie (2018) as well as Al-hasan (2015), one avenue through which households in rural areas can benefit from this important diversification, is to improve upon and expand the coverage of critical social infrastructure such as electricity, irrigation schemes and road network to facilitate participation in non-agricultural activities in order to raise more income for consumption and re-investment.

Ali and Khan (2013) studied the role of livestock ownership in ensuring food security among agricultural households in Pakistan by employing propensity score matching approach. The empirical results show that food security levels were higher in the range of 19 to 41 percent for households having livestock compared to households having no livestock. Moreover, the study established a significant positive link between level of formal education attained by households' heads and food security, and called for increase in formal education for rural farm households. In a related study, Mousseau (2014) applied structural equation modelling to determine the underlying factors that explain the correlation among a large number of variables hypothesised to influence household food security. Results of the study show that vulnerability to food insecurity and market access, technology adoption, and assets (including farmland) owned by the households, and per capita consumption expenditure on food are all critical factors determining food insecurity.

Ramakrishna and Demeke (2002) carried out a study to examine the determinants of food security among households in the North Wello Province of the Amhara Region of Ethiopia. Using food balance sheet and aggregate food security index as dependent variables, the authors noted a high incidence of food insecurity in the province, with the majority of sampled households found to be dependent on emergency food relief. Moreover, empirical results from the logit model indicated that the stock of food grains produced, education, fertiliser adoption, livestock ownership and farm size increased the probability of being food secure while household size reduced it. From the marginal effects provided by this study, it can be deduced that a one unit increase in tropical livestock unit will result in 24.38 percent increase in the likelihood of being food secure; one hectre increase in farm size could lead to a 57.66 percent increase in the probability of being food secure whereas a 100kg increase in fertiliser use was associated with 80.22 decline in food insecurity. Beyene and Muche (2010) came to a similar conclusion regarding the significant positive relationship between household food security and farm size, livestock ownership, and fertiliser adoption based on their analysis of data on households in the Ada Berga District of Ethiopia.

Yusuf, Balogun and Falegbe (2015) investigated the determinants of food security of farm households in Ibadan Metropolis of Nigeria. Data were analysed using the Foster-Greer-Thorbecke index and probit regression technique. Results of the study show that there is a strong positive relationship between food security and farm size. Other factors that were identified by the study to be associated with increased food security are male-headship, marital status, farming experience, and access to extension services. Habyarimana (2015) notes that while farm size, livestock size, household durable assets, number of livelihood activities and participation in social organisation improves food security, household size, extent of soil erosion, distance to nearest market, and age of household head had significant negative impacts on household food security.

Basu, Gajanan and Sanyal (2014) employed k-mean cluster analysis to classify households on food security and poverty dimensions in Malawi. Using data on 604 households, the study identified six sets of households. The first group, which he termed income rich but relatively asset poor and food insecure, had per capita household consumption expenditure slightly above

17.27 Kwacha per household size, owns an average land size, had almost no livestock, and lived far from the nearest public urban centre. The second cluster, relatively asset rich and food secure but income poor, consisted of households which were significantly more efficient in local maize production but were still income poor owing to distress sales of farm produce and lower average market price per output. The third cluster included households that were poor in all three dimensions. Households in this cluster have no accumulated assets and may not be able to finance any adequate nutrition.

Basu *et al*. (2014) also identified a fourth cluster of households was food secure by virtue of their relative dominance in asset possession, but less efficient in maize production compared to the second group and income poor. Closely related to this group was the sixth cluster, which is found to be land rich but both food insecure and income poor. In spite of having large farmlands, households in this cluster achieved the lower levels of efficiency in crop production. Another key feature of this group is that they are located in sparsely populated settlements and remote areas where there is not much fertile land and little opportunities for generating income from non-farm sources. Finally, the fifth cluster consisted of households who are rich in all three dimensions. This group is asset rich, adequately nourished, wealthy and well served by the relevant social amenities including electricity, piped water, paved roads, and adequate health facilities. Sadly, the small size of this cluster (n=10) suggests that only a handful of the general Malawian population may not be at risk of food insecurity. The study's findings also imply that mere land possession does not guarantee food security unless it is exploited productively and efficiently.

Similarly, Fisseha (2014) identified three comparative clusters of households on the basis of their food security status and assets possessions. These are: *the food secure*, *food insecure without hunger*, and *food insecure with hunger*. The *food secure cluster*, like Basu's *et al*. (2014) fifth cluster, had more household assets including land, livestock, and consumer durables than the rest. This group was also the smallest in terms of the number of households falling into it compared to the last cluster which was dominated by landless households, reflecting the significant positive association between landholdings and household food security.

Terefe (2016) modelled the determinants of food security among households in the Ethiopian highlands by grouping the determinants into supply side factors and demand side factors. From the supply side factors, technology adoption (use of improved seeds and agronomic practices) and farm size emerged as the significant determinants of food security; while among the demand side factors household size, livestock ownership, and access to market determined food security. The study also shows that the demand side factors are statistically significant and more important in affecting the extent of food security than supply side factors. The results of a multivariate-ordered logit analysis of data on 396 households in Nigeria indicate that, among other factors, farm size significantly and positively determines household food security (Obayelu, 2012).

Farm size is also thought to influence the adoption of modern techniques of production (Abdul-Hanan *et al*., 2014). It can affect agricultural productivity through its, often inverse, relationship with other factors of production such as cost, risk perceptions, human capital, and credit constraints which can undermine the development and successful implementation of agricultural technology packages (Feder, 1985; Guo, Akudugu, & Al-Hassan, 2013). Moreover, access to credit is expected to increase agricultural production and improve the welfare of peasant households (Peprah, 2011). Yet to be eligible for credit, the size of agricultural enterprise has been found to be a critical factor. Farmers operating large plots and thus making profits tend to have better access to credit for expansion than smallholder farmers (Abdulai & Huffman, 2000; Debrah, 2015). Similarly, when agricultural households do not have the right size and quality of farmland, they are less likely to provide meaningful livelihoods to their family members, no matter how efficient they may be as producers.

Babatunde and Qaim (2010) studied the major factors responsible for variations in household food security and nutrition intake among households in Nigeria. The study used instrumental variable probit regression technique. Results show that having a large farm size, total farm income, and off-farm income contribute significantly to higher household calorie intake. Specifically, the study found that an increase in annual off-farm income by 100 Naira per adult equivalent leads to an average improvement in calorie supply by 22kcal per day. Farm size also contributed significantly to calorie supply with a marginal effect of 193 kcal per day. Regarding food security, however, the study found different results. While total farm and off-farm income continued to have positive significant effects, the education of the household head was negative and insignificant; having a male household head was positive and insignificant, whereas farm size, household size, and age of the household head were all negative but insignificant.

Jamhari (2011) examined the determinants of food security among households in Indonesia employing an ordinal logistic regression model. Like this thesis, the study by Jamhari also utilised secondary dataset from the 2007 National Socio-Economic Survey conducted by the Indonesian Central Bureau of Statistics. In contrast to the present study which used a binary indicator for household food security, Jamhari measured food security by the cross analysis between share of food expenditure and consumption of energy. Results show that household food security was sensitive to price variations, household size, household income, asset ownership, age, education and type of employment undertaken by the household. Whereas rural and urban households did not differ in terms of observed food security scores, the food security situation of farm households was found to be lower than that of non-farm households. This finding underscores the theoretical proposition that agricultural households are susceptible to food insecurity and poverty than the rest of the population (Cruz, 2010; Kuwornu *et al.*, 2013; Valdés *et al*., 2009). For example, Cruz and Valdés *et al*. have showed that more than 80 percent of the smallholder farmers in the world are food insecure and depend on land as their primary source of livelihoods. Moreover, Kuwornu *et al*. maintained that three out of every four poor people live in rural areas and depend on agriculture either directly or indirectly for a bulk of their livelihood.

Lipton and Saghai (2017) advanced that state-led land reform policies which address inequalities in land ownership between the rich and the poor remains the only major and ethically defensible route for addressing household food insecurity and related disadvantages. Consequently, they recommended that increasing the amount of farmland and tenure security of lands cultivated by poor peasant households could be more successful in improving overall food security than other ambitious development strategies. Bogale (2012) indicates that the probability of a given household's food consumption expenditure falling below the agreed national minimum cut-off level of 2100 calorie is strongly associated with several factors including the size of cultivated landholding, soil fertility status of plots, access to irrigation, and adoption of fertiliser and improved crop seeds. Similarly, Deneke (2004) indicated that family size, farmland size, and size of livestock holdings are the only significant factors accounting for variations in household food security among their respondents.

Sikwela (2008) examined the determinants of household food security in two districts in Zimbabwe and found that among thirteen variables identified by the literature, six variables (access to irrigation, farm size, and cattle ownership, and fertiliser application, household size and per capita aggregate production) were significant and had positive signs except farm size which was negative. Analysis of partial effects revealed that household size, farm size, cattle ownership and per capita aggregate production led to a greater probability of household being food secure. Carman and Zamarro (2016) viewed food insecurity as more of a financial constraint than a constraint related to food safety. According to these authors, households who fail to smooth spending between pay periods as well as those who lack access to credit may struggle to ingest adequate food throughout the year. Generally, their analysis shows that policies designed to reduce food insecurity only by providing cash income may not be sufficient unless they are linked to financial literacy that enables households to take informed financial decisions.

Bashir, Schilizzi and Pandit (2013) studied the socioeconomic factors affecting household food security in the rural areas of Pakistan and concluded that livestock assets, monthly income, family size, family structure, household head's age and educational levels are the major correlates of rural household food security. Furthermore, when they ranked these factors in terms of their relative importance to food security, they observed that livestock assets and monthly income were the most important factors. This study underscores the crucial role that livestock production and alternative income sources can play in improving the welfare of the rural folks in developing countries.

More recently, Bhalla, Handa, Angeles and Seidenfeld (2018) studied the determinants of household food security in Zimbabwe. Unlike Sikwela (2008) who measured food security using a binary indicator, Bhalla *et al*. developed a composite food security score based on households' responses to constructs of the Household Food Insecurity Access Scale. In addition, they also obtained information on household per capita food consumption which was regressed on the same explanatory factors with a view to complementing the empirical findings of the first approach. By employing this integrated approach, Bhalla *et al.* were able to identify the significant demand side and supply side factors impacting household food security and consumption.

Bhalla *et al*. (2018) found that household food security score is inversely and significantly related to number of children between the ages of 6 to 17 years, age of main respondent, distance to nearest food market, labour constraints, low monthly remittances, suffering from a shock, and income from cash transfer. They also found a positive relationship between number of livestock owned and household food security score, depicting the significance of domestic livestock production to ensuring household food security. Moreover, household food security score was observed to be positively explained by distance to input market, productive assets score, household amenities score, and number of food crops planted in the previous season.as well as income from wage labour, thus confirming Sen's (1981) argument that households experience hunger when their possessed assets fall below the minimum set required to ensure food availability for proper nourishment.

Onasanya and Obayelu (2016) investigated the determinants of food security among maize-based farming households in Nigeria and found that maize output, gender, primary occupation of the farmer, farm size and farming experience had a positive influence on food security status while age had a negative influence on the food security status. Results also showed of male-headed households were food secured than those headed by females. The outcomes of this study suggests need for specific support to improve maize production. They also underscore the importance of making age and gender-specific programmes an integral part of food security and rural development policies in developing countries as this is one the surest ways to ameliorate the food security status of the vulnerable, maize-based, aging and female-headed households. According to Gebre (2012), household food insecurity is related to the old age of a household head, education of household head, household size, access to credit, access to employment, and ownership of consumer durables and productive assets of which farmland is part. Nonhebel (2005) found a significant negative relationship between household food security and the production of crops meant for biofuels and attributed it to the reduction of agricultural land for the production of food crops.

Cushion, Whiteman and Dieterle (2010) posit that as the production of most biofuel feedstock are strongly oriented towards exports, the impact of biodiesel crops and general expansion of bioenergy development can have dire consequences on household food security by causing land use change, soil degradation, deforestation and loss of biodiversity, all of which can adversely affect food crop production and thus household food security. Similarly, Evans *et al*. (2015) observed that the cultivation of commercial crops can reduce the amount of agricultural land dedicated to the cultivation of household food staples, thus increasing the risk of food insecurity and struggles over productive resources. Their analysis indicates a delicate balance between participation in commercial value chains and the production of crops meant for household consumption and survival.

Abdulla (2015) implemented a study to identify the determinants of household food security in Ethiopia. Using primary data collected from 140 households and a logistic regression model, the study found a significant positive relationship between food security and household income, cultivating fertile lands, use of improved seeds, total livestock size, and male household headship. A positive and significant relationship was also found between farm size and household food security. Significant positive relationship between farm size and household food security has also been documented by a number of empirical studies including Hussein (2015), Mada (2015), Muhoyi, Mukura, Ndedzu and Munamati (2014), Kabui (2012) as well as Bogale and Shimelis (2009). Nonetheless, Sikwela (2008) found a significant inverse relationship between farm size and household food security, and suggested land scarcity can serve as a motivation for agricultural producers to step up their resource use efficiency. Moreover, land scarcity can serve as a motivation for the adoption of modern agricultural technologies and intensification of production processes, both of which have been identified as significant determinants of food crop availability and dietary diversity.

Haile, Alemu and Kudhlande (2005) applied various methodologies to investigate the determinants of food security among peasant households in the Oromia zone of Ethiopia. According to this study, the most important and statistically significant determinants of household food security are livestock ownership, farm size, amount of family labour used for food crop production, number of farm implements, local off-farm employment opportunities, access to input and output markets, levels of technology application, family size and level of education of household head. The study also established a significant positive relationship between rainfall availability and household food security, signaling the importance of agro-ecological conditions on food security. Similarly, Quaye (2008) examined the determinants of food security and coping strategies among households in northern Ghana and found that erratic rainfall patterns, high cost of agrochemicals, lack of knowledge on improved farming practices, post-harvest losses, lack of access to credit, and distance to market were the most significant variables for policy attention.

Employing data of the fourth and fifth rounds of the Ghana Living Standards Survey, Annim, Dasmani and Armah (2011) found a significant positive relationship between household food consumption expenditure and household size, inflation, and log of household income; and a negative relationship between household food expenditure and age of economic head. Other factors investigated by the study included sex of the economic head of household, and access to credit. A major policy conclusion of this study is that access to credit does not directly translate into significant increase in household food consumption expenditure. Interestingly, the authors were fast to note that access to credit could increase food consumption via other channels such as through its positive link with agricultural production, and thus called for improvement in the amount and timing of credit intended to mitigate food constraints.

Analogously, Donkoh, Alhassan and Nkegbe (2014) investigated the determinants of household food expenditure and the interconnection between food expenditure and household welfare. Their analysis shows that land ownership significantly and positively affect expenditure on food and household welfare. However, they found that household welfare declines as the share of food in total expenditure rises. In a related study, Kuwornu *et al*. (2013) found a significant positive relationship between the quantity of own farm production and measured food security among households in the forest belt of the Central Region of Ghana and argued that increasing the capacity of farm households to expand their agricultural production has the potential to improve the food security situation and welfare of farming households. One approach through which this could be done is to provide agricultural households with the right amount of farmland and supporting inputs such as fertiliser and credit to expand output.

Asmah (2011) examined the influence of livelihood diversification on household welfare and found that households that live in communities with access to fertilisers, public transport, and local produce markets were more likely to engage in non-farm diversification, and enjoy improved welfare compared to households who lived in communities without these factors. Asmah also reports that access to television and newspapers are important in the diversification process and improvement of household welfare. Male-headed households and households with educated heads were also found to have higher incidence of non-farm diversification and improved welfare compared to their counterparts. Although Donkoh *et al*. (2014), Annim *et al*. (2011) and Asmah did not specifically investigate the determinants of household food security, the association of their findings with food security is self-evident, given that food expenditure and household welfare are some of the indicators commonly used for food security (Bala, Alias, Arshad, Noh, & Hadi, 2014). Moreover, improved welfare can be taken to include food security because the welfare of a household cannot be described as improved if the majority of its members lack access to a basic life sustaining item such as food.

A study by Mensah, Aidoo and Tuffour (2013) in the Sekyere-Afram Plains District of the Ashanti Region of Ghana shows that farm size is one of the most important variables that had a statistically significant positive impact on the likelihood that a household will be food secure. Contrary to conventional wisdom that households headed by unmarried people and women are more food insecure, the study by Mensah *et al.* has advanced our knowledge that such households can achieve very high levels of household food security if they have equal access to the productive resources including farmland, credit and education. Moreover, they found significant positive between household food security and off-farm income as well as access to credit, signaling that farmland consolidation and provision of off-farm employment opportunities can effectively be used to increase agricultural production so as to ensure household food security.

Summary

This chapter presented literature on the concept of efficiency and the various approaches used to measure efficiency. It also covered empirical studies on the factors affecting efficiency, agricultural technology adoption and household food security. Studies included in the review cut across the globe. With respect to studies on efficiency, the SFA was used by about 82 percent of the studies reviewed, making it the most utilised estimation technique compared to the DEA.In addition, it was observed that among the studies which used the SFA approach, 76.8 percent of them found the Cobb-Douglas functional form to be the most preferred functional form compared to the translog specification.

Moreover, less than 18 percent of the studies reviewed used panel dataset whereas less than 5 percent combined the SFA and DEA approaches. Further, there were marked differences in the estimated mean technical efficiency across the estimation methods, functional forms, enterprise, and geographical location. The highest mean technical efficiency score of 0.997 was obtained from the SFA approach based on Cobb-Douglas functional form applied to dataset on livestock farmers in Europe whereas the least mean efficiency score of 0.182 was estimated with the DEA method using dataset on multiple-output food crop farmers in Sub-Saharan Africa.

On the relationship between farm size and efficiency, the main area of interest of this study, a total of 189 studies from different countries were examined. The findings show that 81 studies, representing about 43 percent of the total studies consulted, found significant negative relationship between farm size and efficiency while 60 studies reported a significant positive relationship. Results on insignificant relationship is evenly split with 12 studies and 18 studies reporting positive and negative outcomes respectively. Moreover, 17 studies found nonlinear association between farm size and efficiency; reflecting that no universal generalisation can be made regarding the exact relationship between farm size and efficiency.

The major finding with respect to household food security is that there is an extricate relationship between household food security and many of the factors hypothesised to affect it including farm size. In particular, it was observed from the literature that the relationship between household food security status and farm size is not entirely positive or negative. In almost all countries, evidence of both positive and negative relationship between farm size and household food security have been documented, signalling that agricultural households can achieve food security regardless of farm size endowment.

Although not of the same magnitude, the majority of empirical literature reveals that adoption of inorganic fertiliser significantly improves household food security by increasing food crop production and availability. This implies that the potential for achieving household food security exists if farmers embrace chemical fertiliser. Another humbling evidence from the literature is that livelihood diversification in the form of off-farm activities can act as an informal insurance against poverty as a higher order deprivation and food insecurity at the lower end of the continuum of household deprivations.

It was also revealed that access to electricity improves household food security by fostering the ownership and successful management of home-based businesses. This put into perspective the need for more efforts towards diversifying the economic base of rural and peri-urban environments in Ghana through a nationwide extension of electricity since these are the areas where household food insecurity is endemic. Furthermore, it was noted that widespread promotion of cash crops in general and crops for biofuels in particular has the potential to cause household food insecurity by reducing the amount of agricultural land dedicated to food crops meant for domestic consumption.

Evidence on the relationship between household food security and most of the sociodemographic variables included in the estimation were so varied that a definitive conclusion about the relationship between household food security and any single one of them is not possible. Generally, however, evidence was more pronounced in favour of a negative relationship between household size and food security, and in favour of a positive link between livestock ownership and food security. It was also observed from the literature that results on the relationship between land size and farm mechanisation are varied and inconclusive. Generally, however, the evidence was more pronounced in favour of a negative relationship between household size and choice of ploughing technology, and in favour of a significant positive link between livestock ownership and adoption of animal traction.

CHAPTER THREE

RESEARCH METHODS

Introduction

This chapter presents the research methods employed for the study. It is organised into six sections. The chapter begins with an exposition on research philosophy in the first section. The first section also highlights challenges associated with positivism as a research philosophy and provides justification for the choice of positivism as the philosophical position of the study. The geographical setting of the study is covered in the second section. The source of dataset used for the analysis is discussed in the third section followed by the measurement of the variables in section four whereas the analytical models are addressed in section five. The sixth and final section presents the descriptive statistics of the dataset used for the study and issues related to the validity and reliability of the dataset. In a nutshell, this chapter is concerned with the research design, which represents the master plan for specifying the methods as well as the procedures for identifying and processing collected data.

Research philosophy

Basically, research is the systematic investigation into a phenomenon which involves data collection, analyses, and interpretation in an attempt to understand the causes and predict the effects of social events in order to advance knowledge and empower people whereas the theoretical framework that guides and shapes this process is termed the research philosophy or paradigm (Babbie, 2005; Kuhn, 1962). In a layman's view, therefore, social science research can be defined as the investigation of phenomena employing a social science perspective.

Kuhn (1962) outlines two instances in which the term paradigm may be used. On the one hand, paradigm refers to the entire constellation of beliefs, values, techniques and all such desirable attributes shared by members of a given community as codes of rules. Paradigm also denotes one sort of element in that constellation which defines explicit rules for understanding the remaining constellation of beliefs. Paradigm has also been considered to be a collection of logically related assumptions, concepts and propositions that directs thinking and research (Bogdan & Biklin, 1998; Clark, 1998). This put into perspective Silverman's (2005) conceptualization of paradigm as the ontological and epistemological assumptions that shape the purpose of research, its methodologies and the level of abstraction and deductions which can be made from the results it generates.

Mackenzie and Knipe (2006) advanced that a research paradigm provides the overall framework through which reality is viewed, the basic elements it contains, and the kinds of abstractions which can be made from them. Likewise, Proctor (1998) posited that consistency between the aims of a research, the research questions to be addressed, the methods to use, and the personal philosophy of the researcher is paramount for any research work. In their view, nominating a paradigm constitutes the first and most important step without which there is no basis for subsequent choices regarding methodology, methods or literature.

Although a number of philosophies have been identified and discussed in the literature, della Porta and Keating (2008) and Guba and Lincoln (1994) maintain that only four of these paradigms vie for acceptance as the ‘paradigms of choice’’ in guiding social research. These are: critical theory, constructivism, positivism, and postpositivism. Moreover, Clark (1998) and Proctor (1998) argued that only positivism and post-positivism need to be explored and understood before any decision on a sound research method can be made. According to Proctor, most other paradigms can basically be viewed as extensions of positivism and postpositivism. Similarly, Galliers (1991) argues that the two principal philosophical dimensions in the tradition of science are positivism and postpositivism.

Meanwhile, Patton (2002) indicates that the main difference between these two philosophies is that positivism confesses knowledge about the real world to be limited and relative rather than being absolute whereas postpositivism maintains that only through the subjective interpretation and intervention in reality can that reality be fully understood. Nevertheless, Patton maintains that constructivism is much more relevant for the study of the human world. In Patton’s view, constructivism is a formidable alternative paradigm which proposes that the human world is completely different from the natural science and thus studies based on it should also be different. Constructivism posits that reality is socially patterned and constructed by humans based on their understanding and accounts of the world based on their lived experiences. This is completely at variance with the positivist view that the human world can be studied without resorting to personal judgment. In this thesis, positivism is discussed in some details due to its dominance in liberal economics research.

Positivism is based on the rationalistic and empiricist philosophy that originated with the writings of August Comte and Emile Durkheim and reflects a deterministic philosophy in which causes determine effects and outcomes (Creswell, 2003). Positivism operates on the principle of the 'received model' of natural sciences conceptualized as the set of epistemological views about the nature of the universe, the place of humans in it, and the specific means by which objective knowledge of it can be generated (Perri 6 & Bellamy, 2012).

This 'received model' stance taken by the positivist philosophy to research is predicated on the existence of an 'objective' reality independent of human perceptions and interpretations. It asserts the ability of humans to perceive via the sensory organs, cognitively and linguistically unmediated aspects of reality, and aims to construct a perfectly impersonal, objective, and value-free cognitive representation of reality in order to allow for generalisation and discovery of universal laws of behaviour (Corbetta, 2003). Positivists hold the view that man's capacity to understand and explain his environment lies in his ability to deduce from a general and objective law (Outhwaite, 1987). Positivists also belief that reality is stable and can be objectively established without resorting to subjective interpretations or metaphysics. They further maintain that the only best way to understand a phenomenon is to remove personal emotions and subject it to scientific validation through empirically verifiable and repeatable methods of inquiry.

According to the positivist paradigm, social sciences are similar to the natural sciences in many respects. With this background therefore, the social world, like its natural counterpart, can be studied in the same objective way.

In other words, there exists a method for studying the social world as an objective entity, outside of the mind of the observer, and in principle it is knowable in its entirety. Thus, the task of the social science researcher is to aim to describe and analyze this reality without allowing personal emotions to influence the process. Alternatively put, the positivist paradigm shares the assumption that, in natural as in social sciences, the researcher can be separated from the object of his or her research and therefore observes it in a neutral and value-free manner. As advanced by Babbie (2005) and Creswell (2003), positivism describes epistemologies which seek to objectively measure, explain, and predict events in the social world by highlighting regularities and causal relationships between events. This approach to research combines deductive logic with precise measurement in order to discover and confirm causal laws that will permit the prediction of human behaviour.

Though positivism has shaped most researches in the social sciences and continues to have an overarching influence on the advancement of economic thinking, several questions have been raised concerning its central ontological and epistemological assumptions as well as its applicability to human research subjects. In particular, the notion of an independent and external reality driven by immutable natural laws and mechanisms has come under severe critique by leading philosophers. For example, Popper (1959) remarks that positivism is built solidly on verification; which is a commitment to testing theories empirically by searching for confirming instances. However, Popper argues that rather than following this simplistic and mechanistic path, researchers should concentrate on what a theory predicts will not happen and then investigate to see whether it can happen, thus providing a disconfirming instance. Popper points out that confirming instances can be found for almost all theories, but by simply adding more and more confirming instances is not a fair way to test a theory. To be useful and able to meet scientific standards of rigour, theories must be stipulated in ways that make them empirically testable and falsifiable. Falsification, according to Popper, is much more useful than verification as it provides purposeful research questions and practices.

Perri 6 and Bellamy (2012) suggest that besides puzzling the public with patterns and observations emerging from synthesized data, positivists do nothing to explain ‘how’ and ‘why’ the patterns they observe work the way they do. Accordingly, positivists claim that the questions of ‘how?’ and ‘why?’ are illegitimate ones and that any explanations that do not consist in empirically observable and data-driven patterns belong to the realm of metaphysics.

Laudan (1977) advanced that positivists usually misconstrue scientific progress, including progress in social science, to mean the application of sophisticated methods to existing data in ways that produce explanations which are richer, more satisfying, and conceptually better organised, even when they do not predict new observations. In Laudan’s view, this progress in better specifying theories is sustained, in practice, not by the pursuit of maximising variance predicted by correlations but by the pursuit of explanations which take causality seriously by proposing causal paths and explanations that rely on facts. Consequently, any other philosophical position that promises to do better on methodology than positivism has to provide an ever-more complex conceptual and theoretical dimension. Clark (1998) views positivism as an outmoded philosophy which should cease to shape scientific inquiry since there are other means through which knowledge can be advanced without confinement to what can be physically observed from data.

Lincoln and Guba (1985) observed that positivists' preoccupation with cause and effects which is demonstrated through their reverence for objective verification from data as the only source of tangible scientific knowledge and nothing else rests on their need for prediction, control, and power rather than a commitment to knowledge itself. In this regard, della Porta and Keating (2008) report that predictability, which is one of the trump cards of the positivist approach, is impossible since human beings change so rapidly in time and space. Thus, any claim to an objective social science knowledge built on the false promise of statistically synthesized data remains tenuous.

Perhaps, the subtlest but yet damning critique of the positivism as a research philosophy is that made by Ryan (2006) who argues that the divisions between scientific and emotional knowledge are socially constructed. Ryan reports that just as these artificial divisions are important, methodological dualism is also legitimate in the sense that it provides various ways of viewing and interpreting the world and the knowledge contained in it. According to Ryan, knowledge cannot be divorced from ontology as well as personal emotions and experiences.

The claim that studies based on the positivist philosophy are more robust, value-free, and thus an improvement over metaphysics has also come under critical scrutiny. For example, Kuhn (1962) points out that the line between dogma and reasoned belief is very thin and not always as clear as the traditional philosophy of science assumed by social science researchers. He argues that it is sometimes, if not most often, very difficult to assess when it is reasonable to maintain faith in an unconfirmed hypothesis and when to abandon it. His analysis shows that man's comprehension of science and of the world can never rely solely on objectivity alone but must account for subjective perspectives as well since all objective conclusions are ultimately founded upon subjective conditioning. In other words, dogmas could be better than a dedication to unproven theories for which counterevidence are not always beyond reach.

Nagel (1961) indicates that the scientific method itself does not preclude dogma, and that if dogma is applied with integrity it can minimise the maintenance of unwanted beliefs based on logically sound and statistically appealing theories that are no less precise than dogmas in their attempts to explain and predict reality. Nagel posits that the best way to test dogmas is not to discourage them but to continue to gauge them against theories supposedly borne out of the scientific method. The positivists' approach of attributing knowledge to only that which is observable and empirically verifiable is also criticised by Popper (1959) when he indicates that there are many routes to knowledge of which dogma is part. Popper maintains that knowledge and theories can be developed from multiple channels including determination, dreams, personal experiences, and beliefs which could be described as non-scientific and that none of these methods is inferior to the 'received model' championed by the positivists in general and liberal economists in particular.

Popper (1959) shows that it makes very little difference how a theory or knowledge originates. It does not, as implied by the positivists, have to come from prior observations and analysis of data. Popper indicates that researchers can develop theories however they wish including through dreams and moments of inspiration. Broad and Wade (1982) also recognised that there is dogma in every field of knowledge, scientific or social, by advancing that the nature of myth of the scientific knowledge is that it is hypothetical-deductive in that it works from general thinking to more specific testing based on data. More clearly, Broad and Wade argued that the maintenance of belief in and strict adherence to theory, as pertains in many areas of the social science research and particularly in economics, without subjecting these theories to the falsicationist epistemology is itself a dogma.

One other area in which the positivism has received some negative evaluation is its proposition of a supposedly 'unethical' mechanism of theory testing. The view of positivists, and particularly in liberal economics, is that it does not matter whether explanations in theories or models are plausible provided that they accurately fit the data. That is, if the predictions of a theory are borne out by the evidence based on data, then the theory is accurate and must be accepted. Particularly in economics, this view was championed by Friedman (1953) and re-echoed by Hausman (1994) who advanced that this tradition allows researchers to move away from unobservable beliefs and desires and to offer parsimonious theories and models.

According to Friedman (1953), the design of positivism, and the quantitative approach to research, is to provide a system of generalisations that can be used to make correct predictions about the consequences of events. Thus, the performance of positivism and methodological approaches based on the tenets of positivism is to be judged by the precision, scope and conformity with the experiences of the predictions they yield, but not the realism of their assumptions. As Friedman succinctly puts it, provided the predictions of an economic theory about how a decision-making unit behaves in the face of change is borne out by actual behaviour then it does not matter what happens in the decision-making processes of that unit. Friedman (p.5) further illuminates that in order 'to avoid confusion it should be noted explicitly that the predictions by which the validity of a hypothesis is tested need not be about phenomena that have not yet occurred, they may be about phenomena that have occurred but observations on which have not yet been made or are not known to the person making the prediction'.

Strangely, rather than avoiding confusion as Friedman (1953) intends, this line of inquiry has been a subject of confusion and critique by a number of authors. For example, Perri 6 and Bellamy (2012) labelled the mechanistic approach to theory testing proposed by Friedman as "limits to savings theories and models'' or "curve fitting'' (p.41), and argued that it makes explanations just too easy to be interesting. In their view, researchers can always come up with assumptions that will yield goodness of fit with the distribution of data points such that on the grounds of statistics alone we cannot fail to confirm any theory. In fact, a lot has been published of late by a cross-section of liberal economists which tells the general public that they have been disenchanted with certain aspects of the positivist philosophy, especially the part which regard knowledge as emanating from the "received model". Very good examples of this include the book by Moosa (2017) entitled *Econometrics as a con art: exposing the limitations and abuses of econometrics* as well as the articles by Kennedy (2002) and Leamer (1983) which acknowledge the limitation of not only the positivist philosophy but econometrics as its anchorage.

Without belittling the merits of the various critiques of positivism as a philosophical option for empirical research, this study uses it as its guiding philosophy for three main reasons. First, the objectives outlined in the first chapter of the thesis and the nature of the dataset being relied upon to execute them makes it impossible to resort to any other alternative paradigm. A further advantage in utilising the positivist approach, despite its shaky foundation, is that it advances the mathematical rigour of the study and could provide more nuanced findings and explanations.

Finally, no research philosophy is totally unproblematic. All the paradigms competing for the attention of researchers have their inherent strengths and limitations. Positivism cannot be an exception. In fact, Mackenzie and Knipe (2006) implore social scientists to move away from the spurious arguments about which paradigm is best and which is not and between the choice of whether qualitative and quantitative data is best. Rather they should concentrate on what combinations of these will make use of the most valuable features of each and in what field and under what instance researchers may adopt one paradigm and at what point the other. Similarly, Kuhn (1962) reports that every paradigm governs, in the first instance, not a subject matter but rather a group of practitioners, and that any study must begin by locating the responsible group or groups. Since the positivist approach is suitable for and has been used extensively by liberal economics as a social science discipline, its application in the current study is well grounded and appropriate.

Research design

Creswell (2003) conceptualises research design as the scheme or overall plan that connects the conceptualised problem to the pertinent and achievable empirical findings. The author maintains that research design serves as a guide for generating answers to research problems to permit the testing of formulated hypotheses.

Two main forms of research designs are identified in the literature. These are: the qualitative and quantitative research designs. Naturally, the qualitative research design takes the constructivists paradigm as its starting point whereas the quantitative methodology follows positivism. The main focus of a qualitative research, like the philosophical dimension from which it originates, is to explore and discover reality. In that regard, induction is used predominantly, signaling theory generation rather than theory-testing which is the focus of the quantitative approach. Because of its reliance on inductive reasoning and enquiry, the qualitative research design is not steered by theoretically driven hypotheses, but by questions in search for the truth. In contrast, with the quantitative research design, the investigator is expected to decouple his or her personal emotions from the phenomena under investigation and in many instances may even depend on existing dataset to test certain hypothetical propositions. The quantitative research design is based on the positivist's view of the received model which rests on the formulation and verification of theoretical hypotheses using empirically verifiable estimation techniques.

The study was implemented to examine the relationship among farm size, efficiency, ploughing technology, and household food security among maize growing households in the Northern Region of Ghana. Understanding the link between farm size, efficiency, ploughing technology and food security among maize growing households in the Northern Region of Ghana is important for many reasons. To begin with, low efficiency, weak or non-existing mechanisation, and high incidence of food insecurity among agricultural households in developing countries are recognised as major issues of concern for governments and policy makers in these countries and the international community.

Secondly, because farmland is the immediate and most important productive asset at the disposal of many agricultural households in developing countries including Ghana, its relationship with efficiency, ploughing method and food security is imperative for policy formulation and implementation. Therefore, getting to know and understand how many factors including farm size affect the three issues outlined in this thesis will inform policy regarding effective agricultural land management and use. For example, if it turns out that large farm owners have been doing well on all or most of the issues being investigated by for the thesis, then it may be worthwhile to adopt policies that encourage agricultural land consolidation and facilitate the provision of alternative sources of decent livelihoods to households whose agricultural land endowment is currently incapable of ensuring higher efficiency, greater mechanisation and improved welfare for family members. In addition, investigating the effect of farm size on efficiency, ploughing technology and household food security will contribute to the limited existing research on the efficiency and household welfare of maize producers.

A non-experimental research design which relied solely on quantitative analysis of secondary household panel dataset collected by the Innovations for Poverty Action (IPA) in three districts of the Northern Region covering the 2008/2009, 2009/2010, and 2010/2011 farming seasons was chosen for the study. The use of secondary data meant that the researcher had no influence over how the respondents were selected and ultimately no control over the units of measurement used for the responses. However, the panel nature of the dataset granted some reliefs and benefits including the ability to control for certain time-dependent heterogeneities.

The study setting

The spatiall setting within which a research is conducted plays a crucial role in the overall process of the research (Adu-Frimpong, 2012). Hence, it is important to provide some background information or characteristics of the study area(s) for every research. This study was conducted among maize farmers in three districts in the Northern Region of Ghana (Figure 2).

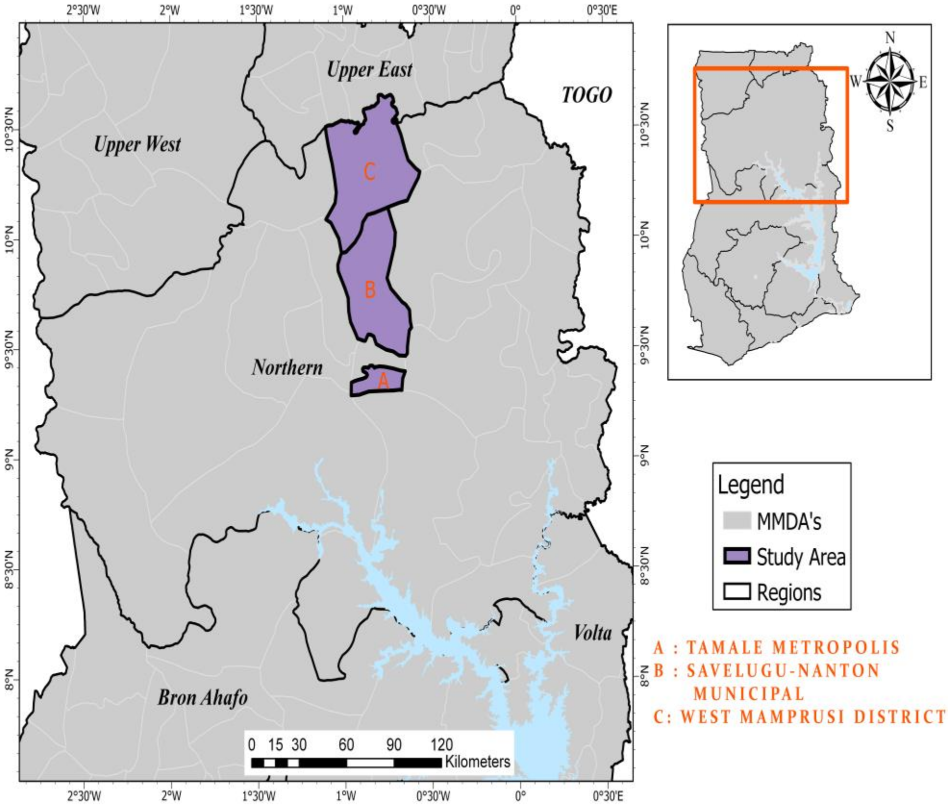

Figure 2: Map of Ghana showing the study areas

Source: Cartography & Remote Sensing Unit, Department of Geography and Regional Planning, University of Cape Coast.

Background information on the Northern Region and the study areas are presented next.

Profile of the Northern Region

Northern Region is the largest of the 10 regions of the country in terms of landmass, occupying about 70,384 square kilometres and accounting for 29.5 per cent of the total land area of Ghana (GSS, 2013a) and 16.1 percent of the country's food crop area (Diao *et al.,* 2014). It shares boundaries to the north with the Upper East and the Upper West Regions, to the south by Brong Ahafo and Volta Regions whereas to the east and west it is bounded by Togo and Ivory Coast respectively. In 2010, the total population of the region was estimated to be 2479461 with an annual growth rate of 2.9 percent, and a density of 35 persons per square kilometre of land. Northern Region has 318119 households and an average household size of 7.7.

Eighty-five percent of households in the area have male household heads and the rest are headed by females. Most of the households in the region are engaged in agriculture; with the majority into crop production followed by livestock production and the least being fish farmers. The main ethnic groups in the region are Dagomba, Nanumba, Mamprusi, Gonja, Komkomba, Bimoba, Chekosi, and Vagla. Northern Region is characterised as the third fastest growing region in Ghana (GSS, 2013b) while Tamale, the regional capital, is regarded as West Africa's fastest growing city (Fuseini, Yaro, & Yiran, 2017; Fuseini & Kemp, 2016).

Northern Region is located in the Guinea Savanna agro-ecological zone, with a mono-modal rainfall season which begins circa May and ends around October (Wiredu, Gyasi, Abdoulaye, Sanogo, & Langyintuo, 2010). Agriculture in the region is predominantly rain fed. Annual rainfall throughout most parts of the region varies between 750 and 1200 millimetres. Daily mean temperatures in the area are typically high; with the highest of about 40°C occurring circa March while the lowest measuring about 14°C is experienced during the harmattan period when temperatures in Northern Ghana fall below the rest of the country.

Though soils in the Northern Region are heterogeneous, the majority of them have been classified as tropical black and brown clays, groundwater laterites, rubrisols, alluvisols, savannah ochrosols, savannah lithosols, savannah gleisols, and ironpan soils (Obeng, 2000; Sidibé *et al.*, 2016). These soils are suitable for the cultivation of a variety of crops. In terms of food crops grown, maize is regarded as most widely grown crop in terms of land area put under cultivation. For instance, it has been reported that nearly 60 percent of farms in the region are used for maize production (GSS, 2013a).

Mono cropping is the dominant type of cropping on farms in the region and is practiced on 279386 out of the total number of farms enumerated in 2010. The three main technologies used for land preparation in the region are hand hoe, tractors and animal power. Average farm size throughout the region is estimated to be about 5.6 hectares (Chamberlain, 2007). By virtue of the 2010 census data census, less than a quarter of the adult population in the Northern Region is literate. Evidence also shows that nearly 70 percent of the people in the region reside in rural areas (GSS, 2013a). In terms of food security, it is estimated that about 10 percent of the total population of the region are food insecure, with transitory food insecurity affecting a significant proportion of agricultural households in the region (Sagre & Haruna, 2016).

Like other regions in northern Ghana, agricultural land in most parts of the Northern Region is held under customary land tenure arrangements, though privately owned and titled land registration are not uncommon. The family system practiced in most parts of the Northern Region is predominantly that of the traditional extended family type in which parents, children, grandparents, uncles, aunts, and other close and distant relatives may live together. Consequently, average household size in the region is greater than the mean national estimate. Islam is the dominant religion and was practised by about 60 percent of the population as at 2010 (GSS, 2013a). The data for this study were collected in three administrative areas in the Region. These areas are discussed next.

Profile of Tamale Metropolis

Tamale Metropolis is the most densely populated area in the Northern Region. It also has the highest percent of literate adult population and the least proportion of households in agriculture as well as the minimum number of households in the region classified as food insecure (Sagre & Haruna, 2016). Located within longitudes 0°36'W and 0°57'W and latitudes 9°16'N and 9°34'W, it shares boundaries with the Sagnarigu Municipality to the north, East Gonja District to the south, Mion District to the east, Tolon District to the west, and Central Gonja District to the south-west. The metropolis is located about 180 metres above sea level, fairly flat with isolated hills (Tamale Metropolitan Assembly [TMA], 2016).

Following the carving out of the Sagnarigu Municipality in 2012, the Tamale Metropolis now has a total land area of about 636 square kilometres and a population of circa 223,252 (GSS, 2014a). The Metropolis is a cosmopolitan area with Dagomba being the dominant ethnic group (TMA, 2016). Food crop production is one of the dominant agricultural activities in the metropolis, accounting for nearly 53 percent of economic activities undertaken by households in the metropolis. The major food crops grown in the area are maize, groundnuts, and rice. Livestock rearing accounts for 49.8 percent and 50.2 percent of the employment of urban and rural households respectively.

Profile of Savelugu-Nanton Municipality

Savelugu-Nanton Municipality (SNM) is located within the boundary box 1°2’8’’W and 10°8’18’’ N to the north-west and 0°36’47’’W and 9°27’35’’N to the south-east and has an average elevation of about 165 metres above sea level. It was carved out of the West Dagomba District in 1988 and elevated to a municipality status in 2012 (Savelugu-Nanton Municipal Assembly [SNMA], 2016). SNM shares boundaries with the West Mamprusi District to the north, Sagnarigu District to the south, Karaga District to the east, and Tolon and Kumbungu Districts to the west. There are about 149 communities in the municipality; most of which are concentrated in the southern part. As at 2010, the municipality had a total population of 139283 with an intercensal growth rate of three percent and a crude birth rate of 30.9 percent. The population density in the area is estimated to be 78 persons per square kilometre of land (GSS, 2014b).

With a total land area of 1790.70 square kilometres, representing 2.52 percent of the land size of the Northern Region, SNM is one of the smallest administrative areas in the region. Sixty percent of the municipality’s population resides in rural areas where agriculture is the main economic activity. Common food staples cultivated in the municipality are maize, rice, yam, cassava, and sorghum with maize being the most dominant. SNM has limited industrial activities. Moreover, nearly 70 percent of the population in the municipality is not literate (SNMA, 2016).

Profile of West Mamprusi District

West Mamprusi District (WMD) was carved out of Gambaga District in 1988. In 2012, however, it was subdivided, culminating in the creation of the Mamprugu Moaduri District. Consequently, the area now recognised as the West Mamprusi District lies roughly within longitudes 0°35’W and 1°45’W and latitudes 9°55’N and 10°35’W. With a total land area of about 2610 square kilometres and an estimated population of 121117, the West Mamprusi District is one of the least urbanized districts in the Northern Region, having more than 70 percent of its population living in rural areas and as peasant farmers (GSS, 2014c).

Currently, 12340 households in the district, representing over eighty-six percent of all households, are engaged in agriculture (Sidibé *et al.*, 2016). The district is served by about a total of 476.3 kilometres of roads, of which about 76 percent becomes inaccessible during the rainy season, a situation recognised as a severe barrier for agricultural production and household food security (West Mamprusi District Assembly [WMDA], 2016). Available statistics show that about 60 percent of adults in rural communities of the WMD own at least one cow; 80 percent own at least a goat or sheep; and 90 to 100 percent have at least one form of domestic bird (Danse, 2015; WMDA, 2016).

Regarding education and extent of literacy, West Mamprusi has one of the lowest literacy rates in the Northern Region. For instance, while the average literacy rate in the region was 27.3 percent as at 2010, the literacy rate of the West Mamprusi District is estimated to be 23.3 percent. The average years of formal education of household heads in the district rarely exceeds three years, while the mean household size of 8.8 persons is about 14.28 percent more than the average for the entire region (WMDA, 2016).

Agricultural land in the district is acquired mainly by inheritance from family heads or allodia rights from the overlord of the Mamprugu Skin. Anecdotal evidence shows that while outright purchase of small plots of land for building purpose is allowed in the district, the sale of agricultural land is prohibited (WMDA, 2016). West Mamprusi District is a major hub for maize production in the Northern Region. However, the district is prone to floods (Sidibé *et al*., 2016). Consequently, inundation of field crop farms and farm produce is endemic in the area, and a major threat to household food security.

Data and source of data

The dataset used for the study is part of a three-year household panel survey conducted by Innovations for Poverty Action (IPA) in collaboration with Presbyterian Agricultural Services (PAS). A more detailed description of the dataset and sampling procedures employed for the survey can be found in Chapoto, Sabasi and Asante-Ado (2015) and Karlan, Osei, Osei-Akoto and Udry (2014).

As discussed by Chapoto *et al*. (2015) and Karlan *et al*. (2014), the households who participated in the survey were selected using a cluster random design adopted from the fifth round of the Ghana Living Standards Survey based on a census of selected enumeration areas in the 23 Millennium Development Authority districts in Ghana. The number of households surveyed varied slightly from one year to the other due to sample attrition which was deliberately planned to assess the impact of experimental interventions.

A questionnaire consisting of 26 sections was used for the data collection. The first section of the questionnaire was a household roster with questions requesting information on household members. Like all households, every household member was listed and provided with a unique identification number. Then, within each household, the key decision-maker for agricultural production was requested to answer questions relating to all household members regarding age, gender, marital status, education, and employment by the IPA team. Specific questions in this section for each member of the household included whether they had ever attended school, highest level of formal education completed as well as their literacy and numeracy competencies. The questionnaire also had a section on health which sought information on self-evaluated health status of household members and the number of days that each member was absent from normal work due to illness.

Detailed information with respect to crop cultivation, production inputs, household assets (including livestock possession), farm characteristics (size, distance, ownership, and number of plots), and quantities of crops harvested were also collected. Leveraging on the weather information from nearby rainfall stations, data was also collected on rainfall figures in each community (Karlan *et al*., 2014). The dataset is also rich in information on household food consumption and food security as well as the types of technologies used for land preparation including animal traction and tractor services.

Although the dataset contained detailed information about crop production, it does not come in a ready to use format for analysis beyond the primary purpose for which they were collected. In order to surmount this challenge, a balanced panel was constructed by merging all variables of interest using the unique household and plot identification numbers. Due to this, the sample of households used for this study differs slightly from that of original data set. But this difference is not expected to pose any major problem since it represents a trivial fraction of the original dataset. As pointed out earlier, the survey collected information on a wide range of crops. However, the focus of the present study is on maize production due to the scanty nature of information on the other crops in the various rounds of the panel.

Three main reasons influenced the choice of maize over other crops. First, maize is the most important cereal crop grown in the study area and the most widely consumed food staple for most households in the area (Wiredu *et al*., 2010). Second, it is the crop with the highest number of households who participated in the survey and provided the most up-to-date information on production and inputs utilisation rates for the three-year period (Chapoto *et al*., 2015). Third, maize has yielded more compelling success stories with the adoption of new technologies that has increased agricultural production in Ghana over the years (Doss & Morris, 2001). Therefore, this success story can provide important lessons for increasing farm mechanisation and household food security in Ghana.

After merging and removing redundant data and outliers, a balanced sample of 787 households with complete data for the three years was left for the analysis. This represents nearly 74 percent (73.55%) of the original sample size, and thus is considered appropriate to address the objectives outlined in the thesis. But is this dataset reliable to allow the drawing of policy from studies based on it? This issue is addressed by gauging it to a more nationally representative household dataset for the region.

Measurement of variables

The variables used for the analyses are divided into three categories namely: dependent variables, production inputs, and explanatory variables. There were four dependent variables, four input factors, and seven socioeconomic characteristics and their interaction terms which served as explanatory variables in the various models.

The dependent variables for the efficiency analysis were the technical efficiency and scale efficiency scores. For the food security equation, a binary variable measuring household food security situation served as the explained variable whereas the type of technology used in preparing the land for planting was used as the dependent variable in the farm mechanisation model. The four independent variables considered in the production functions used to estimate the efficiency scores were land, labour, intermediate inputs, and health shock. Land was estimated as the total land area (in acres) under cultivation during the survey period and was represented by the sum of the area of all plots used for maize production in each period. The choice of land area under cultivation, as against total area in possession as in previous studies, was motivated by the fact that there were inter-seasonal variations in plot size and this could be attributed to fallowing. As a response strategy to soil erosion problems, portions of a household's farm plot may be fallowed to regain fertility. Since areas used for this purpose would not be cultivated there will be no output harvested from it. This provides justification for the use of land under cultivation.

Labour was calculated as the total man-days of workers from all sources (household, hired, exchanged, and communal) used for maize production. Intermediate inputs were measured as the sum of expenses incurred by households in relation to maize production and relates to expenses on pesticides, weedicides, purchased seeds, and other materials. Due to the disruptive effects of poor health on agricultural production, a variable measuring health shock was included in the study. Health shock was computed as the total number of days that all household members fell sick during the farming period and could not participate in normal day work.

Taking cues from United States Agency for International Development (2012), maize output reported in number of bags by the households was converted into weights in kilogrammes at the rate of 135kg per bag. Other variables used in the study include age, gender, education, marital status, access to credit, fertiliser application, number of plots, average plot size, household size, household assets, access to electricity, and participation in social network.

Another independent variable considered in the study was household size. This variable measured the total number of members found in a household. A vast body of research on the relationship between household size and efficiency, ploughing technology and food security in the developing world shows that the results are mixed and inconclusive. The coefficient of household size varies greatly by time and place and ranges from negative to positive, depending on the spatial setting. In this particular study, however, the coefficient of household size is expected to be negative.

Household assets were obtained by counting and adding across all categories of durable assets owned by the household. Typical assets captured by the original data include television sets, radio, refrigerator, bicycles, motorbikes, and mobile phones. Another explanatory variable considered by the study was livestock ownership. Because different livestock have different pathways through which they promote or inhibit household welfare and production, including all the different types of livestock as separate explanatory variables may hide vital information about the complex causal role of livestock ownership. To negotiate this problem, many empirical studies suggest the use of a single measure of livestock endowment based on feeding weights or grazing requirement. Following this conventional wisdom, all domestic livestock possessed by a household were transformed into an endowment index called tropical livestock units (TLU) using conversion factors reported in Chilonda and Otte (2006).

To control for the variations in efficiency, ploughing technology and food security that may arise as a result of differences in social capital, dummy variables were included in the estimation to capture membership in community based associations and access to electricity. Membership in a social network and connection to electricity may influence the decisions regarding ploughing technology and household food security and enhance or inhibit the on-farm performnance of maize farmers.

Finally, rather than concentrating on whether respondents had formal education or not, this study also examined the impact of interaction between formal education and respondents' literacy and numeracy competencies since these two have been proven to be more critical than the actual attainment in formal education in explaining differences in efficiency and technology adoption (Jamison & Moock, 1984; Zerbo, 2014), and appear to be more relevant for the majority of maize farm households in the Northern Region of Ghana to handle the agricultural production technology in place.

Analytical models

After a comprehensive review of existing literature, three econometric models were adapted and used as the analytical models to address the objectives of the study. This section presents the analytical models employed for the study. It is divided into three subsections. The first subsection presents the stochastic frontier and data envelopment approaches used to examine the relationship between farm size and efficiency in line with the first objective of the study. The second section discusses the model for farm mechanisation and helps us to answer the question of whether or not farm size has a significant impact on farm mechanisation while the third and final subsection covers the model for household food security in order to establish whether a significant positive relationship exists between farm size and household food security.

The Stochastic Frontier model

A plethora of functional forms and estimation procedures have been proposed and applied to estimate efficiency. Developed initially for cross-sectional data, the SFA approach has been expanded to accommodate panel data. Following Battese and Coelli (1995), the general model of the SFA is stated as:

$$Y_{it} = f(X_{it} : \beta)\exp(V_{it} - U_{it}) \quad (1)$$

Where Y_{it} denotes the output of production at the time t (t=1, 2, 3), X_{it} is a $(1 \times k)$ vector of values of known quantities of inputs of production and other explanatory variables associated with output, and β denotes a $(k \times 1)$ vector of constant parameters to be estimated.

Before the SFA can be empirically implemented, a decision has to be first made regarding the appropriate functional form for the production technology. Though literature shows that the Cobb-Douglas specification is restrictive and does not allow for the inclusion of interaction and quadratic terms of production inputs (Dasmani, 2015), the proposed translog approach is not without flaws. For example, Nkegbe (2011) indicates that excess parameters often included to capture the flexibility of production decisions may exacerbate multicollinearity problems in the data, and if this is high, the variance of parameter estimates will be increased to the extent that it may be impossible to determine how much variation in output is explained by different explanatory variables. In otherwords, rather than increasing the power of the estimates, this translog formulation may actually decrease it. Moreover, it has been argued that, besides being difficult to implement, the estimated coefficients of inputs in the translog are not directly interpretable (Abatania, 2013). Similarly, unlike the Cobb-Douglas functional form, estimations based on the translog specification often have to pass through a lot of complex and laborious statistical maneuvering in order to satisfy the monotonicity conditions (Henningsen & Henning, 2009; Lau, 1978; Terrell, 1996).

Further, implementing the translog functional form invariably implies additional loads since it cannot be estimated independently without recourse to the restrictive functional form it seeks to replace. Griffin, Montgomery, and Rister (1987) argued that while less restrictive functional forms would always be desirable over restrictive ones, the opportunity cost associated with flexibility makes it not a desirable objective. In the view of Griffin *et al.*, though greater flexibility can usually be achieved by adding arbitrary and non-redundant terms to any given function, it also has the potential to increase collinearity problems at the expense of parameter estimation.

Griffin *et al.* (1987) argued that the determination of the true functional form of a given relationship is impossible, reflecting that the most important criteria should not be about the complexity of mathematical forms but whether the chosen functional forms fit the task for which they are chosen. This supports the views expressed by Rashidghalam *et al.* (2016) and Abedullah and Ahmad (2006) that researchers interested in estimating average elasticities of inputs and testing the sensitivity of technical efficiency scores to agronomic and managerial variables should endeavour to use functional forms which are simple, more meaningful and easier to implement and comprehend. Their analysis suggests that complex functional forms which seek to depart from simpler ones may be confusing and uninformative.

With specific reference to Ghana, only a handful of empirical studies have found evidence in favour of the Cobb-Douglas specification (Abdul-Rahaman, 2016; Bhasin, 2002; Yiadom-Boakye, Owusu-Sekyere, Nkegbe, &

Ohene-Yankyera, 2013). Given the general lack of consensus regarding the choice of functional form, this study employs the flexible translog specification as a starting point and applies formal econometric testing to select the most appropriate functional form.

Taking cues from Dasmani (2015) and Wongnaa and Awunyo-Vitor (2017), the econometric model of the frontier production function is specified as:

$$\ln Y_{it} = \alpha_0 + \sum_{j=1}^{4} \alpha_j \ln X_{jit} + \sum_{j=1}^{4}\sum_{k=1}^{4} \alpha_{jk} \ln X_{jit} * \ln X_{kit} + (v_{it} - u_{it}) \quad (2)$$

Where Y is the quantity of maize produced by i-th household at time period t, X_{ijt} is the j-th input used by the i-th household at time t. The explanatory variables considered in the estimation are the natural log of land, labour, health shocks, and intermediate inputs as well as the interaction between them.

In equation (2), the random errors, V_{it} are assumed to be identically distributed independently of U_{it} as $N(0, \delta_v^2)$. On the other hand, U_{it} are the non-negative random variables associated with technical inefficiency of production, which are assumed to follow a half-normal distribution process such that the econometric model for the SFA efficiency is expressed as:

$$\begin{aligned} SFTE_{it} = {} & \delta_0 + \delta_1 farm\_size_{it} + \delta_2 Loan_{it} + \delta_3 Farm * Loan_{it} + \delta_4 Age_{it} + \delta_5 School_{it} \\ & + \delta_6 \operatorname{Re}ad_{it} + \delta_7 Numeracy_{it} + \delta_8 Sch * \operatorname{Re}ad_{it} + \delta_9 Sch * Numeracy_{it} \\ & + \delta_{10} Livestock_{it} + \delta_{11} hhsize_{it} + \delta_{12} Hoes_{it} + K_{it} \end{aligned} \quad (3)$$

Where K_{it} is a random variable defined by the truncation of the normal distribution with zero mean and variance (σ^2), such that the point of truncation is $-z_{it}\delta$ for all K_{it} greater than or equal to $-z_{it}\delta$.

The Data Envelopment Analysis model

The DEA approach is one of the approaches to the measurement of efficiency. The approach was introduced by Charnes, Cooper and Rhodes (1978) as an alternative to the index number approach which was identified as incapable of providing reliable estimates and the influence of policy variables on estimated performance indicators. The initial DEA model developed by Charnes *et al*. assumed constant returns to scale but this was later extended by Banker *et al*. (1984) to cater for variable returns to scale.

Apart from the SFA, the DEA approach has been noted as one of the viable approaches that can be used in the estimation and explanation of efficiency scores. This approach is employed in this study as a backstop approach to the SFA to examine how technical efficiency is influenced by farm size within a nonparametric framework. Following Li *et al*. (2016) and Nkegbe (2011), the input-oriented efficiency score is calculated by solving the following linear programming problem:

$$\begin{aligned}
&Min_{\eta,\psi}\psi_{it} \\
&s.t - Y_{it} + \sum_{j=1}^{4}\eta_j Y_{ijt} \geq 0, i = 1,\ldots,M \\
&\psi X_{it} - \sum_{j=1}^{4}\eta_j X_{ijt} \geq 0, i = 1,\ldots,K \\
&\eta_j \geq 0.
\end{aligned} \quad (4)$$

Where ψ_{it} is a scalar and η_j is the weight of each household not located on the efficient frontier for which a vector $\bar{\eta} = (\eta_1,\ldots,\eta_{N)}$ is defined. The primary objective in equation (4) is to minimise the proportion of inputs used by households in the relative peer group to produce the same level of output as the 'best' producer. Thus, an optimal value of ψ_{it} measures the technical efficiency score of the ith household with constant returns to scale. It satisfies the condition that $\psi_i \geq 1$, with 1 indicating full technical efficiency. ψ_i is the estimated technical efficiency score, with $(1-\psi_i)$ representing the proportion by which households that are not fully efficient can reduce their inputs of production in order to achieve the same level of output as efficient ones. The non-negative technical efficiency estimates obtained from the maximisation problem in equation (4) are used as the dependent variable in a second stage truncated regression to identify the correlates of DEA technical efficiency through the following equation:

$$\begin{aligned} DTE_i = {} & \alpha_0 + \alpha_1 farm\_size_{it} + \alpha_2 Loan_{it} + \alpha_3 Farm*Loan_{it} + \alpha_4 Age_{it} + \alpha_5 School_{it} \\ & + \alpha_6 Read_{it} + \alpha_7 Numeracy_{it} + \alpha_8 Sch*Read_{it} + \alpha_9 Sch*Numeracy_{it} \\ & + \alpha_{10} Livestock_{it} + \alpha_{11} hhsize_{it} + \alpha_{12} Hoes_{it} + \varepsilon_{it} \end{aligned} \quad (5)$$

Further, the empirical equation for scale efficiency is formulated as:

$$\begin{aligned} SEF_i = {} & \lambda_0 + \lambda_1 farm\_size_{it} + \lambda_2 Loan_{it} + \lambda_3 Farm*Loan_{it} + \lambda_4 Age_{it} + \lambda_5 School_{it} \\ & + \lambda_6 Read_{it} + \lambda_7 Numeracy_{it} + \lambda_8 Sch*Read_{it} + \lambda_9 Sch*Numeracy_{it} \\ & + \lambda_{10} Livestock_{it} + \lambda_{11} hhsize_{it} + \lambda_{12} Hoes_{it} + \varepsilon_{it} \end{aligned} \quad (6)$$

Where SEF is the ratio of technical efficiency score under constant returns to scale to technical efficiency score under variable returns to scale, α and λ represent the set of unknown parameters to be estimated while ε is a random error term.

Literature shows that results of technical efficiency analyses are affected by the number and type of variables included in the production function and the efficiency equation. Moreover, the inclusion of at least one variable in the both production function and the efficiency equation has been well documented (Abatania, 2013; Coelli, Perelman, & Romano, 1999; Dasmani, 2015). However, since there is no formal econometric rule to follow in deciding which factors to simultaneously include in the frontier function and in the efficiency function.

Table 2: *Expected signs of variables in efficiency functions*

Variable	Expected sign
Farm size	+
Loan amount	+
Farm size* Loan	+
Age of household head	-
School	+
Read	+
Numeracy	+
School* Read	+
School*Numeracy	+
Livestock size	+
Household size	+
Number of hoes	-

Source: Author's construct (2018).

Nkegbe (2011) advanced that what variables in the production function should be also be used in the efficiency model should be left to the discretion of researchers. In this thesis, the total land area under maize cultivation is used for this purpose. It is represented by farm_ size in the efficiency equations. In addition to farm size, it is expected that efficiency will be affected by the amount of credit received by households (Loan), interaction between farm size and loan amount (Farm*Loan), age of household head (Age), school attendance of household head (School), literacy skills of household head (Read), numeracy skills of household (Numeracy), interaction between schooling and literacy skills (Sch*Read), interaction between schooling and numeracy skills (Sch*Numeracy), livestock size (Livestock), household size (hhsize), and the number of hoes owned by the household (Hoes) (as proxy for extent of capitalization). The variables which served as explanatory factors in the various efficiency functions and their expected signs are shown in Table 2.

Estimation methods

Two estimation methods for analysing the determinants of technical efficiency based on the stochastic production function have been suggested in the literature. The first is the two-stage estimation technique in which the stochastic production function is first estimated to obtain farmer-specific resource use efficiency scores. Then in the second stage, the efficiency estimates derived from the first-stage estimation are regressed on a set of explanatory factors using either the OLS or Tobit regression model. While this approach has been utilised by a growing body of empirical studies, it is recognised to be defective and inappropriate due to its violation of key axiomatic conditions (Caudill & Ford, 1993). Consequently, an alternative approach has been proposed which addresses these deficiencies. This new approach applies a one-stage procedure in which the inefficiency effects are expressed as an explicit function of a vector of farm-specific variables and estimated jointly with the production function (Abdulai & Eberlin, 2001; Nkegbe, 2011). In this study, the one-stage estimation method is used due to its good axiomatic properties.

Likelihood ratio test

Being a parametric technique, the SFA requires specification of the correct functional form representing the production technology. Since the best functional form cannot be determined by physical inspection of estimated coefficients, formal econometric testing procedures must be employed. Moreover, because most of the functional forms competition for attention are often nested within each other, selecting the most appropriate statistical procedure is a critical requirement for any study on this issue. One test which has been proven very useful in this respect is the likelihood ratio test [LHRT] (Asante *et al.*, 2014; Baten, Kamil, & Haque, 2010; Constantin, Martin, & Rivera, 2009; Wongnaa & Awunyo-Vitor, 2017).

According to Wongnaa and Awunyo-Vitor (2017), LHRT allows for the evaluation of a restricted model with respect to an adopted model. Following these authors, the statistic associated with the LHRT is expressed as:

$$\lambda = -2\left\{\ln\left[L(H_0)/L(H_1)\right]\right\} = -2\left[\ln L(H_0) - \ln L(H_1)\right] \quad (7)$$

Where $\ln L(H_0)$ and $\ln L(H_1)$ denote the values of the log likelihood function under the Cobb-Douglas technology and translog specification respectively. The null hypothesis of the likelihood ratio test relates to the adequacy of Cobb-Douglas model relative to the translog whose validation means that all second order coefficients and cross products are equal to zero (Dasmani, 2015).

The model for ploughing technology

The empirical model for the determinants of ploughing technology is rooted in the technology acceptance model (TAM). TAM, which was derived from Fishbein's (1979) theory of reasoned action, is an ex-ante behavioural model that generally aims to identify and test the relevance of certain factors in explaining users' decision on how and when to make use of a new technology (Pierpaoli, Carli, Pignatti, & Canavari, 2013). As suggested by Pierpaoli *et al.*, perceptual and attitudinal aspects of human behaviour are the core constructs of TAM, with the focus of this approach directed towards the attitude to adopt or use a particular technology.

Developed initially for understanding the adoption of information and communication technologies by Davis (1986), this theory has been extended to other kinds of technologies. Its application to agricultural technology in general and farm mechanisation in particular is not uncommon. A number of empirical studies have applied different variants of TAM to investigate the factors driving the adoption of agricultural technology including farm mechanisation. The empirical model used in this study is based on the study by Mabuza *et al*. (2013), but unlike Mabuza *et al*., hoe is used as the reference category and is evaluated against animal traction and the use of tractor.

The choice of hoe as the base outcome in this study is motivated by the fact that hoes are recognised as a primitive and high health-risk farm tool that needs to be replaced with more modern ploughing techniques. For example, Ismaila, Adogbeji, Kuye, Ola and Banmeke (2013) reported that working with a hoe entails high energy demand in trying to combat the force of gravity, and this leads to low work output and risk of health hazards. Meanwhile, Nwuba and Kaul (1986) as well as Oyedemi and Olajide (2002) showed that weeding with a hoe puts the spinal muscles in tension in order to counter-balance the force of gravity and this result in spinal disorders. Moreover, it has been widely documented that increasing the proportion of smallholder farmers in developing countries with access to animal traction and tractors for ploughing must be a priority if economic growth and development will take place and have a meaningful impact on the lives of the majority of the citizens (FAO, 2008). Ghana cannot be an exception in this regard, much less the Northern Region where smallholder farming is one of the major economic activities undertaken by households.

Assuming that the probability associated with the choice of one ploughing technology over another by the i-th household is denoted by P_{ij} with j=1 if the household uses hoe, j=2 if animal traction is used and j=3 if a tractor is used, the general model for ploughing technology is formulated as:

$$P_{ij} = \frac{e^{(\beta x_{ij})}}{\sum_{j=1}^{3} e^{(\beta x_{ij})}} = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \ldots + \beta_n x_{ni} \quad (8)$$

Where $\beta_0, \beta_1, \beta_2, \ldots, \beta_n$ are the unknown parameters to be estimated and x_{ni} is a vector of explanatory variables.

Setting $\beta_0 = \beta_1 = \beta_2 = \ldots = \beta_n = 0$ for the base technology, the conditional probability of a household using animal traction or tractor for ploughing its maize farm becomes:

$$P(j = \frac{1}{x_i}) = \frac{1}{\sum_{j=1}^{3} e^{(\alpha x_{ij})}} = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \ldots + \beta_n x_{ni}$$, and

$$P(j \geq \frac{2}{x_i}) = \frac{e^{(\alpha x_{ij})}}{\sum_{j=2}^{3} e^{(\alpha x_{ij})}} = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \ldots + \beta_n x_{ni} \tag{9}$$

The full econometric model following from Equation (9) is expressed as:

$$\begin{aligned} FM_{it} &= \alpha_0 + \alpha_1 Plot\_size_{it} + \alpha_2 Distance_{it} + \alpha_3 Years_{it} + \alpha_4 Age_{it} + \alpha_5 Livestock_{it} \\ &+ \alpha_6 hhsize_{it} + \alpha_7 Loan_{it} + \alpha_8 Member_{it} + \alpha_9 Rights_{it} + \alpha_7 Owner_{it} \\ &+ \alpha_{11} Disputes_{it} + \alpha_{12} Male_{it} + \alpha_{13} Married_{it} + \alpha_{14} School_{it} + \varepsilon_i \end{aligned} \tag{10}$$

Taking cues from existing empirical literature, equation (10) is estimated using the multinomial logit regression technique with hoe as the reference category. It is hypothesised in this study that the probability that maize plots will be cultivated by animal traction or tractor is affected by plot size (Plot_size), distance of plot from home (Distance), number of years for which plot has been owned by the household (Years), age of household head (Age), tropical livestock units (Livestock), household size (hhsize), amount of loan (Loan), membership in social network (member), rights over land (Rights), ownership of plot (Owner), experience of disputes on plot (Disputes), sex of household head being a male (Male), having a household head who is married (Married), and having a household head who has ever attended school (school). Marginal effects for the independent variables were computed using the approach proposed by Long and Freese (2014).

Having addressed the relationship between plot size and the choice of ploughing technology based on the plot level data, the study also examines the association between total farm size and the proportion of land allocated to animal traction and tractor services. This was undertaken in order to gain further insights on the intensity of adoption of each mechanisation type as well as to address the methodological flaws in existing studies. Consequently, one model each for the proportion of land allocated to animal traction and tractor services are estimated by normalising the sum of size of all plots ploughed respectively by animal traction and tractor by total farm size. These are implemented through the empirical equations numbered (11) and (12) respectively:

$$\begin{aligned} Animal\_share_{it} &= \alpha_0 + \alpha_1 Farm\_size_{it} + \alpha_2 Age_{it} + \alpha_3 livestock_{it} \\ &+ \alpha_4 hhsize_{it} + \alpha_5 Loan_{it} + \alpha_6 Hoes_{it} + \alpha_7 Member_{it} \\ &+ \alpha_8 Male_{it} + \alpha_9 Married_{it} + \alpha_{10} School_{it} + \varepsilon_{it} \end{aligned} \quad (11)$$

$$\begin{aligned} Tractor\_share_{i} &= \gamma_0 + \gamma_1 Farm\_size_{it} + \gamma_2 Age_{it} + \gamma_3 livestock_{it} \\ &+ \gamma_4 hhsize_{it} + \gamma_5 Loan_{it} + \gamma_6 Hoes_{it} + \gamma_7 Member_{it} \\ &+ \gamma_8 Male_{it} + \gamma_9 Married_{it} + \gamma_{10} School_{it} + \varepsilon_{it} \end{aligned} \quad (12)$$

Unlike equation (10), equations 11 and 12 are estimated with Tobit regression technique considering that a significant proportion of the dependent variables are zeroes (Greene, 2017; Tobin, 1958). The *a priori* signs of the independent variables used for the analysis in this section are reported in Table 3.

Table 3: *Expected signs of variables in ploughing technology models*

Variable	Expected sign
Plot/fam size	+
Distance	+
Years	+
Age	-
Livestock size	+
Household size	-
Loan amount	+
Member	+
Rights	+
Owner	+
Disputes	-
Male	-
Married	+
School	+

Source: Author's construct (2018).

The model for household food security

In investigating the relationship between farm size and household food security, this thesis first borrows from the classical agricultural household model. Originally developed by Chayanov (1926) and augmented by other researchers, the agricultural household model posits a strong linkage between household consumption and own production, and argues that agricultural households act simultaneously as producers and consumers. As producers, the model predicts that agricultural households participate actively in the production and processing of food and other agricultural products by making their labour effort available for use in day-to-day activities of farm production whereas as consumers they derive utility from the consumption of food through the satisfaction found in a set of taste characteristics as well as the health effects of the nutrients consumed.

Like other regions in Ghana, agricultural production in the Northern Region of Ghana is characterised by the intense behavioural interactions between household and farm economy described by the agricultural household model because almost all households in the region act as agricultural producers as well as as consumers of their farm output. They also constantly have to take economic decisions related to allocating their family labour and other resources between both segments of production and consumption, reflecting the inseparability between consumption and production decisions.

Chayanov (1926) maintains that since the number one motivating factor for most agricultural households' participation in economic activity is the necessity to satisfy the demands of its consumers, and its work hands are the chief means for this, every analysis of their consumption process must first of all expect their volume of economic activity to quantitatively correspond more or less to these basic elements in family composition.

Hart (1992) divides the agricultural household model into two submodels. The first submodel, which he terms the unitary model, assumes that household production and consumption decisions are taken by one person, usually referred to as the 'head of the family', who principally takes all decisions regarding production and consumption. This submodel maintains that the household has a single set of preferences, failing to consider intra-household inequality and conflicts in relation to resource allocation. However, following the lack of success of the unitary model with respect to empirical applications due to its neglect of intra-household inequality and conflicts in relation to resource allocation, the collective model was proposed which corrects the bias associated with the unparalleled powers bestowed on the household head by assuming separate and equal powers of household members (Apps & Rees, 1993; Ochieng, 2015).

Apps and Rees (1993) modified the collective model to include domestically produced household goods and services. They advanced that because domestic production is a significant phenomenon, the results obtained by ignoring home production may be empirically inapplicable. They showed that with data on market wages, non-wage incomes, demographic variables, supply of market labour, and time allocations to domestic work, their model could provide fairly reliable estimates compared to the traditional collective model which ignores domestic chores. The approach by Apps and Rees changes the interpretation of household production and consumption activities from one of transfer among household members to one of exchange based on division of total household labour between market and household production.

Though some researchers have argued that it is not possible to achieve pareto efficiency in intra-household resource allocation decision-making with the collective model, this model has been recognised as superior to the unitary model since it treats the household as if it were an individual unit engaged in production and consumption activities subject to constraints imposed both by its human and non-human resources. At least, Ochieng (2015) provides a justification why family preferences may be aggregated even when community indifference curves cannot exist. He maintains that if within the family there can be assumed to take place such a thing as an optimal allocation of productive resources so as to keep each member adequately well-nourished, then there can be derived for the whole family a set of well-behaved indifference contours relating to the total of what it consumes. In other words, the family can be said to act as if it maximises a group utility subject to the constraints it faces.

According to Ochieng (2015), the collective model represents a fair approximation of the real world in which interests of individual household members may diverge. This is so because households try to maximise their benefits by increasing their utilisation of productive resources up to the point where an extra unit gained is offset by what they have to give up at the margin to obtain it. In addition to the head of the family, every household member has a role they play to satisfy the household's needs. For instance, they provide labour for farm work and food production by sacrificing the potential gains from the marginal unit of their services. In a nutshell, all members of the household make marginal choices on which the theory of demand for goods and supply of factors of production is built.

This thesis capitalises on the agricultural household model as augmented by Ochieng (2015), who avers that agricultural models, regardless of their level of aggregation, are meant to capture the interactions between household consumption and production behaviours theoretically in order to allow for the examination of the impact of certain policy variables on household welfare and food security. The extent of household food is modelled with the agricultural household theory serving as a guide.

Taking cues from past studies, the probability of a household being food secure is expressed as:

$$P_i = E(Y = \frac{1}{x_i}) = \frac{1}{1 + e^{-(\alpha_0 + \sum_{k=1}^{n} \alpha_k x_{ik} + \varepsilon_i)}} \tag{13}$$

By substituting $FS_i = \alpha_0 + \sum_{k=1}^{n} \alpha_k x_{ik} + \varepsilon_i$, and making e^{FS_i} the subject, the following equation is obtained:

$$e^{FS_i} = \frac{p_i}{(1 - p_i)} \tag{14}$$

Applying natural logarithm to both sides of equation (14) leads to the following:

$$\ln(\frac{p_i}{1 - p_i}) = FS_i = \alpha_0 + \sum_{k=1}^{n} \alpha_k x_{ik} + \varepsilon_i \tag{15}$$

Here FS is the dependent variable, x is a (1 $\times$K) vector of explanatory variables hypothesised to influence FS, and ε is the stochastic error term. The empirical econometric model based on equation (15) is written as:

$$FS_{it} = \alpha_0 + \alpha_1 Farm\_size_{it} + \alpha_2 Eff_{it} + \alpha_3 Farm * Eff_{it} + \alpha_4 Animal\_share_{it} + \alpha_5 Tractor\_share_{it} + \alpha_6 Num\_plots_{it} + \alpha_7 Age_{it} + \alpha_8 hhsize_{it} + \alpha_9 livestock_{it} + \alpha_{10} health_{it} + \alpha_{11} Loan_{it} + \alpha_{12} Fert\_adopter_{it} + \alpha_{13} Connected_{it} + \alpha_{14} Male_{it} + \alpha_{15} Married_{it} + \alpha_{16} Schooled_{it} + \varepsilon_{it} \quad (16)$$

Table 4: *Expected signs of variable in household food security models*

Variable	Expected sign
Farm size	+
Number of plots	+
Age	-
Household size	-
Livestock size	+
Health shocks	-
Loan	+
Adopter	+
Connected	+
Male	+
Married	+
School	+
DEA_VRTS	+
Farm size * Eff	+
Animal_share	+
Tractor_share	+

Source: Author's construct (2018).

The expected signs of the variables used in the estimation of the household food security models are shown in Table 4. The dependent variable, food security, is measured as a binary outcome and equal to 1 if in the last 12 months did any member within the household did not our household miss meals because the family could not afford enough food and 0 if otherwise. Due to data constraints, a limited number of predictor variables were employed for the analysis namely: farm size (Farm_size), number of plots (num_plots), age of household head (Age), household size (hhsize), livestock size (Livestock), health shocks (Health), loan amount (Loan), fertiliser adoption (Adopter), connection to electricity (connected), household head being a male (Male), household head being married (Married), and having a household head who has ever attended school (School). The rest were:

technical efficiency (DEA_VRTS), interaction between farm size and technical efficiency (Farm*Eff), proportion of total farm ploughed by animal traction (Animal_share), and proportion of total farm ploughed by tactor (Tractor_share).

Estimation technique

Given that the main variable under investigation in this section is a binary outcome, the ordinary least (OLS) regression technique will be inappropriate. In such instances, regression techniques which are capable of handling binary outcomes, such as the logit and probit, overcome this problem because they estimate the parameters of the underlying distribution rather the response itself (Daykin & Moffatt, 2002). Moreover, considering the fact that the study aims to investigate the relationship between farm size and household food security using both cross-sectional and panel data, estimation methods which are capable of handling both situations with little extensions are very relevant. In the empirical estimation, the random-effects approach is used for the panel model because of its adaptability to time-invariant covariates. Unlike the OLS, however, the coefficients of the independent variables estimated by these models do not have any direct interpretation. To overcome this limitation, the marginal effects are estimated employing the approach proposed by Long and Freese (2014).

Summary statistics of dataset

Table 5 presents the summary statistics of the continuous variables used for the study, followed by the description of the tabulation of the categorical variables. As is evident from Table 5, the mean value of maize output in 2009 and 2011 was higher than that of 2010. Generally, however, Table 5 shows that most households were able to produce more than 50 kilogrammes of maize throughout the three years of study.

The mean area of land put under cultivation varied from 19.97 acres at the beginning of the panel through 12.76 acres in 2010 to 8.32 acres 2011. Equivalently, if household land endowments are transformed into hectares using the conversion factor of one acre to 0.404686ha then this will translate to a mean (M) farm size of 4.24ha and standard deviation (SD) of 8.08ha in 2009, 4.33ha (SD=5.16) in 2010, and mean of 3.37 ha and standard deviation of 3.28 in 2011. Generally, Table 5 shows that majority of the households were small-scale farmers. The result with respect to farm size corroborates the findings by Chamberlain (2007) that agricultural production in Ghana is carried out predominantly by smallholder farmers cultivating between 2 and 3 hectares of farmland; using human labour supplied by family sources. The small nature of farm holdings by the sampled households means that they should be willing and prepared to use innovative agricultural technologies such as animal traction and tractor services that can be used to increase food production thereby increasing household food security.

Largely, most households cultivated close to two plots on average. Over the same period, labour utilisation rates varied from an average of 196.22 man-days in 2009, 189.97 days in 2010 and 219.50 days in 2011. On average, the households experienced 66.43 days of illness in 2009, 97.55 days in 2010, and 118.16 days in 2011. The mean value of intermediate inputs (cost of materials) also ranged from GH¢313.02 in 2009, passing through GH¢352.31 in 2010 to GH¢317.38 in 2011.

Table 5 also presents information on land ownership, livestock ownership, hoe ownership, fertiliser application, and household food security. On average, most households were endowed with an average of 6.67 tropical livestock units in 2009, 8.66 units in 2010, and 7.09 units in 2011. The average number of hoes owned was about 5 over the three years. The information in Table 5 also shows that most of the households were headed by people in their mid-40s, with the mean age of household heads being 44.27 in 2009, 45.27 in 2010, and 46.27 in 2011. The maximum household size was the same between 2009 and 2010, but rose to 30 people in 2011, resulting in an average household size of 7.91 for that year. It can also be observed from Table 6 that the majority of households were asset poor as the average count of durable assets did not exceed 20 units throughout the study period.

From an average of 5.69 bags in 2009, the amount of fertiliser used by the respondents rose to 6.51 bags in 2010 whereas by 2011 it had climbed to 7.35 bags. Generally, this finding implies that the extent of fertiliser adoption among the respondents increased as years went by. According to Table 5, the proportion of total land ploughed by animal traction (Animal_share) was 14 percent in 2009; 8 percent in 2010, and 21 percent in 2011. Similarly, the proportion of ploughed with tractor (Tractor_share) was 75 percent in 2009; 85 percent in 2010, and 73 percent in 2011.

With respect to access to electricity, the tabulation of the categorical variable for connection to electricity showed that a little over a third (35.58%) of households had access to electricity in 2009, but by the time that the panel terminated nearly 45 percent of the households were connected to electricity. This implies that the rate of electrification was on the increase. Data on the information of the sex of the household responsible person indicate that most of the households were headed by males (98.08%) compared to those headed by females (1.91%). However, this finding is not strange because household headship in most communities in the Northern Region tend to move from one adult male to the other, implying that females get to be become heads of household in rare cases. Given the fact that household headship in the Northern Region is usually a role played by older male adults (Oppong, 1973), it is very possible to have a higher proportion of household heads being males. Households headed by married people were the majority, constituting 92.25 percent of the sample as against the unmarried (7.75%). This suggests that most of the households were headed by settled family men and women with responsibilities and would most likely be willing to adopt or seek out innovative farming techniques that can increase their food production capacity and improve the welfare of their family members.

Lack of formal education was widespread among heads of the sampled households. According to the results, 73.70 percent of household heads have never attended any formal school compared to 18.30 percent who had basic education, 6.23 percent with secondary education and 0.51 percent who had tertiary education. Consequently, the respondents' level of literacy and numeracy competencies were also low. According to the results, 24.14 percent of household heads could read whereas only 18.42 were competent in numeracy. Juxtaposed with the 26.30 percent who reported having attended school, it implies that not every household head who attended school was able to acquire literacy and numeracy skills prior to completion or termination of his or her education. But both outcomes are not surprising at all.

Northern Region has one of the highest illiteracy rates in the country. According to 2010 population and housing census report, the region as a whole has 62.80 percent of its population being illiterate, with the Savelugu-Naton Municipality dominating 69.40 percent of non-literature inhabitants followed closely by the West Mamprusi District with 65.10 percent. Even in the Tamale Metropolis, the area with the highest proportion of literate people, nearly 40 percent (39.90%) of the population there is still not iterate whereas only 24.70 percent are literate in English only (GSS, 2013a).

Table 5: *Summary statistics of continuous variables*

Variable	2009		2010		2011	
	M	SD	M	SD	M	SD
Output	2297.9	2037.42	2199.45	2037.91	2428.98	2148.46
Land	19.97	10.48	12.76	10.70	8.32	8.10
Plots	1.41	0.65	1.437	0.65	1.61	0.72
Labour	196.22	192.47	189.97	167.96	219.50	180.86
Health shocks	66.43	31.20	97.55	36.12	118.16	32.27
Hoes	4.70	3.05	4.82	3.11	4.51	3.19
Inter. inputs	313.02	241.56	352.31	308.78	317.38	361.87
Livestock	6.67	2.83	8.67	5.29	7.09	5.22
Assets	14.84	13.66	17.81	12.69	17.84	15.71
Fertiliser	5.69	4.93	6.51	6.48	7.35	7.21
Credit	207.26	113.53	243.98	175.40	197.56	78.99
Age	44.27	15.24	45.27	15.24	46.27	15.24
Household Size	7.29	3.36	7.29	3.36	7.91	3.55
Animal_share	0.14	0.31	0.08	0.23	0.21	0.25
Tractor_share	0.75	0.37	0.85	0.30	0.73	0.28

Source: Author’s construct (2018).

As noted by Tsikata and Seini (2004), formal education was introduced into the northern territory of the Gold Coast, which comprises the Northern, Upper East, and Upper West Regions of present day Ghana, only very slowly. The first school to be opened in the area by the missionaries was in December 1907 whereas the first government school started operation in 1909. This can be one of the reasons why a majority of the household heads in this thesis reported that they have no formal education. Considering the fact that household headship in most communities in northern Ghana is usually a role played by older adults (Alenoma, 2013), it is very possible to have a higher proportion of household heads being illiterate since most of them might have been in their youthful age and thus ripe to start formal education during the pre-independence era where opportunities for education were restricted (Kay, 1972).

With respect to type of ploughing technology, the use of tractor was more prevalent in all years followed closely by animal traction in 2009; and by hoe in 2010 and 2011 respectively. It was observed that the proportion of households being food insecure declined throughout the period, ending at 15.50 percent in 2011. Moreover, participation in social network was high among the sampled households, with nearly 88 percent of the respondents being members of a social network in 2011 compared to 82 percent at the start of the panel. Similarly, the proportion of households with access to credit increased from 50.70 percent in 2009 to 61.37 percent in 2010, but declined to 36.21 percent by 2011. In terms of land ownership, 66.64 percent of the households owned their farmlands (with inherited lands dominating the category of ownership) whereas 33.36 percent were borrowed users. Overall, the standard deviation for all continuous variables were less than their means whereas the least proportion of categorical variables was 6.77 percent, suggesting that the observed values generally clustered around the mean values. In other words, there were no wide variations in the observed variables around their central tendencies.

Data quality and representativeness

Though data from secondary sources are one of the best forms of information for understanding social phenomena, users of such dataset have a task of ensuring that data from such sources are reliable and nationally representative of the population from which the respondents of such data are drawn. This implies that due statistical validation processes are strictly adhered to. Moreover, whereas codebooks associated with most secondary data may suggest the appropriateness of the dataset, close inspection sometimes reveals genuine inaccuracies that can render the dataset ineffective for an intended use, especially when this was not the main focus of the primary investigator(s). Validation also requires that the sourced dataset should be precise, and assuming no change in the phenomenon under investigation, available information should yield the same or identical results on re-measurement.

In order to ensure that the results obtained in this thesis would be relevant for policy purposes, the dataset used for the empirical estimation and analysis were subjected to statistical validation in order to ensure that they met some minimum standards in terms of reliability and representativeness. To achieve this purpose, the IPA dataset was compared to the sixth round of the

Ghana Living Standards Survey, given that this is the only nationally representative dataset that come close to the IPA survey in terms of information on farm size and other socioeconomic characteristics of the respondents in our dataset. However, because information was not available from GLSS6 based on the three districts used for the thesis, the comparison was done with dataset on the Northern Region as a whole.

Results of this comparison as reported in Table 6 show that the mean farm size in the IPA dataset of 3.37 ha was lower than the 5.03 ha in GLSS dataset. It was also observed that values of the mean household size and mean age of household head in the IPA dataset were higher than their corresponding values in the GLSS dataset whereas the proportion of household's head that were literature in the IPA was lower than the figure captured by the GLSS dataset.

Table 6: *Results of validity check of the dataset used for the study*

Variable	IPA				GLSS			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Farm size	3.37	3.28	0.2	58.68	5.03	6.71	0.4	159.45
Family size	7.91	3.55	1	30	5.59	3.39	1	25
Age	46.27	15.24	20	92	44.41	15.50	15	98
Male (%)	98.09				88.48			
Married (%)	92.25				79.66			
Literacy (%)	26.30				39.98			
Electricity (%)	44.85				39.37			

Source: Author's construct (2018).

Similarly, the results revealed that the proportion of households with access to electricity in the IPA dataset was slightly higher than that reported in the GLSS6 dataset. The distribution of the sample on the basis of sex and marital status of the household head shows that IPA dataset reported a greater number of households headed by males compared to females as well as households headed by married people compared to the information in GLSS6. But I suspect that these disparities could steam from the specific population covered by the IPA survey. Very generally, however, Table 6 shows that the disparities between the two datasets are not so wide, implying that the IPA dataset was representative and hence can be used for the study.

Summary

This chapter presented and discussed the philosophical and methodological choices used for the study as well as the justification for the chosen approaches and variables. The positivist philosophy underlying the study was discussed and its various strengths and weaknesses highlighted. The chapter also provided justification for the choice of dependent variables as well as the explanatory variables included in the various models together with the descriptive statistics of the variables for the empirical analysis. The chapter was organised into six sections starting with an exposition on research paradigms, and ending with the descriptive statistics of the variables.

The remaining part of the study presents estimated empirical results covering the various objectives. First, the factors affecting various dimensions of efficiency among the maize farm households are estimated and discussed in chapter 4. In chapter five, the factors explaining farm mechanisation are investigated and discussed with the view to identifying the specific relationship between plot/farm size and farm mechanisation. This is followed by results on the link between farm size, efficiency, choice of ploughing technology and household food security in Chapter Six.

CHAPTER FOUR

FARM SIZE AND EFFICIENCIES

Introduction

This chapter presents and discusses the empirical findings concerning the effect of farm size on the technical and scale efficiencies attained by the sampled households. The role of this chapter is to answer the first objective of the study, which is to test the hypothesis of whether or not there is a significant positive relationship between farm size and efficiency in maize production. Implicitly, the chapter also tests for the appropriate functional form of the deterministic production function which suits the dataset. To accomplish this, the likelihood ratio test was used to select between the Cobb-Douglas and translog specifications whereas the DEA approach served as an alternative and confirmatory approach to the SFA procedure in estimating efficiency scores and identifying the impact of farm size and other socioeconomic characteristics on the estimated technical and scale efficiency scores.

The chapter is organised into three main parts. The first part presents results of the estimated production function of the SFA approach. The results of bivariate analysis between the various efficiency estimates from the two alternative approaches and predictor factors considered in the study are presented in the second section. The third part which is divided into three subsections provides results of the multiple regression analysis between the various dimensions of efficiency and the same explanatory variables used for the bivariate analysis. Results of the SFA approach are presented in the first part of this section. This section is followed by the summary to the chapter.

Results of stochastic frontiers analysis

As mentioned earlier, the implementation of the stochastic frontier approach to efficiency requires the selection of the most ideal functional form employing formal econometric procedures. Like all other studies, the LHRT was applied to select between the Cobb-Douglas and translog specifications. Results of the test shown in Table 7 indicate that, at the five percent level of significance, the null hypothesis that the Cobb-Douglas functional form is the most appropriate specification for the dataset should be rejected in favour of the translog specification.

Table 7: *Results of likelihood ratio test*

Period	$\ln L(H_0)$	$\ln L(H_1)$	Test Statistic	Critical value	Decision
2009	-847.32	-833.31	28.02	17.67	Reject H_0
2010	-772.71	-754.23	36.94	17.67	Reject H_0
2011	-842.06	-827.20	29.72	17.67	Reject H_0
Panel	-2508.22	-2483.71	49.01	17.67	Reject H_0

Source: Author's construct (2018).

Given that the translog specification is selected by the likelihood ratio test as the preferred model, the rest of the empirical analysis in this section is restricted to the translog function. Results of the estimated production frontier based on the translog specification as reported in Table 8 indicate that variations in output among the sampled households is explained by input levels and the interaction between inputs. Specifically, Table 8 shows that the coefficients of eight variables are statistically significant. It also shows the importance of cross products between some of the regressors and the nonlinearity of land, labour, and intermediate inputs.

Table 8: *Results of translog production frontier*

Variables	2009	2010	2011	Panel
lnLand	0.312[a]	0.245[a]	0.163	0.266[a]
	(0.0375)	(0.0327)	(0.433)	(0.0219)
lnLabour	0.521	0.918[a]	0.463	0.548[a]
	(0.325)	(0.325)	(0.503)	(0.211)
lnHealth	-0.199	-0.420[b]	-0.465[b]	-0.0852
	(0.182)	(0.167)	(0.200)	(0.107)
lnMaterials	0.345[a]	-0.0430	-0.0843	0.388[a]
	(0.200)	(0.220)	(0.284)	(0.0154)
lnLand squared	-0.0665[b]	0.417[a]	0.347[a]	-0.0310[c]
	(0.0234)	(0.0253)	(0.0290)	(0.0168)
lnLabour squared	-0.0356	-0.0962[a]	-0.0654	-0.0487[b]
	(0.0369)	(0.0353)	(0.0533)	(0.0230)
lnMaterials squared	0.0616[a]	0.0571[a]	0.0713[a]	0.0528[a]
	(0.0158)	(0.0155)	(0.0208)	(0.0093)
lnLand*lnLabour	0.145[b]	0.127[a]	0.131[c]	0.128[a]
	(0.0574)	(0.0487)	(0.0768)	(0.0322)
lnLand*lnHealth	0.0008	0.0233	0.0577	0.0055
	(0.0298)	(0.0285)	(0.0421)	(0.0190)
lnLand*lnlnMaterials	-0.0520	-0.0460	-0.158[a]	-0.0500[b]
	(0.0349)	(0.0352)	(0.0576)	(0.0201)
lnLabour*lnHealth	0.0203	-0.0444	0.0267	-0.0057
	(0.0346)	(0.0297)	(0.0410)	(0.0199)
lnLabour*lnMaterials	-0.0833[b]	0.00490	0.00829	-0.0279
	(0.0350)	(0.0355)	(0.0507)	(0.0218)
lnHealth*lnMaterials	0.0330[c]	-0.0021	-0.0054	0.0159
	(0.0200)	(0.0243)	(0.0263)	(0.0131)
Constant	5.016[a]	3.428[a]	5.702[a]	4.147[a]
	(0.968)	(0.993)	(1.453)	(0.620)
LogLikelihood	-833.315	-754.239	-827.204	-2483.720
Wald (χ^2)	596.76[a]	683.55[a]	551.83[a]	1704.37[a]
Sigma v	0.5041	0.4854	0.4549	0.4787
Sigma u	0.8163	0.6779	0.8925	0.1082
Sigma-Squared	0.9206	0.6952	1.0035	0.5870
lnsig2v	-1.370[a]	-1.446[a]	-1.575[a]	
lnsig2u	-0.406[a]	-0.777[a]	-0.227[c]	
Lambda				
lnsigma2				-0.533
ilgtgamma				-1.487
mu				-1.295
Gamma				0.184
N	787	787	787	2361

Standard errors in parentheses, [a] p<0.01, [b] p<0.05, and [c] p<0.10.
Source: Author's construct (2018).

In addition, Table 8 indicates that the square of health shocks and the interaction between some of the variables are not statistically significant. In addition, it can be observed that the sigma squared values for the various models are significantly different from zero, reflecting a good model fit and correctness of the specified distribution assumption. Other model fit indices associated with the results, such as the Wald (χ^2) confirm high predictive ability of the estimated models. Furthermore, the estimated value of gamma which measures the total variation of observed output from the frontier output is consistent with theoretical proposition that the parameter lies between zero and one (Battese & Coelli, 1995). The estimated value of gamma of 0.1843 indicates that about 18.43 percent of variation in output was caused not only by inefficiencies in production but other stochastic noise. This confirms the argument that agricultural production is attenuated by uncertainties, many of which are mostly outside the control of farmers (Dasmani, 2015).

Estimated output elasticities of the various input variables are reported in Table 9. According to Table 9, land is the most important input variable in terms of output elasticity. The estimated output elasticity of land was 0.2119 in year 2009, 0.2142 in 2010, and 0.3621 in 2011. The estimated coefficient of land of 0.2156 in the panel model implies that a 10 percent increase in land area will lead to about 2.2 percent increase in maize output. This result is not strange at all since bigger land size is one of the dominant means through which crop output can be increased in technologically backward agricultural regimes. Because most maize producers in the sampled communities are not financially sound to adopt modern techniques or hire extra hands for their operations, extensive agriculture comes in handy.

Table 9: *Estimated output elasticities of inputs*

Variables	2009	2010	2011	Panel
Land	0.2119	0.2142	0.3621	0.2156
Labour	0.1881	0.1173	0.1824	0.2083
Health shocks	-0.2481	-0.2522	-0.2813	-0.1541
Materials	0.0865	0.1624	0.0691	0.0712

Source: Author's construct (2018).

Compared to other input variables with positive coefficients, the coefficient of land was the highest in the panel model. This suggests that there is plenty of scope to increase maize output by expanding farmland. After land, labour usage had the next highest output elasticity, reflecting the importance of this variable in maize production. Most agronomic practices and processes with respect to maize production in the Northern Region of Ghana are often done manually using traditional farm tools and animal drawn implements. This underscores the crucial role of labour in maize production among households in the selected districts.

Health shock was statistically significant at one percent and negatively related to output. The estimated elasticity for health of -0.1541 in the panel model indicates that an additional day of illness suffered by a household, holding other factors constant, reduced maize output by about 1.5 percent whereas it caused about 2.5 percent and 2.8 percent reductions in output in year 2009 and 2011 respectively. This result is unsurprising. The negative relation between health shocks and output can be explained via two routes. The first, termed short-term impacts, include absenteeism from work due to morbidity, diversion of productive family time into caring for the sick which leads to delay in farm preparation and planting, reduction in the ability to control agricultural pests and diseases as well as loss of savings and assets which could otherwise be used to purchase production inputs into curing or dealing with ailments.

In the long-term, ill health can also affect output negatively through the loss of agricultural knowledge and management skills, shift away from market-oriented production techniques and crops to subsistence agriculture, reduction of land under cultivation, cultivation of less labour-intensive but low yielding crop varieties, and reduction in the degree of diversification particularly when the burden of sickness falls more on the most experienced hands in the family in terms of agricultural production. According to literature, poor health conditions can reduce agricultural investment by limiting the ability of farm households to adopt modern or improved technologies (Rahm & Huffman, 1984). This result confirms the empirical findings of Osei-Akoto, Adamba and Osei (2013) who reported that health shock has a significant negative influence on farm output through its adverse effects on labour availability for production and crowding-out of funds which could otherwise be invested to increase farm output for healthcare expenses.

Moreover, it can be observed from Table 9 that intermediate inputs contributed more to output in the various years than it did in the entire panel. The estimated elasticity of intermediate inputs in the panel model of 0.0712 implies that if this variable was increased by 10 percent points, holding other factors constant, output could be raised by about 0.7 percent. Intermediate inputs as used here captures the monetary value of all purchased seeds, agrochemicals and other non-labour inputs and services that helped the farmers in maize production. Given that agricultural producers are price takers as well as the similarities in agricultural input pricing in the sampled districts (Chapoto *et al*., 2015), a higher cost on intermediate inputs for a household would mean that this household is able to purchase and use more intermediate inputs compared to households with lower cost on intermediate inputs. A higher cost on intermediate inputs does not only ensure the timely availability of inputs, it also provides farmers with a longer planning horizon on the best combination of relevant inputs to produce the desired output. The result is consistent with Dasmani (2015) who found significant positive relationship between expenditure on intermediate inputs and maize output and Yiadom-Boakye *et al*. (2013) who found similar results in their analysis of rice production.

Results of bivariate analysis

Prior to the implementation of the multiple linear regression analysis on the effect of farm size on efficiency, bivariate analysis were conducted between the various indicators of technical efficiency and all the independent variables including farm size. In line with the statement of the problem and the contributions of the study, attention is on the results of panel model with results of individual years serving as comparative statistics.

Results of the bivariate analyses of all the independent variable and the various estimated efficiencies are reported in Appendix A through to Appendix D. The impact of the dependents of technical efficiency is explained by reversing the signs of the coefficients on technical inefficiency. Thus, a positive sign in the technical inefficiency equation means that as that factor increases technical efficiency will decrease whereas a negative sign shows that an increase in that factor will cause technical efficiency to decrease.

As is evident from Appendix A, farm size does not significantly explain variations in technical efficiency, although it has a positive coefficient. Meanwhile, loan amount, livestock size, household size and number of hoes owned by the households had statistically significant and positive impact on SFA technical efficiency based on the panel estimation whereas age of the household exerted a significant negative influence on technical efficiency. With respect to the individual years, Appendix A shows that year 2009 recorded a greater number of significant independent variables compared to year 2010 and 2011 which had equal of explanatory variables being significant. Apart from livestock size and household size, the remaining factors with significant coefficients had negative influence on technical efficiency, signalling that increasing these factors will lead to a reduction in technical efficiency. Since these variables are categorical in nature, they signify that households in the base category did relatively better in terms of technical efficiency.

In relation to the DEA technical efficiency under variable returns to scale, Appendix B shows that seven out of the twelve independent variables considered in the analysis had significant impact in predicting the variations in technical efficiency. More specifically, the results show that farm size, loan amount, interaction between farm size and loan, age of household head, household size and number of hoes affected technical efficiency negatively while livestock size promoted it. It can also be observed from Appendix B that a greater number of explanatory factors were significant and negative in year

2009 compared to 2010 and 2011.

Respectively, Appendix C and D shows that the factors which were significant in predicting panel DEA technical efficiency under constant returns to scale and scale efficiency were farm size, interaction between farm size and loan amount, age of household head, livestock size, household size and number of hoes whereas Appendix D shows that farm size, loan amount and age predicted scale efficiency better than the other variables. In addition, Appendix D reveals a greater number of significant negative explanatory factors in year 2009 compared to 2010 and 2011. Worthy of note is the fact that numeracy competence now has a statistically significant and positive influence on technical efficiency in year 2010. But, would the same relationships be established if these variables are analysed within a multiple regression framework? This issue is addressed in the next section.

Results of multivariate regression analysis

One of the objectives of the study was to examine the relationship between farm size and technical efficiency. The first and second parts of this chapter presented results of the stochastic production frontier and the bivariate relationship between estimated efficiencies and the independent regressors. Table 10 presents results of the multivariate regression analysis based on the multivariate framework. In particular, it can be observed that only the panel model had the highest number of significant factors. Specifically, six of the explanatory variables included in the models were statistically significant at various levels of probability values.

The coefficient of farm size is negative and statistically significant, suggesting that technical inefficiency decreases as farm size increases. The negative and significant coefficient of this variable indicates that technical efficiency increases with farm size, holding all other things constant. Specifically, Table 10 shows that if farm size is expanded by 10 percent extra, technical inefficiency will fall by about 0.03 percent points. The coefficient of farm size suggests that there is a strong positive relationship between technical efficiency and farm size, invalidating the inverse farm size-productivity hypothesis proposed by Sen (1962). The result on this variable shows that the null hypothesis that there is no significant positive relationship between farm size and efficiency should be rejected. This means that farm size affects technical efficiency in a positive fashion.

Table 10: *Maximum likelihood estimates of the SF model*

Variables	2009		2010		2011		Panel	
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.	S.E
Farm size	0.009	0.300	-0.059	0.500	-0.015	0.009	0.003[a]	0.001
Loan	0.123	0.390	0.411	0.277	0.008	0.560	0.324[a]	0.080
Size* Loan	-0.252	0.217	-0.170	0.152	-0.149	0.597	0.536	0.469
Age	-0.017[a]	0.003	-0.011[a]	0.003	-0.013[a]	0.004	-0.001[c]	0.000
School	-0.047	0.192	-0.028[c]	0.017	-0.209	0.214	-0.022	0.044
Read	-0.162	0.229	-0.199	0.199	0.044	0.255	-0.130	0.528
Num.	-0.263	0.337	0.028	0.323	-0.143	0.412	-0.022	0.085
Sch*Read	0.027	0.317	-0.003	0.325	0.025	0.413	0.009	0.085
Sch* Num.	0.038	0.447	0.476	0.411	0.160	0.524	0.005	0.109
Livestock	0.041[a]	0.008	0.031[a]	0.007	0.043[a]	0.009	-0.004[b]	0.001
Hsize	0.049[a]	0.018	0.024	0.015	0.067	0.190	-0.024[a]	0.004
Hoes	-0.056	0.120	0.153	0.170	0.081[a]	0.022	0.014[a]	0.004
Constant	0.618[a]	0.021	0.640[a]	0.019	0.581[a]	0.024	0.943[a]	0.005
N	787		787		787		2361	

[a] $p<0.01$, [b] $p<0.05$, and [c] $p<0.10$.
Source: Author's construct (2018).

Three related empirical studies in Ghana on the relationship between farm size and technical efficiency are Asante *et al.* (2014), Dasmani (2015), and Wongnaa and Awunyo-Vitor (2017). Nonetheless, these studies used different estimations methods and were also focused on different category of producers. For instance, Asante et al. focused on yam producers in the transition and savannah agro-ecological zones and assessed the impact of farm size and the adoption of minisett technology and the technical efficiency estimated with the SFA based on translog functional form. Dasmani as well as Wongnaa and Awunyo-Vitor investiaged the of farm size on the technical efficiency of maize farmers in the different agro-ecological zones of Ghana based on only cross-sectional dataset.

Given the above limitations, evidence from closely related studies in other countries will be advanced to support the discussion on this variable in order to properly situate the study's findings in the available literature. Generally, no satisfactory explanation exists on the relationship between farm size and technical efficiency. Moreover, empirical research has not been able to refute a significant positive link between farm size and technical efficiency based on the panel data technique. Previous studies including Aly *et al*. (1987) found significant positive relationship between farm size and technical efficiency, and concluded that large farm owners tend to adopt new technology faster than smaller farm owners due to better access to credit, extension information, and other scarce resources.

Perhaps, the most apt explanation for the strong positive relationship between technical efficiency and farm size is the one provided by Geta, Bogale, Kassa and Elias (2013), who argued that large farm owners make more use of mechanised ploughing technologies and hence are able to overcome bottlenecks associated with labour scarcity for production. In fact, in most districts in the Northern Region, including those from which dataset for this study were collected, mechanised ploughing such as the use of tractor and animal traction are fast replacing manual labour for land preparation and other on-farm processes, with large farm owners having an upper hand over small farm owners in the ownership of livestock and adoption of mechanically powered farm tools.

Further, as will be revealed in subsequent stages of the analysis, large farm owners adopted mechanised production techniques more than smaller farm owners, which could account for the strong positive relationship between farm size and technical efficiency. Nevertheless, some studies have also argued that small farm owners compensate for their technological backwardness by utilising family labour more intensively. For instance, Deolalikar (1981) contends that because small farm operators usually do not have alternative sources of livelihoods in addition to farming and thus will be heavily affected when the harvest from their farm plots is poor, they are motivated to pay more attention to production activities on their farms more than large farm owners.

The negative and significant coefficient of loan size signals that households that received more credit were more technically efficient compared to those that received little or no credit at all. The results suggest that the technical inefficiency of credit recipients was about 44.87 percent points lower than those who did not receive credit. This could be due to the fact that maize producers that had the opportunity to receive credit increased their production capabilities and capacity through the use of improved seeds and adoption of modern technologies. Moreover, the relatively smaller coefficient of credit means that removing bottlenecks in the provision of credit and increases in the efficiency of the credit delivery mechanism would boost maize production through improvements in technical efficiency.

A number of reasons can be adduced to support this finding. The most plausible reasons are as follows. First, most maize producers in the sampled communities are poor and thus do not have the financial resources to be able to buy required farm inputs in time. Agricultural credit reduces this constraint and enables them to purchase the relevant inputs needed for production, thus increasing technical efficiency. The estimated positive effect of credit on technical efficiency is consistent with the hypothesis that credit constraint is a major factor holding smallholder farmers from increasing productivity. The finding corroborates the results of Bempomaa (2014) and Yiadom-Boakye *et al*. (2013) who found significant positive relationship between technical efficiency and amount of access credit received, but contradicts Asravor, Onumah and Osei-Asare (2015) who found significant inverse relationship between access to credit and technical efficiency among pepper farmers in the Volta Region.

In addition to farm size and loan amount, the analysis also included the interaction between farm size and amount of credit borrowed. Although the inclusion of the interaction did not improve the overall explanatory power of the estimated models, the negative sign of this variable means that the effect of farm size on technical efficiency varies with the size of credit available to households and vice versa. The result with respect to this variable is consistent with theoretical analysis by Stiglitz and Weiss (1981) and with the empirical findings of Sabasi and Kompaniyets (2015) and Peprah (2011) who found that credit-constrained and non-constrained farm households are significantly different in terms of their level of technical efficiency. Nonetheless, better understanding of the credit needs of different segments of smallholder maize farmers is important in increasing technical efficiency, considering the fact that Dasmani (2015) found no significant relationship between access to credit and technical efficiency among maize farmers in the Bole District of the Northern Region.

The coefficient of age of household head is negative and statistically significant at the 10 percent level of probability. This means that technical efficiency increases with the age of household head. The estimated coefficient of this variable shows that increasing the mean age of household heads by one year will cause technical efficiency to increase by about 0.02 percent points. Compared to other studies in Ghana, the estimated impact of age reported in this thesis can be regarded as low, which implies that this factor had little influence on observed efficiency.

While no satisfactory explanation exists about the relationship between age and technical efficiency, the most plausible reason why households headed by older people could be more technically efficient might be due to their experience about traditional farming methods and command over land resources. Naturally, ageing can have a positive effect on technical efficiency because it partly determines stock of human capital due to increase in experience and better knowledge on sustainable farming practices. Since agriculture is an experience-based enterprise, the more is the stock of knowledge of a household's head the better is his or her ability to use the little farm inputs at the disposal of the household more efficiently.

Moreover, due to impatience and the desire to be rich quick, households with younger heads may tend to diversify towards off-farm economic activities with higher and quicker returns, and participating in farming as a secondary activity. This can cause inefficiencies in farm input utilisation. The finding is consistent with the results of studies by Abdul-Rahaman (2016) and Bempomaa (2014) which also found significant positive relationship between age of household head and technical efficiency of maize production, and argued that it was due to differences in experience and resource endowments between households headed by older people and those by relatively young people. In contrast, Yiadom-Boakye *et al*. (2013) and Abdulai and Huffman (2000) as well as Bhasin (2002) found significant inverse relationship between age of household head and technical efficiency, and argued that younger farmers are more agile and receptive of modern technologies of farming compared to older ones. Similarly, Kibaara (2005) found a significant inverse relationship between age and technical efficiency among maize producers in Kenya and argued that although farmers become more skillful as they grow older, the learning-by-doing effect is attenuated as they approach middle age and as their physical strength starts to decline with age.

It has been advanced that because formal education makes people to easily embrace and make more profitable use of improved agricultural innovation, households headed by educated people are expected to be more technically efficient in production than those headed by people without formal education (Bempomaa, 2014; Bhasin, 2002; Dasmani, 2015). For example, Bhasin indicates that one means through which formal education can enhance technical efficiency is via the adoption of improved technology. Against this background, the present study expected a significant positive relationship between the formal education attainment of household head and technical efficiency. Regrettably, Table 10 shows that apart from year 2010, the coefficients of the various indicators included for formal education are not statistically different from zero. This implies that formal education did not significantly explain variations in technical efficiency among the sampled households. Moreover, the coefficients of the various measures included for education contradict the widely held view that formal education improves efficiency through its positive effects on information seeking and utilisation.

On the contrary, a number of empirical studies including Kabwe *et al.* (2016) and Bempomaa (2014) have found that educational attainment has no statistically significant positive impact on technical efficiency. Moreover, people with formal education have been noted to devote a significant proportion of their time and skills to highly paid off-farm jobs, thus reducing the amount of attention dedicated to farm work (Benjamin & Guyomard, 1994). More recently, Paul *et al*. (2017) found a significant negative relationship between education and technical efficiency among table egg producers in Nigeria, and suggested that the conventional wisdom that education improves technical efficiency by increasing the adoption and use of improved technological innovations might not be applicable to all agricultural producers.

However, the findings of the present study are comforting in the sense that significant positive relationship was observed between numeracy and efficiency in the bivariate analysis (Appendix E). In addition, the coefficients of the interaction between school attendance and literacy competence and between school attendance and numeracy competence are both positive, albeit insignificant. Consequently, it can be argued that whereas formal education might not influence technical efficiency per se, an educational policy which ensures that people do not merely attend school for its seek but are able to acquire the needed competencies in reading and numeracy through other forms of education could increase the level of technical efficiency of maize producers. For example, Al-Hassan (2008) obtained a significant positive relationship between the interactive term of education and experience and efficiency among rice producers in northern Ghana, and suggested that when farmers combine education with accumulated knowledge, they are able to plan, keep simple farm records and manage their farms more accurately. Experienced and educated farmers are also able to do early planting and timely weeding as well as use quality seeds more readily than their counterparts.

Table 10 also shows that livestock endowment has a significant positive influence on technical efficiency. Specifically, the negative coefficient of livestock size implies that if tropical livestock unit endowment is raised by 10 percent, technical inefficiency will fall by about 0.04 percent points. This variable was used as a proxy for a variety of things including wealth, animal manure application opportunities, and draft power availability. Holding all other factors constant, households with more flock of animals would tend to be wealthier than those who possess fewer or no livestock at all. Consequently, these households would be in a better position to use their endowment in livestock to increase their technical efficiency by taking advantage of the opportunities associated with this wealth including utilising animal sources of power provided by the livestock for ploughing, transportation and other on-farm processes. Moreover, higher livestock endowment has been found to reduce many liquidity problems that smallholder farmers face with respect to agricultural inputs demand and utilisation through direct sales for money and as collateral for credit from local level micro-credit operators (Owusu, Abdulai & Abdul-Rahman, 2011). This result is similar to Bachewe (2009), who found significant positive relationship between livestock ownership and technical efficiency among farmers in Ethiopia, and attributed it to larger protein intake among households with many animals.

In contrast to livestock endowment, household size had a significant negative impact on technical inefficiency, signaling that technical efficiency increases as household size increases. Given that agricultural production in Ghana thrives on manual labour based on traditional farming implements, this result may be regarded as counterintuitive. In fact, it was the expectation of the study that a significant positive relationship will be found between household size and technical efficiency since family labour is an important source of power for agricultural production in the study area. Other things held constant, a larger household size provides enough persons for farm work and less spending on hired services by external workers. Unfortunately, the estimated results show that each additional household member increases technical inefficiency by about 0.24 percent points. This result confirms the conclusions reached by Al-Hassan (2008) that a large household size enhances technical efficiency by providing farmers with a variety of labour skills which lead to division of labour and specialisation. Although the sign and coefficient of household size with respect to technical efficiency, other past studies have also found similar strong inverse impact, and attributed it to shirking and crowding-out effects resulting from competition over household resources (Asante *et al*., 2013; Mango *et al*., 2015).

The coefficient of number of hoes, a proxy for capital accumulation, has been found to be positive and significant, reflecting that as number of hoes increases technical efficiency decreases. Table 10 also shows that as number of hoes increase by one, technical inefficiency increases by about 0.14 percent. Households with many hoes may think that they have already incurred a huge cost in purchasing productive capital. Consequently, such households could be more focused on continuing to use this asset, and hence less willing to adopt modern and efficient techniques. The result reported here synchronises well with the theoretical proposition that lagged investment in durable capital has significant negative impact on agricultural productivity as a result of lock-in effects (Foxon, 2002).

With respect to individual years, Table 10 reveals that farm size has no statistically significant impact on technical efficiency across the different years. Furthermore, it can be observed from Table 10 that the sign of this variable was not consistent across the years. This inconsistency could be due to the inability of the cross-sectional dataset to address heterogeneities which could be correlated with farm size or with efficiency or both. Age of household head and livestock size were the only variables that significantly predicted technical efficiency across the individual years with age of household head, livestock size and household size significantly explaining variations in technical efficiency in year 2009; age of household head, education and livestock being the only significant factors in year 2010 whereas age of household head, livestock size and number of hoes were the only factors which significantly predicted technical efficiency in year 2011.

Distribution of Stochastic Frontier Analysis technical efficiencies

The frequency distribution of the technical efficiency scores based on the SFA approach as presented in Table 11 shows that the mean technical efficiency was highest in 2010 with that in year 2011 being the lowest. Although no household achieved full technical efficiency, the mean technical efficiency scores show that the respondents were able to achieve over 50 percent of their potential output throughout the period. In particular, the sampled households were able to achieve about 57.36 percent, 61.08 percent and 55.51 percent of potential output in the respective years. However, with a mean technical efficiency of 55.51 percent in 2011, inefficient producers could increase their output levels by approximately 44 percent if they were to achieve full technical efficiency. This could have been done by investing more on health improvements in order to reduce the number of illness days suffered or by increasing the use of intermediate inputs or both.

Overall, the mean technical efficiency scores for the various years and in the panel demonstrate that there was plenty of scope for increasing technical efficiency without shifting the production frontier upwards. More specifically, the results imply that inefficient producers could have increased their efficiencies by about 42.64 percent in 2009, 38.92 percent in 2010 and 44.49 percent in 2011 if they adopted the techniques utilised by fully efficient households in the period. Table 11 also shows that the average technical efficiency score for the entire panel was larger than those for the individual years, signaling the superiority of the panel model estimation due to the availability of more observations on each participant. More importantly, more y households were found to be in the 80 percent to 90 percent and 90 percent to 100 percent brackets of technical efficiency in the panel model compared to the individual years. In fact, apart from year 2010 where one household managed the 90 percent to 100 percent range, no household attained this technical efficiency estimate in the remaining two years.

Table 11: *Frequency distributions of SFA technical efficiency scores*

TE Score	2009	2010	2011	Panel
< 0.4	129	78	154	100
0.4-0.5	110	105	122	176
0.5-0.6	161	134	156	179
0.6-0.7	195	214	179	122
0.7-0.8	164	219	142	113
0.8-0.9	28	36	34	77
0.9-1.00	0	1	0	20
Minimum	0.1083	0.1185	0.0573	0.3468
Maximum	0.8807	0.9058	0.8964	0.9768
Mean	0.5736	0.6108	0.5551	0.7866

Source: Author's construct (2018).

The disparity in the technical efficiency performance between the panel model and the model for the individual years could possibly be attributed to technical change linked to learning efforts and experimentation with new and improved methods and crop varieties. It could also be due to reduction in heterogeneities negatively associated with efficiency due to the availability of more data points on the sample (Newey, 2007). Generally, literature shows that time has a significant influence on the learning efforts of farmers and can contribute to technological change, especially when new crop cultivars are adopted (Foster & Rosenzweig, 1995; Goodwin, Featherstone, & Zeuli, 2002; Luh & Stefanou, 1993). Moreover, the ability of the panel data estimation to control for producer specific heterogeneities that might be negatively correlated with technical efficiency can account for the differences in the technical efficiency estimates (Rashidghalam *et al.*, 2016; Wang & Schmidt, 2002).

Results of Data Envelopment Analysis

Estimated results of multiple linear regression analysis of the input-oriented DEA technical efficiency scores under variable returns to scale (VRTS) and constant returns to scale (CRTS) are reported in this section of the study. The frequency distributions of the results as shown in Table 12 indicate that there were wide variations in the levels of technical efficiency scores among the sampled households, with estimates ranging from 0.4696 to 1.00, with a mean score of 0.6951 under VRTS and 0.6514 under CRTS. Table 12 also shows that 429 households, representing 54.51 percent of the sample, had technical efficiency scores below the mean score under the assumption of variable returns to scale. Moreover, it can be observed from Table 12 that 419 households, representing 53.24 percent of the total sample, achieved technical efficiency scores below the sample mean technical efficiency under constant returns to scale. In addition, only 26 households (3.30 %) and 7 households (0.89%) achieved full technical efficiency under VRTS and CRTS respectively. This implies that there was wide technical inefficiency among the sampled households.

On a year-by-year basis, it was observed that many households achieved full technical efficiency under the assumption of variable returns to scale than under constant returns to scale. Table 12 also reveals that except year 2010 where efficiency of most households fell within the 0.7 to 0.8 brackets, the estimated efficiency scores under variable returns to scale were heavily concentrated within the 0.6-0.7 range with only 11 households recording technical efficiency ranging from 0.4 to 0.5. Moreover, it can be observed that under constant returns to scale, technical efficiency was heavily concentrated within the 0.6-0.7 range.

Table 12: *Frequency distributions of DEA Technical efficiency scores*

TE score	VRTS				CRTS			
	2009	2010	2011	Panel	2009	2010	2011	Panel
< 0.4	0	0	0	0	0	0	2	0
0.4-0.5	0	0	0	11	15	3	14	41
0.5-0.6	81	45	38	156	128	56	120	227
0.6-0.7	274	210	276	277	297	282	339	292
0.7-0.8	241	285	270	216	225	281	202	156
0.8-0.9	123	157	140	78	89	118	87	53
0.9-1.00	38	51	41	23	19	28	13	11
1.00	30	39	22	26	14	19	10	7
Minimum	0.51	0.52	0.53	0.47	0.42	0.49	0.39	0.42
Range	0.49	0.48	0.47	0.53	0.58	0.51	0.61	0.58
Mean	0.73	0.76	0.74	0.70	0.69	0.73	0.68	0.65

Source: Author's construct (2018).

Although the mean technical efficiencies reported in this study can be described as low, they are within the thresholds of estimated mean technical efficiencies on smallholder farmers in empirical studies around the globe. For instance, they are slightly higher than the mean technical efficiencies obtained by Abatania (2013) but lower than those of Bhasin (2002). Awuma (2008) observed that the technical efficiency of cassava farmers in the Awutu Bawjiase District of the Central Region varied between 2 percent and 99 percent, with the mean level of technical efficiency observed to be 58 percent.

Further, Croppenstedt and Muller (2000) reported that the average farm-specific technical efficiency score of farmers in Ethiopia varies from 51 to 76 percent, depending on the assumed functional form and distribution of the one-sided error term.

In sum, the results show that a great deal of opportunity existed for the sampled households to save productive resources without any harm to output. For example, Dao (2013) and Vu (2008) maintained that by following the steps of the producers at the frontier, all other decision-making units can reduce inputs usage by a factor of $\left({}^{1}\!/_{TE_{VRTS}} - 1 \right)$ without having to change the level of output of production. Taking cues from this proposition, it can be argued that the amount of inputs used by households in this study could have been reduced by about 37.15 percent in 2009, 32.14 percent in 2010, and nearly 35 percent (34.84%) in 2011. This translates to about 43.86 percent of reduction in input usage for the entire panel.

Ranking of households on the basis of Data Envelopment Analysis

Surprisingly it was observed that, consistent with the SFA approach, the mean technical efficiency of the Panel under the DEA approach was lower than the mean figures for the various years. Generally, it was expected that the mean technical efficiency under the panel model will be higher than their counterparts for the individual years due to the isolation of heterogeneities that may be negatively correlated with efficiency. Given this contradiction, the characteristics of the sampled households with respect to the quantity of maize produced and inputs used together with other sociodemographic factors at the start of the panel were further examined to find out whether differences in initial conditions played a significant role in the panel technical efficiency scores. Considering the small number of households attaining full efficiency under the CRTS, the analysis in this part was restricted to estimations under VRTS.

All the households were categorized in top, medium, and bottom performers using the estimated technical efficiency scores arranged in descending order of magnitude. The 26 households which achieved technical efficiency scores of one were regarded as the top performers. These households were compared to households with the last 26 values of technical efficiency scores characterised as the 'bottom performers' whereas the remaining 735 households, representing 93.39 percent of the sample, with technical efficiency scores falling between these two extremes were regarded as medium performers.

Table 13 shows the information of the sampled households on the basis of their technical performance. As is evident from Table 13, top performers produced nearly four times the output of bottom performers and incurred 0.78 times on material cost as medium performers, signaling the importance of intermediate inputs to maize production. Additionally, it was observed that top performers (M=22.02, SD=87.45) and bottom performers (M=12.54, SD=6.57) were endowed with more acres of farmland compared to medium performers (M=10.00, SD=12.67). However, bottom performers used more labour and had more hoes than everyone else. Moreover, fewer number of illness days were reported by top performers and medium performers compared to bottom performers; purporting a plausible negative relationship between technical efficiency and health shocks. Similarly, the results show that bottom performers had the highest mean values of credit and household size but little livestock endowment compared to the remaining two categories. Further, top performers were headed by relatively old people (M=50.24, SD=15.35) compared to bottom performers (M=44.02, SD= 15.15) and medium performers (M=42.231, SD= 15.91).

Table 13: *Classification of households based on DEA efficiency scores*

	Top Performers		Medium Performers		Bottom performers	
Variable	M	SD	M	SD	M	SD
Output	4330.39	7627.96	1992.86	1862.91	1201.50	626.27
Materials	188.85	383.76	241.33	313.93	331.86	231.44
Land	22.02	87.45	10.00	12.67	12.54	6.57
Labour	120.81	234.20	179.09	172.32	637.92	265.65
Hoes	4.81	6.230	4.65	2.84	6.00	4.07
Health	8.23	13.77	31.20	66.84	46.44	84.88
Livestock	2.84	4.84	2.89	6.89	1.47	2.04
Credit	89.92	188.20	114.55	209.51	163.80	204.94
Family size	7.08	4.17	7.21	3.28	9.400	4.19
Age	50.24	15.35	44.02	15.15	42.23	15.91
Sex of head						
Male		26		711		25
Female		0		24		1
Marital Status						
Married		3		670		25
Unmarried		23		65		1
Education						
Uneducated		20		540		15
Educated		6		195		11
Literacy skills						
Can read		6		181		12
Cannot read		20		554		14
Numeracy Skills						
Capable		6		142		21
Not capable		20		593		5
Food security status						
Secure		20		579		4
Insecure		6		156		22
Access to electricity						
Yes		18		263		9
No		8		472		17

Source: Author's construct (2018).

As is also evident from Table 13, top performers were headed by males whereas only one household among the bottom performers was headed by a female. If detailed information which could lead to the identification of the households was available in the original dataset and time had allowed for follow-up investigations and cross-validations, this lone household could have served as an interesting case study. Moreover, it can be observed that households headed by females were almost equal to the entire group of top performers and bottom performers. This could probably explain why sex of household head has been identified as an insignificant determinant of technical efficiency by a number of past studies. Households headed by people who had formal education were more prevalent in the bottom performing farms compared to top performers. For example, whereas nearly 80.77 percent of bottom performers were headed by people with numeracy skills, only 23.08 percent of households in the top performers' bracket had heads that possessed numeracy skills.

According to Table 13, 11 of the households in the bottom performers' group were headed by people who did not attend school compared to only 6 households in the top performers' category. This could be the reason why many of the measures included for formal education had negative coefficients in the regression models. We had expected that level of education of the household head to trickle down to other members of the household and thus play a positive role in agricultural production by increasing the efficiency with which the household will allocate farm inputs. Unfortunately, Table 13 suggests that it was wrong to assume that household head's attainment in formal education will play an active part in differentiating efficient producers from inefficient ones. This result could be an indication of an inverse relationship between education and technical efficiency.

Though smallholder farming in general and maize production in particular does not require a very high level of formal education before high success can be attained, low levels of literacy rates among household heads can present a lot of challenges to other members in understanding and applying modern inputs and agricultural technologies. Literature (Bhasin, 2002; Dasmani, 2015; Peprah, 2011) shows that high illiteracy affects the ability of agricultural households to understand, appreciate and respond to changing trends in production and weather conditions, both of which can reduce on-farm production processes and efficiency.

With respect to other background characteristics, Table 13 shows that most of the bottom performers compared to top performers were headed by married people. A very high proportion of top performers were food secured (76.92%) and also had access to electricity (69.23%) compared to bottom performers.

Results of multiple regression analysis of DEA efficiencies

Considering the existence of inefficiencies in production and the wide variations in technical efficiency scores between the top and bottom performers, further econometric analyses were carried out to examine the influence of agronomic, sociodemographic and institutional factors on the estimated efficiency scores. Unlike the results of the SFA estimation (Table 10) where the effects of independent factors were discussed through their effects on technical inefficiency so that negative signs become positive and positive signs become negative in the examining the significance of each factor on efficiency, the results in this section are explained directly without reversal of signs. Here too, emphasis is on the results of the panel model though attempts are made to explain those of individual years.

Table 14: *Results of multivariate regression analysis of DEA efficiency (VRTS)*

Variables	2009		2010		2011		Panel	
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.	S.E
Farm size	-0.086	0.277	-0.108[c]	0.042	-0.343[a]	0.053	0.116[a]	0.028
Loan	0.321[c]	0.155	-0.314	0.222	-0.768[c]	0.321	0.038[c]	0.016
Size* Loan	0.040	0.020	0.144	0.122	0.837[c]	0.342	0.015	0.028
Age	-0.970[a]	0.274	-0.710[b]	0.272	-0.824[a]	0.248	0.020	0.016
School	-0.139	0.136	0.145	0.013	-0.637	0.122	-0.123	0.013
Read	-0.167	0.163	-0.182	0.160	-0.204	0.146	0.016	0.017
Numeracy	0.238	0.265	0.390	0.259	0.483[c]	0.236	0.016	0.027
Sch*Read	-0.241	0.268	-0.336	0.026	0.571	0.002	0.042	0.027
Sch* Num	0.101	0.337	-0.160	0.033	-0.345	0.300	0.021	0.035
Livestock	0.154[b]	0.060	0.172[b]	0.0583	0.131[c]	0.011	0.192[b]	0.097
Hsize	-0.293[c]	0.129	-0.201	0.126	-0.185	0.113	-0.211[c]	0.121
Hoes	-0.262	0.153	0.935	0.014	-0.073	0.126	-0.261[c]	0.133
Constant	0.808[a]	0.001	0.805[a]	0.002	0.824[a]	0.014	0.782[a]	0.015
Adj. R^2	0.056		0.026		0.082		0.065	
F-Stats.	4.849[a]		2.733[a]		6.826[a]		4.808[a]	
N	787		787		787		2361	

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

Source: Author's construct (2018).

Table 14 and Table 15 present the estimated results of the data envelopment analysis. As is evident from Table 14 and Table 15, there is a significant positive relationship between farm size and technical efficiency. Specifically, both tables show that increasing farm size by one acre will lead to about 19.15 percent points increase in technical efficiency under variables returns to scale and by about 31.95 percent points increase in technical efficiency under constant returns to scale, holding another factors constant. Once more, this shows that inverse farm size-efficiency relationship which is common with the cross-sectional models is invalid as far as results of the panel estimation approach are involved. The results also indicate that access to credit and livestock size had significant positive effects on efficiency while household size and number of hoes were negative. This implies that households who received more credit compared to those that received little or no credit were more technically efficient; and that households with many livestock units compared to those with fewer or no livestock units were more efficient.

The significant and negative coefficient of household size means that households with more family members were less efficient compared to households with fewer members. The findings are counterintuitive, even though similar results have been reported by Okoye *et al.* (2016) and Asante *et al*. (2014). The estimated coefficient of number of hoes of -0.2608 indicates that increasing the number of hoes owned by households by one additional unit will cause DEA technical efficiency under variable returns to scale to decrease by about 26 percent points (Table 14). Furthermore, none of the variables included for education significantly explained variations in technical efficiency.

Under the assumption of variable returns to scale, livestock size had a significant positive effect on technical efficiency for the individual years as well as in the panel model. In addition, the results indicate that among the factors having significant positive influence on technical efficiency, the variable for livestock endowment had the greatest effect on panel technical efficiency and in 2010. Moreover, Table 14 shows that with the exception of 2010, livestock size had a significant positive effect on technical efficiency under the assumption of constant returns to scale. This means improving livestock production is important for technical efficiency improvements.

Furthermore, both Table 14 and Table 15 indicate that formal education has a negative but insignificant effect on the DEA technical efficiency. Although this finding is counterintuitive, it is not strange given that Nkegbe (2011) obtained similar results in his study on resource conservation and production efficiency among smallholder farmers in the Northern, Upper East and Upper West Regions of Ghana. Moreover, my findings agree with Paul *et al.* (2017) and Ansah *et al.* (2014) as well as Bempomaa (2014) who advanced that formal education can create inefficiencies in crop production by diverting attention away from on-farm production to high paying off-farm activities.

Table 15: *Results of multivariate regression analysis of DEA efficiency (CRTS)*

Variables	2009		2010		2011		Panel	
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.	S.E
Farm size	0.178	0.216	-0.151[a]	0.038	-0.207	0.167	0.320[a]	0.053
Loan	-0.279	0.027	0.139	0.207	-0.596	0.322	0.279	0.13
Size* Loan	-0.207	0.149	0.112	0.110	0.068[c]	0.034	-0.078	0.077
Age	-0.100[a]	0.026	-0.054[c]	0.024	-0.100[a]	0.024	-0.080[a]	0.014
School	-0.109	0.131	0.179	0.123	-0.084	0.123	-0.072	0.729
Read	-0.085	0.157	-0.161	0.146	-0.102	0.146	-0.134	0.088
Num.	0.115	0.256	0.041	0.236	0.043	0.237	0.1584	0.144
Sch*Read	-0.238	0.254	-0.112	0.238	-0.034	0.237	-0.635	0.014
Sch* Num.	0.054	0.325	-0.108	0.300	-0.254	0.301	0.480	0.018
Livestock	0.152[b]	0.057	0.088	0.053	0.144[b]	0.054	0.145[a]	0.031
Hsize	-0.169	0.125	-0.216	0.115	-0.106	0.113	-0.254[a]	0.067
Hoes	-0.229	0.148	-0.100	0.127	0.057	0.126	-0.078	0.764
Constant	0.076[a]	0.001	0.783[a]	0.014	0.765[a]	0.014	0.741[a]	0.008
Adj. R^2	0.0371		0.0474		0.0704		0.0336	
F-Stats.	3.52[a]		4.264[b]		5.965[a]		7.656[a]	
N	787		787		787		2361	

Note: Standard errors in parentheses, [a] p<0.01, [b] p<0.05, and [c] p<0.10.
Source: Author's construct (2018).

Results of multivariate regression analysis of scale efficiency

This section presents the estimated results of the multiple regression analysis on scale efficiency to conclude the first empirical chapter; which answers the first two hypotheses set out to be tested by the study. Like other sections, emphasis is placed on the results of the panel model although attempts are made to explain results of individual years. As is evident from Table 16, all the variables hypothesised to influence scale efficiency had the expected signs but only three of them were statistically significant in the panel model.

The significant and positive coefficient of farm size indicates that large farm owners achieved higher levels of scale efficiency compared to households with smaller farmers. Specifically, the estimated coefficient of this variable shows that increasing farm size by one more acre will result in about 52.69 percent points increase in scale efficiency. This could be explained by the fact that large farm owners were able to use certain scale-biased and indivisible but highly productive technologies such as tractors compared to their counterparts with smaller farms.

Table 16: *Results of multivariate regression analysis of scale efficiency*

Variables	2009		2010		2011		Panel	
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.	S.E
Farm size	0.030[c]	0.010	0.060[b]	0.020	-0.131	0.572	0.527[b]	0.209
Loan	-0.099	0.020	-0.278[c]	0.138	-0.271	0.346	0.014[c]	0.008
Size* Loan	-0.157	0.109	0.612	0.755	0.220	0.369	0.013	0.016
Age	0.199	0.193	-0.172	0.169	0.543[c]	0.267	0.119	0.232
School	-0.399	0.963	0.3116	0.835	0.138	0.132	-0.030	0.106
Read	0.130	0.115	-0.199	0.993	-0.165	0.157	0.017	0.030
Num.	0.158	0.187	0.060	0.002	0.515	0.025	0.013	0.018
Sch*Read	0.901	0.186	0.105	0.162	0.211	0.255	0.0149	0.212
Sch*Num.	-0.585	0.238	-0.112	0.204	-0.149	0.323	0.011	0.024
Livestock	-0.218	0.420	0.105[b]	0.036	-0.573	0.577	0.240[b]	0.012
Hsize	-0.192[c]	0.091	0.170	0.782	-0.124	0.122	-0.012	0.010
Hoes	-0.437	0.011	0.279[b]	0.086	-0.277[c]	0.136	-0.060	0.087
Constant	1.062[a]	0.010	1.029[a]	0.009	1.087[a]	0.002	1.075[a]	0.013
Adj. R^2	0.0116		0.051		0.0028		0.0467	
F-Stats.	1.766[c]		4.523[a]		1.185		2.25[a]	
N	787		787		787		2361	

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

Source: Author's construct (2018).

It is also evident from Table 16 that a significant positive relationship exists between livestock ownership and scale efficiency. With an estimated coefficient of 0.240, it can be concluded that livestock size significantly explained variations in scale efficiency across the households. Generally, the results show that if the number of livestock owned by a household is increased by one extra tropical unit, scale efficiency will rise by about 24 percent.

Summary

This chapter presented estimated results on the effect of farm size on efficiency. The main focus of the chapter was to establish whether or not there is a significant positive relationship between farm size and resource use efficiency measured by the technical and scale efficiencies.

Two estimation approaches, namely the SFA and DEA, were used to estimate technical efficiency scores whereas bivariate and multiple regression analyses were employed to investigate the relationship between the estimated efficiency scores and a set of explanatory variables of which farm size was part. The results revealed that land, labour, intermediate inputs and health shock significantly contributed to variations in output. Estimated efficiency scores across the two estimation methods show that there was substantial variability in the output of production and inefficiency among the sampled households, reflecting that maize productivity can be increased through improvements in technical and scale efficiencies. To gain more insights into the technical and scale performance of the respondents studied, regression analyses were conducted on the determinants of technical and scale efficiencies. Both bivariate and multivariate models were considered and the results linked to existing studies.

Results of the multiple regression analysis showed that some of the control variables and the main variable of interest (farm size) significantly explained variations in efficiency scores across the households. Among the control variables, access to credit, age of household head, household size, and number of hoes owned had statistically significant effects on technical efficiency scores obtained from the alternative estimation approaches. Also, scale efficiency was significantly and positively related to farm size. Moreover, the bivariate analysis also indicated significant and mixed relationship between efficiency and the independent variables used for the study.

CHAPTER FIVE

FARM SIZE AND PLOUGHING TECHNOLOGY

Introduction

This chapter presents empirical results on farm size and choice of ploughing technology. The main focus of the chapter was to examine the relationship between farm size and ploughing technology. Specifically, it was hypothesised that there is no significant positive relationship between farm size and ploughing technology. The chapter is divided into three sections. The first section presents results of the multinomial regression analysis of the effect of farm size and other agronomic and sociodemographic factors on the choice of ploughing technology for land preparation, using plot-level information. This is closely followed by the Tobit regression analysis of the factors affecting the intensity of mechanisation; conceptaulised as the proportion of total farmland ploughed by animal traction and tractor in the second section. The third and final section of the chapter presents the summary.

Results of multinomial regression analysis of ploughing technology

Results of the econometric estimation with the decision to use hoe, animal traction or tractor for ploughing as the dependent variable and farm size and other sociodemographic and agronomic factors as regressors are presented and discussed in this section. In the empirical estimation, the reference category is hoe against which the reported results of animal traction and tractor use are compared. Hoe was used as the base category due to the negative health effects and high manpower requirements associated with the use of the hoe as a farm tool relative to animal traction and tractor. The interpretation of the two models is the probability of the odds of using animal traction and tractor for ploughing relative to hoe. With respect to estimated coefficients, positive coefficients of the independent variables in any estimated model will imply that households were more likely to employ that technology as this independent variable increases in the case of continuous factors or change from the base category to the used category in the case of categorical dependent factors whereas negative coefficients will imply the exact opposite.

Table 17 and Table 18 show the regression results of the variables affecting use of animal traction and tractor respectively. It is evident from Table 17 that nine of the regressors were statistically significant in the decision to use animal traction instead of hoe, with 10 of them doing so in the choice of tractor over hoe. Model fit indices associated with the results such as the Log Likelihood and Wald chi-squared indicate that the regression models as a whole fitted the dataset better than models without independent variables. They further statistically validate that the explanatory variables included in the models contributed significantly as a group to the variations in the choice of competing ploughing technologies and that their coefficients are statistically different from zero. This implies that the regressors as a group distinguished well between households' choice of animal traction or tractor relative to hoe.

Table 17: *Results of multinomial regression analysis of ploughing technology-Panel*

Variable	Animal traction					Tractor				
	Coef.	S.E	dy/dx	+1	+SD	Coef.	S.E	dy/dx	+1	+SD
Farm size	0.1000^{a}	0.0250	0.001	0.001	0.004	0.1100^{a}	0.0240	0.011	0.010	0.068
Distance	-0.0900^{a}	0.0160	-0.008	-0.008	-0.043	0.0058	0.0070	0.007	0.007	0.041
Years	0.0040	0.0032	-0.000	-0.000	-0.005	0.0060^{c}	0.0030	0.001	0.001	0.033
Age	-0.0080^{b}	0.0045	-0.000	-0.000	-0.001	-0.0080^{a}	0.0020	-0.001	-0.001	-0.014
Livestock size	0.0041	0.0063	0.000	0.000	0.000	0.0040	0.0040	0.000	0.000	0.003
Household size	-0.0280^{c}	0.0151	-0.000	-0.000	-0.001	-0.0300^{a}	0.0110	-0.003	-0.003	-0.010
Loan amount	0.0001	0.0004	0.000	0.000	0.006	0.0010^{b}	0.0004	0.000	0.000	0.019
Member	0.9720^{a}	0.1100	0.016			1.1470^{a}	0.0720	0.132		
Rights	0.4500^{a}	0.1310	0.046			-0.1120	0.9000	-0.051		
Owner	0.3900^{a}	0.1460	0.032			0.2090	0.1010	0.025		
Disputes	-0.5550^{c}	0.3200	0.0135			-0.6750^{b}	0.2790	-0.188		
Male	-0.5500	0.3630	-0.013			-0.4570^{c}	0.2700	0.030		
Married	-0.1850	0.1880	-0.049			-0.3900^{a}	0.1410	0.085		
School	0.3490^{a}	0.1260	0.018			0.1620^{c}	0.0930	0.001		
Constant	0.0060	0.4000				1.1920^{c}	0.3060			
Log Likelihood	-4387.94									
Wald (χ^2)	471.79^{a}									
Pseudo R^2	0.0644									
N	2361									

^{a}p<0.01, ^{b}p<0.05, and ^{c}p<0.10.

Source: Author's construct (2018).

In line with the hypothesis set out for this section, Table 17 and Table 18 indicate that, except for animal traction use in 2011, the coefficient of farm size was positive and highly significant in all other models, confirming that the decision to use animal traction for ploughing instead of hoe was more prevalent among households having with large plots of farmland compared to those with smaller plots.

The marginal effects ($^{dy}/_{dx}$) reported in Table 17 measure the expected change in probability of using animal traction and tractor with respect to the explanatory variable. In all cases, the estimated coefficients of the explanatory variables are compared with the use of hoe as the base category. The predicted probabilities indicate that a standard deviation increase in farm size will increase the likelihood of using animal traction compared to hoe by a factor of 0.004 whereas the same amount of change in farm size will increase the likelihood of using tractor by 0.068. Simply put, farmers who have large plots have a 0.001 higher probability of using animal traction instead of hoe compared to farmers with small plots. Again, farmers with large plots have 0.011 higher probability of using tractor plough than those with small plots.

Generally, a greater land endowment relative to labour is posited to increase the probability of farm mechanisation because most mechanised agricultural technologies require a sufficiently large scale of operation for successful application (Binswanger, 1986; Maranan, 1985). From the farming system evolution perspective, agriculture in most parts of Northern Region has reached the level where overall demand for mechanised ploughing is high, given that the average land holding per household exceeds five hectares

(Chamberlain, 2007), and mechanised ploughs replace manual labour depending on the socioeconomic status of the household. This finding means that the bigger the farm plot a household uses for maize production, the higher the chance of using mechanised technology compared to hoe, which presents similar findings as those reported by Takeshima *et al.* (2015), Mabuza *et al.* (2013) and Mbata (2001) who found significant positive link between farm size and choice of mechanised land preparation technology. The result is also similar to the result of Mottaleb *et al*. (2016) who reported significant positive relationship between farm size and small-scale agricultural machinery adoption among households in Bangladesh. However, they contradict the results of Oladeji, Ogunleye and Aderinto (2012) who found that farm size does not significantly influence animal traction adoption decisions.

The coefficient of distance of farm from home was negative and significant for animal traction but positive and insignificant for choice of tractor. This implies that the probability of selecting animal traction in place of hoe reduces as the distance between the plot and farmers' homestead increases. The result on this variable is counterintuitive. Literature shows that farms which are remotely located tend to be used inefficiently due to the loss of productive time in travelling to and from these farms (Bhasin, 2002: Dovring & Dovring, 1960). Thus, it was expected that as distance to the farm increases households will be more motivated to adopt mechanised ploughing technologies since these technologies act as full or intermediate transport and hence have the potential to reduce both the time taken to reach the farm and the drudgery associated with manual land preparation using hoes. Nonetheless, Bachewe (2009) shows that farms located far from home tend to be more fertile, less fragmented and easier to till than those closer to the home. This can account for the counterintuitive relationship between farm distance and animal traction. Another plausible explanation for the inverse relationship between distance to farm and animal traction use could be the difficulties involved in moving yorked oxen to farms that are far from home. A lot of time and energy is expensed in getting draft animals to remote farms, especially when these animals are being sent to such farms for the first time by inexperienced and strange individuals. This is not the case with tractors and hoes which are completely under human control in full-use conditions.

Furthermore, the results show that the number of years for which households have been using their farms has a significant positive impact on the choice of tractor over hoe for ploughing, and a positive, albeit insignificant, effect on animal traction. The negative and significant coefficient of the age of the household head reflects that households headed by younger people adopted mechanised ploughing technologies much more compared to those headed by older people. Specially, Table 17 indicate that a standard deviation increase in the age of household head decreases the likelihood of animal traction compared to hoe by a factor of 0.01 whereas a similar increase in the same variable causes tractor use to fall by 0.033. These results are consistent with expectation.

Literature shows that households headed by younger people are more receptive to modern production technologies compared to those headed by older people (Bhasin, 2002). Moreover, young farmers have been found to prefer agricultural technologies that make use of less human effort and generate higher returns (Agarwal, 1984). In addition, because households headed by younger people tend to face many challenges in terms of access to agricultural land, they are more likely to rely on production processes which make it possible to maximise the gains from the little resources at their disposable including the adoption of mechanised and easier to use ploughing types. In many areas in the Northern Region of Ghana, land is predominantly owned by older people and transferred from one generation to the other along paternal lines (Oppong, 1973). Therefore, households headed by young adults may lack access to land and other rights associated with it. In addition, even when younger people are able to access land, the lack of permanent ownership can act as a catalyst for impatience, and hence the adoption of production technologies which generate higher yields per unit of farm area.

Table 17 also shows that participation in social network exerted a significant positive influence on the decision to use animal traction and tractor for ploughing compared to hoe. The estimated marginal effects of the variable for membership in social network indicate that belonging to a social network increases the probability of adopting animal traction by 1.6 percent and tractor use by over 13 percent. This implies that social networking well differentiated households which mechanised their farms from those who did not participate in any social network.

Membership in community-based organisations, as a form of social capital, is an important source of information to farming households in the study area in making decision regarding the adoption of modern farming technology. An expansive body of empirical research has documented the positive effect of participation in social networks on household maximisation decisions including those relating to adoption of modern farming technologies, food consumption expenditures and household welfare (Arun, Annim, & Arun, 2016; Bandiera & Rasul, 2006; Magnan, Spielman, Lybbert, & Gulati, 2015; Liverpool-Tasie, Kuku, & Ajibola, 2011). For example, Magnan *et al*. and Bandiera and Rasul analysed the relationship between participation in social network and agricultural technology adoption and found that the likelihood of adoption was higher among farmers who were members in a social network compared to those farmers who did not participate in social network. This underscores the importance of social networking to the choice of alternative ploughing technologies.

Strangely, households which indicated that they had full rights over their lands were less likely to use tractors for ploughing compared to households without such rights, although Table 17 shows that the same households were more likely to use animal traction compared to hoe. Holding other factors, households with full land rights were associated with 4.6 percent likelihood of using animal traction compared to hoe. The positive and statistically significant coefficient of land ownership signifies that the probability of using animal traction, as opposed to hand hoe, was higher on self-owned plots compared to plots with other tenure arrangements. Table 17 shows that land owners were about 3.2 percent more likely to use animal traction compared to hoe. Land tenure security has been identified as a significant determinant of agricultural investment and choice of new technologies and households with more secured farm plots are more likely to accept and utilise mechanised ploughing technologies because of the possibility of reaping all the benefits associated with this investment (De Soto, 2000).

Dispute over farm land was included in the regression as a proxy for property rights and land tenure security. As is evident from Table 17, the coefficient of this variable is statistically significant and negative, indicating that households whose farm plots were under disputes were less likely to adopt animal traction and tractors for ploughing their farms. A number of past studies have found significant positive relationship between land tenure security and investment in agricultural technology. For example, De Soto (2000) points out that the underdevelopment of formal land rights in developing countries in general and the limited share of land administered through statutory land title documents devoid of disputes in particular, has hindered agricultural development in many countries by maintaining very productive capital as a "dead asset". Compared with weak and insufficient property rights under customary land tenure arrangements, secure land rights, on the basis of economic theory, are thought to increase credit use through greater incentives for investment, improved credit worthiness of agricultural projects and enhanced collateral value of land, all of which are considered important for adopting improved agricultural methods over traditional ones (Binswanger, 1986; Maranan, 1985).

A positive and significant relationship was expected between livestock ownership and choice of animal traction and tractor services compared to hand hoe. Generally, agricultural households who own large herds of cattle and other draft animals will find it relatively cheap to use animal traction compared to those who do not. Moreover, livestock are a stock of wealth and can easily be sold to pay for motorised farm services.

Another interesting finding of the study is the estimated coefficient of household size. In both models, the coefficient of household size is negative and statistically significant. Though the estimated parameter is insignificant in the models for the individual years, the general negative sign of this variable in the panel model suggests that increasing household size discourages the use of animal traction and tractors compared to hoe. This may be due to the fact that a higher household size increases the amount of labour available for manual land preparation. Naturally, households with abundant supply of cheap labour do not experience labour shortage for agricultural production and hence will not find it relevant to adopt labour-saving technologies of which tractors and animal traction are part. This finding is consistent with the prediction that human capital endowments increases the demand for manual work and reduces farm mechanisation (Akinola, 1987; Takeshima, 2015).

Akinola (1987) submits that household size plays dual and opposing roles in determining the adoption of agricultural technology. On the one hand, it provides the necessary manpower needs. But it also has certain demands which may motivate the use of new farm practices that would increase the household's income to enable it meet these demands. Akinola also notes that the strength of family ties has the effect of encouraging agricultural producers to improve their earning potential because many family workers may tolerate, at least in the short-run, extremely bad conditions of employment or very poor remunerations as a result of the family loyalty. The occurrence of these conditions puts agricultural producers in a financially advantageous position to spend more resources which could otherwise have been used to pay commercial workers on the adoption of new farm practices. On the contrary, household size can crowd out new farming practices as a result of competition over scarce financial resources (Takeshima, 2015). Further, a high dependency ratio on farmers may weaken their motivation to work harder since they know that their success might result in more claims from other family members. This suggests that the actual relationship between household size and the adoption of alternative ploughing techniques depends on the balance of these opposing effects.

The coefficient of loan size is positive and significant in the choice of tractor over hoe. The estimated probabilities reported in Table 17 demonstrate that a standard deviation increase in the amount of credit received by households will translate to about increase in the choice of tractor over hoe by a factor of 0.019, holding other factors at their means. Also, though not statistically significant, the positive coefficient of loan size in the model for animal traction signifies that access to credit encouraged the respondents to choose animal traction over hand hoe for their farm operations. This can be attributed to the fact that households which have the opportunity to receive credit are able to build their capacities to produce more by expanding the size of land put under cultivation, and thus increased demand for improved ploughing technologies.

Since most farmers in the communities covered by this study do not own tractors and consequently have to rely on hired services, it can be argued that credit makes it easier for them to pay providers of tractor services. In other words, the availability of credit eases the financial burdens of farm households and expands the opportunity for the optimal utilisation of mechanised technologies and modern agricultural machinery and implements.

This result is similar to Ghosh (2010) who found significant positive relationship between access to credit and farm mechanisation. It also corroborates the theoretical propositions by Giné and Klonner (2008) that credit limitations are a binding constraint to modern agricultural technology adoption in developing countries.

Compared to households headed by unmarried people, the results indicate that households headed by married people were less likely to use tractor compared to hoe. This implies that households in which the head was married had a lower chance of using tractors to plough their maize farms compared to households headed by unmarried people. Moreover, the results show that education is a significant positive determinant of farm mechanisation. Specifically, the results show that households headed by people who have ever attended school were more likely to use animal traction and tractor for ploughing compared to hoe. This means that increasing formal education increases farm mechanisation. Education is regarded a significant determinant of exposure to and evaluation of information about the benefits of modern farming technologies (Bhasin, 2002), and can speed up the pace of farm mechanisation by reducing skepticism and conservativeness. The finding confirms the results of Challa (2013) who found that level of education significantly and strongly influenced the intensity of tractor adoption but contradicts those of Akpeintuik (2003) who report that education does not significantly affect the adoption of animal traction among farmers in the Builsa District of the Upper East Region.

Significantly, Appendix E shows that farm size, distance to farm and rights over land were the factors which influenced households' choice of animal traction in year 2009 with farm size, years of land occupancy, household size, loan size and marital status of the household head doing so for tractor use over hoe during the same period (Appendix E). Similarly, it can be observed from Appendix F that farm size, distance to farm, rights over land, land disputes and education contributed significantly to animal traction adoption in 2010 compared to the use of hoe whereas farm size and age of household emerged as significant covariates for tractor adoption during the same period. Appendix F also shows that livestock size had a significant positive impact on animal traction compared to hoe in year 2010. According to Appendix F, a standard deviation increase in livestock size will lead to about 2.6 percent rise in the probability of using animal traction compared to hoe. This result is similar to Mabuza *et al.* (2013) and Mbata (2001) who observed significant positive relationship between livestock ownership and choice of ploughing technology.

Finally, Appendix G indicate that the choice of animal traction over hoe in 2011 was significantly explained by distance to farm, years of occupancy of farm, age of household head, rights over farms, land ownership, and disputes compared to farm size, age of household head, rights over land, sex of the household head, and marital status which explained the probability of selecting tractor in place of hoe.

Results on intensity of mechanisation

This section presents results on the effect of farm size on the intensity of mechanisation. Together, these two sections answered the third and fourth objectives of the study. Table 18 presents the results from the Tobit model indicating the factors infleuning the intensity of mechanisation. Diagnostic statistics associated with the results show that hypothesis that the independent variables included in the regression have zero influence on the dependent variable should be rejected. The estimated average prediction of the explanatory variables was 0.141. This implies that the various factors included as regressors in the model explained 14.1 percent of variations in the proportion of farmland cultivated by animal traction.

According to Table 18, age of household head, livestock size, household size, number of hoes, sex of household head, and schooling have no significant influence on the proportion of farmland ploughed by animal traction. However, the results indicate that farm size was a major factor which positively explained the proportion of land ploughed by animal traction. The predicted probabilities associated with the results, show that a standard deviation increase in farm size will increase the proportion of land allocated to animal traction by 12 percent. This means that as farm size increase, the proportion of land cultivated by animal traction also increases. Since large farm size imposes constraints on manual labour, the results emphasise the importance of farm size for mechanisation.

Table 18: *Tobit regression estimates of intensity of mechanisation-Panel*

Variables	Animal_share					Tractor_share				
	Coef.	S.E	dy/dx	+1	+SD	Coef.	S.E	dy/dx	+1	+SD
Farm size	0.0004[b]	0.0002	0.000	0.000	0.120	0.0459[b]	0.0190	0.004	0.004	0.162
Age	-0.0003	0.0003	-0.000	-0.000	-0.005	-0.0002	0.0004	-0.000	-0.000	-0.003
Livestock size	0.0012	0.0008	0.001	0.001	0.008	0.0082[a]	0.0030	0.001	0.001	0.006
Household size	-0.0014	0.0018	-0.001	-0.005	-0.001	-0.0005	0.0022	-0.001	-0.001	-0.002
Loan amount	0.0419[c]	0.02.52	0.000	0.000	0.009	0.0941[a]	0.0306	0.000	0.000	0.021
Number of hoes	-0.0016	0.0019	0.002	0.002	0.005	-0.0003	0.0024	-0.000	-0.000	0.001
Member	0.0869[b]	0.0347	0.140			0.4920[c]	0.2830	0.001		
Male	-0.0146	0.0442	-0.015			-0.0719	0.0536	-0.072		
Married	-0.0457[c]	0.0242	-0.046			0.0913[a]	0.0294	0.091		
School	0.0106	0.0128	0.011			0.0243	0.0155	0.024		
Constant	0.1980[a]	0.0554				0.7770[a]	0.0617			
Log Likelihood	-198.371					-653.172				
LR (χ^2)	18.48[c]					23.73[a]				
Sigma_u	0.055[b]					0.0481[b]				
Sigma_e	0.263[a]					0.318[a]				
N	2361					2361				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.
Source: Author's construct (2018).

The positive and statistically significant coefficient of loan amount shows that respondents who received bigger loans allocated more proportion of their farmland to animal traction. On average, the proportion of land ploughed by animal traction increased by 0.9 percent for every one standard deviation increase in loan amount. Farmers who were members in a social network were more likely to allocate more land to animal traction than those who were not. The probability of allocating more land to animal traction among members of a social network was higher by 14 percent compared to non-members. This underscores the crucial role that social networking plays in the use of animal traction.

Table 18 shows that households headed by married people were less likely to allocate more land to animal traction. The marginal effect value of -0.046 shows that the proportion of land ploughed by animal traction by households headed by married people was about 5 percent (4.6%) less compared to those under the leadership of unmarried people. While marriage sometimes increases the demands on household financial resources and thus decreasing the amount of resources available for investment into improved agricultural methods, it can ensure the production of new members for the family and hence increased availability of man power for farming purposes. This is can reduce the need to invest on labour-replacing ploughing technologies, ceteris paribus.

Turning to results on the proportion of total land ploughed by tractor, Table 18 shows that farm size is a statistically significant and positive predictor. This implies that as farm size rises, the proportion of land ploughed with tractor also rises. This finding is quite understandable because bigger land owners tend to invest in labour-saving agricultural methods due to the increased opportunity cost and time implications of using outmoded ploughing techniques on such farms.

The positive and significant influence of livestock size on the proportion of land ploughed by tractor may be because of the fact that livestock endowment served as a wealth which enabled respondents to raise money to pay for the services of for-hire tractor operation or to engage in barter with tractor owners. This result is consistent with the theoretical propositions that livestock is a form of stored wealth for rural households (Savadogo *et al*., 1998). The result also corroborates the findings by Mottaleb *et al*. (2016). These authors concluded that livestock ownership is effective in influencing the decision to adopt alternative ploughing methods to traditional farm tools by providing a ready source of income for financially distressed households.

Loan amount has a significant positive influence on the proportion of land ploughed by tractor. Access to credit enables farmers to use tractors in preparing their farms for planting more readily as well as paying for other supporting inputs and services such as fuel and repairs on broken parts. Besides affording them the opportunity to easily pay for modern agricultural technology, recipients of credit may also be under intense pressure to adopt high yielding production technology in order to repay borrowed funds and generate income to take care of other household expenses. As it is shown in Table 18, a standard deviation increase in the amount of loan received by the respondents will increase the proportion of land ploughed by tractor by about 2.1 percent.

Other significant determinants of the proportion of land ploughed by tractor revealed by the study were: membership in a social network and marital status. Unlike animal traction where marital status was observed to be have a significant inverse influence, Table 18 shows that marital status affects the proportion of land ploughed by tractor positively. This implies that households headed by people who were married ploughed more proportion of their farmlands by tractor than unmarried respondents.

Results for the individual years reported in Appendix H, I and J show that only loan amount explained variations in the proportion of land ploughed by animal traction in 2009 with only marital status significantly influencing the proportion of land ploughed by animal traction in 2010 whereas farm size and loan amount did so in 2011. It can also be observed from Appendices H, I and J that the significant determinants of the proportion of land ploughed by tractor in 2009 and 2011 were farm size and loan amount with the sex and marital status of the household head doing so in 2010.

Summary

This chapter reported empirical results and discussion of findings on the effect of farm size on choice of ploughing technology. The empirical analyses were guided by the innovation diffusion theory and technology acceptance model with the multinomial probit and Tobit regression methods serving as the estimation techniques. The main focus of the analysis in the chapter was to examine whether or not there is a significant positive relationship between farm size and choice of ploughing technology. It also probed the statistical relationship between total farmland endowment and the proportions of cultivated with animal traction and tractor services. Results revealed that, in line with the hypothesis, plot size had a significant positive impact on the probability of choosing animal traction and tractors over hoe. It was also observed that farm mechanisation proxied by the use of tractors and animal traction adoption was significantly and positively explained by land ownership, access to credit, household size and participation in social network. With respect to the proportion of land ploughed by the two technologies, results from the Tobit regression revealed that the main significant independent variables were farm size, loan amount, livestock size, marital status and membership of social network.

CHAPTER SIX

FARM SIZE AND HOUSEHOLD FOOD SECURITY

Introduction

The aim of this chapter was to examine nature of relationship between farm size and household food security. In particular, the study posited a significant positive relationship between farm size and household food security. In pursuit of this goal, probit regression models were estimated linking farm size and other factors to household food security status. This chapter presents the results and discussion of the empirical estimation.

The chapter is organised into five sections. After this introduction, the next section continues with the descriptive statistics of the households on the basis of their food security status and socioeconomic characteristics. This is followed by findings on the effect of farm size on household food security, holding efficiency and the proportion of total land cultivated by animal traction and tractor constant. The joint effect of farm size and efficiency as well the impact of proportion of total land cultivated by animal traction and tractor on household food security is presented in the third section. The final section summarises the chapter.

Descriptive statistics of variables

This section presents the descriptive statistics of the variables used for the third empirical chapter. From Table 19, it is evident that there is no discernible difference between food secure households and food insecure households in terms of farmland. For example, whereas the mean farm size for food secures households is 20 acres that of food insecure households is 20.04.

This means that farm size does not well differentiate food secure households from those that are not food secure. Moreover, Table 19 shows that standard deviation of farm size was larger than the mean farm size for both groups. This large standard deviation is indicative of the vast heterogeneity in farm size and corroborates the proposition by Chamberlain (2007) that there are sharp disparities in access to land among households in Ghana.

Table 19 also shows that the mean DEA technical efficiency score under the assumption of variable returns to scale achieved by households reporting food secure was higher than that achieved by food insecure households by about 0.03 points, and resonates with the work by Liverpool-Tasie *et al*. (2011) and Saleh and Mustafa (2018) which indicates that agricultural productivity affects household food security directly by increasing available supply of food for consumption and indirectly by increasing the income earning potentials of households.

The results also indicate that households which reported being food secure were headed by older people and also ploughed a slightly higher proportion of their total farmland with tractor than food insecure households. It is further indicated in Table 19 that food secure households cultivated many farm plots than food insecure households. According to Bempomaa (2014), older people have easier access to farmland than younger ones. As a result, households headed by older people are expected to have more access to farmland for food production. It is also widely acknowledged in the literature that, due to their lived experiences, older people are able to take good and well-informed production and consumption decisions, thus their ability to ensure food security for their family members. Moreover, because such inividuals are usually not energetic enough to provide the necessary manpower needed to cultivate their large farms, they tend to rely on new farming technologies that allow them to increase their production and improve the food security of their household members (Ifeoma & Agwu, 2014). The average family size of food secure households was lower than that of food insecure households (Table 19). This implies that food secure households had fewer people to feed, which could possibly serve as an indirect insurance against food shortages and competition over available food resources.

The mean livestock owned by food secure households was about 4.0 (3.976) tropical units and the maximum was 115.75 compared to 2.8 (2.796) and 56.5 respectively by food insecure households. On the basis of health shocks, Table 19 shows that food secure households recorded fewer days of illness than food insecure households. Specifically, the results indicate that the average number of illness days experienced by food insecure households exceeded those experienced by food secure households by about 9 days. Meanwhile, Table 19 shows that food secure households received more loan than food secure households. This could imply that the loans accessed by the former were misapplied or used for seeking medical treatment instead of being invested in directly productive agricultural production.

Information on fertiliser adoption suggests that a significantly high proportion of food secure households adopted fertiliser compared to food insecure households. According to the results, 68.52 percent of food secure households adopted fertiliser compared to 62.17 percent of food insecure households. The distribution of the households on the basis of access to electricity also revealed that most food secure households were connected to electricity than were food insecure households. Specifically, Table 19 reveals that whereas 58.72 percent of all households recognised to be food secure did not have access to electricity, 65.49 percent of food insecure households did not have access to electricity.

Table 19: *Descriptive statistics of variables for food security analysis*

Variable	Food secure		Food insecure	
	M	SD	M	SD
Farm size	20.00	25.19	20.04	22.52
Age	45.912	26.872	44.878	15.05
DEA_VRTS	0.747	0.108	0.721	0.11
Tractor_share	0.791	0.311	0.715	0.370
Animal_Share	0.135	0.262	0.167	0.296
Number of plots	2.527	1.130	2.042	0.558
Household size	7.479	3.466	7.558	3.313
Livestock size	3.976	7.162	2.796	4.089
Health shocks	31.455	102.33	40.54	65.28
Loan amount	122.35	223.85	123.88	207.3
Married	93.58		93.09	
School	96.16		41.79	

Source: Author’s construct (2018).

The dataset also showed that 93.58 percent of food insecure households were headed by married people compared to 93.09 percent of food secure households. Data on the educational attainment of household heads showed that food secure households were mostly headed by people who ever attended school compared to food insecure households. However, less than a third of both categories of households were headed by literate people.

Effect of farm size on household food security

This section presents the results on the effect of farm size on household food security. Apart from sociodemographic characteristics which were included as covariates, technical efficiency (DEA_VRTS) as well as ploughing technology did not feature in the regression equations. The estimated econometric results of this first-level analysis reported in Table 20 show that six explanatory variables are statistically significant. Moreover, diagnostic statistics associated with the results such as the Log Likelihood and Pseudo R-squared indicate that the models are within the thresholds of correctly specified and fitted models. It should be stressed once more that emphasis is on results for the panel though attempt is made to explain results of individual years.

First, Table 20 shows that the study's null hypothesis of no significant positive relationship between farm size and household food security cannot be rejected. Contrary to the hypothesised positive relationship between farm size and food security, the results show that farm size has a negative impact on household food security. Moreover, the estimated coefficient of farm size shows that this variable does not significantly differentiate food insecure households from those who did not experience food insecurity.

It is however evident from Table 20 that the coefficient of number of plots is significant and positive, which suggests that households that cultivated more plots were more likely to be food secure compared to those with fewer plots. According to Table 20, a standard deviation increase in the number of plots under cultivation will lead to about 4.3 percent increase in the probability of being food secure, if all other factors are held constant. Therefore, it can be argued that the greater number of plots that a household has and uses for crop cultivation, the higher the probability that it will not experience food insecurity. This could be attributed to the ability of households with multiple plots to produce different varieties of food crops, thus making it possible for their members to have assured access to diversified diets and adequate food throughout the year.

Having dispersed farm plots has been found to be a risk management mechanism which gives farm households the opportunity to withstand sudden weather shocks through the use of multiple agro-climates and soils (Blarel, Hazell, Place, & Quiggin, 1992). More number of farm plots can also facilitate food diversity by making it possible for agricultural households to grow different varieties of crops that mature at different times of the year, so that they can pay attention to different plots at different times, thereby avoiding household labour constraints and micro-nutrient deficiencies. These practices are a way of hedging against risks of drought, irregular temperatures, and rainfall variability, which have been identified as significant obstacles to agricultural production and food availability in low-income economies (Dasmani, 2015).

Households who hold all their farmlands as a single contiguous piece may not enjoy the opportunities associated with risk diversification and hence may not be able to withstand crop failure linked to localised environmental problems. Because land fragmentation enables farmers to disperse and reduce risk by using a variety of soils and other environmental variations, farmers can increase their resilience to food insecurity. Farm dispersing can also facilitate food diversity by promoting the cultivation of different food crops, thus increasing households' ability to produce and consume different food varieties and hence food security. This finding corroborates the results of Ciaian, Guri, Rajcaniova, Drabik and Paloma (2015) and Musambayi (2013) who found strong positive relationship between number of farm plots and household food security, and argued that land fragmentation contributes to household food security by fostering crop diversification and increasing the variety of food produced and consumed by peasant households.

Household size is another significant factor affecting food security. Table 20 shows that households that are composed of many members were less likely to be food secure. The estimated marginal effects of household size indicate that increasing household size by one extra member reduces the probability of being food secure by a factor of 0.016. Moreover, Table 20 shows that a standard deviation increase in household size decreases food security by a factor of 5.6 percent. A higher household size signifies a greater number of people to feed and hence the likelihood of experiencing food insecurity. This is more likely to be the case when most of these members are either too young or too old to work for themselves thus leading to a high dependency ratio and competition over scarce food resources. For example, it has been widely documented that in a system where households depend on less productive and heavily contested agricultural land, increasing household size results in increased pressure on land resources and demand for food (Kendie, 2002; Kendie & Enu-Kwesi, 2011). If these demands are not matched with existing food supply from own cultivation, the possibility of being food secure is severely hampered (Ali & Khan, 2013).

As a region with one of the highest dependency ratios in the country (GSS, 2013a), it is not surprising to establish a significant negative relationship between household size and food security. These findings conform to literature. For example, Tefera and Tefera (2014) reported that increase in household size by one person increases the odds of being food insecure by about 0.4 percent points. Kabunga, Dubois and Qaim (2014) and

Sekhampu (2013) also found significant negative relationship between various indicators of food security and household size, and argued that larger household sizes require increase food expenditure and competition over limited food resources. From the tenets of the intra-household resource allocation theory, if the number of members within a household exceeds carrying capacity with respect to food availability, discrimination against vulnerable and less favoured family members becomes highly probable. This leads to food insecurity (Quisumbing & Smith, 2007).

It was also revealed that livestock size has a significant positive influence on household food security. The positive coefficient of livestock size implies that food security increases as the tropical livestock units attained by the household increases. The estimated marginal effect value of 0.025 shows that the probability in favour of household food security will increase by about 3 percent for each additional unit of livestock owned. This finding agrees with the theory underlying household production and consumption behaviour which argues that hunger and starvation are a function of assets which can either be directly consumed as food or exchanged for food through other means (Sen, 1981).

Generally, livestock ownership contributes to household food security through a variety of channels such as by providing cash income through direct sale of animal products (meat and manure) and indirectly through the hiring out of draft power. They are also an important form of stored wealth and a cushion against starvation when food from own production is scarce and hence can act as an insurance against food insecurity. Moreover, livestock are an important source of manpower for agricultural households in northern

Ghana. For example, literature shows that the number of oxen owned by a household is an important substitute for human labour in most farm works and can have a direct impact on the quality of life by reducing drudgery and calorie requirements by household members (Hesse, 1997; Houssou, Kolavalli, Bobobee, & Owusu, 2013; Panin, 1986; Panin & de Haen, 1989).

The significant and positive relationship between livestock size and household food security reported in the present study is consistent with studies by Kaur, Graham, and Eisenberg (2017) and Kidane *et al*. (2005) which also identified the protective effect of livestock ownership on household food security and stunting. Moreover, Ali and Khan (2013) reports that livestock ownership contributes to increased food production, and suggested that animal traction facilitated by oxen ownership is important for improving household food security because it gives farmers the capacity to expand production by reducing labour bottlenecks during land preparation. In addition, the number of different livestock types owned by households can facilitate income generation by fostering direct marketing of life animals and animal products, all of which can prove vital for wealth accumulation and food availability.

The coefficient of health shock was negative and statistically significant at the one percent level of probability. This implied that households that experienced more number of illness days during the farming season were more likely to experience food insecurity compared to those who experienced little or no illness days. From the estimated coefficient, the likelihood of a household being food secure falls by 0.1 percent for every additional day of illness experienced during the farming season. In addition, the results indicate that a standard deviation increase in health shocks will cause household food security to decrease by a factor of 0.065.

Health status is a significant determinant of food security because it affects agricultural production as well as participation in off-farm activities. Directly, ill-health affects physical strength and the number of active days available for work. Since productivity in most traditional agriculture, including Ghana, depends on physical strength and stamina, it is more probable that poor health can increase the risk of crop failure and food insecurity. The rationale is that poor health itself can create competing demands on time allocated to farming and in seeking care. It can also deprive agricultural households of valuable productive assets including cultivable land, livestock, and even standing field crops. The consequence of this includes reduction in food production, weakened earning abilities and higher odds of food shortages. According to Huang, Guo and Kim (2010), people with disabilities are more vulnerable to food insecurity than their counterparts without disabilities. Hesselberg and Yaro (2006) and Nolan, Rikard-Bell, Mohsin and Williams (2006) also found that the health condition of the household head significantly contributed to measured household food insecurity.

Another variable which was found to have a significant positive impact on household food security was the use of fertiliser. The coefficient of the variable adopter is statistically significant. This implies that fertiliser adoption well differentiated households who were food secure from those who were not. The positive coefficient of this variable implies that households which used fertiliser on their farms achieved food security compared to those who did not. The estimated marginal effect of adopter of 0.154 implies that household who adopted fertiliser were about 15.4 percent more likely to be food secure compared to those who did not adopt fertiliser. The reason why fertiliser adoption had a significant impact on household food security could be that it enabled the sampled households that adopted it to increase the amount of food they grew thereby increasing the amount of food resources available for consumption purposes.

Table 20: *Estimated results of factors affecting household food security-Panel*

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0010	0.0010	-0.002	-0.002	-0.037
Number of plots	0.1660[a]	0.0250	0.001	0.001	0.186
Age	-0.0010	0.0010	-0.001	-0.001	-0.011
Household size	-0.0160[c]	0.0080	-0.000	-0.000	-0.006
Livestock size	0.0240[a]	0.0070	0.005	0.005	0.167
Health shocks	-0.0010[a]	0.00370	-0.001	-0.001	-0.065
Access to credit	-0.2010[a]	0.0530	-0.123		
Adopter	0.1840[a]	0.0690	0.154		
Connected	0.2270[a]	0.0550	0.107		
Male	0.1270	0.1210	0.002		
Married	-0.5720[c]	0.2980	-0.129		
School	0.0180	0.0610	0.014		
Constant	0.3990[a]	0.1470			
Log Likelihood	-1494.712				
Wald (χ^2)	104.96[a]				
lnsig2u	-5.513[a]				
N	2361				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.
Source: Author’s construct (2018).

The findings with respect to fertiliser adoption imply that encouraging fertiliser use among small-scale farmers could go a long way to improve household food security. Evidence based on other empirical studies shows that fertilize use improves crop yields and increases the total level of agricultural productivity which in turn helps to increase farm income and food security.

Specifically, Diao and Sarpong (2007) observed that soil fertility depletion is one of the main biophysical root causes of per capita food production decline in Ghana, and called for the intensification of soil fertility improvement practices including chemical fertiliser adoption. Moreover, Asmah (2011) shows that households residing in communities with access to fertiliser and supporting public infrastructure such as transport and local produce markets were more likely to engage in off-farm activities to have and enjoy improved welfare compared to households in communities without such opportunities. In addition, Nata, Mjelde and Boadu (2014) found significant positive relationship between fertiliser use and food security among smallholder farm households in the Greater Accra Region, and suggested that fertiliser adoption enabled smallholder farmers to increase crop production and food availability for household consumption. The finding is also in agreement with Beyene and Muche (2010) who found significant positive relationship between fertiliser adoption and household food security.

Very unexpectedly, the results show that access to credit had a significant negative impact on household food security. Specifically, Table 20 indicates that households which received credit were 12.3 percent more likely to experience food insecurity compared to those who did not receive credit. Though the result is contrary to expectation, it is in line with the study by Wiranthi, Suwarsinah and Adhi (2014) which also found significant inverse relationship between access to credit and household food security. A plausible explanation which could offered in support of this finding could be that households which had access to credit did not use it wisely, hence fell into debts and consequently had to sell valuable assets which could otherwise have been used to purchase food to feed the family.

It is a widely documented that farmers often misdirect credit and thus do not realise the full impact on their productivity and for that matter their livelihood. For instance, Reddy (1990) advanced that diversion is one of the ubiquitous features of farm credit in many countries. According to Reddy, many farmers treat loans as if it is just any ordinary production input, ignoring the fact that a unit of borrowed money is identical to other units of money held by the borrower. Reddy notes further that credit diversion occurs even in well-administered situations. Moreover, even when loans are disbursed in kind such as bags of fertiliser or sachets of agrochemicals, they are often sold into cash and then diverted. Danso-Abbeam, Cobbina and Antwi (2016) have similarly highlighted significant difference between the amount of credit accessed by farm households and the amount of received credit allocated to actual production.

Rather than being a drag on household financial resources and thus causing food insecurity, the estimated results show that access to electricity had significant positive impact on observed household food security status. Specifically, the results show that households which were connected to electricity were more likely to be food secure compared to those without access to electricity. A plausible explanation could be that households connected to electricity were able to use it to increase food availability by engaging in off-farm activities which provides income to supplement output from farm production. This finding is similar to those of Wiranthi *et al*. (2014) and Faridi and Wadood (2010) who found that access to electricity positively influenced food security among households in Indonesia and Bangladesh respectively. It is also similar to Adu *et al*. (2018) who found that a significant positive relationship between access to electricity and the probability of owning a non-agricultural enterprise and the income from non-agricultural enterprises among households in rural areas of Ghana, and suggested that establishment and operation of non-agricultural enterprises constitute an important channel through which rural electrification affect the economic outcomes (income and welfare) of rural households in the country.

The results also revealed that households in which the head is not married had higher odds of being food insecure compared to those with married people as their heads. From Table 20, it is evident that having a household head that is unmarried is associated with about 13 percent increase in the likelihood of being food insecure. Marital status affects a number of socioeconomic outcomes including assess to farm land and critical inputs that can influence food production and food utilisation, with married people standing a better chance compared to their unmarried counterparts. Thus, having a household head that is not married can lead to food insecurity. However, both Mensah *et al.* (2013) and Sekhampu (2013) found that households headed by unmarried people were more food secure compared to those headed by the married. In particular, Mensah *et al*. emphasised that residing in a household in which the head was unmarried translated to about 5 percent increase in the probability of being food secure.

On a year-by-year basis, Appendices K and L indicate that there was significant relationship between number of plots, livestock size, health shocks, fertiliser adoption and household food security in 2009; and between number of plots, livestock size, fertiliser adoption, electricity connectivity, access to credit and food security in 2010 respectively. Moreover, Appendix M reveals significant relationship between household food security in 2011 and number of plots, age of household head, access to credit, electricity connection, and sex of household head. With respect to predicted probabilities, it can be observed from Appendix K that among the significant factors in 2009, number of plots had the highest marginal effects followed by fertiliser adoption. On the other hand, a standard deviation increase in livestock size had the highest factor change on household food security in 2010 followed by number of plots (Appendix L). Similarly, the results show that access to electricity had the highest marginal effect on household food security in 2011 (Appendix M).

Effect of efficiency and ploughing technology on household food security

The previous section presented results on the effect of farm size on household food security with other socioeconomic variables as covariates without accounting for the role of technical efficiency and ploughing technology in this relationship. It did not also test for the effect of interaction between farm size and technical efficiency. These omissions are addressed in this section by testing the joint effect of farm size and efficiency on household food security.

Appendix N presents estimated results of the regression model with household food security status as the dependent variable and the interaction between farm size and technical efficiency as an additional explanatory variable. This factor was included to test whether technical efficiency moderates the relationship between farm size and household food security. As is evident from Appendix N, most of the explanatory variables (including farm size itself) which were initially insignificant still remained insignificant, despite a significantly high proportion of the variations in the dependent variable being explained as reflected by the relatively high Pseudo R-squared values.

Moreover, the coefficient of the interaction term is positive, signalling the potential moderating effect of technical efficiency on the relationship between farm size and household food security. However, given that statistical significance of variables of this nature are not determined by resorting to the estimated parameters associated with the regression output (Hill, Griffiths, Judge, & Reiman, 2001; Wooldridge, 2010), the *testparm* command in Stata was employed to test the joint significance of the interaction between farm size and technical efficiency. Results of this procedure, displayed at the tail end of Appendix N shows that the null hypothesis of no interaction cannot be rejected. More specifically, with a probability value greater than the minimum acceptable level in all models ($P \leq 0.10$), the null hypothesis that the coefficient of the interaction between farm size and technical efficiency is equal to zero was not rejected. This implies that a model which does not include the interaction term is the most preferred model. Consequently, the interaction term was dropped from the regression.

Having established through formal econometric procedures (the *testparm* command in Stata) that the interaction between farm size and technical efficiency is not statistically different from zero, this variable was dropped and the regression model re-estimated. Results of the re-estimated model as shown in Table 21 indicate that technical efficiency, proportion of land ploughed by tractor (Tractor_share), proportion of land ploughed by animal traction (Animal_share), number of plots, livestock size and access to electricity were the significant determinants of the food security status of the sampled households. In line with previous section, model fit indices associated with the results in this section, such as the Log-Likelihood, Wald chi-square and average predictions, are within good statistical estimates, indicating that the models are fit for explaining the effects of the various factors on the probability of household food security. For example, the average marginal effect value of 1.619 depicts that there is 161.9 percent assurance of the probability that a household randomly selected will be food secure and correctly predicted by the empirical model.

Table 21: *Effect of farm size, efficiency and mechanisation on household food security- Panel*

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0025	0.0023	-0.003	-0.003	-0.064
DEA_VRTS	2.5810[a]	0.5520	2.581	2.581	0.279
Tractor_share	1.0360[a]	0.2310	1.036	1.036	0.336
Animal_Share	0.5000[c]	0.2840	0.500	0.500	0.135
Number of plots	0.5730[a]	0.0655	0.573	0.573	0.609
Health shocks	-0.0470[a]	0.0157	-0.024	-0.024	-0.066
Adopter	0.2560[b]	0.1150	0.256		
Connected	0.3160[a]	0.1170	0.316		
Constant	-2.8180[a]	0.6890			
Log Likelihood	-1066.081				
Wald (χ^2)	141.18[a]				
lnsig2u	-4.817[b]				
N	2361				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.
Source: Author's construct (2018).

As can be observed from Table 21, the positive and highly significant coefficient of the variable DEA_VRTS signifies that technical efficiency affects household food security status. The results suggest that households with higher technical efficiency scores were more likely to be food secure compared to technically inefficient households. The predicted probabilities shown in Table 29 indicate that a standard deviation increase in DEA_VRTS technical efficiency will lead to about 28 percent increase in the likelihood of a household being food secure. This means that the higher the technical efficiency score, the more likely that the household would be food secure. The study's finding of a significant positive relationship between technical efficiency and household food security resonates well with both the theoretical proposition (Liverpool-Tasie *et al*., 2010) and empirical validation that higher agricultural productivity contributes positively to household food security via food supply availability and improved earnings (Saleh & Mustafa, 2018).

The proportion of farmland ploughed by tractor also had a positive and statistically significant coefficient at one percent probability level. This implies that households who used tractors to plough large proportions of their farmland achieved more food security compared to those who did not undertake such an investment. From Table 29, the predicted probability associated with a standard deviation increase in the proportion of farmland ploughed by tractor of 0.336 means that the likelihood of a household being food secure will go up by about 34 percent if it increased the share of farmland ploughed with tractor by one standard deviation. The proportion of farmland ploughed by animal traction (Animal_share) also had had a positive and significant coefficient at 10 percent level of probability. The marginal effect value of 0.50 suggests that if the proportion of farmland ploughed by animal traction is increased by doubled, the likelihood of households being food secure will be increased by 50 percent. This indicates that the higher the proportion of total farmland ploughed by animal traction the higher the probability of being food secure.

Similarly, the results of the study revealed that even if technical efficiency and ploughing technology are accounted for, risk diversification through the cultivation of more number of farm plots will still continue to play a major role in household food security status. With a positive and highly significant coefficient, Table 21 shows that there is a strong positive relationship between number of farm plots and household food security status. According to Table 29, a one percent increase in the number of plots put to use will be associated with about 5.73 percent increase in the probability of being food secure.

Another interesting finding of the study relates to the effect of health shocks. The negative and highly significant coefficient of health shocks signifies that while technology and technical efficiency and improved agricultural methods are important for household food security, human capital sustained by good health is equally critical for household food security. The result re-affirms the conclusion reached in the previous section, by suggesting that health shocks lead to a reduction in the probability of being food secure. This finding may not be a surprising one at all because for most smallholder agricultural households, operating in unstable climatic conditions and with unreliable income flows, good health is highly indispensable for ensuring the stability of the household economy as well as active participation in agricultural production. Thus, any threats to stable health could worsen the condition for effective participation in production.

In addition, the results also show that fertiliser adoption and access to electricity contributed to explaining variations in household food security even in the presence of efficiency and ploughing technology. Specifically, Table 29 shows that households that adopted fertiliser were about 26 percent (25.6%) more probable to be food secured compared to households which did not use fertiliser whereas households connected to electricity were 31.6 percent more likely to be food secure relative to those who do not have access to electricity.

On a yearly basis, Appendix O indicates that the factors which significantly explained variations in household food security status in 2009 were: technical efficiency, proportion of land ploughed by tractor, number of farm plots, and loan amount. In addition, Appendix P shows that technical efficiency, proportion of land ploughed by tractor, number of plots, health shocks and access to electricity differentiated households which were food secure in 2010 from those that were not. Moreover, Appendix Q reveals that there was significant relationship between household food security status and technical efficiency, proportion of farmland ploughed by tractor, proportion of farmland cultivated by animal traction, number of plots, and access to electricity in 2011.

Summary

This chapter examined the effect of farm size, efficiency and ploughing technology on household food security status. The main hypotheses tested were whether or not: (1) there is a significant positive relationship between farm size and household food security, and (2) technical efficiency moderate the relationship between farm size and household food security. Using the agricultural household model as the theoretical underpinning and the logit estimation technique, it was established that the null hypotheses that farm size does not significantly influence household food security and that the interaction between farm size and technical efficiency has no material influence on household food security were both supported. However, number of farm plots positively and significantly explained variations in household food security. The results also show that fertiliser adoption, household size, health shocks, access to electricity, technical efficiency and livestock ownership well differentiated households that were food secure from those that were not food secure.

CHAPTER SEVEN

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

Agriculture is one of the important sectors of the economy of Ghana. Despite a decline in the contribution of agriculture to the country's Gross Domestic Product in recent times, hopes still remain high that the agricultural sector is critical for the socioeconomic development of the country through the creation of jobs and provision of cheap raw materials for agro-industries and food for household consumption. This is manifested in a renewed vigour behind a national agricultural programme dubbed 'Planting for food and Jobs'. Unfortunately, agricultural production in Ghana has always been carried out by smallholder farmers using traditional farm tools and equipment. Consequently, food production has not kept pace with population growth, thus resulting in food insecurity for 2.1 million people, the majority of whom reside in the northern parts of the country.

Recognising the contributions that maize production can make to household food security and sustainable land use practices, successive governments have focused on developing new planting materials that will make it possible to increase the production of this crop with no further land degradation. In spite of the availability and widespread adoption of these new varieties, maize production in many parts of the country continues to lag behind achievable levels by about 72 percent. This suggests that there could be considerable inefficiencies among maize producers in the country and hence the need for more nuanced empirical studies to identify the factors accounting for the variations in efficiency and the extent of mechanisation among maize growing households.

Summary

Three empirical chapters were covered in this study. The first empirical chapter presented and discussed results on the effect of farm size on technical and scale efficiencies. It tested two main hypotheses: (1) there is a significant positive relationship between farm size and technical efficiency in maize production, and (2) there is a significant positive relationship between farm size and scale efficiency in maize production. These hypotheses were formulated and tested to contribute to the raging and inconclusive debate on the relationship between the size of agricultural land holding and technical performance. Additionally, the analysis provided insights into the extent and predictors of resource use efficiency among maize farmers in the Northern Region utilising both cross-sectional and panel data estimation procedures. This chapter employed both the stochastic frontier analysis with translog functional form and data envelopment analysis to estimate and investigate the relationship between farm size and resource use efficiency. Based on a comprehensive review of existing literature, a wide range of demographic and socioeconomic indicators were included as control variables in the various efficiency functions.

The comparison between the bivariate analaysis of farm size on technical and scale efficiencies in this chapter and the multivariate analysis which included farm size and other factors provided further understanding of the link between farm size and resource use efficiency. The effect of the two sets of analyses demonstrate the fact that farm size has a direct effect on resource use efficiency but also an indirect effect through other factors.

The second empirical chapter provided results and discussions on the relationship between farm size and choice of ploughing technology. The main hypothesis tested in this chapter was to examine whether or not there is a significant positive relationship between farm size and the choice of ploughing technology. Three types of ploughing technologies were modelled. These are: hoe, animal traction and tractor services. In line with calls for reduction in the use of manual farming technologies, hoe was used as the base category. To achieve the objective spelt out in the chapter, the study employed multinomial regression techniques to investigate the relationship between farm size and the decision to choose animal traction or tractor over hoe in preparing maize farms for planting and other on-farm operations. Two levels of analysis were implemented in this chapter. First, a multinomial regression model with hoe as the base category was estimated to examine the relationship between plot size and choice of ploughing technology using plot-level dataset.

After examining the relationship between farm size and choice of ploughing technology at the plot level, the study moved to the second level of analysis by examining the relationship between total farm size and intensity of mechanisation. One model each for the proportion of land cultivated by animal traction and tractor were estimated by normalising the sum of all plots ploughed by animal traction and tractor by total farm size, such that the endogenous allocations to individual categories were in the form of percentages. Given the presence of a significant number of zero observations in the dependent variable in this instance, I used the Tobit regression model that made it possible to account for the censored nature of the dataset. Explanatory variables in the model included total farm size as one of the independent variables and other demographic and socioeconomic factors as covariates. Results from both approaches revealed a strong positive relationship between farm size and the adoption of modern ploughing techniques, thus confirming the study's alternative hypothesis of a positive link between size of agricultural land holdings and choice of ploughing technology.

The third empirical chapter examined the effect of farm size on household food security. Since the dependent variable considered for the analysis in this chapter was a binary outcome; resulting in a linear probability model which precludes the use of OLS regression, I applied the logit and xtlogit models for individual and panel estimations respectively. The analysis in this chapter also considered the interaction between farm size and technical efficiency. Results show that there is a positive, albeit insignificant relationship between farm size and household food security whereas the interaction between farm size and technical did pass first-level econometric test for inclusion as an explanatory factor.

Conclusions

This thesis investigated the extent and determinants of technical and scale efficiencies among maize growing households in three districts of the Northern Region of Ghana by combining parametric and non-parametric estimation techniques and a three-year balanced panel data on 787 households. In the empirical estimation on determinants, both bivariate and multivariate models were considered and observed patterns discussed in relation to existing theoretical positions and empirical research. Employing data on the same sample, the study also examined the effect of plot size on the choice of ploughing technology at the plot-level using multinomial regression model with hoe as the reference category and the effect of total farmland endowment on the proportion of land ploughed by animal traction and by tractor using the Tobit regression technique. With the same data, the study also examined the effect of farm size on household food security status. The results revealed that there were considerable variations in technical and scale efficiencies as well as the choice of ploughing technology and food security among the respondents studied.

Following from the exposition on the individual empirical chapters, it is concluded that three out of the four hypotheses formulated and tested by the study were supported by the empirical estimations. First, the hypothesis that there is a significant positive relationship between farm size and technical efficiency was supported based on results from both the SFA and DEA estimations. In addition, the hypothesised positive relationship between farm size and scale efficiency was established. Similarly, the hypothesis that there was a significant positive relationship between farm size and choice of ploughing technology was also supported. However, the study failed to reject the null hypothesis of no significant positive relationship between farm size and household food security. In addition, the studies also tested for the existence of a significant positive relationship between land ownership security and ploughing technology, and found that most of the proxies included for this variable had the expected signs and were statistically significant.

Recommendations

In order to improve the resource use efficiency of maize producers and increase the adoption of improved agricultural methods as well as ensure household food security in the sampled districts used for the study, the following recommendations are put forward:

Land consolidation and conflict prevention

As much as is practicable, we suggest that efforts should be put in place to facilitate farm size growth through the encouragement of farmland consolidation since this is the only safest channel through which households can be assisted to have access to farmlands of appreciable sizes to benefit from the economic and technological gains associated with large-scale agriculture. This recommendation steams from the significant positive link established between farm size and efficiency as well as choice of ploughing technology and negative association between land disputes and adoption of mechanised ploughing.

One of the ways to implement a farmland consolidation policy that is likely to be accepted and supported by the majority of households in the sampled districts would be to provide alternative non-farm jobs in which households with smaller farms can be engaged in order to entice them to release their lands to bigger farm operators. Alternatively, policy makers can develop contract farming schemes in which several households with smaller farms are be brought together under one umbrella and affiliated to nucleus farmers. This strategy has been proven successful among smallholder farmers in other countries and hence may also succeed among maize farmers in the Northern Region of Ghana. What is required is to learn from existing best practices and modalities in order to gain the confidence and support of maize producers while guarding against the negative effects of land consolidation including appropriation by more successful households, few elites and politicians.

Given the significant negative relationship between land disputes and farm mechanisation, investment in land disputes prevention and early detection will also be a worthwhile venture. Investing in land disputes prevention and timely resolution can also go a long way to encourage farm mechanisation and contribute to household food security through improvement in food production and availability. The Ministry of Food and Agriculture, Ministry of Lands and Natural Resources, and Ministry of Local Government and Rural Development in collaboration with the National Commission for Civic Education and traditional authorities in the selected districts can play an active role in this effort by constantly engaging with households in the selected communities about the need to use peaceful means in settling land issues. Award schemes could be instituted to reward documented instances of peaceful land dispute resolution mechanisms. Effective monitoring systems should also be put in place to pick up early signs of potential land disputes.

Increase fertiliser adoption

Considering the significant positive relationship between fertiliser adoption and household food security, it is strongly advised that maize growing households should be encouraged and supported to use fertiliser on their farms. One channel through which this can be achieved is to make it possible for these households to have access to fertiliser in a timely manner. With this, there is the need for stakeholders in the country's fertiliser industry to put in measures which will ensure that agricultural households in the sampled district have unimpeded access to fertiliser. Management need to modify existing campaigns by highlighting the benefits of fertiliser adoption in a manner that attract the attention of maize farmers. In particular, efforts should be implemented to educate farmers on the need to support the country's fertiliser programme by bringing issues militating against it to the attention of authorities and through their voluntary contributions.

Livestock production and oxen availability

A significant positive relationship was established between livestock ownership and most of the issues investigated. Thus, I propose that livestock production in the selected districts should be enhanced. To begin with, livestock ownership must be encouraged through improved access to credit and veterinary services in order to increase not only the number of livestock that households can possess but the traction power of existing animals used for draft ploughing. The Animal Division of the Ministry of Food and Agriculture and affiliate institutions with technical competencies in livestock breeding and genetics should develop livestock with high disease tolerance and traction power potential for use by farmers in the sampled areas. This will make it possible for households to increase maize production and food security among their members through the benefits offered by more resilient domestic livestock production such as manure and non-farm income. It will also play a fundamental role by directly increasing animal traction adoption as an intermediate farm mechanisation approach and indirectly increasing the utilisation of tractor services by making income available to engage the services of for-hire-tractor operators in cases where maize farm households cannot afford to buy their own tractors.

Good road network

Given the significant inverse relationship between the distance to farm and adoption of animal traction, there is the need for active government intervention through the relevant sector ministries such as the Ministry of Roads and Highways as well as the Ministry of Local Government and Rural Development towards the rehabilitation and construction of motorable feeder roads linking major maize growing areas in the sampled districts. This will reduce the amount of time and energy required to move oxen and tractors to maize farms. It will also enable maize growing households to conveniently move working animals and other implements to their farms without much difficulty. In addition, such a transportation system will facilitate early arrival to their farms in order to reduce the amount of time and energy lost as a result of travelling on bad roads and encourage the adoption of animal traction for ploughing.

Acess to credit

Because the study established significant positive relation between the amount of credit received by households and efficiency as well as farm mechanisation, policies that increase access to credit must be encouraged. Considering the fact that most of the households considered in the study are smallholders and hence may be in a better in a position to provide the kinds of collaterals that financial institutions usually require for large sums of loans, the active participation of more able institutions will be required before this goal can be achieved.

One way through which this can be done is for government to offer incentives to financial institutions operating in the affected districts in the form of concessionaries loan for on-ward lending to farmers at reduced interest rates and tax rebates for financial institutions that risk with their own capital. Indirectly, government can also offer non-cash assistance in the form of subsidies on inputs to farmers in order to reduce the difficulties that agricultural households of the type used in this thesis usually go through in trying to access farm inputs.

Encouragement of social networking

As membership in social network plays an important role in ensuring the choice of alternative ploughing methods to traditional farm tools, policies should be put in place to encourage and improve upon social networking among maize producing households. Also, because community based organisations are important avenues through which farmers get to know the significance and proper use of fertiliser and other agrochemicals for increased food production, they could be critical in increasing household food security. Consequently, public campaign on the importance of social networking and participation in community-based associations by representatives of the Ministry of Food and Agriculture in the selected districts used for the study is proposed. This will increase interest in social networking among maize farmers and increase the spread of information about the benefits of adoption of animal traction and tractor services. Agricultural extension officers in the chosen areas should include social networking building among farmers as part of their extension service delivery strategies.

Adult numeracy education

Considering the importance of numeracy competence to agricultural labour productivity, which was at least partially supported by the positive and highly significant bivariate relationship between numeracy and DEA technical efficiency (CRTS) in year 2010, it is strongly suggested that household heads and other adults likely to be heads of their households in future should be encouraged and supported to improve upon their numeracy skills. There are a number of options through which this can be achieved. But the one which appears to be more practicable and cost-effective is the intensification of adult numeracy education in the various districts. The Ministry of Education through its relevant sector agencies such as the Ghana Education Services should develop and deploy effective adult numeracy education programmes for agricultural households in the study area. Alternatively, they can provide funding and other incentive packages to institutions with more technical competencies in this regard.

Suggestions for further research

This study did not investigate all the variables identified in the literature as potential determinants of efficiency, ploughing technology and household food security. Typical examples of such variables with respect to the efficiency analysis include soil quality and application of organic manure. In relation to the ploughing technology, information on taste and preference and cost were unavailable. Similarly, the study lacked information on the actual calorie intake and dietary diversity to adequately capture the true constraints and difficulties that smallholder households go through in accessing and utilising food. Thus, future studies should endeavour to use quantitative measures of the variables which have been identified as lacking in this study.

Further, the study used secondary dataset. Since the data was not collected with the primary goal of addressing this research, and in particular because the data was not collected by the research himself, a number of issues regarding data measurement and approximations remain unresolved and contentious. Future studies should endeavor to address this limitation. In addition, an extended panel dataset covering maize farmers in all the districts of the region should be employed to allow for comparison of results scores across districts. Efficiency analysis using panel data should also be conducted on other crops, given that the nature of information available to this study did not permit the investigation of other crops besides maize. Finally, additional testing of the study's findings using dataset on households in other regions of the country woulb be very interesting and insightful.

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APPENDICES

A: Bivariate analysis of factors affecting SFA efficiency

Variables	2009	2010	2011	Panel
Farm size	0.0001	-0.0752	-0.0005	0.0001
	(0.0002)	(0.3000)	(0.0007)	(0.0002)
Loan	-0.0956	0.0282	0.0987	0.0352[b]
	(0.2700)	(0.0199)	(0.3140)	(0.0148)
Size *Loan	-0.0131	-0.0562	-0.0107	0.0666
	(0.0148)	(0.9020)	(0.0319)	(0.0815)
Age	-0.0011[a]	-0.0007[b]	-0.0006	-0.0008[a]
	(0.0003)	(0.0003)	(0.0004)	(0.0002)
School	-0.0163	-0.0037	-0.0112	-0.0104
	(0.0127)	(0.0110)	(0.0141)	(0.0074)
Read	-0.0277[b]	-0.0037	-0.0017	-0.0110
	(0.0131)	(0.0114)	(0.0145)	(0.0076)
Num.	-0.0317[b]	0.0121	-0.0084	-0.0093
	(0.0144)	(0.0125)	(0.0160)	(0.0084)
School*Read	-0.0265[c]	0.0054	-0.0037	-0.0082
	(0.0153)	(0.0133)	(0.0170)	(0.0089)
School* Num.	-0.0286[c]	0.0166	-0.0050	-0.0056
	(0.0154)	(0.0134)	(0.0171)	(0.0090)
Livestock	0.0042[a]	0.0031[a]	0.0043[a]	0.0040[a]
	(0.0008)	(0.0007)	(0.0009)	(0.0004)
Hsize	0.0041[b]	0.0023	0.0019	0.0022[b]
	(0.0016)	(0.0014)	(0.0017)	(0.0009)
Hoes	0.0018	0.0021	0.0064[a]	0.0038[a]
	(0.0018)	(0.0015)	(0.0019)	(0.0010)
N	787	787	787	2361

Standard errors in parentheses, [a] p<0.01, [b] p<0.05, and [c] p<0.10.

B: Bivariate analysis of factors affecting DEA efficiency (VRTS)

Variables	2009	2010	2011	Panel
Farm size	0.0749	-0.0008[a]	-0.0029[a]	-0.0004[a]
	(0.2000)	(0.0003)	(0.0004)	(0.0001)
Loan	-0.0613[a]	-0.0181	-0.0119	-0.0223
	(0.0191)	(0.0159)	(0.0184)	(0.0101)
Size *Loan	-0.0370[a]	-0.0985	-0.0256	-0.0159[a]
	(0.0104)	(0.0718)	(0.0186)	(0.0055)
Age	-0.0009[a]	-0.0007[a]	-0.0009[a]	-0.0008[a]
	(0.0002)	(0.0002)	(0.0002)	(0.0001)
School	-0.0137	0.00755	0.00182	-0.00143
	(0.0090)	(0.0088)	(0.0082)	(0.0050)
Read	-0.0205[b]	-0.0001	0.0019	-0.0062
	(0.0092)	(0.0090)	(0.0084)	(0.0052)
Num.	-0.0075	0.0148	0.0094	0.0055
	(0.0103)	(0.0099)	(0.0093)	(0.0057)
School*Read	-0.0235[b]	0.00588	0.00369	-0.00464
	(0.0109)	(0.0106)	(0.0099)	(0.0060)
School* Num.	-0.0126	0.0125	0.0059	0.0019
	(0.0110)	(0.0107)	(0.0100)	(0.0061)
Livestock	0.0012[b]	0.00139[b]	0.0004	0.00118[a]
	(0.0005)	(0.0005)	(0.0005)	(0.0003)
Hsize	-0.0043[a]	-0.00298[a]	-0.00445[a]	-0.0039[a]
	(0.0011)	(0.0011)	(0.0010)	(0.0006)
Hoes	-0.0035[a]	-0.0011	-0.0042[a]	-0.0029[a]
	(0.0013)	(0.0012)	(0.0011)	(0.0007)
N	787	787	787	2361

Standard errors in parentheses, [a] $p<0.01$, [b] $p<0.05$, and [c] $p<0.10$.

C: Bivariate analysis of factors affecting DEA efficiency (CRTS)

Variables	2009	2010	2011	Panel
Farm size	-0.0878	-0.0014[a]	-0.0026[a]	-0.0006[a]
	(0.1000)	(0.0002)	(0.0004)	(0.0001)
Loan	-0.0370[b]	-0.0113	-0.0443	-0.0352
	(0.0183)	(0.0147)	(0.0184)	(0.0972)
Size *Loan	-0.0239[b]	-0.0161[b]	-0.0203	-0.0119[b]
	(0.0100)	(0.0066)	(0.0186)	(0.0053)
Age	-0.0009[a]	-0.0007[a]	-0.0010[a]	-0.0009[a]
	(0.0002)	(0.0002)	(0.0002)	(0.0001)
School	-0.0110	0.0076	0.0028	-0.0001
	(0.0086)	(0.0081)	(0.0082)	(0.0048)
Read	-0.0152[c]	0.0006	0.0077	-0.0022
	(0.0088)	(0.0083)	(0.0084)	(0.0050)
Num.	-0.0081	0.0164[c]	0.0131	0.0071
	(0.0098)	(0.0092)	(0.0093)	(0.0055)
School*Read	-0.0188[c]	0.0061	0.0067	-0.0019
	(0.0104)	(0.0097)	(0.0099)	(0.0058)
School* Num.	-0.0109	0.0143	0.0096	0.0043
	(0.0105)	(0.0098)	(0.0100)	(0.0059)
Livestock	0.0012[b]	0.0003	0.0007	0.0008[a]
	(0.0005)	(0.0005)	(0.0005)	(0.0003)
Hsize	-0.0031[a]	-0.0040[a]	-0.0032[a]	-0.0037[a]
	(0.0011)	(0.0010)	(0.0010)	(0.0006)
Hoes	-0.0032[a]	-0.0035[a]	-0.0027[a]	-0.0029[a]
	(0.0012)	(0.0011)	(0.0011)	(0.0006)
N	787	787	787	2361

Standard errors in parentheses, [a] $p<0.01$, [b] $p<0.05$, and [c] $p<0.10$.

D: Bivariate analysis of factors affecting scale efficiency

Variables	2009	2010	2011	Panel
Farm size	0.0001	0.0009[a]	-0.0003	0.0002[c]
	(0.0001)	(0.0001)	(0.0004)	(0.0001)
Loan	-0.0362[a]	-0.0105	-0.0152	-0.0313[a]
	(0.0132)	(0.0100)	(0.0190)	(0.0081)
Size *Loan	-0.0195[a]	0.0101[b]	-0.0095	-0.0670
	(0.0072)	(0.0045)	(0.0193)	(0.0444)
Age	0.0001	0.0300	0.0003	0.0002[c]
	(0.0001)	(0.0001)	(0.0002)	(0.0001)
School	-0.0029	-0.0005	-0.0021	-0.0018
	(0.0062)	(0.0055)	(0.0085)	(0.0040)
Read	-0.0077	-0.0009	-0.0084	-0.0057
	(0.0064)	(0.0057)	(0.0087)	(0.0041)
Num.	0.0020	-0.0027	-0.0061	-0.0022
	(0.0070)	(0.0062)	(0.0096)	(0.0046)
School*Read	-0.0055	-0.0012	-0.0034	-0.0034
	(0.0075)	(0.0066)	(0.0103)	(0.0048)
School* Num.	-0.0004	-0.0037	-0.0060	-0.0033
	(0.0076)	(0.0067)	(0.0104)	(0.0049)
Livestock	-0.0002	0.0012[a]	-0.0006	0.0001
	(0.0004)	(0.0003)	(0.0005)	(0.0002)
Hsize	-0.0018[b]	0.00163[b]	-0.0019[c]	-0.0003
	(0.0008)	(0.0007)	(0.0010)	(0.0005)
Hoes	-0.0006	0.0036[a]	-0.0028[b]	-0.0001
	(0.0009)	(0.0007)	(0.0011)	(0.0005)
N	787	787	787	2361

Standard errors in parentheses, [a] $p<0.01$, [b] $p<0.05$, and [c] $p<0.10$.

E: Results of multinomial regression analysis of ploughing technology in 2009

Variable	Animal traction					Tractor				
	Coef.	S.E	dy/dx	+1	+SD	Coef.	S.E	dy/dx	+1	+SD
Farm size	0.1390[a]	0.0373	0.002	0.002	0.004	0.1510[a]	0.0367	0.017	0.016	0.113
Distance	-0.0690[a]	0.0195	-0.008	-0.008	-0.051	0.0028	0.0124	0.007	0.007	0.045
Years	0.0097	0.0085	-0.000	-0.000	-0.000	0.0119[c]	0.0061	0.001	0.001	0.015
Age	-0.0070	0.0061	-0.000	-0.000	-0.003	-0.0065	0.0045	-0.001	-0.001	-0.010
Livestock size	-0.0007	0.0081	-0.000	-0.000	-0.000	-0.0008	0.0070	-0.000	-0.000	-0.001
Household size	-0.0147	0.0241	0.002	0.002	0.005	-0.0351[b]	0.0177	-0.005	-0.005	-0.019
Loan amount	0.0003	0.0005	0.000	0.000	0.010	0.0010[b]	0.0004	0.000	0.000	0.029
Member	0.7850[a]	0.1630	0.001			0.9720[a]	0.1180	0.125		
Rights	0.3620[c]	0.2040	0.053			-0.1340	0.1530	-0.059		
Owner	-0.2940	0.2150	-0.044			0.1050	0.1590	0.048		
Disputes	-0.0288	0.4370	0.053			-0.5790	0.3960	-0.118		
Male	-0.5620	0.539	-0.022			-0.4500	0.4190	-0.029		
Married	-0.0462	0.2830	-0.048			-0.4350[c]	0.2220	0.094		
School	0.1880	0.1890	0.016			0.0539	0.1490	-0.007		
Constant	-0.1830	0.5810				0.6340	0.4610			
Log Likelihood	-1744.302									
Wald (χ^2)	154.30[a]									
Pseudo R^2	0.0597									
N	787									

[a]p<0.01, [b]p<0.05, and [c]p<0.10.

F: Results of multinomial regression analysis of ploughing technology in 2010

Variable	Animal traction					Tractor				
	Coef.	S.E	dy/dx	+1	+SD	Coef.	S.E	dy/dx	+1	+SD
Farm size	0.0872[c]	0.0448	0.001	0.001	0.005	0.0858[b]	0.0435	0.007	0.007	0.044
Distance	-0.1250[a]	0.0377	-0.009	-0.008	-0.041	0.0080	0.0123	0.008	0.008	0.041
Years	0.0018	0.0032	-0.000	-0.000	-0.006	0.0037	0.0029	0.000	0.000	0.025
Age	-0.0102	0.0072	-0.000	-0.000	-0.001	-0.0110[b]	0.0048	-0.001	-0.001	-0.016
Livestock size	0.0078	0.0115	0.000	0.000	0.003	0.0025	0.0080	-0.000	-0.000	-0.001
Household size	-0.0431	0.0301	-0.001	-0.001	-0.004	-0.0275	0.0207	-0.001	-0.002	-0.006
Loan amount	0.0002	0.0005	0.000	0.000	0.003	0.0006	0.0004	0.000	0.000	0.013
Member	1.1430[a]	0.2160	0.005			1.2510[a]	0.1330	0.131		
Rights	0.5330[b]	0.2450	0.041			-0.0749	0.1610	-0.043		
Owner	-0.4580	0.2840	-0.021			-0.1900	0.1850	0.001		
Disputes	1.1470[c]	0.6850	0.200			-0.5910	0.5890	-0.229		
Male	-0.5480	0.6930	-0.008			-0.4910	0.5040	-0.033		
Married	-0.2930	0.3590	-0.048			0.3510	0.2600	0.077		
School	0.4880[b]	0.2420	0.020			0.2210	0.1740	0.002		
Constant	0.1500	0.7700				1.6490[a]	0.5800			
Log Likelihood	-1293.596									
Wald (χ^2)	185.80[a]									
Pseudo R^2	0.0733									
N	787									

[a]p<0.01, [b]p<0.05, and [c]p<0.10.

G: Results of multinomial regression analysis of ploughing technology in 2011

Variable	Animal traction					Tractor				
	Coef.	S.E	dy/dx	+1	+SD	Coef.	S.E	dy/dx	+1	+SD
Farm size	0.0003	0.0070	0.001	0.001	0.002	0.0640[a]	0.0200	0.008	0.008	0.016
Distance	-0.1660[a]	0.0630	-0.012	-0.011	-0.018	-0.0124	0.0110	0.000	0.000	0.012
Years	0.0020[a]	0.0001	-0.000	-0.000	-0.004	0.0005	0.0008	0.000	0.000	0.018
Age	-0.0080[c]	0.0041	-0.000	-0.000	-0.003	-0.0110[a]	0.0030	-0.001	-0.001	-0.014
Livestock size	0.0280[a]	0.0090	0.002	0.002	0.026	0.0080	0.0110	0.001	0.001	0.010
Household size	0.0180	0.0019	0.002	0.002	0.048	-0.0150	0.0150	-0.002	-0.002	0.005
Loan amount	0.0001	0.0005	0.000	0.000	0.010	0.0003	0.0005	0.000	0.000	0.030
Member	0.2800	0.1720	0.034			1.0080[a]	0.1020	0.156		
Rights	0.550[a]	0.1660	0.041			0.2070[c]	0.1210	-0.035		
Owner	0.3580[b]	0.1580	0.024			0.1310	0.1210	0.013		
Disputes	-1.4220[a]	0.3770	0.158			0.3900	0.4470	0.020		
Male	-0.0457	0.3730	-0.008			0.4060[c]	0.2120	0.052		
Married	-0.1030	0.3470	0.001			-0.0596[a]	0.1980	0.085		
School	0.0223	0.1660	0.003			0.1240	0.1280	0.017		
Constant	3.0900[a]	0.3500				0.5800	0.6830			
Log Likelihood	-1937.296									
Wald (χ^2)	210.45									
Pseudo R^2	0.0711									
N	787									

[a]p<0.01, [b]p<0.05, and [c]p<0.10.

H: Tobit regression estimates of intensity of mechanisation in 2009

Variables	Animal_share					Tractor_share				
	Coef.	S.E	dy/dx	+1	+SD	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0066	0.0042	-0.007	-0.007	-0.145	0.0017[b]	0.0007	0.002	0.002	0.039
Age	-0.0054	0.0034	-0.005	-0.005	-0.084	0.0007	0.0011	0.001	0.001	0.012
Livestock size	0.0020	0.0072	0.002	0.002	0.014	0.0009	0.0023	-0.001	-0.001	-0.006
Household size	0.0147	0.0159	0.015	0.015	0.049	-0.0006	0.0052	-0.001	-0.001	-0.002
Loan amount	0.0004[c]	0.0002	-0.000	-0.000	-0.103	0.0002[a]	0.0011	0.000	0.000	0.047
Number of hoes	-0.0268	0.0181	0.027	0.027	0.082	-0.0005	0.0060	-0.001	-0.001	-0.002
Member	0.1500	0.1030	0.150			-0.0127	0.0332	-0.013		
Male	-0.2260	0.3790	-0.226			-0.0229	0.1200	-0.023		
Married	0.0827	0.199	0.083			0.0368	0.0659	0.037		
School	0.1430	0.1090	0.143			0.0492	0.0366	0.049		
Constant	-0.5870	0.3970				0.6560[a]	0.1290			
Log Likelihood	-484.721					-536.064				
LR (χ^2)	15.39					19.38[b]				
Pseudo R^2	0.016					0.018				
Sigma	0.980[a]					0.428[a]				
N	787					787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

I: Tobit regression estimates of intensity of mechanisation in 2010

Variables	Animal_share Coef.	S.E	dy/dx	+1	+SD	Tractor_share Coef.	S.E	dy/dx	+1	+SD
Farm size	0.0021	0.0016	-0.007	-0.007	-0.145	0.0004	0.0004	0.002	0.002	0.039
Age	-0.0019	0.0040	-0.005	-0.005	-0.084	-0.0004	0.0008	0.001	0.001	0.012
Livestock size	0.0033	0.0079	0.002	0.002	0.014	0.0014	0.0017	-0.001	-0.001	-0.006
Household size	-0.0012	0.0194	0.015	0.015	0.049	-0.0025	0.0039	-0.001	-0.001	-0.002
Loan amount	0.0001	0.0002	-0.000	-0.000	-0.103	0.0525	0.0482	0.000	0.000	0.047
Number of hoes	-0.0128	0.0210	0.027	0.027	0.082	-0.0019	0.0041	-0.001	-0.001	-0.002
Member	0.0933	0.1290	0.150			0.0227	0.0262	-0.013		
Male	0.5950	0.5180	-0.226			-0.2350[b]	0.0934	-0.023		
Married	-0.477[b]	0.217	0.083			0.1970[a]	0.0507	0.037		
School	0.0471	0.1270	0.143			0.0128	0.0271	0.049		
Constant	-1.2860[b]	0.5490				0.9170[b]	0.0961			
Log Likelihood	-343.300					-299.339				
LR (χ^2)	9.94					20.290[b]				
Pseudo R^2	0.014					0.032				
Sigma	1.006[a]					0.320[a]				
N	787					787				

[a]p<0.01, [b]p<0.05, and [c]p<0.10.

J: Tobit regression estimates of intensity of mechanisation in 2011

	Animal_share					Tractor_share				
Variables	Coef.	S.E	dy/dx	+1	+SD	Coef.	S.E	dy/dx	+1	+SD
Farm size	0.0059[a]	0.0008	-0.007	-0.007	-0.145	0.0035[a]	0.0005	0.002	0.002	0.039
Age	0.0648	0.1100	-0.005	-0.005	-0.084	-0.0007	0.0007	0.001	0.001	0.012
Livestock size	0.0023	0.0023	0.002	0.002	0.014	0.0004	0.0015	-0.001	-0.001	-0.006
Household size	-0.0062	0.0051	0.015	0.015	0.049	0.0041	0.0032	-0.001	-0.001	-0.002
Loan amount	0.0001[c]	8.16e-05	-0.000	-0.000	-0.103	0.0001[b]	4.99e-05	0.000	0.000	0.047
Number of hoes	-0.0052	0.0056	0.027	0.027	0.082	-0.0015	0.0035	-0.001	-0.001	-0.002
Member	0.0055	0.0436	0.150			0.0073	0.0270	-0.013		
Male	-0.1690	0.1270	-0.226			0.0441	0.0816	-0.023		
Married	-0.0180	0.0776	0.083			0.0350	0.0487	0.037		
School	0.0402	0.0370	0.143			0.0264	0.0232	0.049		
Constant	0.1540	0.1320				0.7170[a]	0.0845			
Log Likelihood	-478.552					-113.075				
LR (χ^2)	59.50[a]					52.15[a]				
Pseudo R^2	0.059					0.187				
Sigma	0.402[a]					0.275[a]				
N	787					787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

K: Estimated results of factors affecting household food security in 2009

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0007	0.0010	-0.000	-0.000	-0.003
Number of plots	0.2310[a]	0.0520	0.062	0.056	0.059
Age	0.0002	0.0030	0.000	0.000	0.003
Household size	-0.0190	0.0150	-0.005	-0.005	-0.018
Livestock size	0.0230[c]	0.0130	0.006	0.006	0.048
Health shocks	-0.0010[b]	0.0024	-0.000	-0.000	-0.040
Access to credit	0.2060[b]	0.0980	0.057		
Adopter	-0.0700	0.0920	-0.019		
Connected	0.1000	0.0960	0.027		
Male	-0.2100	0.2640	-0.052		
Married	-0.1270	0.1740	-0.033		
School	0.0530	0.1060	0.014		
Constant	0.5990[b]	0.3000			
Log Likelihood	-495.009				
Wald (χ^2)	37.74[a]				
Pseudo R^2	0.052				
N	787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

L: Estimated results of factors affecting household food security in 2010

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0031	0.0020	-0.001	-0.001	-0.019
Number of plots	0.1200[a]	0.0440	0.035	0.033	0.036
Age	0.0023	0.0030	0.001	0.001	0.012
Household size	-0.0160	0.0150	-0.005	-0.005	-0.017
Livestock size	0.0370[a]	0.0120	-0.011	-0.011	-0.059
Health shocks	-0.0030	0.0029	-0.000	-0.000	-0.021
Access to credit	0.2300[c]	0.1360	0.070		
Adopter	-0.2650[a]	0.0900	-0.077		
Connected	0.2520[a]	0.0960	0.071		
Male	0.0580	0.2660	0.017		
Married	0.0170	0.1660	0.005		
School	0.1330	0.1070	0.038		
Constant	0.1630	0.3100			
Log Likelihood	-522.067				
Wald (χ^2)	45.92[a]				
Pseudo R^2	0.041				
N	787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

M: Estimated results of factors affecting household food security in 2011

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0025	0.0020	-0.001	-0.001	-0.011
Number of plots	0.1640[a]	0.0390	0.039	0.036	0.043
Age	-0.0060[b]	0.0030	-0.002	-0.002	-0.026
Household size	-0.0090	0.0140	-0.002	-0.002	-0.008
Livestock size	0.0180	0.0160	0.004	0.004	0.024
Health shocks	-0.0020	0.0023	-0.000	-0.000	-0.001
Access to credit	0.1160	0.1590	0.029		
Adopter	-0.2190[b]	0.0980	-0.054		
Connected	0.3110[a]	0.0970	0.072		
Male	0.4460[b]	0.2150	0.118		
Married	-0.2940	0.2050	-0.065		
School	-0.1340	0.1060	-0.032		
Constant	0.6850[a]	0.2240			
Log Likelihood	-460.112				
Wald (χ^2)	39.28[a]				
Pseudo R^2	0.044				
N	787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

N: Joint effect of farm size and efficiency on household food security

Variable	2009		2010		2011		Panel	
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.	S.E
Farm size	-0.004	0.027	-0.016	0.020	-0.090	0.058	-0.009	0.014
Eff.	2.206[c]	1.162	1.272	1.246	1.613	1.450	2.409[a]	0.660
Farm size* Eff.	0.003	0.028	0.015	0.025	0.137	0.088	0.008	0.018
Tractor_share	0.878[a]	0.346	0.774[c]	0.437	1.891[a]	0.555	1.030[a]	0.231
Animal_Share	0.319	0.417	-0.172	0.557	1.686[a]	0.630	0.497[c]	0.285
Number of plots	0.625[a]	0.0715	0.769[a]	0.076	0.333[a]	0.117	0.573[a]	0.066
Age	0.003	0.007	0.009	0.006	0.002	0.007	0.005	0.004
Household size	-0.026	0.032	-0.041	0.032	-0.012	0.029	-0.023	0.018
Livestock size	0.045	0.031	0.051[b]	0.022	0.046	0.049	0.047[a]	0.016
Health shocks	-0.003	0.002	-0.001	0.0007	-0.003	0.005	-0.006	0.004
Access to credit	0.010[b]	0.005	-0.002	0.003	-0.007[c]	0.004	-0.001	0.002
Adopter	0.353[c]	0.196	0.272	0.202	0.0662	0.226	0.255[b]	0.115
Connected	0.0432	0.201	0.358[c]	0.214	0.447[b]	0.222	0.317[a]	0.117
Male	-0.721	(0.867)	0.470	0.668	0.294	0.837	-0.0211	0.430
Married	-0.041	0.410	-0.088	0.422	-0.803	0.555	-0.191	0.249
School	0.0493	0.221	0.340	0.240	-0.169	0.239	0.0855	0.130
Constant	-1.881	1.273	-2.774[b]	1.305	-1.924	1.655	-2.681[a]	0.747
Log Likelihood	-368.5		-360.1		-316.1		-1066.0	
Wald (χ^2)	103.8[a]		120.57[a]		37.63[a]		141.62[a]	
Pseudo R^2	0.094		0.102		0.068			
lnsig2u							-4.865[b]	1.935
testparm results								
χ^2 (2)	0.07		2.30		2.42		1.45	
Prob.> χ^2	0.965		0.317		0.299		0.485	
N	787		787		787		2361	

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

O: Effect of farm size, efficiency and mechanisation on household food security in 2009

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0010	0.0038	-0.000	-0.000	-0.003
DEA_VRTS	2.2550[b]	1.0030	0.340	0.181	0.036
Tractor_share	0.8780[b]	0.3460	0.133	0.105	0.045
Animal_Share	0.3190	0.4170	0.048	0.044	0.014
Number of plots	0.6240[a]	0.0707	0.094	0.080	0.080
Health shocks	-0.0449	0.0313	-0.007	-0.007	-0.042
Adopter	0.3530[c]	0.1960	0.055		
Connected	0.0432	0.2010	0.016		
Constant	-1.9190	1.1920			
Log Likelihood	-368.523				
Wald (χ^2)	103.51[a]				
Pseudo R^2	0.094				
N	787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

P: Effect of farm size, efficiency and mechanisation on household food security in 2010

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	-0.0040	0.0027	-0.001	-0.001	-0.018
DEA_VRTS	1.7280[c]	0.9700	0.255	0.158	0.026
Tractor_share	0.7940[c]	0.4340	0.117	0.095	0.033
Animal_Share	-0.1580	0.5550	-0.023	-0.024	-0.005
Number of plots	0.7700[a]	0.0757	0.114	0.093	0.096
Health shocks	-0.0517[b]	0.0220	-0.008	-0.008	-0.047
Adopter	0.2630	0.2010	0.040		
Connected	0.3580[c]	0.2140	0.052		
Constant	-3.1450[a]	1.1440			
Log Likelihood	-360.300				
Wald (χ^2)	119.32[a]				
Pseudo R^2	0.103				
N	787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.

Q: Effect of farm size, efficiency and mechanisation on household food security in 2011

Variable	Coef.	S.E	dy/dx	+1	+SD
Farm size	0.0012	0.0049	0.000	0.000	0.003
DEA_VRTS	3.4860[a]	1.2290	0.430	0.149	0.039
Tractor_share	1.8530[a]	0.5560	0.229	0.125	0.054
Animal_Share	1.7670[a]	0.6390	0.218	0.123	0.048
Number of plots	0.3430[a]	0.1180	0.042	0.038	0.042
Health shocks	-0.0472	0.0489	-0.001	-0.001	-0.005
Adopter	0.0969	0.2240	-0.006	-0.006	-0.035
Connected	0.4690[b]	0.2220	0.012		
Constant	-3.2680[b]	1.5220			
Log Likelihood	-317.719		0.057		
Wald (χ^2)	35.92[a]				
Pseudo R^2	0.064				
N	787				

[a] p<0.01, [b] p<0.05, and [c] p<0.10.
Source: Author's construct (2018).