FEED THE FUTURE GHANA AGRICULTURE POLICY SUPPORT PROJECT (APSP)

Productivity Heterogeneity of Rice Production in Ghana: Policy Implications for Farmer Innovations and Improved Agricultural Technologies

Contract No. 641-C-14-00001

August 2017

FEED THE FUTURE GHANA AGRICULTURE POLICY SUPPORT PROJECT (APSP)

Productivity Heterogeneity of Rice Production in Ghana: Policy Implications for Farmer Innovations and Improved Agricultural Technologies

Contract No. 641-C-14-00001

PREPARED BY:

FRANKLIN NANTUI MABE

ABSTRACT

In recent times, rice production can be said to be receiving some attention in Ghana. This not withstanding, there are still wide variations in rice yield across regions due to differences in production systems and technologies. This study analyses rice productivity heterogeneity among agro-ecological zones and policy implications for adoption of farmer innovation systems (*FISs*) and improved agricultural technologies (*IATs*) to enhance yield in Ghana. The study used primary data obtained from nine-hundred and seven (907) rice farmers from Guinea Savannah Zone (GSZ), Forest Savannah Transition Zone (FSTZ) and Coastal Savannah Zone (CSZ). Principal component analysis was used to typologically classify farmers into non-adopters, adopters of *FISs*, adopters of *IATs* and adopters of both. The new two-step stochastic metafrontier model was used to estimate and identify the determining factors of productivity performances of farmers in GSZ, FSTZ and CSZ. The generalised linear model (GLM) and multinomial endogenous switching regression model were used to analyse the drivers of the technology gap ratio (TGR) and the impacts of technology adoption typology on rice yield and metafrontier technical efficiency, respectively. Farmers in CSZ had the highest rice yield. The adoption of IATs has the highest impact on rice yield and metafrontier technical efficiency, followed by joint adoption of *FISs* and *IATs*. While fertilizer, farm size, labour, capital and pesticides each increases rice output, the opposite is true for rice seed. Farmers in CSZ are the most technically efficient. Technical inefficiencies of farmers are negatively influenced by age, sex, household size, education years, extension visits, contract farming, access to improved seeds, access to irrigation, high rainfall amount, less lodging of rice, and well-coordinated and synergised adoption of technologies. Albeit farmers in CSZ are doing well in terms of rice yield, they still have the highest potential of increasing rice yield since they had the lowest TGR. Factors which increase TGR are contract farming, access to irrigation facilities, good condition of road from district capital to farming communities, nearness of rice farm to the farmers' houses, non-lodging of rice, high actual mean annual rainfall amount within the district, *FISs* and *IATs*. It is recommended that government through the ministry of food and agriculture, development partners and individual private companies promote the adoption of *IATs* as well as educate farmers on how to coordinate and synergise the adoption of the whole package. The designed policy for the promotion of this superior technology should be intensified and farmer targeted in the whole country, especially GSZ, considering the high percentage of non-adopters of the superior technology package. Contract farming concept should be vigorously pursued to the latter. In the long term, government and development partners should provide good road infrastructure and irrigation facilities in rice production communities. Lastly, concerted and co-ordinated efforts should be made for researchers in national agricultural research institutions (eg. Savannah Agricultural Research Institute and Crop Research Institute) and academic agricultural research centres (agricultural research centres in the various universities) to vigorously research into rice production *FISs* and improved upon and made available to farmers to adopt. It is important to note that all these efforts should incorporate the needs of farmers in the respective agro-ecological zones, but not just a holistic approach.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AE	Allocative Efficiency
AEAs	Agricultural Extension Agents
AR	Ashante Region
ASRP	Agricultural Services Habitation Project
ATT	Average Treatment Effects on the Treated
ATU	Average Treatment Effects on the Untreated
BA	Brong-Ahafo
CARD	Coalition for African Rice Development
CCR	Charnes, Cooper and Rhodes
CR	Central Region
CRI	Crop Research Institute
DEA	Data Envelopment Analysis
DIM	Diffusion of Innovation Model
DMU	Decision Making Units
EE	Economic Efficiency
ER	Eastern Region
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FASDEP	Food and Agriculture Sector Development Policy
FISs	Farmer Innovation Systems
GA	Greater Accra
GADCO	Global Agricultural Development Company
GCAP	Ghana Commercial Agricultural Project
GDP	Gross Domestic Product
GF	Group Frontier
GPRS	Ghana poverty Reduction Strategy
HRFZ	High Rain Forest Zone
IATs	Improved Agricultural Technologies
ICOUR	Irrigation Company of Upper Region
IFPs	Indigenous Farming Practices
IMF	International Monetary Fund
IMR	Inverse Mills Ratio
IRRI	International Rice Research Institute
ISSER	Institute of Statistical, Social and Economic Research
IVRDP	Inland Valley Rice Development Project
MESR	Multinomial Endogenous Switching Regression
METASIP	Medium Term Agricultural Sector Investment Plan
MFTE	Metafrontier Technical Efficiency
MiDA	Millennium Development Authority
MoFA	Ministry of Food and Agriculture

MPP	Marginal Physical Product
MT	Metafrontier
MTADP	Medium Term Agriculture Development Programme
MTR	Metatechnology Ratio
NARS	National Agricultural Research Stations
NAT	Norm Activation Theory
NEP	New Environmental Paradigm
NERICA	New Rice for Africa
NGOs	Non-Governmental Organisations
NR	Northern Region
NRDP	NERICA Rice Development Project
NRDP	NERICA Rice Dissemination Project
NRDS	National Rice Development Strategy
Ph.D	Doctor of Philosophy
PPI	Productivity Performance Indices
RER	Random Error Ratio
RY	Rice Yield
SAP	Structural Adjustment Programme
SARI	Savannah Agricultural Research Institute
SDRFZ	Semi-Deciduous Rain Forest Zone
SRI	Soil Research Institute
SRID	Statistics Research Information Directorate
SSA	Sub-Sahara Africa
TAM	Technology Acceptance Model
TE	Technical Efficiency
TER	Technical Efficiency Ratio
TGR	Technology Gap Ratio
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
UE	Upper East
US	United States
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
UW	Upper West
VBNT	Value-Belief-Norm Theory
VR	Volta Region
WARDA	West African Rice Development Association
WR	Western Region

CONVERSIONS OF UNITS

Metric units	
1Kg	0.001T
1T	1000Kg
1ha	2.471acres
1acre	0.404Ha
1bag of paddy rice	84Kg

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background

Agriculture has remained the cornerstone employing 48% of the popluation in Africa and contributing significantly to Gross Domestic Product (GDP) in most countries (Blein, 2013). According to the Food and Agriculture Organization (FAO) (2012), most of the food produced and consumed in developing countries in Africa and Asia are done by half a billion of smallholder farmers. The economy of Sub-Saharan African (SSA) countries is largely dependent on agriculture. The centrality of agricultural sector in SSA countries is strongly linked to the fact that it employs 60% of the population. Also, the sector has been integral by constituting a large share of national output in most developing countries (Diao *et al*., 2007). In the current decade, people especially policy makers and scientists are very conscious of helping farmers increase agricultural productivity.

In 2013, the population growth rate of Ghana stood at 2.19%. The general population in Ghana has over the years been fed with the help of farmers, especially the industrious contributions of smallholder and medium scale farmers. Undoubtedly, the importance of agricultural production in Ghana cannot be overemphasized. The agricultural sector contributes significantly to the overall development of Ghana. Over the years, its share of the gross domestic product (GDP) has been so significant that it cannot be down played irrespective of the current emerging oil and gas industry. According to Institute of Statistical, Social and Economic Research (ISSER) (2014), the agricultural sector recorded a growth rate of 5.2% in 2013, thereby contributing 22.6% to the overall GDP of Ghana. It is important to note that in 2013, the sector yielded foreign exchange earnings of US$2,709 million to the economy (ISSER, 2014).

In Ghana, agriculture is often regarded as the engine of growth because it plays a critical role through the provision of food for the population and raw materials for the industrial sector. The sector also provides avenue for the absorption of the majority of Ghanaian labour force. It is the only sector which employs more than half the population in both the formal and informal sectors. In 2013, the sector employed 56% of the Ghanaian population.

The millennium development goal (MDG) of reducing hunger to the barest minimum is hinged on increasing agricultural production especially the crop yields. Also, the Ministry of Food and Agriculture (MoFA) (2010) noted that the possibility of attaining at least five of the MDGs is heavily rooted in the improvement of agricultural production.

Of all these contributions, the crop production subsector is indispensable in Ghana. The subsector provides a myriad of staple food crops, with maize, rice, sorghum, millet, cocoyam, cassava, yam, groundnut, cowpea and plantain as the notable ones. The commercial cash crops grown in the country are cocoa and oil palm. Non-traditional agricultural crops such as cashew, pineapple, mangoes etc. are grown both on small scale and commercial bases for exports. Among all these crops, the contribution of cereals to household food security in Ghana is unprecedented. Many rural and urban households depend greatly on cereals. It is a well-known fact that greater

proportions of Ghanaian meals contain cereals in one way or the other. Among all the cereals produced and consumed in Ghana, rice is ranked second after maize (MoFA, 2011 and ISSER, 2014).
In Ghana, rice has become a major food security and staple crop which is consumed all year round by both rural and urban folks. This is premised on the fact that the taste and preferences of Ghanaians have changed over the years towards rice. Rice meals which were consumed occasionally in Ghana are now being consumed almost every day. Rice cuisines are consumed in Ghanaian domestic homes, Ghanaian hospitality industries, during official functions, funerals and traditional durbars. Also, the urbanisation and the engagement of most Ghanaians in full time jobs make people busy leaving just a limited time for cooking of foods such as rice which requires less time. Asuming-Brempong *et al.* (2011) noted the demand for rice has been increased due to the changing food preferences in both urban and rural areas, high population growth and rapid urbanization.

Considering the important role rice played and continues to play in Ghana, its demand by Ghanaians far exceeds the domestic production level. According to MoFA (2014), "the country has been food secure in all the major food staples since 2008, with the exception of rice". As noted by Millennium Development Authority (MiDA) (2010), the domestic demand for rice in Ghana is projected to grow at a compound annual growth rate of 11.8%. There is a deficit of rice production in Ghana and this deficit is being filled by importation.

Due to numerous projects such as Inland Valley Rice Development Project (IVRDP), NERICA Rice Dissemination Project (NRDP), Food Security and Rice Producers Organisation Project (FSRPOP), Support to Ghana Rice Inter-Professional Body (SGRIPB), Lowland Rice Development Project (LRDP), Ghana Commercialization of Rice Project (G-CORP) etc. that MoFA rolled out in rice sector across the country, the deficit in rice production is decreasing gradually since 2008 (MoFA, 2014). Companies such as Prairie Volta Limited, Global Agricultural Development Company (GADCO), Brazil Agro Business Limited etc. have put large amounts of land under irrigation with the aim of cultivating rice all year round. The cardinal objective of rice projects has been to improve rice yield and increase the country's production level thereby reducing the high import bills on rice.

Irrespective of the numerous rice productivity improvement projects, local rice is not available all year round. It is imperative to note that the availability of local rice throughout the year will stabilise rice prices and make it affordable for consumers to purchase, save some money and raise the income levels of smallholder rice farmers (Diako *et al*., 2010). This calls for concerted efforts by all stakeholders to implement policies and programmes aimed at expanding and increasing rice production to meet domestic demand. As a net importer of rice, there is the need for resources in the country to be invested in increasing rice production so as to make local rice available all year round (Abdulai and Huffman, 2000) and thereby reduce rice importation.

Rice production is widely spread in Ghana, covering all the ten administrative regions. The climatic and soil conditions of large proportions of the land in Ghana support rice production. Rice is grown in all the ten regions but the regions where rice is cultivated most are Greater Accra, Volta, Northern, Upper West and Upper East regions. These regions are in agro-ecological zones which support rice cultivation. There are five main agro-ecological zones in Ghana namely Rain Forest Zone (RFZ), Deciduous Forest Zone (DFZ), FSTZ Zone (FSTZ), CSZ Zone (CSZ) and

Northern Savannah which is made up of GSZ Zone (GSZ) and Sudan Savannah Zone (SSZ)). Farmers in each of the regions have their own methods of rice production based on environmental conditions.

Naturally, the environmental conditions in Northern savannah (SSZ and GSZ) support only one cropping season of rice and all other arable crops. The same cannot be said about other four agro-ecological zones. The other four agro-ecological zones have bimodal rain distributions in a year.

Due to the use of different Indigenous Farming Practices (*IFPs*), Farmer Innovation Systems (*FISs*) and Improved Agricultural Technologies (*IATs*) among farmers in the various agro-ecological zones as well as differences in environmental conditions, rice productivity has not been homogenous. In Ghana, some of the rice farmers still produce using indigenous practices. *IFPs* are the relatively unimproved older farming practices handed over to farmers by their foreparents or any other older family members or friends. *FISs* and *IATs* have all emanated from *IFPs*. Farmer innovations are continuous processes which started long ago before scientific development of improved farming technologies (Biggs, 1981). For instance, over the years, farmers have single-handedly selected crop varieties which are high yielding, disease resistant, draught resistant and possess long shelf lives. The criteria and features used by the local farmers in the selection process are not documented and scientifically verified. Farmer innovations are crop specific even though some are universal and can be used in the production, storage and process of two or more crops. Meanwhile, *FISs* are relatively improved farming systems which are ingeniously developed by farmers with the aim of improving agricultural productivity, product quality or shorten maturity period. They include extensively modified or uniquely combined indigenous farming systems and/or *IATs* (Tambo and Wuscher, 2014). It is also defined as the combination of existing techniques or technologies in new ways in order to enhance their impact (Wills, 2012).

On the other hand, *IATs* are highly improved externally developed technologies by national or international research institutions. For rice, some of them have been developed by research department of MoFA, Centre for Scientific and Industrial Research (Savannah Agricultural Research Institute, SARI; Soil Research Institute, SRI; and Crop Research Institute, CRI), FAO, International Rice Research Institute (IRRI) etc. Unlike FISs which equally improved ways of increasing rice yield are, vigourous efforts have been made to help farmers adopt IATs through project interventions, agricultural investment policy frameworks among others.

1.2 Problem Statement

The agricultural investment policy framework, the Medium Term Agricultural Sector Investment Plan (METASIP) enumerated six strategic programmes for the improvement and modernisation of the agricultural sector by 2015 (MoFA, 2010). The METASIP and the second Food and Agriculture Sector Development Policy (FASDEP II) documents all aimed at increasing food security and emergency preparedness, growth in incomes, competitiveness and integration into domestic and international markets, sustainable management of land and environment, and the application of science and technology in agricultural production (MoFA, 2007 and MoFA, 2010). All these strategic plans predominantly aim at improving agricultural productivity of priority staple food crops including maize, rice, yam, cassava and cowpea.

FASDEP I identified rice as one of the important food crops that need special attention for the country to attain food sufficiency. This is premised on the increased demand for rice cuisines in the country. Even though maize is the most important cereal crop in Ghana, the concentration of all stakeholders in the agricultural production and marketing subsectors is gradually shifting to rice availability in the country all year round. Policies, projects and programmes such as National Rice Development Strategy (NRDS), Inland Valley Rice Development Project (IVRDP) and NERICA Rice Development Project (NRDP) are being implemented to increase rice productivity and improve the quality of processed rice so as to reduce large importation of foreign rice into the country with its economic implications.

Considering the high demand for rice in Ghana, many efforts are being made by government to increase the local production of rice, especially in Greater Accra, Volta and the three Northern Regions. The past half decades have witnessed unprecedented heavy investments in rice value chain by both government and private organizations. Notable among these investments are the rehabilitation works that have been carried out on irrigation dams at Botanga, Golinga, Tono, Bunglung and Kukobila. Also, irrigation dams at Dawa, Ave Afiedenyigba, Akomadan, Dawenya, Tankase, and Koori are currently under construction and rehabilitation. According to Mabe (2014), the Golinga dam in Tolon District and the Libga, Bunglung and Kukobila dams in Savelugu-Nanton Municipality were constructed to make water available for irrigation of rice and vegetables all year round.

Large area of land has also been acquired by government and made available to organisations for the cultivation of rice in the Volta Region of Ghana. Prairie Volta Limited, the management of Aveyime Rice Project has over the years increased the land put under rice cultivation in order to meet the local rice demand. The NERICA variety has been introduced and well adopted by farmers in Hohoe and its environs in the Volta Region. Part of Accra Plains has also been developed and put under rice cultivation. Through the Inland Valley Rice Development Project (IVRDP) in Ghana, five improved rice varieties (Jasmine 85, ARC Baika, Marshall, ITA 324 and Bouake 189) have been developed by experienced scientists and made available to farmers for adoption. All these efforts are aimed at increasing rice yield.

In recent years, the Government of Ghana had secured a loan of US$100 million from the World Bank and a grant of US$45 million from the United States Agency for International Development (USAID) for the provision of the necessary facilities for commercial production of rice. Through the Ghana Commercial Agricultural Project (GCAP), 10,000 hectares of land have been developed for rice cultivation in the Nasia-Nabogo inland valley in the Northern Region of Ghana.

The investments priorities indicated in the preceding paragraphs aimed at increasing rice productivity levels. This is to help farmers increase their incomes levels and reduce importation of foreign rice. The increase in rice production in Ghana and many African countries is attributable to area expansion rather than yield improvement. While rice yield in developed countries stands at 8.3Mt/ha, rice farmers in Ghana are struggling to attain just half of this value. According to MoFA (2011), farmers in Ghana have the potential of achieving an average rice yield of 6.5Mt/ha but they are only able to actually realize an average yield of 2.4Mt/ha. Many researchers have ascribed this low yield to rudimentary technologies used by farmers, incidence of diseases and pests and unavailability of certified seeds. Inasmuch as the land productivity of rice in Ghana is low, the worrying trend is its huge heterogeneity among farmers in different agro-ecological zones (regions). Interestingly, these agro-ecological zones are distinct for regions with unique rice yields.

Characteristically, the soil and climatic conditions of the entire country differ slightly across agro-ecological zones. The rice production systems used by farmers in different agro-eco-ecological zones share many things in common. Even though the agro-ecological areas are different, the traditional rice production system (indigenous rice farming practices), which involves the use of hoe and cutlass, dominates in all the agro-ecological zones. The externally developed *IATs* used for rice production across the regions (agro-ecological zones) are fairly the same. The greatest distinguishing feature in rice production across agro-ecological zones in Ghana may largely depend on differences in innovativeness of farmers, which involves the adoption of farmer innovation rice production systems. Over the years, rice productivity among agro-ecological zones has been highly heterogeneous and the drivers of this heterogeneity still remain a mistery.

Evidently, rice cultivated in different agro-ecological zones in Ghana yields different land productivity levels (yields) (see table 1.1). Table 1.1 shows output, area cultivated and yields of rice in the ten administrative regions in Ghana for 2013 and 2014 cropping seasons. Whilst farmers in the Greater Accra Region (CSZ) always obtained rice yield above 6Mt/ha, their counterparts in Northern (GSZ), Upper West (Sudan Savannah), Upper East (Sudan Savannah) and Volta (Transitional Savannah) Regions where most of rice is produced always struggled to obtain 4Mt/ha. In 2014, farmers in Greater Accra obtained rice yield of 6.69Mt/ha whilst those in Northern, Upper West, Upper East and Volta Regions obtained 2.12Mt/ha, 1.62Mt/ha, 2.70Mt/ha and 3.41Mt/ha respectively (see table 1.1). It is clear that over the years, rice yield in Greater Accra Region (CSZ) doubles other regions except Volta Region.

Table 1.1 Production Output, Area Cropped and Yield of Rice in 2013 and 2014

Region	Quantity (Mt)		Area (ha)		Yield (Mt/ha)	
	2013	2014	2013	2014	2013	2014
Western	28,604	33,080	22,500	25,914	1.27	1.28
Central	2,648	2,846	1,630	1,645	1.62	1.73
Greater Accra	19,808	21,528	3,057	3,219	6.48	6.69
Volta	160,467	188,952	40,200	42,873	3.99	4.41
Eastern	29,939	33,205	8,900	9,572	3.36	3.47
Ashanti	38,399	34,614	13,300	11,449	2.89	3.02
Brong Ahafo	6,713	7,435	4,128	4,448	1.63	1.67
Northern	162,297	164,979	75,000	77,961	2.16	2.12
Upper East	113,523	109,394	42,088	41,788	2.70	2.62
Upper West	7,127	8,008	5,102	5,587	1.40	1.43
Total	**569,524**	**604,041**	**215,905**	**224,457**	**2.64**	**2.69**

Source: Statistics, Research and Info. Directorate (SRID), Min. of Food & Agric.-March, 2015

As noted by Abdulai and Huffman (2014), it is possible for farmers to increase the productivities of crops through adoption of modern farming practices, and the same may be said specifically about rice farmers. When high-yielding, pest- and disease-resistant varieties are made available, affordable and accessible to smallholder farmers, some will adopt and be able to increase their productivities close to the potential values or even commercial level. Farmers can adopt modern rice cropping systems and farmer innovation rice cropping systems to help bridge the heterogeneity in the agro-ecological productivities of the selected crops.

Low productivity is critical to farmers and hence it is important for them to adopt innovations. Due to this desire, farmers who obtain low rice yields often visit high-yield farmers or more efficient farmers to learn specific innovations from them. Thus, within the indigenous farming systems, farmers themselves pay critical attention and make efforts to improve the system. The result is that these agricultural enhancing efforts have led to extensive modifications or unique combinations of the indigenous farming systems (Tambo and Wuscher, 2014)

Over the years, research institutions and other stakeholder organizations have not relented in their efforts to developing scientifically improved technologies and making them available to rice farmers for adoption through agricultural extension agents (AEAs). Meanwhile, this supply-driven concept of developing improved technologies is not yielding results satisfactorily, especially increasing rice yield significantly. During an interaction (during preliminary survey) with farmers at Golinga in the Tolon district of the Northern Region, one of the farmers lamented that "policies are designed and implemented for the development of improved technologies with the notion that there is a farmer out there who will need them". Another farmer at Chinderi in the Volta Region of Ghana bemoaned that agricultural productivity enhancing technologies are developed without conscious efforts of assessing whether they are demand driven or not. Many of the farmers may feel that their own farmer innovations are better and therefore, they fail to adopt externally developed *IATs*. It is an open secret that irrespective of many developed rice productivity enhancing agricultural technologies, the actual rice yield is still below the potential yield and varies across agro-ecological zones.

In a developing country like Ghana, farmer innovations, which according to the World Bank (2011) are critical to improving agricultural productivity, have not been fully harnessed, documented and improved upon and made available to farmers for adoption. Most of these farmer innovations remain with farmers and some of the farmers even die without revealing or passing on the innovative ways of their production processes. Teeken *et al.* (2012) observed that through innovative ways, farmers are able to combine Asian and African rice to develop new promising rice varieties, but their innovations and technologies are seen as traditional and not recognized by research institutions and development organizations. Therefore, productivity analysis of farmers' innovations is not done and subsequently not mainstreamed in government policies.

Also, the discrepancies in rice productivities across agro-ecological zones raise questions on whether the variations are stemming from the differences in *IFPs*, *FISs* and *IATs;* or efficiencies of farmers in the production process; or climatic and soil conditions; or regional specific and policy factors. The efforts to support farmers to increase rice production to meet quality standards of imported rice as well as meet domestic demand and help the country reduce rice import bills of the country must be interrogated from the first principle. The first principle of researching into factors affecting efficiency performances of rice farmers across agro-ecological zones in Ghana is lacking.

Many research studies have explored the drivers of efficiency performances of rice farmers, but none of these did a cross-country analysis let alone investigated the impact of *FISs* and *IATs* on the efficiency of rice farmers. Additionally, efficiency studies on rice in Ghana have been location specific and lack policy credibility for the entire nation. For instance, Al-hassan (2012) examined farm-specific technical efficiency of smallholder rice farmers in the Upper East region of Ghana; Asuming-Brempong, *et al*. (2011) assessed the extent of exposure and adoption of the NERICA varieties across the rice growing districts (Ejura-Sekyedumase, Hohoe and Tolon-Kumbungu) in Ghana, and determined the key factors that affect adoption; Sena (2011) analysed economic efficiency of NERICA rice farms in the Volta Region of Ghana. Donkor *et al.* (2016) analyse the impact of row-planting technology on rice productivity in two districts, Kasena Nankana East and Bawku Districts in the Upper East Region of Ghana. All these studies limited the study area to one agro-ecological zone or two or more districts. Since there are no empirical studies on the causes of rice productivity heterogeneity among the agro-ecological zones in Ghana, the attributable factors can only be guessed and hence the need for this research.

Additionally, gender dimensions of adoption of farmer innovations and scientifically improved agricultural technologies cannot be overlooked when it comes to rice farming in Ghana. Gender affects the adoption of agricultural innovations and technologies (Doss and Morris, 2001). There is heterogeneity in the involvement of women in rice production across agro-ecological zones in Ghana.

Methodologically, all the above-mentioned studies have not examined the impact of rice farmers' adoption of *FISs* and *IATs* on productivity performance indices (technical efficiency, TE; technology gap ratio, TGR; and metafrontier technical efficiency, MFTE) using instrumental variables especially multinomial endogenous switching regression model excep Abdulai and Huffman (2014). The study by Abdulai and Huffman (2014) was limted to soil and water conservation technology.

From the above statements, the following research questions become pertinent:

1. What technology adoption typology can rice farmers in Ghana be classified into?

2. What are the reasons why farmers adopt a particular technology and what are the constraints facing farmers in adopting improved agricultural technologies for rice production?

3. What are the factors influencing rice production and what are the levels of technical inefficiencies of farmers?

4. What factors influence agro-ecological zone-specific technical and metafrontier technical inefficiencies of rice farmers?

5. What are the drivers of TGRs of rice farmers in Ghana?

6. What are the econometric and empirical impacts of technology adoption typology on farmers' rice yield?

7. Are there differences in resource-use efficiencies between males and females?

1.3 Objectives of the Study

The principal objective of this study is to analyse rice productivity heterogeneity and policy implications for farmer innovation systems (*FISs*) and improved agricultural technologies (*IATs*) in Ghana. In order to achieve this prime objective, the following specific objectives were pursued: To

1. classify farmers into technology adoption typology and descriptively estimate the impact of each typology on rice yield and statistically test their differences across the three agro-ecological zones (guinea savannah and forest savannah transition and coastal savannah zone)

2. identify reasons for the choice of each technology typology and the constraints faced in adopting the superior technology, *IATs* in rice production.

3. model the determinants of rice output and estimate agro-ecological zone specific technical efficiency and metafrontier technical efficiency of rice farmers in Ghana.

4. insvestigate the determinants of agro-ecological zone specific technical efficiency and metafrontier technical efficiency of rice farmers in Ghana.

5. estimate *TGR* and identify the influencing factors

6. assess the impacts of each technology adoption package on rice yield in the study area

7. analyse gendered effects of resource-use efficiency of farmers across agro-ecological zones.

1.4 Hypotheses of the study

The principal hypotheses to be tested in this research are:

A. H_0: There is no statistical significant productivity differences between rice farmers in any of the two agro-ecological zones
   H_1: There is statistical significant productivity differences between rice farmers in any of the two agro-ecological zones

B. H_0: There is no statistical significant differences in rice productivities between farmers using *FISs* and *SIATs*
   H_1: Rice pproductivity of farmers using *FISs* is significantly lower than rice productivity of farmers using *SIATs*

C. H_0: There is no statistical significant differences between *TGR* of rice farmers in any two agro-ecological zones
   H_1: *TGR* of rice farmers in agro-ecological zones which are closer to coast of Ghana is significantly greater than that of farmers in agro-ecological zones which are further way from the coast of Ghana

D. H_0: There are no statistically significant differences between gender resource-use efficiencies

H_1: There are statistically significant differences between male and female resource-use efficiencies

1.5 Justification of the Study

This research will provide comprehensive information on factors which significantly influence the efficiencies of farmers across the regions under study. The research has relevance in the area of academia, policy design and implementation, farming and agricultural extension delivery and advocacy.

In Ghana, the typology, the impacts and policy implications of rice production FISs and *IATs* are unknown. The full extent of the level of differential productivity performances of rice farmers using farmer innovations and *IATs* across agro-ecological zones is not known. The typology and comparative analysis of FISs and *IATs* and their contributions and empirical applications to firm (farmer) productivity performance will help guide policy directions for rice productivity enhancement in the country. To make innovations demand driven and widely acceptable, research of this nature is critical to identifying, classifying typologically and documenting rice production farmer based-innovations. Recommendations will be made for researchers to improve on the identified and typological classified farmer innovations for onward dissemination to local farmers to help them improve upon rice yield, as well as minimise wide rice yield differentials among agro-ecological zones. Rice productivity levels in Ghana can therefore be enhanced through policy directions towards technological change (new technologies) and/or technical change (improving upon the existing technology) and farmers' adoption of the technologies rather than expansion of farm sizes

Over the years, the rice subsector in Ghana has experienced tremendous area expansion. Meanwhile, increase in rice production through area expansion is not a viable and sustainable option considering physical limitation of land availability. Bravo-Ureta and Pinheiro (1993) noted that when firms are operating below the frontier, it presupposes that there is a shortfall in efficiency. The authors therefore suggested that in such a situation, there is a possibility to increase the output without necessarily acquiring additional inputs.

In conducting this empirical study, the researcher will be able to determine the actual gap between the frontier output and the observed output as well as metafontier output and group frontier output. Modelling the drivers or determinants of these productivity performance indices of farmers will provide information on the factors which can easily be modified to improve upon productivity performances of farmers. From such revelation, recommendations will be made for farmers to adjust their production processes so as to increase their efficiency levels. When the socioeconomic factors, as well as policy and institutional factors that determine the productivity performances of farmers are identified, recommendations will be made for policy makers to design policies that can be implemented to improve upon rice productivity levels. With this, farmers with low efficiencies will be able to bridge the gap through improvement in their management practices or government provision of enabling conditions without farmers necessarily changing the technology.

This study is the first of its kind which assesses the impact of *IFPs, FISs* and *IATs* on the ability of farmers to produce rice using frontier and metafrontier analysis in Ghana. Numerous studies have focused mainly on the quantitative impact of externally developed agricultural innovations on agricultural productivity or efficiency. Rigorous quantitative analysis of the effects of farmer innovations and IATs on technical efficiency and TGR is deficient. Therefore, this study will assist policy makers to know whether *IFPs* or *FISs* or *IATs* or a combination of them have the potential of improving upon productivity performances of rice farmers.

More importantly, the study will contribute to knowledge on how *FISs* and *IATs* and socioeconomic factors (farmer characteristics, policy and institutional variables and shocks) affect *TE* and *TGR* differently across agro-ecological zones. Institutional factors affecting *TGR* which can easily be targeted will be known from this study and this will provide information for policy makers to design and implement demand driven country-wide policies to deal with wide rice yield heterogeneity among agro-ecological zones in Ghana. Also, the results of this study will assist agricultural extension agents know the specific causes of inefficiencies and low productivity of rice in Ghana.

Many researchers both local and international have used stochastic frontier analysis to determine technical and allocative efficiencies and prescribed remedial actions that can be adopted to improve upon these efficiencies. However, there has not been any comparative analysis of agro-ecological efficiencies of rice production in Ghana to the best of the researcher's knowledge. Therefore, the findings of this study will be unique and more policy driven since it analyses the causes of differences in rice productivity across the whole country. Also, the knowledge in gender effects of resource-use efficiency will help in making recommendations that are gender specific for easy implementation.

Lastly, there has not been enough methodological analysis of productivity heterogeneity among groups with different characteristics. In academia, the research will contribute to the existing literature on metafrontier analysis. The unique knowledge that this study will contribute to existing literature on metafrontier is the use of multinomial endogenous switching regression to assess the impact of adoption of *FISs* and *IATs* on rice yield. Lastly, the use of fraction logit regression to ascertain the determinants of TGR is unique.

1.6 Organization of the Research

The research is organised into nine chapters. Chapter two briefly describes rice policy and production systems in Ghana whereas literature on the relevant thematic areas related to the study is reviewed and presented in chapter three. Chapter four presents the method of data analyses for each of the objectives. The sampling techniques and the study area are also described in chapter four. Chapter five analyses and presents the results on technology adoption typology and rice yield differentials. In chapter six, the reasons and constaints for technology typlolgy choices are analysed. The empirical results on the determinants of rice output and productivity performances of rice farmers in Ghana are presented and discussed in chapter seven. Chapter eight presents and discusses the impacts of technology adoption on rice yield in Ghana. The gender effects of resource-use efficiency are presented in chapter nine whereas the summary, conclusions policy recommendations and suggestions for future research are presented in chapter ten

1.7 Scope and Limitations of the Research

This study used a group benchmarking method of analysis (i.e. stochastic metafrontrier analysis). Irrespective of its strengths, researchers have criticised its ability to provide policy directions for improving farm specific productivity performances. The arguments have been that the environmental conditions under which each group of farmers operates might differ significantly to the extent that policy recommendations cannot be farmer specific but rather group specific. Hence, recommendations of this study do not provide farmer specific strategies in enhancing farm specific productivity. Irrespective of this, results from group benchmark method of analysis can be used to identify where inefficient spatially located farmer groups (either those in GSZ or FSTZ or coastal zones) could improve their technical efficiency.

This research provided suggestions that can be implemented to improve upon rice farmers productivity performances across specific agro-ecological zones and Ghana at large. These recommendations are not cast in iron and hence need modifications during implementations based on monitoring and evaluation at each stage of the implementation.
Also, the study fails to incorporate marketing efficiencies, since production efficiency alone cannot assure maximum output potential of the local rice industry.

CHAPTER TWO

RICE PRODUCTION AND POLICY IN GHANA

2.1 Overview of Rice Policies in Ghana

A policy is a plan, or a course of action developed and adopted by an organization (in this study government) for implementation with objective of achieving desirable results. Over the years, Ghana's agricultural sector has had many policy documents which specify the investment direction of government and development partners. There are different types of government policies. Policies can be designed to target a particular sector, or they can be designed to target the national, regional or decentralised levels. There are agricultural policies, trade policies, environmental policies, health policies etc. In terms of level, policies can be grouped into national policy, regional policy, local policy or district policy just to mention few.

In Ghana, most rice policies are embedded in the agricultural policy documents. Considering the importance of rice to the food security status of Ghana and the impact of its importation on the economy, several governments over the years have not relented on their efforts at developing the rice sector. As noted by Boansi and Favour (2015), rice sub-sector has received several attentions under various umbrella policies, programmes and strategies. During the post-colonial period (1957-1982) or the rice policies that were embedded in agricultural policy documents all aimed at mechanizing rice production for increased yield. The post independence era policies were socialist orented policies (1957-1982). That policy document was strategically designed to help the country achieve self-sufficiency status of priority staple crops including rice. During the pre-trade liberalization period (1958-1982) which concided with post-colonial period, rice commercialization agenda was pursued vigorously. This was done through provision of fertilizer subsidy to farmers as well as waiving of tax on other agricultural inputs such as tractor and its implements.

From 1986-1988, the country designed, adopted and implemented a strategic document called "Ghana agricultural policy: Action plan and strategies". The main objective of this policy was to achieve self-sufficiency in priority starchy food staples such as maize, rice and cassava in order to attain national food security. This policy document was comprehensive because it included ways of improving agricultural research for enhancing rice, maize and cassava productivities.

The "Agricultural Services Habitation Project (ASRP)" is another agricultural policy document which was implemented from 1987 to 1990. ASRP did not neglect the rice subsector as it was aimed at investing in the expansion of agricultural research, extension service delivery and irrigation. Even though, other thematic areas of ASRP targeted the rice subsector, the investment in irrigation development was mainly directed to modernizing production. Another principal policy agricultural document called "Medium Term Agriculture Development Programme (MTADP)" was developed and implemented from 1991 to 2000 in order to increase productivity and competitiveness of agricultural sector including rice sub-sector. It aimed at sustaining agricultural growth and development.

In 1996, the "Accelerated Agricultural Growth and Development Strategy was prepared but its implementation did not see the green light. According to MoFA (2007), FASDEP I was developed and implemented within the period 2002-2006 and its main objective was to modernise agricultural sector in order to transform rural economy. It is important to note that FASDEP I was developed based on the tenets of the Accelerated Agricultural Growth and Development Strategy.

FASDEP II was developed in 2007 based on the national policy document; GPRS II which came into being from 2006-2009. FASDEP II was developed and implemented with the aim of commercializing agriculture and enhancing the productivity of prioritized crops namely rice, maize, cowpea, yam, cassava and peanut with the application of science and technology. The development and improvement of the value chain of these prioritized crops by the application of science and technology was also pursued under FASDEP II. FASDEP II implementation spanned the period of 2008-2010.

To achieve the long-term goals enshrined in FASDEP II, MoFA developed and begun the implementation of "Medium Term Agriculture Sector Investment Plan (METASIP)". It is a medium-term investment plan and its years of implementation spanned the period 2011-2015. METASIP has the investment of achieving agricultural GDP growth of at least 6% annually, halving poverty by 2015 through increased budgetary allocation to agricultural sector by at least 10% (MoFA, 2010). This was to be done through investment in agricultural production, agro processing, the creation of markets, application of scientific methods etc.

The "National Rice Development Strategy (NRDS)" 2008 -2018 which was put in place at doubling domestic production of rice by the end of the 10-year period. With the NRDS, the government continuous to invest in improving the quality of domestically produced rice through the development and processing of quality rice varieties. As part of the efforts to increase and improve the quality of rice locally produced rice and conserve foreign exchange earnings through rice import substitution, a concessional loan of US$ 3,840,000.00 from African Development Bank and US$730,000.00 from government of Ghana was invested in promoting the upland NERICA rice variety in Ghana (Ghana@www.mofa.gov.gh/site/?page_id=4626(accessed 29/09/2015). This upland NERICA Rice Dissemination Project (NRDP) and its implementation started in 2003 and ended 2011. The NRDP has the following thematic areas; seed production and distribution and adaptive research establishing the fertilizer requirement levels, weed management regimes, spacing for NERICA rice etc. The project was implemented in three Savannah, transitional and forest agro-ecological zones of the country. The NRDP achieved significant results including the cumulative production of 56, 4000MT of paddy NERICA rice, establishment of rice milling centres, feeder road construction to create market access, block farm promotion, and marketing.

2.2 Types of Rice Production Systems in Ghana

It is very difficult for researchers and policy makers and implementers to classify rice production systems in Ghana unless they types are classified or categorized by using the agro-ecological names. The source of water used to produce rice is also used in categorizing rice production systems in Ghana. In Ghana, rice production is typologically classified as irrigated, rainfed lowland and rainfed upland. Of all these systems, lowland rainfed system of rice production is the main type followed by irrigated system.

The rainfed upland system of rice production is not common in Ghana but of late it is gaining grounds in certain areas of the country especially Hohoe and its environs. According to MoFA

(2009) and Coalition for African Rice Development (CARD) (2010), the rainfed lowland system (lowland rain-fed ecology) covers 78% of the arable land area and it involves the planting of rice in receding (withdrawing or ebbing) waters of the Volta and other rivers, the irrigated system covers 16% and the rainfed upland system covers 6%. Due to differences in environmental and climatic conditions as well as technological differences, rice yields differ according to the type of production system and the ecology. Rice produced under rain-fed ecologies records the lowest yield averaging 1.0-2.4metric tonnes per hectare while irrigated rice ecology produces the highest average yields of 4.5MT per hectare (CARD, 2010). This is due to the availability of adequate water throughout the critical stages of rice growth. The various rice production systems in Ghana are shown in table 2.1.

Table 2.1 Agro-Ecological Zones and Rice Production Ecologies in Ghana

Agro-ecological zones	Rainfall mode	Descending order of dominant rice ecologies
Interior Savannah	Monomodal	• Rain fed lowlands • Hydromorphic Drylands • Irrigated Upland
High Rain Forest	Bimodal	• Rain fed • Drylands • Swamps Irrigated
Semi-deciduous Rain Forest	Bimodal	• Rain fed drylands • Rain fed lowlands • Inland swamps
CSZ	Bimodal	• Irrigated rain fed • Lowland swamps • Rain fed drylands
Transitional	Bimodal	• Rain fed drylands • Rain fed lowland swamps • Irrigated

Source: FAO (2006)

Alternatively, Conen *et al.* (2010) classified the world's rice cropping systems according to the ecosystems under which they are produced and their flooding patterns. Under the ecosystems, Conen *et al.* (2010) noted that the world over, rice is produced under lowland, upland and deep water/flood prone ecosystems. Under lowland ecosystem, the flooding patterns are irrigated either fully or partially. On the other hand, upland ecosystem is mainly rainfed. These classifications of rice cropping systems in the world over are in tandem with classification of rice production systems in Ghana MoFA (2009).

2.3 Typology of Rice Farmers

The typology of rice farmers is based on the scale of production and access to resources. In terms of the scale of production, the area of land put into rice cultivation is used. Some farmers can cultivate only an acre of rice whereas others cultivate up to and sometimes above 6 acres of rice. Access to resources such as land, labour and credits is another criterion used for classifying rice farmers. Accordingly, rice producers are classified into four types and these are ultra-poor rice growers, marginal rice smallholders, viable small-scale rice growers and the emerging commercial growers (MoFA, 2009). The table 2.2 shows features/characteristics and the percentages of farmers with those characteristics in Ghana.

Table 2.2 Typology of Rice Farmers and Related Percentages in Ghana

Types	Main Features	Proportion of farmers (Percentage)
Ultra-poor rice growers	Dominated by female and elderly head households, are subsistence farmers who are often food insecure and are faced with labour and improved input constraints.	15%
Marginal rice smallholders	They are relatively productive compared to the ultra-poor, have more land and financial resources, produce to feed household and have small marketable surplus	25%
Viable small-scale rice growers	These are viable small-scale farmers with some levels of production resources. They are hampered by poor market access, infrastructure and unfavourable weather	40%
Emergent commercial growers	These farmers are commercially oriented who can access and use improved technologies such as irrigation systems and inputs (tractors)	20%

Source: MoFA (2009)

The rice farming household is made up of a family head who owns the land and other productive resources and household members. Farming is done by the household members based on the instructions of the family head. The members of the household are the young adults and children. According to MoFA (2009), each household was able to cultivate averagely 0.4hectares of rice in 2008 in Ghana. In that year, an approximate total number of 295,000 households engaged in rice production and they were able to cultivate 118,000ha of rice.

2.4 Challenges of Rice Production in Ghana

Notwithstanding the massive investments made by governments to promote the rice sector in Ghana and the achievements made, the sector is still beset with many challenges. Some of these challenges are enumerated below.

2.4.1 Indigenous Cultural Norms

It is often said culture is dynamic and changes to reflect the development stage of a society. In northern Ghana, the culture that women are not land owners and cannot own land affects their ability to access and own land for rice cultivation. Rice production is a monoculture in Ghana. Monoculture is the farming system whereby the same piece of land is devoted for the cultivation of one crop from season to season and year to year. This type of farming occurs when a farmer has access to land (own or rented) from the medium to long term. Women in certain parts of the country especially in the north face difficulties accessing land for long term use due to certain cultural norms.

In household decision making in agriculture, women' s role and voice are most often relegated to the background with this situation pronounced in northern Ghana due to socio cultural conditions. In addition, socio cultural inhibitions prevent women from associating with males who are not their husbands or from their households. These socio-cultural conditions affect the opportunities of women to have access to improved technology for adoption and productivity enhancement.

In Ghana, many traditional areas across the country celebrate agricultural festivals at harvest time to showcase the major crop(s) cultivated by the people to achieve foods security in the local economies. One such festival is the rice festival in the Volta Region during which several cuisines from rice are displayed. The agriculture related festivals had spiritual significance in that the people offered the crop to the gods as sacrifices to thank them for the blessings of bumper harvests. Though, these agricultural festivals serve to inspire people to look up to agriculture for food security and livelihoods, many farmers still do not consider these opportunities as offering sufficient financial incentives to undertake commercial rice production. Commercial rice production is generally hampered by low literacy levels of the farmers which affects the adoption of improved rice technologies. As a result, farmers remain adamant thereby continuing with their indigenous rice cultivation methods.

Certain perceptions held by the people especially in the North of the country has influenced to some extent the cultivation of rice on a commercial scale. Some perceptions regard rice as food for birds and not for humans. Eating rice therefore is looked down on and is ridiculed. This is because they consider starchy foods such as "*fufu*, *tuo-zaafi*, yam, *konkonte, banku"* among others as filling and satisfying foods which meet their food security needs. In some villages in Ghana, rice is considered as food for the rich and urban dwellers.

As a consequence of such widely held perceptions, some farmers do not consider large scale rice production. The low levels of consumption of the commodity and therefore demand does not create the incentives to stimulate commercial production in some traditional areas of northern Ghana

2.4.2 Land Tenure System

The land ownership system in Ghana affects agricultural production activities. In Ghana lands are owned predominantly by families. The chief as custodian of lands cannot unilaterally sell land without the family's consent and approval. Any member of the family cannot also sell any piece of land without the consent and approval of key members of the family. This arrangement where key family members have to agree to sell a plot of land for agricultural investment may involve controversies and litigation in the courts, thus taking time. Therefore, land acquisition in Ghana takes a longer time and it is also cumbersome thereby discouraging domestic and foreign investors. Agricultural investors ready to start their agricultural enterprises put their business plans on hold losing potential production and revenue in the process. In many instances, the investors abandon their efforts.

Another challenge faced by rice investors is the unwillingness of land owners to lease land for rice production because the continuous cultivation of the crop over the years renders the land infertile. This situation deprives the land owners of good deals as they must spend money to restore the fertility of the land through the application of heavy amounts of fertilizer.

Lastly, rice production is often regarded as a commercial activity and hence anybody planning to enter that business needs to acquire large hectares of land. In Ghana, lands are owned in fragments by families. It is not an easy task for one to convince families whose lands are adjoining to sell or lease them in large quantities. One family may agree to sell the land whiles the other whose land is next to the land acquired may not be ready to lease his or her land. Most at times, commercial farmers get lands in fragments which are dotted all over but not adjoining. It is more expensive for one to cultivate lands which are dotted as compared to cultivating lands which are adjoining.

2.4.3 Changes in Environmental and Climatic Condition

It is worth noting that currently, rice is the most important staple crop globally. Over 532 million tonnes of rice is consumed by the world's population (Angelucci *et al.,* 2013) making rice a global food security crop. Against this background it has become an issue of great concern that rice production is facing serious challenges due to inadequate rainfall or unreliable weather conditions in many parts of the world. Meanwhile, rice production is facing serious challenges of scarcity of water due to inadequate rainfall or unreliable weather conditions. As a water loving (hydromorphic) crop, it cannot be produced without sufficient water (either rain or irrigation water). With upland and lowland rice production systems in Ghana heavily dependent on rainfall, the domestic rice sector appears to be at great risk considering the evidence that rainfall amounts in the country has been decreasing over the years. It is therefore not an exaggeration to indicate that the already low on farm rice productivity will likely worsen with changing climatic and environmental conditions especially in the north where such conditions are severe.

To overcome this challenge, different water saving rice production technologies (drought tolerant varieties, soil bunding, mulching etc) should be developed to support rice production in the country. More importantly, the country should invest in developing large irrigation facilities for smallholder farmers to use and reduce the impact of low rainfall amount.

2.4.4 Low Adoption of Technologies

Ghana is still struggling to benefit from the "Green Revolution" type of technologies such as high yielding rice varieties, mineral fertilizer and pesticides which transformed agriculture in Asia during the 1960s. Assuming-Brempong *et al.* (2011) posit that adoption of improved varieties of rice especially NERICA variety in Ghana is very low in some areas of the country. Marfo *et al.* (2008) and Assuming-Brempong *et al.* (2011) identified formal education and extension contacts as principal factors influencing adoption of improved rice varieties. Consequently, the benefits of adoption of improved rice varieties are not fully realized in Ghana as majority of rice farmers are not educated. To increase exposure of farmers and improve upon the adoption of improved NERICA rice variety, Assuming-Brempong *et al.* (2011) recommended that efforts and resources should be invested in promotional activities.

Education as a factor facilitates the understanding of people on the use of improved technologies. Farmers who have had formal education are likely to easily understand and assimilate the promotional activities on technology adoption. Therefore, level of education plays a key role in rice technology adoption.

2.5 Rice Productivity Enhancement Technologies

Rice productivity can be improved using certain improved technologies. Most of the technologies come as packages with accompanied good agronomic practices.

2.5.1 Modern Rice Varieties

Through efforts of research institutions in Ghana and other international research institutions, modern and highly improved varieties of rice have been developed. Most of these varieties of rice have been developed with project support from donor agencies (now called partners). The modern high yielding rice varieties have other qualities such as high milling recovery, draught resistance, high grain quality, good tolerance to biotic and abiotic stresses, high yielding, perfumery attributes etc.

Through IVRDP in Ghana, five improved rice varieties (Jasmine 85, ARC Baika, Marshall, ITA 324 and Bouake 189) were developed by experienced scientists. These varieties went through some many stages before they were certified and released to farmers for adoption. Aside this, many other rice improved rice varieties have been developed. To support Government of Ghana's objective/agenda of reducing rice importation, the Crop Research Institute of Ghana (CRIG) of Centre for Scientific and Industrial Research (CSIR) which is located at Femesua in Ashanti Region has developed and release high improved rice varieties; Marshall perfume, ITA 320 among others.

Considering environmental conditions of Africa, the West African Rice Development Association (WARDA) developed the first ever NERICA variety in 1994. It is a high-yielding variety which thrives well in upland ecology because of its resistant to draught, pests and diseases. Even though it is the West African rice type, *Oryza glaberrima*, it was developed to have a higher yielding potential of the Asian species, *Oryza sativa* (Kijima *et al.*, 2006). As of December 2005; through farmer participatory varietal selection trials, WARDA named 18 different NERICA varieties and made them available to farmers (WARDA, 2009).

2.5.2 Fertilizer Management Technologies

Over the years, research institutions within Ghana and outside the country have worked assiduously to develop fertilizer management strategies for rice. The strategies include the use of appropriate timing of fertilizer application, recommended quantities and typologies. The moisture content at which fertilizer should be applied had also been established by research scientists. It is important to put on record that fertilizer management methods are linked with quantity and quality of output the farmer expects to obtain. Irrespective of these, in rice production the fertilizer management technologies should be applied with the objective of increasing rice yield and reducing the production costs.

Fertilizer improves soil fertility thereby making nutrients available for rice plant intake. Rice plant absorbs both major and minor elements and uses these elements for photosynthesis, growth, diseases protection and tasselling.

2.5.3 Water Management Technologies

Water management technologies are also very important in rice production. Under the irrigation method, it is important for the farmer to intermittently irrigate the land up to 5 cm every 14 days. Meanwhile, the amount of water to be irrigated depends heavily on the stage of growth of rice, type of soil and amount of natural rainfall recorded. It also depends on the type of rice. Rice is a hydromorphic crop and hence a decision conceived by a farmer to enter its production must not be taken without due diligence to how the crop will get enough water to grow and yield well.

2.5.4 Quality Seeds

It is necessary to use modern rice varieties such as Marshall Perfume, ITA 320, Jasmine 85, ARC Baika, ITA 324 and Bouake 189 to increase rice yield. Nonetheless, it is not sufficient to focus on modern rice varieties without examining the quality of the seed. Certified rice seeds have certain qualities that distinguish them from the ordinary seeds. The certified seeds should also be disease resistant and should have uniform maturity.

Considering the fact that rice thrives well in waterlog soil conditions and the dependence of the majority of rice farmers on natural rains, it is important for rice seed to be draught resistant with early maturity feature. If the cost of certified seeds does not outweigh the benefits of using certify seeds, then it is financially prudent for farmers to use certified seeds rather than the old practice of using home-saved seeds.

In Ghana, the availability and accessibility of high-yielding quality or certified seed need to be established. These seeds need to be made available and accessible to farmers in all corners of the country. If this is not the case, the cost associated with searching for certified rice seeds, cost of transporting the certified seeds, as well as cost of purchasing these seeds have the tendency of discouraging rice farmers to adopt such technology irrespective of the benefits.

In some jurisdictions (e.g. Philippines), governments, research institutions and other stakeholders in the rice value chain had implemented policies and programmes which led to the development of a strong certified seed production market. The backstopping of certified rice seed producers needs to be done by MoFA. The input dealers need to adopt the practices of selling certified seed to farmers on credit so that they can pay after harvesting. This will establish the market for them since more farmers will be encouraged to take advantage of that system. In a bid to establish a vibrant certified rice seed production unit through the inland valley Rice Development Project, 50 farmers were trained on the production of good quality seeds across the country in the various irrigation schemes.

2.5.5 Hybrid Rice

A breakthrough in rice production technology has been the development of hybrid rice. The development of hybrid rice is part of the green revolution. Hybrid rice is any rice produced from a cross breeding of rice of different features. Hybrid rice has higher yield. The development of hybrid varieties of crop is not a new technology, but the hybrid rice technology development posed a challenge to scientists due to the self-pollination character of rice. With the high-yielding attribute of hybrid rice, if policies are put in place to entice farmers to adopt the cultivation of hybrid rice, Ghana can produce enough to meet the domestic demand.

The hybrid rice technology is labour intensive. As such, it has the tendency of providing rural employment and income generation. Therefore, its use must be thought thoroughly. Irrespective of the environmental conditions or soil conditions hybrid rice can do well in some adverse ecology.

2.5.6 Farm Machinery

FASDEP and METASIP as agricultural policy documents had the objective of modernizing agricultural sector in Ghana through mechanization and technology adoption. It is sad to note that, in this millennium years of technology advancement, agricultural mechanization in Ghana is inadequate and sometimes it is totally absent among subsistence rural farmers. Agricultural modernisation is still at an infant stage in Ghana. Every production activities of rice can now be done mechanically, but this is not the case in a country that prides herself as agriculture based.

In Ghana, small holder farmers who are the majority only adopted the use of tractor for land preparation and the spraying of pesticides/herbicides with knapsack sprayer. They are however ignorant about farm implements used for transplanting, direct seeding, harvesting, moisture testing, drying, threshing, milling and irrigation. Since most farmers do not use these farm machineries, they do not get their benefits. Some of the farming implements inherently increase the efficiency levels of the activities and hence reduce the post-harvest losses leading to reduction of production costs. There are inexpensive farm machineries such as rototiller for land preparation, power tiller-drawn, paddy seeder and drum seeder for direct seeded field seeding, rotary rice reaper, striper harvester, thresher-sheller and panicle thresher for harvesting, bamboo bin dryer among others which farmers could have used.

CHAPTER THREE

LITERATURE REVIEW

3.1 Introduction

This chapter reviews literature on thematic areas related to the study. The thematic areas include *FISs*, *IATs*, principal component analysis (PCA), and theoretical and empirical review of stochastic metafrontier and multinomial endogenous switching regression models.

3.2 Decision Making and the Motivation for Innovation/Technology Adoption

Decision making is defined as the process of rationally reasoning and making a logical choice from the list of available opportunities or options. Consumer behaviour plays a crucial role in decision making and motivation for technology adoption. How a consumer behaves informs the decisions he/she takes. Plausible decision making depends on the rationality of the individual and his/her ability to decipher the bad from the good. One must also have the ability to forecast the outcome of each option. From this explanation, the elements of decision making are reasoning (thinking), processing, making choices and receiving the results (outcome).

Psychologists regard decision making as a cognitive process which involves the brain. The rationality of an individual decision making requires that the decision maker has significant, if not full or explicit knowledge about the possible outcomes of each of the options available. For technology to be adopted, decisions must be taken. According to Rogers (1983), adoption involves the use of new improved technologies (innovations) by a producer at a given time. The adoption could be partial or complete. The adoption of any innovation or technology is done by any decision maker (firm or consumer or government) in anticipation for maximising utility or desirable results.

In agricultural production, the behavior of a farmer can be analysed using a production function, cost function, profit function or supply function. The farming households' objectives are linked to the behaviour of the decision maker. Economic theories have it that farm households aim at maximizing one or more household objectives (Mendola, 2007), subject to some constraints.

3.3 Theoretical Conceptualization of Adoption and Diffusion of Innovation and Technology

From the preceding section, innovation or technology adoption involves decision making which is a cognitive process. Cognitive models and theories of technology adoption are traditionally linked to attitude formation and social psychology (Michelsen and Madlener, 2013).

To decisively agree to adopt a technology, an innovation or a practice, one perceives the benefits accruing from the adoption as significant enough to outweigh the benefits from the alternative option. One's belief is that the opportunity cost of taking the alternative decision is too high and significant. Realistically, external factors such as socio-cultural environment, economic factors, as well as regulatory or institutional factors have the tendency of influencing one's adoption decision. Cognitive and normative decision models do not capture these extrinsically influencing factors. To deal with this, Rogers developed Rogers' diffusion of innovation model (DIM) (Rogers, 2003). The diffusion of innovation spread through social communication processes (factors extrinsically controlled but not intrinsically controlled).

Rogers' diffusion of innovation model has been widely accepted due to the ability of the model to systematically characterize innovation. Also, Rogers (1962) and Feder *et al.* (1985) classified stages of adoption of agricultural innovation as awareness stage (hearing about the innovation), evaluation stage (collecting information about the expected benefits of innovation), trial stage (experimentation of the innovation) and finally adoption stage. The awareness stage is the stage were farmers are being sensitized on the innovations. After the creation of the awareness, data is collected from the farmers and evaluated to know their perception about the expected benefit of the innovation (i.e. evaluation stage). During the trial stage, early adopters try to experiment to know whether the benefit of the innovations is better than the existing indigenous way of farming. After they are convinced that the benefit of the innovation outweighs their indigenous way of farming, they adopt the innovation.

Rogers (1983) distinguished between adoption and diffusion. According to him, adoption involves the use of new or improved technologies (innovations) by a producer at a given time. On the other hand, he defined diffusion as the process of communicating or transferring technology (innovation) from one person to another member of the society through specific channels or space over a period. The four elements in these two definitions are the improved technology (innovation), the communication channels, the social structure (members of the society) and the time. The innovation need to be communicated to the target group through channels like mass media or face-to-face interaction, so the choice of appropriate channel is crucial. The characteristics of the target group which help in selecting the appropriate channel of communication defines the social structure. The appropriate time of delivery of the information about the innovation is also key. This is to ensure that the target population fully participate and understand everything about the innovation.

The models of technology adoption are countless. Another model called technology acceptance model (TAM) was developed by Davis *et al.* (1989). With TAM, technology or innovation adoption is principally determined by the adopters "perceived benefit/usefulness" or "perceived ease of use" of the innovation or technology (Davis *et al*., 1989). The work of Michelsen and Madlener (2003) conceptualizes that technology or innovation adoption is influenced by the perceived ease of use, trialability, result demonstrability and compatibility with societal norms. The innovations are also voluntarily adopted or rejected.

3.4 Indigenous Farming Practices, Farmer Innovation Systems and Improved Agricultural Technologies

Farmers all over the world have specific *IFPs* which they are used to and are comfortable with. From the time of hunting and gathering to subsistent agriculture through to the agricultural intensification and commercialization era, farmers have in one way or the other maintained some of the *IFPs*. However, some of these practices have been modified and improved to ensure higher productivity or efficiency.

The improvement in the management of any organization in this 21st century is hinged on the ability of the organization to develop innovations which make the organisation unique. The innovations developed allow the organization to carve a niche for itself. Similarly, agricultural productivity improvement can be done directly from the improvements in the farming practices used by local farmers. Farmer innovations, which according to World Bank (2011) are critical to improving agricultural productivity, have not been fully harnessed in developing countries including Ghana. Some of these innovations are developed or discovered consciously or unconsciously without using a systematic process (which is characteristic of scientific process). Since some of these innovations are non-scientific, they cannot be verified using scientific methods. Despite this gap, farmers still adopt the innovations they have developed in attempt to improve their productivity.

Even though Rogers (2003) used the word "technology" and "innovation" as synonyms, there are differences between them. The succeeding subsections describe *IFPs*, farmer innovations and improved farming technologies. Alongside the efforts of farmers to improve their own productivity through innovations, formal scientific research is being undertaken to achieve same objective. This has resulted in the developments of *IATs*.

3.4.1 Indigenous Farming Practices

IFPs are local knowledge which are not easily discarded, traditional practices in agricultural production which emanated from local knowledge and transmitted to local farmers in specific geographical zones. It is important to note that due to the fact indigenous farming practices emanate from the efforts of several people and are not documented, no individual or group can claim ownership or patenship. Despite the massive scientific research which has been ongoing and the Green Revolution, *IFPs* still continue to exist. The most commonly used IFPs are mixed cropping, shifting cultivation, mono-cropping, farm yard manure, closer planting, use of hoe and cutlasses, setting of traps, and using of scare crow among others.

3.4.2 Farmer Innovations Systems

In respect of farmer innovations to improve productivity, rice farmers in Ghana have over years engaged in selective combination of different varieties to produce uniquely high-yielding varieties. In other innovations, farmers have developed different types of storage practices such as storage of rice in pots, barns, etc. According to Tambo and Wunscher (2014), some farmers store seeds of crops in bicycle tubes, some use pepper and *neem*[1] (*Azadrata indica*) extract to treat seed before storage.

There are various descriptions that have been given to farmer innovations. The most appropriate one for this study is conceptualized from World Bank's definition. According to World Bank (2011), farmer innovations are dynamically improved IFPs which are consciously developed or unconsciously discovered by local farmers with or without the main objective of improving agricultural productivity. Farmer innovations can conveniently be referred to as local innovations. According to Prolinnova (2004), local (farmer) innovations are dynamically modified indigenous knowledge which emanate and grow within a social group through incorporating learning experiences from generation to generation. It also includes internalization of external knowledge into local settings. Farmer innovations include techniques or practices or processes which are not technical in nature. Wills (2012) stated that "whilst invention often concerns a single technique or technology, innovation frequently involves the combination of existing techniques or technologies in new ways to enhance their impact". They can be applied in everyday life of farming households.

---

[1] Neem is a medicinal tree which is very bitter.

Indigenous and local farmers are not only adopters of externally developed innovations but rather they are also innovators. The process and ability of developing or discovering or inventing an improved way of doing things is an innovation. With innovations, an organisation or individual can carve a niche and advance in the process of doing things. Innovations involve the adoption of new knowledge, technology or practice without assurance of expected outcome or result. As such, innovators are risk lovers. Some innovators are initiators, others are not. Some of the local farmers are innovators and others are initiators of innovations.

Farmer innovations are obtained through experience. Farmer innovations involve the use of new and more effective ideas or practices for agricultural production and marketing activities. The main aim of farmer innovations is the improvement of agricultural productivity for the betterment of indigenous farmers. Farmer innovations are supposed to be original, but sometimes they are not. They are those practices which have never been applied. Sometimes, indigenous farmers try to experiment certain newly discovered wild varieties of crops or try to domesticate wild animals. Farmers also use local material for soil moisture conservation, soil fertility management, weed control and pest and disease control. Through rice farming experience, many farmer innovations are applied by farmers to help them improve upon land preparation, seed planting or nursing, storage of rice, pest control and fertility enhancement.

Farmers in different agro-ecological zones are likely to have different localized *FISs* which are unique due to specific agro ecology. Thus, some farmer innovations are agro-ecological zone specific while others are farmer specific. Despite this situation, farmer innovations tend to spread across agro ecological zones. Due to commonalities in farming practices, crop varieties, socio-economic conditions etc, farmers in the different agro-ecological zones adopt these innovations. It is important that the spread and adoption of these common innovations across the agro-ecological zones are estimated to determine their impact. Recommendations emanating from these researches will provide the basis to further improve the innovations as this is critical to productivity enhancement.

The recognition of farmer innovations is critical to incentivizing local farmers to exercise ingenuity (Tambo and Wunscher, 2014). Teeken *et al.* (2012) opined that farmers' have over the years innovated and developed crop varieties, but their processes of innovation continue to remain almost invisible to research and development organizations in the formal seed improvement sector.

3.4.3 Improved Agricultural Technologies

Generally, technologies emerge from innovations. The definition of technology depends on the field. The universally accepted definition can be traced to the work of Rogers (2003). Rogers (2003: p. 13) defined technology as "a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome". Rogers (2003: p. 259) explained that technology has a hardware component which is "the tool that embodies the technology in the form of a material or physical object," and a software[2] which is "the information base for the tool".

[2] Since software (as a technological innovation) has a low level of observability, its rate of adoption is quite slow (Sahin, 2006).

The concept of IATs emanated from farmer innovations. Researchers over the years observed innovative ways that farmers employed by combining and modifying IFPs for improved agricultural productivity. Some of the IATs stressed the need for specialized production, crop monocultures, mechanization (the use of modern farm machinery such as tractors, harvesters, threshers, etc.), development and use of improved seeds [high-yielding varieties (HYVs)], the use of pesticides and chemical fertilizers, and the construction and use of irrigation systems (Altieri, 1995 and Macmillan Reference, 2006). IATs can be effective when they are developed to suit the needs and priorities of the targeted local farmers.

Modern plant breeding of wheat started in 1940s in Mexico through the Green Revolution. The intensive invention, introduction and promotion of IATs started in 1950s and this was done by hierarchical institutions led by the state and corporations (Buckland, 2004). In the 1960s, national modern rice breeding programmes were established in countries such as Japan, China, Taiwan and Philippines (Buckland, 2004). The Green Revolution started in Asia and Latin America through the development of chemically responsive seed and appropriate chemically improved input technologies. Through the Green Revolution, the public sector in Asia and Latin America established International Rice Research Institute (IRRI) in the 1960s in the Philippines, resulting in the development of many highly improved rice technologies (Buckland, 2004).

Agbanyo (2012) and Bloom *et al.* (2009) noted that though technologies play significant roles in improving agricultural yields, their developments are reflections of the interests of the sponsoring corporations and their supporting institutions. Most of these technologies are patented and their use requires constant purchase from their originators.

The development of *IATs* seeks to achieve the known objective of firms, namely economic profit maximization. Simply, the use of *IATs* such as intensive tillage, monoculture, application of inorganic fertilizer, irrigation and agro-chemicals increase agricultural productivity and maximize economic benefits. These *IATs* are not mutually exclusive. The fundamental and direct reasons for the development of these technologies are to reduce drudgery, labour constraints and make plant nutrient readily available. For instance, irrigation as an improved agricultural technology aims at providing optimum quality water for crops all year round. Irrigation technology also supplements inadequate rainfall water for improved crop yield. Pesticides are applied to minimize crop damage by pests to economic threshold level.

Though the emergence of *IATs* had led to dramatic results in agriculture development, there are several issues concerning their adoption. One such critical issue is the affordability of *IATs* to smallholders. On account of this and other issues, farmers sometimes mix the *IFPs*, *FISs* and *IATs*. In the next section, how principal component analysis (PCA) is used to classify farmers based on adoption of *IFPs*, *FISs* and *IATs* is described.

3.5 Quantitative Approach to Classifying Farmers into Technology Adopters: Principal Component Analysis (PCA)

Due to differences in the contributions of adopted technologies to output in each of the technology packages, it is often misleading for one to count the number of practices or technologies adopted and used it as a measure of the intensity of adoption. The best way is to use the empirical results to generate weights for the measurement of the intensity of adoption. With that, farmers can objectively be classified into different technology adopters. Principal

Component Analysis is one of the best statistical techniques used in generating weights and grouping variables (Han, 2010)

PCA is a statistical estimation procedure in which many correlated variables are converted into smaller number of linearly uncorrelated or correlated variables called principal components. According to Han (2010), PCA is one of the most commonly used selection algorithms to reduce data dimensions, remove noise, and extract meaningful and interpretable information for further analysis. It reduces the number of variables into a few composite variables called principal components. As such, the number of principal components after the analysis is smaller than the number of correlated or uncorrelated variables started with. PCA is an exploratory research method which determines the number of explanatory variables (constructs) which are weakly correlated or strongly correlated and can be used for further analysis (Filmer and Prichett, 2001)

PCA originated from the work of Karl Pearson in 1901 and it was developed and named by Harold Hotelling as principal component analysis in 1930s. With PCA, there is no need for a researcher to unrealistically assume weights or use a subject matter specialist who subjectively assumes weights for variables. Umeh (1990) opined that the model reduces the dimensionality of the variables which consequently constructs the relative contributions (coefficients) of each variable to the composite variables.

As noted by Filmer and Prichett (2001), PCA solves the problem of assigning equal weights to all variables. PCA involves the extraction of components of variables which are weakly correlated or uncorrelated. The computed factor scores are used to extract factor rotations of variables into interpretable principal components. It also includes statistical testing. The components of strongly correlated variables can also be extracted. Two variables are non-collinear when they have zero correlation thereby making them non-factorable.

Bartlett's test of sphericity is used to test for the adequacy of correlations between variables. It involves the calculation of the determinant of matrix of sum of products and cross-products, which is equivalent to Chi-Square statistic. If the Chi-Square value calculated is greater than the critical value, the null hypothesis that the inter-correlation matrix is an identity and hence the variables are non-collinear is rejected in favour of the alternate. The extraction process depends on the type of rotations. Note that in PCA, the communality of a variable is the sum of squares of the factor loadings whereas a factor loading is the correlation between a variable and a factor (component).

Assumptions underlying PCA

1. There are multiple variables
2. Linearity between variables: There are linear relationships between any of the variables. This is because PCA is based on Pearson correlation coefficients.
3. Sample size adequacy: The sample size should be adequate (at least a sample size of 50 with at least 5 variables). This can be established using the Kaiser-Meyer-Olkin test of sample adequacy.
4. Factorability: There should be adequate correlations among variables for data reduction. This can be tested using Bartlett's sphericity.
5. The number of outliers should not be significantly high to reduce heterogeneous influence on the results.

3.6 Meaning of Efficiency and Productivity

Often, many people fail to draw a line of distinction among efficiency, efficacy, and effectiveness. In economics, Farrell (1957) defined the efficiency of a firm as the capacity of the firm to produce output using a given amount of inputs. The degree to which inputs (time, efforts, cost) are well used to produce a given level of output is called efficiency. Generally, efficiency is defined as the level of performance. Efficiency links input to output in a production process. It describes the extent to which inputs are used to produce a certain given level of output. For a firm to be efficient in production, there must be a technical relationship which establishes a linkage between inputs and outputs. Efficiency is a quantitative measure which is defined as the ratio of output per unit input. Time is of essence in the definition of efficiency. Production efficiency is made up of technical and allocative efficiencies. As noted by Farrell (1957), technical efficiency is the ability of a firm to maximize output for a given set of resource inputs, whereas allocative (factor price) efficiency reflects the ability of the firm to use the inputs in optimal proportions given their respective prices and production technology. Efficiency in this study is the ability of a firm to produce maximum attainable output given a certain level of minimum inputs at a certain period.

Most people, even management of companies and renowned researchers use efficiency and effectiveness interchangeably. It should be noted that effectiveness is relatively less quantitative as compared to efficiency. While efficiency is the measure of the ratio of amount of resource produced to the amount of resource used, effectiveness is the ability of successful production of expected results. Effectiveness does not look at how the expected resources are produced. This implies that cost of producing the desirable output is not considered when it comes to the measurement of effectiveness. In a layman's understanding, "doing things right is described as efficiency but doing the right thing is described as effectiveness." Effectiveness measures the degree of results or expected outcome. In labour economics, efficiency tends to examine the use of least quantity of labour to produce higher level of output.

Productivity is another concept in economics which is very important to management of firms, government or any other organization. Efficiency and productivity are two terms which are used interchangeably to mean the same thing by many people. Lovell (1993) defined productivity as the ratio of output to input. This definition does not incorporate the quality level of the output. In fact, productivity is defined as the ratio of quantity and quality of output produced per unit input(s). The quality included in this definition is very important in this study. This is because the rice output considered in the study does not include quantity of consumable or saleable (marketable) output. Output can generate positive or negative externalities. After the seminal paper of Farrell (1957), productivity and efficiency studies have received enormous attention by researchers.

Productivity can be measured for a firm using multiple factor inputs to produce a single output or multiple outputs. In a situation when the productivity is measured as the quantity and quality of output per unit of a single input, it is called partial factor productivity. On the other hand, total or global productivity is a measure of output or aggregated output per aggregated factor inputs.

3.7 Approaches to Estimating Efficiency

In any field of study, it is often possible, but difficult, to trace the original proponent of an idea. The case is not different in economics. Production efficiency of firms became necessary when managers of firms, organizations and public agencies realized that some production units within organization or firm have better productivity performances than others. The increase in competition among firms or government agencies within the same industry has necessitated the quest for improved efficiency. To measure efficiency performances of firms, one needs to use the appropriate approaches.

There are three approaches to measuring or analysing efficiencies of firms. These according to Coelli *et al*. (1998) are parametric techniques (deterministic and stochastic), non-parametric techniques (data envelopment analysis, DEA), and semi-parametric techniques (productivity indices using growth accounting and index theory principles). Efficiencies are measured to enable firms plan and set targets for future productivity improvement. With well estimated efficiencies, management of firms can identify the best practices and reorganize factor inputs and other resources for their efficient allocations and reallocations.

3.7.1 The Parametric Approach (Stochastic Frontier)

The concept of stochastic frontier analysis can be traced back to the work of Koopmans (1951). Koopmans (1951) noted that for a firm to be technically efficient, the firm must be able to produce more output using less input. The observation that the distance between the frontier production function and the observed production function is the measure of technical efficiency was made by Debreu (1951). These revelations brought about a dramatic change or breakthrough in the methodologies of frontier analysis. Following the work of Koopmans (1951), Debreu (1951) and Farrel (1957) empirically estimated productive efficiency (technical efficiency) using stochastic frontier analysis (parametric approach). This approach is more appropriate as it indicates that inefficiencies of farmers are not only determined by factors under their control but also factors beyond their control. The procedure involved in this approached is explained in the methodology of this study (chapter 4).

3.7.2 Non-Parametric Technique: Data Envelopment Analysis (DEA)

In non-parametric technique, parameters[3] used in the model are infinite. The number of parameters is not fixed. It is always difficult to determine the total number of parameters. There is a branch of statistics called nonparametric statistics in which parameters are estimated without probability assumption about the variables. Data Envelopment Analysis (DEA) is a non-parametric approach which can be used to measure the production efficiency of firms.

DEA is a non-parametric approach which uses mathematical or operations research programming technique for the estimation of efficiency performance of decision making units (DMUs[4]). The model was first initiated by Farrel (1957). Even though Brockhoff (1970) was the first to use the DEA model to estimate the marginal productivity of research and development in Germany, Charnes, Cooper and Rhodes are credited for its development. In a seminal paper entitled "measuring the efficiency of decision making units", Charnes *et al.* (1978) used DEA. DEA is often referred to as CCR model in recognition to the official developers; Charnes, Cooper and Rhodes.

The DEA model is a benchmarking model (Cook *et al*., 2014) which does not require knowledge of the functional form of the production function. Managers of companies and supervisors of public agencies aim at achieving higher efficiencies given the available resources and technology.

---

[3] Parameters are characteristics which can be measured and explicitly explained.

[4] DMUs are firms who are homogenous in certain principal features (technology, processes, location etc.) and they are defined as business units (branches of banks, companies within the same industry), government agencies etc.

This is usually done by comparing relative efficiencies of firms in an industry. DEA cannot be used to calculate absolute efficiency, but rather relative efficiency.

As a linear programming technique, DEA uses an optimization approach in determining efficiency. The direction of the target function determines which optimization approaches should be used. The input-oriented model involves the use of a cost minimization procedure and this is since firms reduce the quantity of inputs given certain level of output. For the output-oriented model, output maximizing is used, and this involves increasing output given a combination of some level of inputs. With nonlinear programming, the objective function "the ratio of weighted outputs to weighted inputs of a DMU under consideration" is maximized subject to the constraint that there is no any other DMU within the sample that has greater unit efficiency weights. The firms that have efficiency of one (1) form the frontier which envelopes all DMU in production space. DEA model is also used based on the returns to scale. We have constant returns to scale efficiency measurement and variable returns to scale efficiency measurement. These two classifications result from the assumptions the researcher makes about the level of proportionality changes in output in response to the change in input.

DEA has strengths and weaknesses. It is a model which can be used to measure efficiency of multiple inputs and outputs expressed in different measurement units. DEA is used to construct production frontiers and measure the efficiency relative to the constructed frontiers. In Charnes *et al*. (1978), efficiency is a ratio of weighted sum of outputs to weighted sum of inputs. Their model is appropriate when the inputs are in constant returns to scale. This was a major limitation of the DEA model. To deal with this limitation, Banker *et al.* (1984) developed a model with variable returns to scale.

As a nonparametric approach, DEA assumes that variations in productivity performance of firms are because of inefficiency. This model failed to recognize that uncontrollable factors of management of firms such as measurement errors, omitted variables and shocks from weather can cause inefficiency. Since DEA is not a statistical technique but rather a mathematical programming tool, it can be applied to any type of data be it qualitative or quantitative data.

3.7.3 Semi-Parametric Techniques

Semi-parametric techniques of estimating firm efficiency performance are many. For semi-parametric techniques, the parameters are both finite and infinite. The use of productivity indices, growth accounting and index theory principles are semi-parametric techniques (Del Gatto *et al*., 2011). The semi-parametric techniques of estimating efficiency performances of firms are not common in the literature.

3.8 Theoretical Review of Metafrontier Analysis

The theory of production is used to explain metafrontier analysis. Metafrontier analysis was first conceptualized and used by Hayami in 1969. In his study to determine the sources of agricultural productivity gap among selected countries, Hayami (1969) first mentioned metaproduction function. Two years later, Hayami and Ruttan (1971) defined metaproduction function as the "envelope of commonly conceived neoclassical production functions". Technically, the commonly conceived neoclassical production function is the production function obtained from firms producing a common output by using homogeneous technology, inputs, as well as producing under the same environmental conditions within the same period. The production function is a technical relationship which shows the maximum physical output that can be produced from a given level factor inputs given the technology at a time

Undisputable, Hayami and Ruttan are the official pioneers of the concept of metaproduction function. Meanwhile, Hayami and Ruttan acknowledged that the original conceptualization of metaproduction is inherent in the early works of Salter (1960) and Brown (1966). In a research to determine agricultural productivity across countries, Ruttan *et al* (1978) defined "metaproduction function as the envelope of the production points of the most efficient countries".

The theory of metafrontier analysis is since firms in different industries, regions and/or countries face different opportunities (O' Donnel *et al.*, 2008). Instead of the homogeneous assumption of production technology, resource endowments, climatic conditions etc. made by Farrel (1957) about firms, it is possible to have the opposite assumptions.

Measures of productivity performances defined in the seminal paper of Farrel (1957) are technical efficiency, allocative efficiency and economic efficiency. According to Farrel (1957), productivity performances of firms can be obtained by determining the production frontier. This is not the case for firms operating using different technologies, inputs or operating under different environmental conditions and time. Battese *et al.* (2004) theoretically opined that metafrontier, which originated from Hayami's metaproduction function, is a benchmark production function which envelopes all group-specific production frontiers. All possible combinations of inputs to produce outputs by groups of firms operating with different inputs, technologies and under different environmental conditions define the metatechnology set. A metafrontier is an overarching benchmark function that incorporates different groups of firms using different specific technologies. It allows for the calculation of group-specific efficiencies for firms producing under different technologies and comparing them with potential technology for all the groups within the economy.

Theoretically, metafrontier production function is used when it is hypothesized that all group-specific firms (firms in the same location or firms using similar technology) have the potential to access and use the same technology or inputs or to work under similar environmental conditions. The contributions of early researchers to the development of metafrontier analysis cannot be under estimated. After the use and modification of the metaproduction function, Hayami and Ruttan (1970) and Hayami and Ruttan (1971) adopted and empirically used metaproduction function to analyse and compare agricultural productivity across countries. As the frontier production function is related to the frontier cost function, the metafrontier production function is also related to the metafrontier cost function.

3.8.1 The Stochastic Metafrontier Production Model

The productivity performances of farmers in different agro-ecological zones can be estimated using the stochastic metafrontier production model. The stochastic metafrontier production model is built on the work of Hayami (1969) and it is another form of model which is used in metafrontier studies. The model is an improved version of the Farell (1957) classical stochastic frontier model. Unlike the stochastic metafrontier cost model, the stochastic metafrontier production model uses outputs and inputs in their raw values but not cost in monetary values. A metafrontier production function is a smooth production frontier representing potential technology that envelopes group specific frontiers. Graphically, the metafrontier production function is shown in figure 3.1.

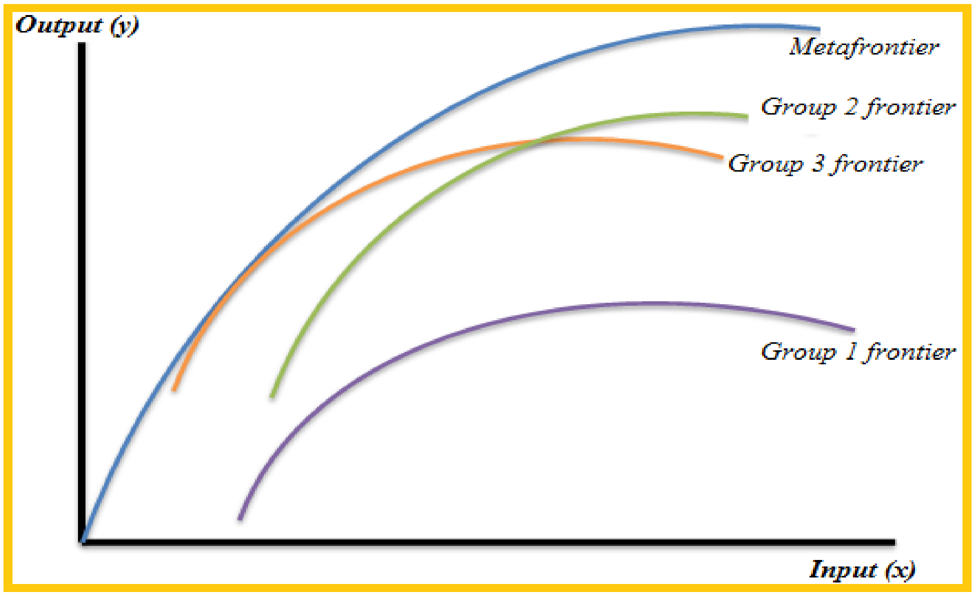


Figure 3.1 Illustration of Metafrontier

From the conceptualization of Battese *et al.* (2004), group specific stochastic production frontier models and stochastic metafrontier production model are respectively specified as in equations 1 and 2 below.

$$y_i^k = f^k(x_i, \beta^k)e^{v_i^k - u_i^k} = e^{x_i\beta^k + v_i^k - u_i^k} \quad [1]$$

$$y_i{*} = f{*}(x_i, \beta{*})e^{v_i{*} - u_i{*}} = e^{x_i\beta{*} + v_i{*} - u_i{*}} \quad [2]$$

Where:

y^k is group *k* output, *x* is a vector of inputs, v_i^k and u_i^k are the error terms for firms in group *k*, β^k is a vector of unknown parameters for group *k* firms. Contrariwise, *y** is metafrontier output and $v_i{*}$ and $u_i{*}$ are error terms for metafrontier and $\beta{*}$ is a vector of parameters of the metafrontier.

From equation [1], group specific technical efficiency can be obtained by dividing the observed output by the frontier output[5]. The frontier output and the observed outputs can be used to estimated productivity performance of a firm.

[5] The frontier output equation is similar to that of observed except that the former does not have the second error term *u* which measures the inherent inefficiency of the firm.

For instance, one can analyze productivity performance indices of firms in group 1. The technical efficiency of firm *A* in group 1 (TE_A^1) is given as

$$TE_A^1 = \frac{\text{Observed output of firm A}}{\text{Frontier output of group 1 firms}} = \frac{y_A^1}{y^1} = \frac{f_A^1(x,\beta^1)e^{v^1-u^1}}{f^1(x,\beta)e^{v^1}} = -u^1 \qquad [3]$$

Also, with output-oriented efficiency, the TGR of firms in group 1 cluster (*TGR*^{l}) can be estimated as:

$$TGR^1 = \frac{\text{Frontier output of firms in group 1}}{\text{Metafronti er output}} = \frac{y^1}{y^*} \qquad [4]$$

Lastly, the metafrontier technical efficiency score (*MFTE*) or the technical efficiency relative to metafrontier (TE^*) can be measured using the equation.

$$TE^* = MFTE = \frac{\text{Observed output of firm A in group 1}}{\text{Metafronti er output}} = \frac{y_A^1}{y^*} \qquad [5]$$

From the above, the stochastic metafrontier production function can be estimated using the pooling stochastic metafrontier model, the two-step mixed model and the new two-step stochastic metafrontier model. The first two are discussed in the next subsections of this chapter, while the latter which this study used is discussed in the methodology.

3.8.1.1 The pooling stochastic metafrontier model

This model was proposed by Battese and Rao (2002). For this model, all the group data are pooled together and used to estimate the stochastic metafrontier as:

$$y_i{}^* = f\left(x_i, \beta_i{}^*\right)\ell^{V_i{}^*-U_i{}^*} = \ell^{x_i\beta_i{}^*+V_i{}^*-U_i{}^*} \qquad [6]$$

Where $\beta_i{}^*$ is a $(L \times 1)$ vector of parameters for metafrontier production function, $V_i{}^*$ and $U_i{}^*$ are the relevant error terms which respectively represent uncontrollable random noise and controllable metafrontier technical efficiency.

Given group specific frontier model:

$$y_i^k = f\left(x_i, \beta_i^k\right)\ell^{V_i^k-U_i^k} = \ell^{x_i\beta_i^k+V_i^k-U_i^k} \qquad [7]$$

Where y_i^k denotes the quantity (*kg*) of rice produced by *ith* farmer in *kth* agro-ecological zone, x_i is a $(1 \times L)$ vector of quantity of inputs used by the *ith* farmer to produce y_i^k quantity of rice, β_i^k is a $(L \times 1)$ vector of parameters for inputs associated with *kth* agro-ecological zone and $f\left(x_i, \beta_i^k\right)\ell^{V_i^k}$ is the suitable functional form (Cobb–Douglas or translog) for farmers in *kth* agro-ecological zone. As noted earlier, the error terms are two (V_i^k and U_i^k) and they are assumed to be independent of each other. The first error term, V_i^k is a symmetric random term which captures the stochastic effects outside the farmer's control (e.g., weather, natural disasters, and luck, measurement errors, and other statistical noise). It is a two-sided random error $\left(-\infty < V_i^k < \infty\right)$. Conversely, the second error term, U_i^k is a one-sided non-negative $\left(U_i^k \geq 0\right)$ efficiency component that captures the technical inefficiency of the farmer within *kth* agro-ecological zone.

It is assumed that V_i^k is independently, identically and normally distributed with zero expectation or mean and homoscedastic (constant) variance $\left[V_i^k \sim N\left(0,\ \sigma^2_{V_i^k}\right)\right]$. Meanwhile, in stochastic frontier analysis, researchers have ascribed different distributional assumptions to U_i^k. According to Battese and Coelli (1995), U_i^k is assumed to follow a truncated normal distribution with a mean value of μ_i^k and a variance of $\sigma^2_{\mu_i^k}$ $\left[U_i^k \sim N\left(\mu_i^k,\ \sigma^2_{\mu_i^k}\right)\right]$. With this assumption, U_i^k is defined by a technical inefficiency model given as:

$$\mu_i^k = 1 - U_i^k = \varphi_0^k + \sum_{m=1}^{m=M} \varphi_i^k Z_{mi}^k + \omega_i^k \qquad [8]$$

Where φ_i^k and ω_i^k respectively denote a $(L \times 1)$ vector of parameters for inputs and error term of the inefficiency model for *ith* farmer in *kth* agro-ecological zone. Also, ω_i^k is non-negative $\left(\omega_i^k \geq 0\right)$and it is defined by the truncation of the normal distribution with zero mean $N\left(Z_m \varphi_i^k,\ \sigma^2_{\omega_i^k}\right)$. From the model, Z_m is a $(1 \times L)$ vector of explanatory variables (socioeconomic factors) under the control of the farmer which explains technical inefficiency in the production process. It is worth noting that when all the coefficients of Z_m are zero $\left(\varphi_1^k = \varphi_2^k =, \ldots, \varphi_J^k = 0\right)$), then the technical inefficiency are not caused by intrinsic controllable factors of the farmer but rather controllable factors such as farmers specific factors, farm specific factors, institutional and policy variables. The technical efficiency model can conveniently be derived and stated as:

$$TE_i^k = \ell^{-U_i^k} = \ell^{-Z_m \varphi_i^k - \omega_i^k} \qquad [9]$$

The index for the technical efficiency ranges from zero to one. If TE score is one, it implies the farmer is fully technically efficient and if it is zero, the farmer is technically inefficient.

According to Battese and Rao (2002), three indices can be derived by taking the ratio of certain terms in the group specific stochastic frontier to the stochastic metafrontier. These indices are *TGR*, random error ratio (*RER*) and technical efficiency ratio (*TER*). The *TGR* is defined as the ratio of the technical efficiency associated with the metafrontier (*TE**) to the technical efficiency associated with the group specific frontier (*TE*^{k}). Boshrabadi *et al.* (2008) explained that *TGR* describes the inability of the firm (farmer) in a particular group (agro-ecological zone) to achieve a potential frontier output due to differences in the environmental conditions and the

technologies. Also, *TER* is the ratio of the technical efficiency of farmers in *kth* group (TE^k) to the technical efficiency of all the farmers (metafrontier) (TE^*).
Using equations (7) and (8), the indices *TGR*, *RER* and *TER* are derived as:

$$TGR_i^k = \frac{y_i^k}{y_i *} = \frac{\ell^{x_i\beta_i^k}}{\ell^{x_i\beta_i *}} = \ell^{-x_i\left(\beta_i^k - \beta_i *\right)} = \frac{D_i *(x,y)}{D_i^k(x,y)} = \frac{TE_i *}{TE_i^k} \quad [10]$$

$$RER_i^k = \ell^{V_i^k} \Big/ \ell^{Vi*} = \ell^{V_i^k - V_i *} \quad [11]$$

$$TER_i^k = \ell^{-U_i^k} \Big/ \ell^{-U_i *} = \ell^{-U_i^k + U_i *} = \frac{TE_i^k}{TE_i *} \quad [12]$$

The product of these three ratios gives the identity property specified as:

$$TGR_i^k \times RER_i^k \times TER_i^k = \ell^{x_i\beta_i^k} \Big/ \ell^{x_i\beta_i *} \times \ell^{V_i^k} \Big/ \ell^{V_i *} \times \ell^{-U_i^k} \Big/ \ell^{-U_i *} = 1 \quad [13]$$

Using the pooled data to estimate stochastic metafrontier model, the metafrontier technical efficiency is given as:

$$MFTE_i^k = \ell^{x_i\beta_i^k} \Big/ \ell^{x_i\beta_i *} \times \ell^{-U_i^k} \times \ell^{V_i^k} \Big/ \ell^{V_i *} = \mathrm{TGR}_{\mathrm{i}}^{\mathrm{k}} \times \mathrm{TE}_{\mathrm{i}}^{\mathrm{k}} \times \ell^{V_i^k} \Big/ \ell^{V_i *} \quad [14]$$

Due to the presence of $\ell^{V_i^k} / \ell^{V_i *}$ in equation [14] above, the metafrontier technical efficiency estimated using the pooling stochastic metafrontier model proposed by Battese and Rao (2002) is not exact. Therefore, its derived metafrontier may not necessarily envelope the group specific frontiers (Huang *et al*., 2014). Therefore, the approach where metafrontier is estimated by pooling the data from all the groups of firms is flawed (Huang *et al.,* 2014).

3.8.1.2 The two-step mixed model (stochastic-deterministic mixed linear programming)

As noted in section 3.8.1, the two-step mixed model is one of the three models used in modelling stochastic metafrontier production function. A two-step mixed approach to estimating the metafrontier production model has the advantage of dealing with the limitations of the simple pooling approach (Battese *et al*., 2004). This two-step mixed approach was proposed by Battese *et al*. (2004) and O'Donnel *et al*. (2008). This approach is called deterministic metafrontier mathematical programming method. The name two-step mixed approach came from the fact that it combines stochastic frontier and mathematical programming techniques in estimating metafrontier model.

As noted earlier in equation [7] and following the work of Battese *et al.* (2004) and O'Donnel *et al*. (2008), the first step of this approach involves the use of maximum likelihood to estimate observed group specific stochastic frontier which is given as:

$$y_i^k = f\left(x_i, \beta_i^k\right)\ell^{V_i^k - U_i^k} = \ell^{x_i\beta_i^k + V_i^k - U_i^k} \quad [15]$$

The observed group specific frontiers are used in the optimization problem to generate metafrontier in the second stage (Huang *et al.,* 2014). The second step involves the estimation of deterministic metafrontier model using mathematical programming as:

$$\min \sum_{k=1}^{K}\sum_{i=1}^{N_k}\left(\ell^{x_i\beta_i*-U_i*} - \ell^{x_i \hat{\beta}_i^k}\right)^2 = \min \sum_{k=1}^{K}\sum_{i=1}^{N_k}(U_i*)^2 \qquad [16]$$

$$subject\ to\ \ \ell^{x_i\beta_i*-U_i*} \geq \ell^{x_i \hat{\beta}_i^k} \qquad [17]$$

Meanwhile, earlier study by Schmidt (1976) revealed that if the metafrontier technical efficiency, U_i* has a half-normal distribution, the optimization in the second stage as shown above is similar to the maximum likelihood estimation. Additionally, if the metafrontier technical efficiency, U_i* has an exponential distribution, then the optimised metafrontier is similar to maximum likelihood estimation. In such an approach the V is missing, thereby making the model to fail to deal with inefficiencies emanating from environmental factors beyond the firm's control. Lastly, the estimate from the second step violates the standard regularity property of maximum likelihood estimates (has unknown statistical property) and hence the interpretation of the estimates has no statistical meaning.

3.8.2 Stochastic Metafrontier Cost Function

Inasmuch as the stochastic metafrontier production function can be used to estimate productivity performance of firms, the stochastic metafrontier cost function can also be used to estimate cost performance of firms. Metafrontier cost function envelopes all individual group specific cost frontiers. Econometrically, stochastic metafrontier cost model can be specified by firms operating under different technologies or environmental conditions as:

$$c_i = f^M(y_i, w_i, \beta^c)e^{v_i^c + u_i^c} \qquad [18]$$

Where c_i is the total cost for i[th] firm, y_i is the vector of output, w_i is the vector of input prices for the i[th] firm, β^c is a vector of unknown parameters to be estimated, v^c and u^c are error terms. The error term v^c is independently and normally distributed with zero expectation and homoscedastic variance (constant variance). Also, v^c measures the stochastic effects which are outside the control of the firm (e.g. measurements or statistical errors, climatic factors etc). Note that *f(.)* is a cost function[6] with suitable functional form and u^c is cost inefficiency.

3.9 Properties of Metafrontier

For easy and practical operationalization of the metafrontier, certain vital axioms and properties of the function must be spelt out. Before that, let *y* and *x* denote non-negative real numbers of output column vector and input row vector of dimension $(L \times 1)$ and $(1 \times L)$ respectively. A metafrontier production function has its basis on a metatechnology set. The metatechnology set is practically and potentially feasible for every firm in each of the groups to adopt. In this study the metatechnology set which envelopes all the group technology sets are represented by *MT*. The metafrontier has a non-negativity property which can be expressed mathematically as:

[6] Cost function is concave and continuous in input prices, homogeneous of degree one in input prices and nondecreasing in output

$$MT = \{(x, y) : y \geq 0; x \geq 0\} \quad [19]$$

The technology sets can be defined in terms of outputs or inputs. The output technology set is defined by the transformation between the output and any input vector as:

$$P(x) = \{y : (x, y) \in MT\} \quad [20]$$

Similarly, the input technology set is given as:

$$Q(y) = \{x : (x, y) \in MT\} \quad [21]$$

Note that the boundary of the output technology set, and the boundary of the input technology set represent production possibility frontier and isoquants respectively. A production possibility frontier is a curve or boundary which shows the maximum combinations of two products that can be feasibly produced by a firm using a given fixed inputs and technology in a given period of time. Alternatively, an isoquant is defined as a curve which shows a combination of all possible bundles of two inputs which can sufficiently produce a given quantity of output in a given period of time. As noted by Fare and Primont (1995), the maximum achievable output set is called metafrontier and it is assumed to satisfy the standard regularity properties which are stated in the next section. The vertical distance between the group frontier and the metafrontier measures the efficiency of the group under consideration. This distance is called metadistance and its function is called output metadistance function,[7] which can be expressed mathematically as:

$$D_Y(x, y) = \inf_{\theta}\left\{\theta > 0 : \left(y/\theta\right) \in P(x)\right\} \quad [22]$$

There is also an input distance function,[8] which shows the maximum degree to which a given input vector can be radially contracted and yet produce the same output vector.

$$D_X(x, y) = \sup_{\rho}\left\{\rho > 0 : \left(x/\rho\right) \in Q(y)\right\} \quad [23]$$

3.10 Properties of Group Frontiers

It is possible to conceptualise the same idea used in theorising the metafrontier in section 3.9 for group specific frontiers. The group specific frontier in this study is analogous to the metafrontier except that it represents a frontier for a group of farmers who share the same features. It is the potentially achievable frontier for all the individual farmers within a particular group. Due to the specificity of the technology and environmental conditions, individual farmers within a specific group can only realise the productivity levels defined by their respective group. Using T^k as the group specific technology function, the non-negativity property can be stated as:

$$T^k = \{(x, y) : y \geq 0; x \geq 0\} \quad [24]$$

k = 1, 2, 3. (This study considers only three groups of farmers, each group drawn from each of the agro-ecological zones; FSTZ, CSZ and GSZ)

[7] Is homogenous of degree one in output

[8] Is homogenous of degree one in input

Also, the group specific output technology set, and the group specific input technology set which follows the standard regularity properties are respectively shown in equations (25) and (26).

$$P^k(x) = \{y : (x, y) \in T^k\} \qquad [25]$$

$$P^k(y) = \{x : (x, y) \in T^k\} \qquad [26]$$

Since the metatechnology (*MT*) is an envelope of the group specific technologies, the metatechnology is the union of all the individual group specific technologies (T^l, T^2, …, T^K) and it is expressed in mathematical symbols as:

$$MT \supseteq (T^1 \cup T^2 \cup T^3) \qquad [27]$$

Correspondingly to the output metadistance function, the group specific output distance function which measures the technical efficiency for firms within the group is stated mathematically as:

$$D_y^k(x, y) = \inf_\theta \left\{\theta > 0 : \left(y/\theta \right) \in P^k(x)\right\} \qquad [28]$$

If $D_y^k(x, y) < 1$, then the firm is producing below the group frontier output and hence is technically inefficient in the group. On the other hand, if $D^k(x, y) > 1$, then the firm is producing above the group frontier output implying it is technically inefficient within the group. If $D_y^k(x, y) = 1$, then the firm is producing on the group frontier and can be said to be technically efficient in the group.

Alternatively, the group specific input distance function is expressed as.

$$D_x^k(x, y) = \sup_\rho \left\{\rho > 0 : \left(x/\rho \right) \in Q(y)\right\} \qquad [29]$$

Agricultural production in developing countries is bedevilled with a lot of challenges and restrictions. In sub-Saharan African countries, smallholder agricultural production activities are preeminent or dominant with the use of traditional indigenous inputs and technologies. The input distance which is formulated on the basis of the ability of a firm (farmer) to reduce input usage so as to still produce on the frontier is impracticable in developing countries like Ghana. Farmers in developing countries do not have the technical know-how to contract the input function and still be efficient in their production process. Therefore, the use of the output distance function is meritorious in this study compared to input distance function. This justifies the use of the output distance function in measuring efficiency in this study.

3.11 Assumptions Underlying Production Technology Sets of Metafrontier Models

Stochastic metafrontier analysis is based on technology sets. There are some assumptions underlying production technology sets which need to be explicitly stated. These assumptions are briefly explained below.

3.11.1 Closeness and Non-Emptiness of Production Function

For any positive output (i.e. $y>0$), a production function is closed and non-empty. A production is said to be closed if the production boundary or frontier is a continuous curve without having holes. The property of non-emptiness implies that any positive output can be produced (Kumbhakar and Lovell, 2000).

3.11.2 No Free Lunch in Production

An input is used in the production process with the objective of producing at least a certain quantity of output. Meanwhile, it is possible to use certain quantity of input to produce zero output. On the other hand, it is impractical to produce positive output without using any quantity of an input. What this means is that a production frontier can intersect the horizontal (input) axis but not the vertical (output) axis. Mathematically,

For input intercept, $P(x):(x,0)\in MT$ and $P^k(x):(x,0)\in T^k$

For the origin, $P(x):(0,0)\in MT$ and $P^k(x):(0,0)\in T^k$

For output intercept, $P(x):(0,y)\notin MT$ and $P^k(x):(0,y)\notin T^k$

3.11.3 Monotonicity

A production function for a particular technology is monotonic if $P(x')\geq P(x)$ when $x'\geq x$. This implies that at the first stage of production and the second stage of production if a firm employs more quantity of input, the firm will at least increase the output. At the first stage of production, as the variable input increases, the output increases at an increasing rate. Also, at the second stage of production, the increase in physical output is at a decreasing rate with factor inputs and hence marginal physical product decreases. This suggests that marginal product of the input is positive, thus $\left(\frac{\partial P(x)}{\partial x}>0\right)$. It is expected in production process that, as more input is employed, more output should be produced. A monotonic function is a function that increases (or decreases) over its entire domain (Dowling, 2012).

3.11.4 Free Disposability

Another property that characterizes a production function is free disposability. It states that it is possible to dispose of any additional non-usable input at no cost (Dowling, 2012). Given $(x,y)\in MT$ or $(x,y)\in T^k$ and $(x',y)\in MT$ or $(x',y)\in T^k$, if *x'*>*x* but *y'*<*y*; then part of *x'* can be disposed of. This suggests that when there is over utilization of inputs, the excess should be disposed of. According to Kiatpathomchai (2008), free disposability property explains the first order curvature condition for the efficient frontier production which states that as input usage increases, output also increases $\left(\frac{\partial P(x)}{\partial x}>0\right)$. This implies that marginal productivity of every input is non-negative.

3.11.5 Convexity

It is assumed that a production function is convex. The convexity of a production function is determined by the second order condition. For convexity of a production function, $f'(x)>0$ and $f''(x)>0$. This indicates that a production function has a decreasing marginal productivity property.

3.12 Empirical Review of Metafrontier Studies

The empirical methodological review of past studies is crucial to helping the researcher know the extent of researches people have conducted and appropriate interpretation of results. Empirical studies help in the testing and validation of data or methodology. Several researchers have empirically conducted efficiency studies across a variety of fields. There are numerous or large body of literature on traditional production or cost frontier studies but the same cannot be said about metafrontier analysis.

Hayami (1969), the originator of the theory of metaproduction function was the first to empirically model the drivers of agricultural productivity differences among developed and less developed countries. He used Cobb-Douglas metaproduction function to identify and explain how conventional inputs (fertilizer, labour, land and machinery) and non-conventional inputs (education and research) affect productivity in less developed and developed countries. It was revealed that less developed countries had inefficient allocation of those factors.

Kudaligama and Yanagida (2000) applied a frontier approach and estimated metaproduction function for the explanation of causes of inter-country agricultural productivity differentials. The empirical results were compared with research previously conducted by Hayami and Ruttan (1971).

Methodologically, the study by Kudaligama and Yanagida (2000) contributed to knowledge by estimating technical efficiency using deterministic and stochastic metaproduction frontier function. The study empirically demonstrated that stochastic frontier output lies above deterministic frontier output. The study also confirmed research findings that developed countries are more efficient in agricultural production than developing countries. Frisvold and Lomax (1969) upheld the findings of Hayami (1969), Hayami and Ruttan (1970) and Kudaligama and Yanagida (2000), that developing countries had fairly low productivity than developed countries. However, it was interesting to find that some developing countries had the capacity or potentials to operate on the same metaproduction frontier function as that of developed countries. Kudaligama and Yanagida (2000) then advocated for the modification of technologies and infrastructure such as transportation and communication in developing countries. The authors also noted that studies have shown that heavy fertilizers subsidization does not provide incentive for farmers to efficiently allocate their resources so as to operate closer to the frontier.

In a study to examine technical efficiency and potential of farmers in four West African countries (Ghana, Nigeria, Cameroon and Cote d' Ivoire), Binam *et al.* (2008) used a stochastic frontier metaproduction function. To avoid the estimation bias inherent in the two-step estimation procedure, Binam *et al.* (2008) used the single-stage maximum likelihood procedure of *FRONTIER 4.1* programme to estimate the parameters of stochastic translog frontier. The researchers used the Lingo software of linear programming to determine the parameters of stochastic metafrontier translog model. This method was used because of the insignificant difference between parameters estimated using linear programming and quadratic programming by Battese *et al.* (2004).

Binam *et al.* (2008) found out that sex of a farmer, number of contacts with extension agents, access to credit and the amount of canopy shade significantly influenced the agricultural performance (technical efficiency) of cocoa farmers in central and West Africa countries. In their study, labour, farm size and tree age were the conventional inputs, which significantly affected the heterogeneity in cocoa productivity across the studied countries.

Mensah and Brümmer (2016) adopted stochastic metafrontier analysis to investigate the performance of the fruit industry in Ghana. With the study, both the TGR (which is outside the control of the farmer) and the technical inefficiency (which is under the farmer's control) were estimated and their determinants identified and analysed. The study revealed that about 94% fruit farmers in northern Ghana lag behind metafrontier output by 52%. Mensah and Brümmer (2016) suggested that policies should be designed to improve upon factors beyond the control of the farmer (thus roads, electricity power supplies, creating a favorable markets etc.), so as to bridge the TGR.

On the other hand, Mensah and Brümmer (2016) identified technical inefficiency to be responsible for low fruit output by farmers in the southern and middle zones of the country, thereby advocating for improvement in farmers' managerial skills in those areas. The authors also analyzed productivity performances of organic and conventional pineapple producers using metafrontier model and found that the average technical efficiencies of conventional and organic pineapple producers were 97% and 95% respectively, whereas the metatechnology gap ratio for both technologies was 95%. These figures are close to 100% suggesting relatively a small scope for output expansion or productivity improvement for both technologies. Therefore, Mensah and Brümmer (2016) recommended that government policies should target agricultural research for the development of more enhanced production technology for pineapple.

In the same study (model to determine the drivers of technical inefficiency of banana production), Mensah and Brümmer (2016) found out that household and socioeconomic factors such as farmers' educational level, experience in farming, household size and regular extension contact significantly influence technical efficiency. Mensah and Brümmer (2016) noted that education reduces inefficiency of banana farmers because it provides the opportunity for farmers to source new information on prices and improved production technologies.

"Metafrontier analysis of organic and conventional cocoa production in Ghana" was studied by Onumah *et al.* (2013). They used a stochastic translog model and the findings showed technical efficiency scores of 80% and 85% for organic and conventional cocoa producers respectively. This suggests that conventional cocoa producers were more technically efficient than organic cocoa producers. Meanwhile, the TGRs for conventional and organic producers were 0.84 and 0.74 respectively, implying that conventional and organic cocoa producers can become technically efficient and increase output by closing the gap of 16% and 26% respectively (Onumah *et al.*, 2013). The metatechnical efficiency scores of 0.71 and 0.59 for conventional producers and organic producers respectively confirmed that the former is more technically efficient than the latter (Onumah *et al.*, 2013).

Similar findings have been established by Kramol *et al.* (2010) and Tzouvelekas *et al.* (2001), with the suggestion that it is difficult for organic producers to adjust to the system.

Lastly, Asravor *et al.* (2015) empirically conducted a research on rice productivity and technical efficiency analysis in Northern Ghana using a stochastic metafrontier approach. The study showed farmers in the study area were operating at decreasing returns to scale. However, this finding is far from reality since most of the farmers in Northern Ghana still lack the necessary farm inputs.

3.13 Technology Adoption Impact Assessment Approaches

There are several approaches to measuring impacts. Impact assessment evaluates the impact of adoption or use of certain technologies or practices on welfare (income, expenditure), productivity, and efficiency, among others. It can also measure the effects of project participation on the socioeconomic well-being of the participants. Impacts studies can be done by using different approaches. The challenge of impact assessment for observational data (non-experimental) is the ability to establish the counterfactual situation (control variable) against which the impact can be measured due to self-selection problem (Shiferaw *et al*., 2014). The impact assessment econometric models which can appropriately be used to deal with selection bias for observational cross-sectional data are propensity score matching (PSM), generalised propensity score (GPS) matching in continuous treatment framework, and instrumental variables (treatment effect and endogenous switching regression models).

PSM is a non-parametric estimation method. This technique does not depend on functional form and distributional assumptions. PSM is used to compare the observed outcomes of technology adopters or project participants with counterfactual outcomes of non-adopters or non-participants (Heckman *et al*., 1998). With PSM, observations of adopters or participants and non-adopters or non-participants are matched and according to the propensities predicted from adopting or participating (Rosebaum and Rubin 1983, Heckman *et al*., 1998 and Wooldridge, 2005).

More importantly, instrumental variables (treatment effect and endogenous switching regression models) have an advantage over PSM, because they account for both observable and unobservable heterogeneity while PSM only accounts for observable heterogeneity. The instrumental variable treatment effect model specifies one selection and one outcome equations where the impact is measured by a simple parallel shift in the outcome equation (Shiferaw *et al*., 2014). Conversely, the endogenous switching regression model estimates the impacts by using one or more selection models and two or more outcome models. Unlike the instrumental variable treatment effect model, the determinants of factors influencing adoption decision of adopters only or non-adoption decision of non-adopters only can be identified using the endogenous switching regression model. The endogenous switching regression model also has an advantage over the treatment effect model, in the sense that it can segregate and estimate the magnitude of the effects of socioeconomic factors on the outcome (welfare, efficiency, productivity etc) for only adopters or only non-adopters. Estimators obtained from PSM are not consistent estimators when there are hidden biases, while the reverse is the case for instrumental variables, especially the multinomial endogenous switching regression model. Due to the advantages of endogenous switching regression and appropriateness of the data, this study used the multinomial endogenous switching regression model (MESRM).

3.13.1 Theoretical Review of Multinomial Endogenous Switching Regression Model

As noted above, MESRM is used when one wants to evaluate the impact of making three or more decisions on the outcome variable. For instance, if one wants to determine the impact of adopting two or more technologies (or participating in two or more project interventions) on the farm productivity, MESRM can be used. There is a binary endogenous switching regression model where the decision maker has only two options (either to adopt or not to adopt or either to participate or not to participate).

The basic concept is that a firm or farmer will adopt a combination of two or more technologies if the total discounted expected utility or benefit is maximised. MESRM uses two or more selection models and two or more outcome models to estimate the impact of a combination of decisions on the outcome variable by controlling both observed and unobserved heterogeneity. It does this by putting all the respondents on the same pedestal and ensures that adopters (treatment groups) are randomly selected and hence their adoption decisions are not influenced by unobservable factors (managerial skills, motivation, information etc.). The selection model is estimated using a probit model, which is based on a random utility model. Contrariwise, the outcome models are estimated using ordinary least squares (OLS).

3.13.2 Empirical Review of Multinomial Endogenous Switching Regression Model

Over the years many researchers have used multinomial endogenous switching regression model to analyse the impact of adoption of two or more technologies or the impact of participation in two or more project interventions on the outcome variable.

Teklewold *et al.* (2013) used a multinomial endogenous switching regression model to determine the impact of farmers' adoption of multiple sustainable agricultural practices (SAPs) on outcome variables (household maize income, agrochemical use and family labour demand) in rural Ethiopia. The decision variables used in the study were maize-legume cropping system diversification, conservation tillage and modern seed adoption. From the research of Teklewold *et al.* (2013), the factors that influenced the adoption of SAPs were as follows: rainfall and plot level disturbances; soil characteristics and distance of the plot from home; social capital in the form of access and participation in rural institutions; the number of relatives and traders known by the farmer; market access; wealth; age; spouse education; family size; the farmer's expectations of government support in case of crop failure; and confidence in the skill of public extension agents. The study found out that household maize income was higher for farmers with a combined adoption of SAPs than farmers who adopted any one of the SAPs. Also, the study revealed that conservation tillage and cropping system diversification had negative impact on nitrogen fertilizer use, but conservation tillage increased pesticide application and household labour demand among maize farmers in Ethiopia.

In a study to determine the impact of multiple interdependent climate change adaptation strategies on net revenue per hectare (outcome) of farm household in Sub-Saharan Africa, Di Falco (2014) used the multinomial endogenous regression model. The result from the research revealed that farmers who combined soil and water conservation strategies and changed crop varieties to minimize the effect of climate change on agricultural production obtained the highest net revenue.

CHAPTER FOUR

METHODOLOGY

4.1 Introduction

This chapter outlines the methods that were used to achieve each of the objectives stated in the introductory chapter. The chapter describes the conceptual and theoretical frameworks of the study. The empirical econometric models for analysing each of the objectives are explained in the chapter. The sampling techniques, the estimation of the sample size, the sources and type of data collected, and the econometric software used for data analysis are also described in the chapter. The last section presents a description of the study area.

4.2 Conceptual Framework

A conceptual framework is a deep thinking (i.e. conceptualization) of the processes or linkages or systems that can be used to simplify the understanding of a particular study (Smyth, 2004). In social science research, it tries to explain the linkages that exist among variables. It starts from a simple to a complex model.

The conceptual framework denoted in figure 4.1 lists four broad categories of factors which influences a farmer's adoption of technologies. The first category of factors is farmer specific factors; relating to the person of the farmer. These characteristics are age, sex, management skills, household size, and education, among others. Aside these farmer specific characteristics, rice production decision of a farmer is strongly influenced by some external factors. The farm specific factors (farm size, typology, soil type); institutional and policy variables of the country (input subsidy, extension service, market access among others) and the agro-ecological location factors (rainfall, temperature among others) are principal external factors which also influence the decision of a farmer to commit or not to commit resources to the cultivation of rice.

Given farm specific characteristics such as inputs availability (soil quality, size of land, topology, soil type among others) and above all, profit maximizing objectives, a farmer will decide whether to cultivate rice or not. The favourability of these factors is enough for the farmer to decide. Farmers are more or less economic agents (firms) who are rational and have access to information. Every rational economic agent aims at maximizing utility or profit. Utility maximization depends on the farmer's ability to make the best alternative choice(s).

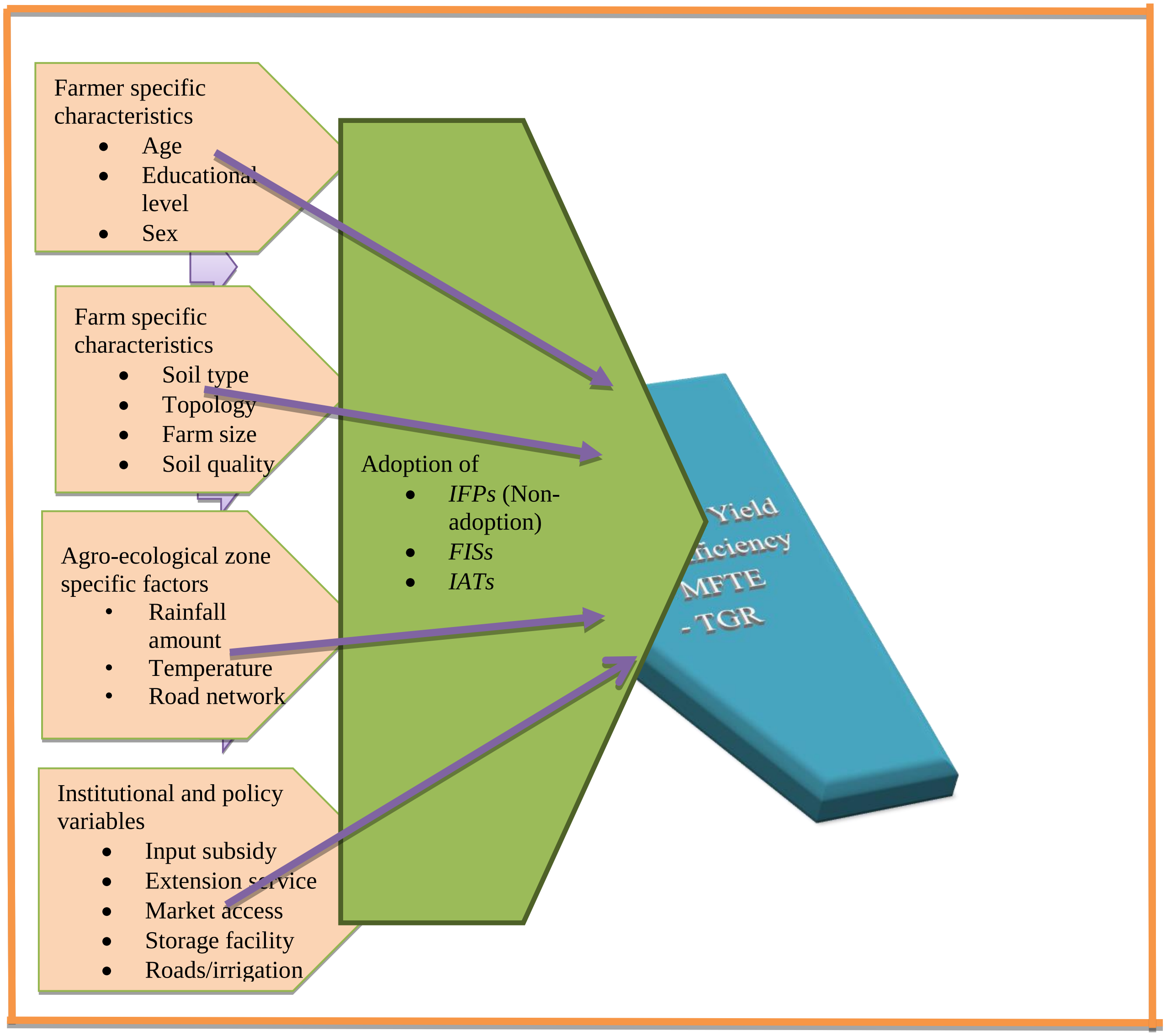


Figure 4.1 Conceptual Framework of the Study

Source: Author's Conceptualization and Modification from Kiatpathomchai (2008)

A farmer who decides to cultivate rice has three alternative choices of technologies to adopt, namely the *IFPs*, *FISs* and *IATs* mentioned in section 1.1. Based on the assumption that a farmer is a rational economic agent, the choice made by the farmer will be to maximize utility or profit subject to available inputs. A farmer will have a production function which is a technical relationship between the technology chosen and output realized. For a number of rice farmers across different agro ecological areas, the rice yields realized will be mediated by differences in production technologies, characteristics relating to the specific farmer, agro ecological differences and institutional and policy factors.

Considering the four categories of factors depicted in figure 4.1, the country will possess a metaproduction frontier which will indicate the maximum yield that is attainable with the categories of factors. The yield attained by a farmer in each agroecological zone within maximum yield boundary (metafrontier) will depend on how efficient that farmer is. This efficiency as explained earlier in section 3.6 has three aspects. These are how resources are allocated efficiently (allocative efficiency) and the technology adopted to obtain the highest yield (technical efficiency) as well as a product of the two (economic efficiency). Against the background that farmer specific and farm characteristics will be different for different farmers in different agroecological areas, it is expected that efficiencies attained by the farmers will be different, ceteris paribus.

To be able to increase the productivity levels and catch up with those on the metafrontier, farmers must improve upon their farmer specific characteristics (management skills etc.) and/or farm specific characteristics (farm size, soil conditions, etc.). Rahman (2010) identified infrastructure, soil fertility, extension service, experience, tenancy and share of non-agricultural income as principal factors affecting efficiency of rice production in Bangladesh. Notwithstanding this, the more practically possible thing they can do is to adopt highly improved technologies (i.e. FISs or scientifically improved technologies).

Conversely, economically efficient farmers have relatively high TGR or high productivity potentials and hence will not have to struggle so much to catch with farmers on the metafrontier. Such farmers can sell the produce (rice) for more incomes which can be used to expand their farms. They are also food secured and well prepared for any unforeseen circumstances. With growth in incomes, they will be able to diversify their livelihoods, pay their children school fees, attend hospitals when indisposed, pay electricity and water bills as well as build better houses.

4.3 Classification of Farmers into Technology Adopters

Since a farmer can use any of the *IFPs*[9] or adopt any of the *FISs* or *IATs* or a combination of any, counting the number of practices or technologies adopted can be a measure of the intensity of adoption. Meanwhile, the level of adoption, and hence the magnitude of contribution of each of the *IFPs* or *FISs* or *IATs* to rice output differs. Therefore, the simple counting of the number of *IFPs*, *FISs* and *IATs* and using the total counts for each farmer as intensity of use of *IFPs* or adoption of *FISs* and *IATs* is unrealistic. Also, it is academically incorrect to group practices, innovations and technologies under *IFPs* or *FISs* or *IATs* without any empirical justification. According to Maggino and Ruvigloni (2011), it is more appropriate to use weights which are objectively derived to indicate the contribution of inputs (for this study, the adopted *FISs* or *IATs*) to output, since each input's magnitude of contribution to aggregate output differs.

The use of marginal effects estimated by multivariate regression as the weights measuring the contribution of technology adoption to output provides statistical and objective argument for grouping the technologies for modelling. As such, Bobko *et al.* (2007) argued that weights estimated from multiple regressions have statistical meaning which is enough for interpretation,

[9] Note that *IFPs* are used because they have been with farmers for a very long time but *FISs* and *IATs* are are relatively new to farmers, hence the term adoption.

and hence there is no need for using subject matter experts to generate weights to show the intensity of adoption or contribution of technologies. Meanwhile, it is an open secret to researchers in the field of economics and statistics that normal ordinary least squares regression provides summary point estimates which measure the average effect of the independent variables on the dependent variable.

In order to objectively classify farmers into non-adopters [users of indigenous farming practice (P)] or adopters of FISs (I) or improved agricultural technology (T), principal component analysis (PCA) was used. The PCA model transforms the technology variables into a linear equation simply by allocating relative weights to each of technology variable which is unique. Each weight (coefficient of the equation) measures the relative correlation of the individual *IFPs, FISs* and *IATs* and hence can be used classify farmers into adopters of *IFPs, FISs* and *IATs* or a combination of any. The use of PCA can be traced back to the work of Kendall (1939), where yields of ten crops were used to construct relative productivity weights of 48 countries.

4.3.1 Theoretical Concept of PCA for Classifying Farmers into Technology Adopters

In determining the correlation among variables with common properties, one needs to estimate eigenvalues using PCA with oblique rotation. An eigenvalue has a standardized variance with a mean of zero and a standard deviation of 1. Hence, any component (IFP or FIS or scientifically IAT) with an eigenvalue of less than 1 is unimportant and dropped but a component with an eigenvalue greater than 1 is important and retained.

In the current study, a four-step procedure proposed and used by Vyas and Kumaranayake (2006) was used to construct the three components for *IFPs*, *FISs* and *IATs*. Firstly, IFPs or FISs or IATs to be included in the model were selected. PCA was then used to extract the components. In PCA with varimax rotation, the principal component that comes first is the one which is constructed with highly weakly correlated variables and vice versa (Duong and Duong, 2008). Conversely, for PCA with oblique rotation (oblimin), the first principal component is the one that is extracted with variables which are highly correlated. According to Han (2010) and Jolliffe (2002), PCA is used in selection algorithms for the reduction of data dimensions, removal of noise and lastly the extraction of information which are meaningful and interpretable for further analysis.

According to Dong *et al.* (2015), PCA is appropriately used when the Gaussian (normal) distribution assumption of the variables are valid. It is important to note that Booysen *et al.* (2008) criticized the use of PCA, which is a continuous and normally distributed variable factor reduction model, for analyzing discrete or categorical variables. Multiple correspondence analysis (MCA) is designed for categorical or discrete variables. Howe and Hargreaves (2008) used MCA and PCA and realized that the results from the two methods are not significantly different from each other. In this study, PCA with oblique rotation was used because it grouped farming practices or technologies which are correlated, unlike PCA with orthogonal (varimax or qaurtimax) rotation. The results of PCA using oblique rotation are more accurate for research involving human decision making, and Williams *et al.* (2010) noted it provides results which can easily be interpreted. More importantly, Tabachnick and Fiddell (2007) suggested a threshold of 0.32 correlations for which one needs to use for choosing the appropriate rotation method. The oblique rotation is chosen over varimax rotation when the correlations observed from the factor correlation matrix are at least 0.32.

4.3.2 Empirical Model of PCA with Oblique Rotation

Following Filmer and Pritchett (2001), the principal component (PC) for a set off number of random IFPs (P), *g* number of random FISs (*I*) and *h* number of IATs (*T*) can be expressed as:

$$PC_1 = \sum_{f=1}^{f=16} a_{1f}^{P} P_{fi} + \sum_{g=17}^{g=31} a_{1g}^{I} I_{gi} + \sum_{h=32}^{h=45} a_{1h}^{T} T_{hi} \qquad [30a]$$

$$PC_2 = \sum_{f=1}^{f=16} a_{2f}^{P} P_{fi} + \sum_{g=17}^{g=31} a_{2g}^{I} I_{gi} + \sum_{h=32}^{h=45} a_{2h}^{T} T_{hi} \qquad [30b]$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$PC_{42} = \sum_{f=1}^{f=16} a_{45f}^{P} P_{fi} + \sum_{g=17}^{g=31} a_{45g}^{I} I_{gi} + \sum_{h=32}^{h=45} a_{45h}^{T} T_{hi} \qquad [30c]$$

Where a_{1f}^{P} , a_{1g}^{I}, a_{1h}^{T} represent coefficients (weights/factor loadings) for the first principal component of f^{th} number of random IFPs (*P*), g^{th} number of random FISs (*I*) and h^{th} number of random improved technologies (*T*) respectively. Since this study used oblique rotation, the ordering of the components ensures that the first principal component explained the largest possible amount of correlation of variables in the original data. Note that a factor loading is the correlation between a variable and a factor (component) that has been extracted. The second principal component explains the next highest correlation in the original data and so on. In all, forty-five variables were used, and their definitions and mode of measurements are shown in table 4.1. Through literature review and informal information gathered from agronomists, each of the technology variables was grouped under *IFPs*, *FISs* and *IATs* as illustrated in appendix 1.

4.4 Estimation Rice Yield Differentials between Technology Adoption Typology of Farmers

Rice productivity is defined as the quantity of paddy rice produced per unit input. In this study, rice productivity is measured in yield. Thus, rice yield is the quantity of rice produced (Mt) per unit area (Ha). Rice yield can be grouped into potential yield, economic yield and actual yield. According to Fermont and Bension (2011), potential yield is the maximum achievable yield of crop produced under optimum environmental conditions and inputs, whereas economic yield is yield that provides the highest returns to production, given all possible constraints of production. In this study, rice yield to be estimated refers to actual rice yield, which is defined as the quantity of paddy rice produced per unit area when the farmer uses available IFPs or farmer innovations systems or IATs or combinations of any of them. Mathematically, the average rice yield for l^{th} technology adopters ($\overline{RY}_l$) is given as:

$$\overline{RY}_l = = \frac{\sum_{i=1}^{i=k} R_i^l}{\sum_{i=1}^{i=k} FS_i^l} \qquad [31]$$

Where R_i^l and FS_i^l are the quantity of rice produced (Mt) and the farm size (Ha) cultivated by ith farmer who adopts lth typology of technology respectively. To test the difference between the rice yields obtained by adopters of technology 1 and 2, appropriate inferential statistics must be used. For unequal sample sizes or variances, the appropriate test is Welch's t-test (Welch, 1947) which can be specified for technology adoption typology 1 and 2 as:

$$Welch's\,t-test = = \frac{\overline{RY}_1 - \overline{RY}_2}{\sqrt{S_1^2/n_1 + S_2^2/n_2}} \qquad [32]$$

Where $\overline{RY}_1$ and $\overline{RY}_2$ denote average rice outputs for adopters of technology typologies 1 and 2 respectively; S_1^2 and S_2^2 are the sample variances for adopters of technology typologies 1 and 2 respectively; n_1 and n_2 are the sample sizes for adopters of technology typologies 1 and 2 respectively.

4.5 Reasons for the Choice of *FISs* and *IATs* and Constraints for Adopting *IATs*

The adoption of technology depends on the constraints face in making the adoption decision. The reasons for the choice of FISs and IATs as well as the constraints facing rice farmers in adopting the superior technologies thus (*IATs*) were identified through literature review and a preliminary informal interview of 60 farmers. During actual data collection, these reasons and constraints were presented to rice farmers to rank according to the degree of importance. The rankings of the constraints were done according to the degree of severity to which a rice farmer cannot adopt or fully adopt the superior technologies thus *IATs*. The rankings and the testing of the agreements among farmers' rankings were done with the help of Kendall's Coefficient of Concordance. Kendall's Coefficient of Concordance (*W)* is used to rank and test the null hypothesis that there is no agreement among the rankings by farmers against the alternate hypothesis that there is agreement.

4.6 Theoretical Framework of Metafrontier Production Function

The metafrontier production function has its root from the traditional production frontier introduced by Farrell (1957). The traditional production frontier model is used to estimate the production efficiency of firms with similar technology. This original production frontier model popularized by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977) has been modified and named "metafrontier production function". It is used when the firms are in groups and each group operates under different technologies or environmental conditions. Many researchers have different views about the originator of metafrontier production model.

The theoretical foundation of metafrontier production function is that firms in different spatial locations have potential access to the same technology through innovation diffusion model. The diffusion of technology from one firm to another or among firms creates the opportunity for firms in different jurisdictions to be able to use similar or nearly similar technologies. With this, heterogeneous firms have the potential to move up and operate on the metafrontier, which is an envelope of group frontiers.

Technically, a metafrontier production function is a benchmark production function which envelopes all the group production frontiers with different technologies or environmental conditions. A stochastic metafrontier production function is used when one wants to compare the efficiency of different groups of firms. As a benchmark model, it yields firm-specific efficiency estimates which are comparable. Consequentially, the productivities of the firms (farmers) will not be the same since environmental conditions and technologies are vital inputs in the production of goods and services. According to Barnes and Revoredo-Giha (2011), a metafrontier production function is used when the researcher perceives that each group operates under different technologies.

In this study, the sample populations are in clusters as they are drawn from different rice growing agro-ecological zones in Ghana. Within the same agro-ecological zone, farmers who cultivate rice under rainfall ecology are naturally grouped together. Similarly, farmers producing rice under rainfed irrigation ecology are also naturally grouped together. Spatially, the farmers are located in different vicinities, namely: FSTZ, CSZ and GSZ with different environmental conditions. The technologies used by these farmers and the environmental conditions under which they operate differ slightly and these translate into differences in rice yield being observed currently. Rice farmers in a particular agro-ecological zone have certain things in common; use the same or almost the same rice production technology, as well as cultivate rice under similar environmental conditions. Such farmers form a group. The clustering of these farmers provides a reasonable yardstick for the researcher to use metafrontier and zonal production frontiers.

4.6.1 Graphical Representation of Group Frontiers and Metafrontier

Generally, it is hypothesized that there is a metatechnology set which wraps all the group technologies in an input-output space. Following Battese *et al.* (2004) and modifying the work of Chen *et al.* (2014), figure 4.2 shows the graphical representation of metafrontier and three group specific frontier production functions. The metafrontier which is a union of all individual group specific frontiers is represented by *MF* whereas the three group frontiers are denoted GF_1, GF_2 and GF_3. In the current research, the group specific frontier specifies the technology used in transforming inputs into output in a particular agro-ecological zone using the same or nearly the same technologies and under the same environmental conditions. The metafrontier production function (*MF*) represents the metatechnology set (*MT*) which shows the technical relationship between the input, x and the output, y. Similarly, each of the group production frontiers (GF_1, GF_2 and GF_3) represents the relationship that transforms the input x into output y in rice production process. It is imperative to note that each group of farmers operates under distinctively different technology sets and environments. The boundary of output set for each group is called the group production frontier[10].

If a farmer operates at point *A*, i.e. the farmer uses x^* quantity of input x to produce y_A quantity of output y, the technical efficiency relative to any group specific frontier or metafrontier can be measured. The efficiency estimations have their foundations from the concept of theory of production and distance functions. The vertical distance between the horizontal axis (i.e. input-axis) and the metafrontier production curve is called output metadistance. The vertical distance between a group frontier and a metafrontier provides the impetus for measuring efficiency of the group. For instance, the technical efficiency for group one is measured as the distance between GF_1 and *MF*.

[10] Mariano *et al.* (2010) defined a group production frontier as the boundary of restricted technology set. It is the potential achievable frontier for the group under consideration.

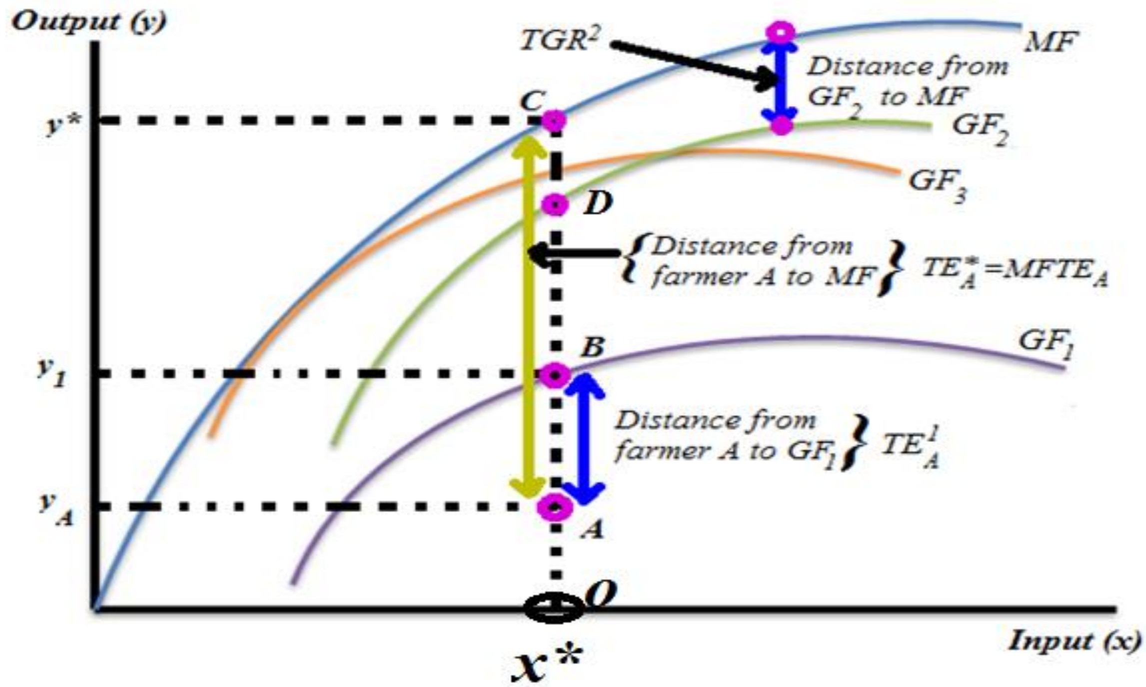


Figure 4.2: Graphical representation of metafrontier

Source: Modified diagram from Battese et al. (2004) and Chen et al. (2014)

Given that farmer *A* is at point *A*, the technical efficiency (*TE*) of that farmer relative to group one frontier using x^* quantity of input is given as:

$$TE_A^1 = \frac{OA}{OB} = \frac{y_A}{y_1} \qquad [33]$$

The higher the technical efficiency index (TE_A^1), the more technically farmer *A* is and vice versa. It is possible to measure group specific technical efficiency relative to the metafrontier production function and this estimate is called metatechnology ratio (*MTR*). The metatechnology ratio (*MTR*) is the ratio of the technical efficiency relative to the metafrontier (TE^*) to the technical efficiency relative to the group frontier (TE^k). Boshrabadi *et al*. (2008) called metatechnology ratio environmental TGR (ETGR) because it accurately describes the inability of a farmer in a particular agro-ecological zone to achieve potential output due to environmental and technological differences. It is also called *TGR* or productivity potential. Using x^* quantity of input, *TGR* relative to farmers operating on group one frontier can be expressed as shown in equation (34).

$$TGR^1 = \frac{TE_1*}{TE_A^1} = \frac{OA/OC}{OA/OB} = \frac{y_A/y*}{y_A/y_1} = \frac{OB}{OC} = \frac{GF\ output}{MF\ output} = \frac{y_1}{y*} \qquad [34]$$

Assuming that a farmer at point *A* could use the joint technology, the metafrontier technical efficiency (MFTE) score or the technical efficiency relative to the metafrontier (TE_l^*) can be determined by using the index:

$$TE_1^* = MFTE = MTR^1 \times TE_A^1 = \frac{OB}{OC} \times \frac{OA}{OB} = \frac{OA}{OC} = \frac{y_A}{y^*} \qquad [35]$$

From equation (35) above, the technical efficiency relative to the metafrontier (TE_I^*) is the product of the technical efficiency relative to the group and the environmental-TGR (*MTR*) between the metatechnology and the TGR.

4.6.2 Properties of Productivity Performance Indices

Group specific technical efficiency falls within the range $0 \leq TE^k \leq 1$. Similarly, each of the metafrontier technical efficiency ($MFTE^k$) and TGR falls within the same range; $0 \leq MFTE^k \leq 1$ *and* $0 \leq TGR^k \leq 1$ respectively. A firm who is able to obtain a unit value for each of these efficiency indices is classified as 100% efficient in its production activities. In the real world, it is impractical for a firm to obtain 100% efficiency in production of goods and services. Therefore, the closer the productivity performance index to unity, the more efficient the firm is and vice versa.

Alternatively, it is possible to produce zero output. With this outcome a firm can obtain zero productivity performance index (thus $TE^k = 0$, $MFTE^k = 0$ and $TGR^k = 0$). Also, $MFTE^k > TE^k$ at the point where group specific frontier '*k*' intersects the metafrontier, the group specific frontier output and metafrontier output will equal. With such a situation, TGR^k will be equal to one. This situation implies that firms in k^{th} group have 100% potential of producing the maximum output irrespective of the heterogeneity of technologies or environmental conditions. The practicality of this observation in the real world is questionable.

4.6.3 The New Two-Step Stochastic Metafrontier Models

The stochastic metafrontier production function can be estimated using the pooling stochastic metafrontier model, the two-step mixed model or the new two-step stochastic metafrontier model. All three models assume that the deviations between the frontier and the observed output are caused by both factors under and beyond the control of the firm (farmer). Due to the fact that the estimates from the new two-step stochastic metafrontier model meet all the statistical conditions[11], this study used it. The first two were discussed in the chapter three.

The new two-step stochastic metafrontier model is the latest estimation approach proposed by Huang *et al.* (2014). It uses two stochastic frontier regressions, thus the group specific stochastic frontier and the stochastic metafrontier regressions. As noted earlier in equation (8) under subsection 3.8.2.1 in chapter three, the group specific stochastic frontier regression is specified as:

$$y_i^k = f\left(x_i, \beta_i^k\right)\ell^{V_i^k - U_i^k} = \ell^{x_i\beta_i^k + V_i^k - U_i^k} \qquad [8]$$

For this model, the above group specific stochastic frontier is first estimated, and the estimated parameters and error terms are pooled together for the estimation of the stochastic metafrontier model as shown in equation (36) below:

[11] The statistical conditions: standard regularity property is violated by the two-step mixed approach and exact estimate of the metafrontier technical efficiency is also violated by the pooling stochastic metafrontier approach.

$$\hat{y}_i^k = f\left(x_i, \hat{\beta}_i^k\right)\ell^{\hat{V}_i^k - \hat{U}_i^k} = f\left(x_i,\ \beta_i *\right)\ell^{V_i * - U_i *} = \ell^{x_i \beta_i * + V_i * - U_i *} \qquad [36]$$

According to Huang *et al.* (2014), the estimated metafrontier technical efficiency $\left(\hat{MFTE}_i^k\right)$ is exact and hence justifies the definition that metafrontier is an envelope of individual frontiers. Therefore, the estimated metafrontier is given as:

$$\hat{MFTE}_i^k = \hat{TGR}_i^k \times \hat{TE}_i^k \qquad [37]$$

Note that $0 \le \hat{MFTE}_1^k \le 1$, $0 \le \hat{TE}_i^k \le 1$, and $0 \le \hat{TGR}_i^k \le 1$. Meanwhile, $\hat{MFTE}_i^k$, $\hat{TE}_i^k$ and $\hat{TGR}_i^k$ are all predicted.

4.7 Empirical Group Stochastic Frontier and Stochastic Metafrontier Models

Under this section, the empirical models used in this study for estimating technical efficiency, metafrontier technical efficiency and TGR, as well as their determinants, are stated and explained.

4.7.1 Empirical Group Stochastic Frontier and Technical Inefficiency Models

There are different functional forms used in modeling production functions. Prominent among them are Cobb-Douglas (linear logs of outputs and inputs), quadratic (in inputs), normalised quadratic and transcendental logarithmic (translog) functional forms. It is important for a researcher to select and use the appropriate functional form when dealing with production function estimations. Even though Ahmad and Bravo-Ureta (1996) and Kopp and Smith (1980) noted that there are little effects of functional forms used on the efficiency, one has to be careful to select the one that gives best estimates. The selected functional form must be flexible, easy in calculating parameters and should also satisfy the homogeneity condition.

The Cobb-Douglas production function which is widely used in production theory estimation imposes a restriction on the technology of the firm (farmer). The traditional Cobb-Douglas production function assumes a constancy of elasticities of substitution between inputs as well as total or partial production elasticities. Also, Sena (2011) indicated that Cobb-Douglas production function imposes arbitrary functional form due to the fact that it is impractical to test the hypothesis for the fitness of the data. It is inflexible in estimation, even though its parameters are easy to calculate, and it meets the homogeneity condition.

Many researchers have resorted to the use of the transcendental logarithmic (translog) functional form. The limitations of the Cobb-Douglas production function mentioned above are all dealt with when one uses translog. As the actual curvature of the curve of transcendental logarithmic functional can be shown graphically, that of Cobb-Douglas production function cannot.

Every econometric model has its merits and demerits. One of the caveats (limitations) of the stochastic translog production frontier is that it lacks the *a priori expectation* for the researcher to select a particular distributional form for one-sided inefficiency term (Thiam *et al*. 2001). It is important to note that for the stochastic translog production frontier model, one needs to estimate many parameters. Also, the estimated parameters of the interaction terms of the stochastic translog production frontier model are always difficult to interpret economically. For a better and meaningful economic interpretation of the parameters, one needs to calculate elasticities by normalising the variables. Irrespective of these limitations, the flexibility of the use of stochastic translog production frontier model is undoubted. It enables the research to establish the interactions between farm inputs (Al-hassan, 2012).

Following Battese (1997) and Huang *et al.* (2014), the empirical model for group specific stochastic frontier for farmers in *k-th* agro-ecological zone is expressed as:

$$\ln R_i^k = \left\{ \begin{array}{l} \beta_0 + +\Omega_1 D_{F_i}^k + \Omega_2 D_{Pc_i}^k + \beta_1 \ln\left\{Max\left(F_i^k, 1 - D_{F_i}^k\right)\right\} + \\ \beta_2 \ln\left\{Max\left(Pc_i^k, 1 - D_{Pc_i}^k\right)\right\} + \beta_3 \ln L_i^k + +\beta_4 \ln S_i^k + \beta_5 \ln Fs_i^k + \\ \beta_6 \ln K_i^k + \frac{1}{2}\beta_{11} \ln\left(NF_i^k\right)^2 + \frac{1}{2}\beta_{22} \ln\left(NPc_i^k\right)^2 + \frac{1}{2}\beta_{33} \ln\left(L_i^k\right)^2 + \\ \frac{1}{2}\beta_{44} \ln\left(S_i^k\right)^2 + \frac{1}{2}\beta_{55} \ln\left(Fs_i^k\right)^2 + \frac{1}{2}\beta_{66} \ln\left(K_i^k\right)^2 + \beta_{12} \ln NF_i^k \ln NPc_i^k \\ + \beta_{13} \ln NF_i^k \ln L_i^k + \beta_{14} \ln NF_i^k \ln S_i^k + \beta_{15} \ln NF_i^k \ln Fs_i^k + \\ \beta_{16} \ln NF_i^k \ln K_i^k + \beta_{23} \ln NPc_i^k \ln L_i^k + \beta_{24} \ln NPc_i^k \ln S_i^k + \\ \beta_{25} \ln NPc_i^k \ln Fs_i^k + \beta_{26} \ln NPc_i^k \ln K_i^k + \beta_{34} \ln L_i^k \ln S_i^k + \\ \beta_{35} \ln L_i^k \ln Fs_i^k + \beta_{36} \ln L_i^k \ln K_i^k + \beta_{45} \ln S_i^k \ln Fs_i^k + \beta_{46} \ln S_i^k \ln K_i^k \\ + \beta_{56} \ln Fs_i^k \ln K_i^k + V_i^k - U_i^k \end{array} \right\} \quad [38]$$

Where:

Ω_1^k, Ω_2^k and are the coefficients for the dummy variables fertilizer (F_i^k) and pesticides $\left(Pc_i^k\right)$ respectively; β_1^k to β_6^k are own first derivatives; β_{11}^k, β_{22}^k, …, β_{66}^k are own second derivatives. Also, $\beta_{12}^k, ..., \beta_{17}^k$; $\beta_{23}^k, ..., \beta_{26}^k$; β_{34}^k, ..., β_{36}^k; β_{45}^k, ..., β_{46}^k; and β_{56}^k are cross second derivatives. Note that $\beta_{12} = \beta_{21}$. Also, F_i^k, Pc_i^k, L_i^k, S_i^k, Fs_i^k and K_i^k respectively denote quantity of fertilizer (kg), quantity of pesticides (litres), quantity of labour (mandays), seed planted (kg), farm size (acres) and capital (Ghana cedis) for ith farmer in kth agro-ecological zone.

During data collection, it was realised that some of the farmers do not apply fertilizer and pesticides. Therefore, there are zero observations for quantity of fertilizer and pesticides used. In order to deal with the biases associated with estimating a production function with some variables having zero observations, the model used by Battese (1997) was adopted. Therefore, $D_{F_i}^k$, and $D_{Pc_i}^k$ were added to the original translog model and $\ln\left\{Max\left(F_i^k, 1 - D_{F_i}^k\right)\right\}$ and $\ln\left\{Max\left(Pc_i^k, 1 - D_{Pc_i}^k\right)\right\}$ were used to replace $\ln F_i^k$ and $\ln Pc_i^k$ respectively. The replacement of $\ln F_i^k$ and $\ln Pc_i^k$ with, $\ln\left\{Max\left(F_i^k, 1 - D_{F_i}^k\right)\right\}$ and $\ln\left\{Max\left(Pc_i^k, 1 - D_{Pc_i}^k\right)\right\}$ in the model was to minimise biases in the coefficients of some of the variables due to zero observations of fertilizer and pesticides. On the other hand, the dummy variables $D_{F_i}^k$ (1 if applied fertilizer, 0 otherwise), $D_{Pc_i}^k$ (1 if used pesticides, 0 otherwise) dealt with changes in the intercept as a result of zero observations (Battese, 1997 and Ogundari, 2013). Also, $\ln\left\{Max\left(F_i^k, 1-D_{F_i}^k\right)\right\}$ and $\ln\left\{Max\left(P_i^k, 1-D_{Pc_i}^k\right)\right\}$ indicate the natural log of F_i^k and Pc_i^k variables generated by adding 1 to the original variables of fertilizer and pesticides respectively. Note that in the own products and cross products, $\ln NF_i^k$ and $\ln NPc_i^k$ is respectively the same as $\ln\left\{Max\left(F_i^k, 1-D_{F_i}^k\right)\right\}$ and $\ln\left\{Max\left(Pc_i^k, 1-D_{Pc_i}^k\right)\right\}$. This is for simplification.

Whether a farmer is technically efficient or not depends on farmer-specific, farm-specific, institutional as well as policy variables. It also depends on the types and levels of technology adoption. The index measuring technical inefficiency of the farmers in *k-th* agro-ecological zone is given as:

$$TI_i^k = U_i^k = \left\{\varphi_0^k + \sum_{m=1}^{m=5}\varphi_m^k FC_{mi}^k + \sum_{m=6}^{m=11}\varphi_m^k IPV_{mi}^k + \sum_{m=12}^{m=13}\varphi_m^k EF_{mi}^k + \sum_{m=14}^{m=17}\varphi_{14}^k RPT_i^k + \omega_i^k\right\} \quad [39]$$

Where φ_S^k denote parameter estimates and *FC_i, IPV_i, EF_i, RPT_i* respectively denote farmer characteristics, institutional and policy variables, environmental factors and rice production technologies of ith farmer. The farmers' characteristics used in the study are number of years of formal education (*Eduyrs*), age (*Age*), household size (*HHS*), rice farming experience (*FarmExp*) and sex (*Sex*). The institutional and policy variables included in the inefficiency model are number of visits by AEAs with advice on rice production (*ExtVisits*), credit access (*CredAcc*), contract farming (*ContFarm*), membership of farmer-based organisation (*FBO*), access to improved seed (*ImpvSeed*) and access to formal irrigation facility (*IrrigAcc*). Lodging of rice (*LodgRice*) and low amount of rainfall (*LowRain*) are the environmental factors considered in the study. Lastly, rice production technologies which are hypothesised to have influence on technical inefficiency are adoption of *IATs* (*Adopt_IATs*), adoption of *FISs* (*Adopt_FISs*), PC index of *IATs* (*IATs_PC_Index*) and PC index of FISs (*FISs_PC_Index*). Note that ω_i^k is the two sided error term which is independently and normally distributed with zero expectation and homoscedastic variance (constant variance).

4.7.2 Empirical New-Two Step Stochastic Metafrontier Translog Model

With the new-two step stochastic metafrontier translog model, the group specific stochastic translog models are estimated. Each of these estimated group specific stochastic translog models is used to predict rice outputs. These predicted rice outputs ($\hat{R}_i^*$) for each of the groups are then pooled together and used to run the metafrontier model. This method, proposed by Huang *et al.* (2014) is relatively new. According to Huang *et al.* (2014), this estimation procedure has the advantage of providing exact and accurate metafrontier technical efficiency than the metafrontier technical efficiency estimates from the two-step mixed model (stochastic-deterministic mixed linear programming) and the pooling stochastic metafrontier approach.

Adapting the new two-step stochastic metafrontier model used Huang *et al*. (2014), this study used the empirical stochastic metafrontier translog model which is specified as:

$$\hat{R}_i^* = \left\{ \begin{array}{l} \beta_0 + +\Omega_1 D_{F_i}^* + \Omega_2 D_{Pc_i}^* + \beta_1 \ln\left\{Max\left(F_i^*, 1 - D_{F_i}^*\right)\right\} + \\ \beta_2 \ln\left\{Max\left(Pc_i^*, 1 - D_{Pc_i}^*\right)\right\} + \beta_3 \ln L_i^* + +\beta_4 \ln S_i^* + \beta_5 \ln Fs_i^* + \\ \beta_6 \ln K_i^* + \tfrac{1}{2}\beta_{11} \ln\left(NF_i^*\right)^2 + \tfrac{1}{2}\beta_{22} \ln\left(NPc_i^*\right)^2 + \tfrac{1}{2}\beta_{33} \ln\left(L_i^*\right)^2 + \\ \tfrac{1}{2}\beta_{44} \ln\left(S_i^*\right)^2 + \tfrac{1}{2}\beta_{55} \ln\left(Fs_i^*\right)^2 + \tfrac{1}{2}\beta_{66} \ln\left(K_i^*\right)^2 + \beta_{12} \ln NF_i^* \ln NPc_i^* \\ + \beta_{13} \ln NF_i^* \ln L_i^* + \beta_{14} \ln NF_i^* \ln S_i^* + \beta_{15} \ln NF_i^* \ln Fs_i^* + \\ \beta_{16} \ln NF_i^* \ln K_i^* + \beta_{23} \ln NPc_i^* \ln L_i^* + \beta_{24} \ln NPc_i^* \ln S_i^* + \\ \beta_{25} \ln NPc_i^* \ln Fs_i^* + \beta_{26} \ln NPc_i^* \ln K_i^* + \beta_{34} \ln L_i^* \ln S_i^* + \\ \beta_{35} \ln L_i^* \ln Fs_i^* + \beta_{36} \ln L_i^* \ln K_i^* + \beta_{45} \ln S_i^* \ln Fs_i^* + \beta_{46} \ln S_i^* \ln K_i^* \\ + \beta_{56} \ln Fs_i^* \ln K_i^* + V_i^* - U_i^* \end{array} \right\} \quad [40]$$

Where:

All the other symbols and letters denote the usual parameters and variables but here they are estimated at the metafrontier level. U_i^* denotes metafrontier technical inefficiency component of the farmers. This metafrontier technical inefficiency model is given as:

$$U_i^* = \left\{ \varphi_0^k + \sum_{m=1}^{m=5} \varphi_m^* FC_{mi}^* + \sum_{m=6}^{m=11} \varphi_m^* IPV_{mi}^* + \sum_{m=12}^{m=13} \varphi_m^* EF_{mi}^* + \sum_{m=14}^{m=17} \varphi_{14}^* RPT_i^* + \omega_i^* \right\} \quad [41]$$

The metafrontier technical efficiency ($\hat{MFTE}_i$ or $\hat{TE}_i*$) is obtained by subtraction the metafrontier technical inefficiency component from one by using the formula given below:

$$\hat{MFTE} = \hat{TE}_i * = 1 - U_i^* \quad [42]$$

Technological gap ratio (*TGR*) is the measure of the ratio of the *kth* group frontier output relative to the potential meta-frontier output given the observed inputs (Battese and Rao, 2002; Battese *et al.,* 2004). *TGR* is defined as the ratio of the technical efficiency of farmers in *kth* group (TE^k) to the technical efficiency of all the farmers in the three agro-ecological zones (metafrontier technical efficiency, $\hat{MFTE}_i$ or $\hat{TE}_i*$). It is possible for farmers with low rice productivity to vary and adopt productivity enhancement technology or FISs to enable them catch-up with farmers who are able to achieve higher productivity. The lower the TGR, the larger the group lag behind in achieving the potential metafrontier output or the greater the *TGR* the closer the group is to the metafrontier and the better it is for the group (Onumah *et al*., 2013). Following the work of Nkamleu *et al.* (2010), TGR (also called productivity potential ratio) implies that if all farmers in kth agro-ecological zone used best practices spelt out by their observed group-specific technology, they can still increase output by $\left(1 - T\hat{G}R_i^k\right)$.

The TGR can be predicted for each farmer using the predicted group specific technical efficiency ($\hat{TE}_i^k$) and metafrontier technical efficiency ($\hat{MFTE}_i$ or $\hat{TE}_i*$) as shown below.

$$\hat{TGR}_i^k = \frac{GF\ output}{MF\ output} = \frac{R_i^k}{\hat{R}_i} = \ell^{x_i\beta_i^k} \Big/ \ell^{x_i\beta_i*} = \frac{\hat{MFTE}_i}{\hat{TE}_i^k} = \frac{1-\hat{U}_i^*}{\hat{TE}_i^k} \qquad [43]$$

4.7.3 Testing the Hypotheses for Appropriateness of Metafrontier Models

In order to choose the appropriate model, the study tested and validated four null hypotheses. These hypotheses are stated below.

1. ***Null hypothesis one:*** H0: $\beta_{11}^k = \beta_{22}^k = ... = \beta_{77}^k = \beta_{12}^k = ... = \beta_{56}^k = 0$. The coefficients of the square and interaction terms of the explanatory variables or second-order variable in the translog model is zero. This implies that Cobb-Douglas production is the statistically valid representation of the data and should be used otherwise the translog model is appropriate.
2. ***Null hypothesis two:*** H0: $\gamma = \varphi_0 = \varphi_1 = ... = \varphi_{12} = 0$

The inherent presence or absence of inefficiency is a way that one can use to determine whether or not a simple average response model or translog production frontier model is appropriate for the estimation. The null hypothesis that there is no inefficiency effect in the model was tested. This hypothesis explains that the inefficiency term (U_i^k) does not exist in the model and hence the model can be estimated by a simple average response model with (V_i^k) as the only error term. If the reverse is observed, then the model can be estimated using translog production frontier.

3. ***Null hypothesis three:*** H0: $\varphi_0 = \varphi_1 = ... = \varphi_{12} = 0$

The significance of exogenous factors (socio-economic factors) in explaining inefficiency among rice farmers needs to be tested and validated. The null hypothesis that the socio-economic factors in the inefficiency model do not explain the variation in the inefficiency term (U_i^k) is tested.

4. ***Null hypothesis four***: H0: $f^1(x,\ \beta) = f^2(x,\ \beta) = f^3(x,\ \beta)$

This null hypothesis states that the technologies used in all the three agro-ecological zones are the same and hence a metafrontier production model is invalid was also tested. As noted by Villano *et al.* (2010), if the data is collected from farmers who use single production frontier with the same technology, it would be unreasonable and inappropriate to use metafrontier analysis. In order to use the stochastic metafrontier production model, a likelihood ratio test was used to test the null hypothesis that the group agro-ecological zone specific models are the same.

All the four hypotheses stated above were validated by using generalized likelihood-ratio test statistic. The likelihood ratio test which is distributed as a chi-square is specified as:

$$LR = -2\frac{\{\ln L(H_0)\}}{\{\ln L(H_1)\}} = -2[\{\ln L(H_0)\} - \{\ln L(H_1)\}] \sim \chi^2 \qquad [44]$$

Where $L(H_0)$ and $L(H_1)$ are the likelihood functions for the null and alternate hypotheses respectively and χ^2 is the calculate chi-square. According to Nkamleu *et al.* (2010), $\ln[L(H_0)]$ is the value of the loglikelihood function for the stochastic frontier estimated by pooling the data for all the three agro-ecological zones, and $\ln[L(H_1)] = \sum_{k=1}^{3} LLF_k$ is the sum of the values of loglikelihood functions for all the three agro-ecological zone frontiers. Coelli (1995) noted that critical values are obtained from the appropriate chi-square distribution. If χ^2-calculated is greater than χ^2-critical at a pre-determined degree of freedom (number of parameters assumed to be zero in the null hypothesis) and appropriate significant level, the null hypothesis is rejected in favour of the alternate. With that, all the group stochastic frontiers of rice farmers in the three agro-ecological zones in Ghana are different thereby providing the justification that the production structure, technology and environmental conditions are heterogeneous.

Additionally, it is important to establish whether technological heterogeneity exists or not. Therefore, uniformity in *TGRs*, which suggests the absence of technological heterogeneity, was tested. This was done by using a multiple comparison test called Turkey-Kramer comparison analysis of variance (ANOVA) test. The hypotheses for testing the appropriateness of the models are summarised in table 4.1.

Table 4.1: Hypothesis Testing for Appropriateness of the Model

Mathematical statement of null hypotheses	**Statement of null hypothesis**	**Decision rule** (**x^2 likelihood ratio**)	**Interpretation**
$\beta_{ss} = \beta_{rr} = \beta_{sr} = 0$	No squares and interaction terms	If $\chi^2 - cal > \chi^2 - crit$, reject H_0	Translog model is valid and appropriate
$\gamma = 0$	No inherent inefficiency effects or inefficiency effects are stochastic	If $\chi^2 - cal > \chi^2 - crit$, reject H_0	There exist inherent farmer inefficiencies and hence stochastic frontier is valid
$\varphi_0 = \varphi_1 = \ldots = \varphi_n = 0$	Socioeconomic factors do not explain inefficiencies	If $\chi^2 - cal > \chi^2 - crit$, reject H_0	Inefficiency term is explained by socioeconomic factors

$f^1(x, \beta) =$ $f^2(x, \beta) =$ $f^3(x, \beta)$	Technologies used in the three agro-ecological zones are homogeneous	If $\chi^2 - cal > \chi^2 - crit$, reject H_0	Technologies used in the three agro-ecological zones are heterogeneous and metafrontier analysis is appropriate

4.7.4 Empirical Fractional Regression Model: Determinants of TGR

One of the objectives of this study is to identify the determinants of TGR. This will provide necessary information for making critical recommendations for policy interventions which to bridge the gap between the actual and potentials rice outputs across the agro-ecological zones in Ghana. Such policy recommendations will be evidenced based and will reflect the real conditions in the zones as opposed to policy formulations unsupported by concrete evidence

Following the work of Mensah and Brümmer (2016), this study modelled the predicted *TGR* scores against government and NGO policy support programmes, infrastructural support variables, environmental shocks and technology variables. A simple average response multivariate regression model was used by Mensah and Brümmer (2016). The use of simple average response multivariate model is inappropriate since *TGR* is an index which ranges from 0 to 1. Papke and Woodridge (1996) opined that irrespective of the continuous values of proportional data ranging from 0 to 1 as extreme values, the use of ordinary least squares (OLS) regression is inappropriate. They argued that the predictions of the dependent variables of such an OLS regression are likely to be outside the range of 0 and 1.

In order to obtain efficient estimates, generalised linear model (GLM) which is an example of a fractional regression was used. Since the dependent variable, TGR is fractional and bounded from 0 to 1, the use of GLM helps to correct the inconsistency and biasness that might be contained in the parameter estimates when OLS regression is used (Ferrari and Cribari-Neto, 2004). Also, the dependent variable is not censored and there is no point in using Tobit regression. Following Ansah and Tetteh (2016), a GLM is made up of a linear predictor which links the fractional dependent variable, TGR to the explanatory variables, *X*s as shown below:

$$E\left(T\hat{G}R_i / X\right) = g(Xb) \qquad [45]$$

Where $E\left(T\hat{G}R_i / X\right)$ is the expected TGR given *X* as a vector of explanatory variables, *b* is a vector of unknown parameters and *g* is the link function which can be identity, logarithmic, reciprocal, logistic and probabilistic functions. The assumption in this study is that the link function *g(.)* follows the logistic distribution and hence equation [46].

$$E\left(T\hat{G}R_i / X\right) = \ln\left(\frac{T\hat{G}R_i}{1 - T\hat{G}R_i}\right) \qquad [46]$$

The problem with this model is that the log-odds cannot be obtained for the $\hat{TGR}_i$ when $\hat{TGR}_i = 0$ or $\hat{TGR}_i = 1$. This is because the log-odds of 0 and 1 are undefined. However, Pryce and Mason (2006) and Grigoriou *et al.* (2005) noted that this problem can be solved by substituting 0 and 1 with close approximations (0 = 0.000001 and 1 = 0.999999). Meanwhile, this is not a forgone conclusion since such approximations is likely to affect the other indices within the range of 0 and 1. To avoid this assumptive approximation, Papke and Woodridge (1996) proposed and defended the use of fractional logit regression model in their seminal paper which examined employee participation rates in pension plans. The fractional model such as GLM restricts the dependent variable $\hat{TGR}_i$ between zero and one. With this, there is no need for data adjustment. The drawback of fractional logit regression is that it is not applicable to cross-sectional data without modifications. For one to use fractional logit regression for panel data, one needs to do further modifications or adjustments (Wagner, 2002) but is not applicable to this study since the data is cross-sectional. In analysing the factors affecting $\hat{TGR}_i$, this study used fractional logit regression model which is given as:

$$E\left(\hat{TGR}_i / X\right) = \frac{\exp(Xb)}{\left[1 + \exp(Xb)\right]} \qquad [47]$$

For robust standard errors and efficient estimates, Papke and Woodridge (1996) estimated fractional logit regression by using Quasi-Maximum Likelihood Estimator (QMLE) which maximizes the Bernoulli log-likelihood function.

$$\ln L(b) = \hat{TGR}_i \ln\left[E(\hat{TGR}_i / X)\right] + \left(1 - \hat{TGR}_i\right)\ln\left[1 - E(\hat{TGR}_i / X)\right] \qquad [48]$$

In Stata 14, the empirical fractional regression model was estimated using the GLM function which is stated as follows:

$$E\left(\hat{TGR}_i\right) = \begin{pmatrix} b_0 + b_1 IrrigAcc_i + b_2 InpSub_i + b_3 ContFm_i + b_4 Road_i + b_5 DistAEA_i + \\ b_6 DistMkt_i + b_7 DistAccra_i + b_8 DistFarm_i + b_9 LodgRice_i + \\ b_{10} LowRain_i + b_{11} Disease_i + b_{12} RainAmt_i + b_{13} Temp_i + \\ b_{14} AdoptFISs_i + b_{15} AdoptIATs_i + \omega_i \end{pmatrix} \qquad [49]$$

The explanatory variables are defined in table 4.2. Since *TGR* has a positive relationship with metafrontier technical efficiency (*MFTE*), the determinants of *TGR* will have the same interpretation for the determinants of *MFTE*. From the estimated simple average multiple regression model, Mensah and Brümmer (2016) explained that a variable with positive effect on *TGR* signifies that the particular variable favourably improves the production environment and therefore enhances the farmer's ability to improve output towards the industrial level (metafrontier) output. Similarly, TGR can enhance a farmer's ability to bridge the production gap between his/her group frontier and the metafrontier.

4.7.5 A Priori Expectations for Factors Influencing Rice Outputs, TE, MFTE and TGR

The mode of measurements and *a priori* expectations for the factors influencing rice output in the stochastic translog frontier and stochastic metafrontier translog models are illustrated in table 4.2.

Table 4.2 Definitions, Measurements and *A Priori* Expectations of Factors Influencing Rice Output

Explanatory variable	**Definition or description**	**Measurement**	**Expected sign of effect on rice output**	
			R_i^k	R_i*
F	Quantity of fertilizer	Kilogramme (Kg)	+	+
Pc	Quantity of pesticides	Litres (lit)	+	+
L	Quantity of labour	Man-days	-	-
S	Quantity of rice seed	Kilogramme (Kg)	-	-
Fs	Farm size	Acres	-	-
K	Amount of capital input	Ghana Cedis (GH₵)	+	+
Each of the cross terms			+/-	+/-
Each of the interaction terms			+/-	+/-

Also, in table 4.3, the expected directions of the effects of the various factors on the technical inefficiency and TGR are presented.

Table 4.3 Definitions, Measurements and *A Priori* Expectations of Explanatory Variables in Inefficiency and TGR Models

Explanatory Variables	Definitions and Measurements	TI_i^k	TI_i^*	$T\hat{G}R_i^k$
Farmer Characteristics				
Age	*Age (years)*	+	+	NA
Sex	*Sex* (1 if male, 0 otherwise)	-	-	NA
HHS	*Household size (numbers)*	-	-	NA
Eduyrs	*Number of years in formal education (years)*	-	-	NA
FarmExp	*Rice farming experience (years)*	-	-	NA
Institutional and Policy Variables				
ExtVisits	Number of extension contacts with advioce on rice farming (number)	-	-	NA
CredAcc	Credit access ((1 if access, 0 otherwise)	-	-	NA
ContFarm	Contract farming (1 if yes, 0 otherwise)	-	-	+
FBO	Farmer-based organisation membership (1 if member, 0 otherwise)	-	-	NA
ImpvSeed	Access to improved rice seed (1 if access, 0 otherwise)	-	-	NA
IrrigAcc	Access to formal irrigation facility (1 if access, 0 otherwise)	-	-	+
InpSub	Inputs' subsidy (1 if access, 0 otherwise)	NA	NA	+
Infrastructure				
Road	Condition of road to district capital (1 if motorable, 0 otherwise	NA	NA	+
DistAEA	Distance from office of AEAs to community (Km)	NA	NA	-
DistMkt	Distance from community to market centres of rice (Km)	NA	NA	-
DistAccra	Distance from Accra to Community (Km)	NA	NA	-
DistFarm	Distance from farm to the house (Km)	NA	NA	-
Environmental Factors or Shocks				

LodgRice	Lodging of rice (1 if rice lodged, 0 otherwise)	+	+	-
LowRain	Affected by low rainfall amount (1 if experienced low rainfall amount, 0 otherwise)	+	+	-
Disease	Affected by diseases (1 if rice is affected by diseases, 0 otherwise)	+	+	-
RainAmt	Actual mean annual rainfall amount within the district (mm)	NA	NA	+
Temp	Actual mean annual temperature within the district (^{0}C)	NA	NA	-
Rice Production Technologies				
Adopt_IATs	Adoption of IATs (1 if an adopter of IATs, 0 otherwise)	-	-	+
Adop_FISs	Adoption of FISs (1 if an adopter of FISs, 0 otherwise)	-	-	+
IATs_PC_Index	Principal component index of *IATs* (indices)	+	+	NA
FISs_PC_Index	Principal component index of *FISs* (indices)	+	+	NA

NA = Not applicable

4.8 Theoretical Framework for Evaluating Impacts of *FISs* and *IATs* on Rice Yield

The adoption decision theory in agriculture has the advantage of helping researchers conceptualise the profit maximisation behaviour of firms or utility maximisation behaviour of consumers. The general theoretical underpinning of agricultural innovation or technology adoption is the theory of consumer behaviour (behavioural theory). A farmer producing rice and other commodities has an option of being a net adopter of *FISs* or *IATs* or a combination of the two. This involves decision making following the assumption that the utility that a farmer derives from adopting *FISs* or *IATs* or a combination can be ordered (ordernalists approach to utility measurement). With this utility maximisation objective, a farmer chooses a combination of adoption options that will provide him or her with maximum utility. The *FISs* and *IATs* are bundles of innovations and technologies respectively. The net benefit or utility (*U*) from each or a combination can be compared (thus completeness assumption). The transitivity assumption states that given a range of innovations and technologies or a combination (y);

if $U(y_1) \geq U(y_2)$ and $U(y_2) \geq U(y_3)$, then $U(y_1) \geq U(y_3)$.

In making decisions, there are eight possible combinations of net adoption options for each farmer in this study. Let *I* and *T* represent *FISs* and *IATs* respectively. In this research, *FISs* and *IATs* are innovative strategies or technologies used by farmers to increase rice productivity. Following the work of Teklewold *et al.* (2013), table 4.4 shows four possible permutations of classified adopters.

Table 4.4 Possible Combinations of Adoptions of FISs and IATs

Choice	*Classified Adopters*	*Binary combinations*	*FISs=I*		*IATs =T*	
			I_0	I_1	T_0	T_1
1	*Non-adopter*	I_0T_0	√	×	√	×
2	*Adopter of FISs*	I_1T_0	×	√	√	×
3	*Adopter of IATs*	I_0T_1	√	×	×	√
4	*Adopter of both FISs and IATs*	I_1T_1	×	√	×	√

Subscript '*1*' implies adoption whereas subscript '*0*' implies non-adoption
√ = choice and × = no choice

Farmers in the same agro-ecological zones face nearly the same environmental conditions, prices and socio-economic circumstances and yet they may make different choices. For control experiment on the field, it is easier to determine the impact of alternative combinations of adoption options on rice yield. Due to the introduction of biases of self-selection when observational data is used (as it is the case in this study), it is inappropriate to simply compare rice yield of differently classified adopters of *FISs and IATs*. According to Teklewold *et al.* (2013), farmers endogenously self-select themselves into adopters and non-adopters and such decisions are likely to be influenced by unobservable factors such as managerial skills, motivation, productivity improvement expectations from adoption etc. which may be correlated with the outcomes of interest (in this study productivity improvement).

Henceforth, selecting either adopters or non-adopters introduces sample selection bias. Due to the adoption of *FISs* or *IATs* or both, selection bias may arise since the decision to adopt any of them is rational but may not necessarily result in improvement of productivity performances of the farmer. This may lead to an endogenous selection bias. According to Maddala (1983), the remedy for the bias is the use of a selection correction model called endogenous switching regression model. Due to multiple adoption setting, this study used the multinomial endogenous switching regression treatment effect model (often called DM model) as used by Dubin and McFadden (1984). It has the strength of estimating the impact of alternative combinations of adoption options on rice yield and also solves the problem of self-selection bias (Mansur *et al.*, 2008).

4.8.1 Multinomial Endogenous Switching Regression Model (MESR) for Estimating Impacts of Technology Adoption on Rice Yield

This study used a two-stage multinomial endogenous switching regression model. The first stage involves the use of a multinomial logit model to determine specific socio-economic factors that influence the decision of rice farmers in adopting the alternative combinations of *FISs* and *IATs* (I_0T_0, I_1T_0, I_0T_1, and I_1T_1). The second stage involves the estimation of the impacts of each combination of *FISs* and *IATs* (I_0T_0, I_1T_0, I_0T_1, and I_1T_1) on rice yield (*RY*) (outcome variables). In the second stage, the selectivity correction term called inverse mills ratio (IMR) from the selection model is incorporated into the outcome model using ordinary least squares (OLS) method.

The choice decision of *i*th farmer is represented by the unobservable selection criterion function *I**. *I** is a latent variable which is a function of a vector of specific socio-economic factors (*F*). Following the work of Noltze *et al.* (2012), the sample selection criterion function for *i*th rice farmer in *k*th agro-ecological zone is given as:

$$I_i^{*k} = \begin{cases} 1 \quad iff \quad U_{1i}^* > U_{mi}^* \quad or \quad U_{1i}^* - U_{mi}^* > 0 \\ \vdots \quad \vdots \quad \vdots \qquad\qquad \vdots \\ J \quad iff \quad U_{ji}^* > U_{mi}^* \quad or \quad U_{ji}^* - U_{mi}^* > 0 \end{cases} \qquad j \neq m \qquad [50]$$

A farmer will choose *j*th combination of adoption option over that of *m* if the utility or benefit he/she will derive from choosing *j*th adoption option is greater than adopting *m*th package. The sample selection criterion models expressing the utility for adopting *j*th package (i.e. choosing any of these: I_0T_0, I_1T_0, I_0T_1 and I_1T_1) and not adopting any package (i.e. choosing I_0T_0) are respectively given as:

$$U_{ji}^{*k} = F_i^k \delta_j + \eta_{ci}^k \qquad [51a]$$

$$U_{mi}^{*k} = F_i^k \delta_m + \eta_{ci}^k \qquad [51b]$$

Where F_i^k is a vector of exogenous variables explaining the choice decision of *i*th farmer in *k*th agro-ecological zone, δ_j and δ_m are vectors of parameters, η_{ci}^k is the error term for *i*th farmer in *k*th agro-ecological zone of the sample selection criterion model. According to McFadden (1973), η_c^k is assumed to be identically and independently Gumbel distributed; $N\left(0, \sigma_c^2\right)$ with the multinomial logit model indicating the probability that farmer i chooses *j*th package ((i.e. choosing any of these: I_0T_0, I_1T_0, I_0T_1 and I_1T_1) given as:

$$P\left(U_{j1i}^{*} - U_{mi}^{*} > 0 / F_i^k\right) = \frac{\exp\left(F_i^k \delta_j\right)}{\sum_{m=1}^{m=J} \exp\left(F_i^k \delta_m\right)} \qquad [52]$$

The parameters were estimated using maximum likelihood method. Meanwhile, in order to solve the endogeneity and selection issues, an instrument which examines the access to agricultural information with advice was included in the model as explanatory variable.

The second stage of MESRM involves the regressing of productivity performance indices [rice yield (RY)] on specific explanatory variables for adopters of any of the combinations (I_0T_0, I_1T_0, I_0T_1 and I_1T_1). For non-adopters of any of the combinations (I_0T_0), $j=0$ while for adopters of I_1T_0, I_0T_1 and I_1T_1, j represents *1, 2* and *3* respectively. The outcome equations for the various regimes are expressed as:

$$\begin{cases} \text{Re}\, gime\ 1: Non-adoption : package\ one\,(I_oT_o) \Rightarrow I = 0:\ PPI_{0i}^k = \rho_0 G_i^k + \varepsilon_{0i}^k & [53a] \\ \text{Re}\, gime\ 2: adoption\ \ of\ \ package\ \ two\,(I_1T_o) \Rightarrow I = 1:\quad PPI_{1i}^k = \rho_1 G_i^k + \varepsilon_{1i}^k & [53b] \\ \quad \vdots \qquad\qquad \vdots \qquad \vdots \qquad \vdots & \vdots \\ \text{Re}\, gime\ J: Adoption\ \ of\ \ package\ \ J \qquad \Rightarrow I = J:\quad PPI_{Ji}^k = \rho_J G_i^k + \varepsilon_{Ji}^k & [53d] \end{cases}$$

$$\text{Re}\, gime\ 1: Non-adoption : package\ one\,(I_oT_o) \Rightarrow I = 0: RY_{0i}^k = \rho_0 G_i^k + \varepsilon_{0i}^k \qquad [53a]$$

$$\text{Re}\, gime\ 2: adoption\ \ of\ \ package\ \ two\,(I_1T_o) \Rightarrow I = 1:\quad RY_{1i}^k = \rho_1 G_i^k + \varepsilon_{1i}^k \qquad [53b]$$

$$\vdots \qquad\qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$\text{Re}\, gime\ J: Adoption\ of\ \ package\ \ J \qquad \Rightarrow I = J:\quad RY_{Ji}^k = \rho_J G_i^k + \varepsilon_{Ji}^k \qquad [53d]$$

Where RY_{Ji}^{k} represents the outcome variable measuring rice yield of the *i*th farmers adopting *j*th package. Also, G_i^k denotes a vector of exogenous variables that affect the outcome variable, *RY* and ρ_0 and ρ_J are vectors of parameters in the regimes *I* and *J* respectively. Also, ε_0^k and ε_J^k denote the error terms for regimes *I* and *J* respectively. The error terms ε_0^k and ε_J^k are respectively distributed as $N(0,\sigma_0^2)$ and $N(0,\sigma_J^2)$.

According to Maddala (1983), the error term of the sample selection equation, η_c^k is assumed to have a correlation with the error terms (ε_0^k and ε_J^k) of outcome equations. Also, the expectation of the error term in the selection criterion model (η_c^k) is nonzero and this violates an assumption of classical linear regression that the expectation of the error term must be zero. Henceforth, the use of OLS to estimate the parameters results in inconsistent estimates. It is also assumed that the error terms (ε_0^k, ε_J^k and η_c^k) have trivariate joint-normal distribution with zero mean vector and non-singular variance-covariance matrix and this was specified by Fuglie and Bosch (1995) as:

$$Cov(\eta_c^k,\ \varepsilon_0^k,\ \varepsilon_J^k) = \begin{bmatrix} \sigma_c^2 & \sigma_{0c} & \sigma_{Jc} \\ \sigma_{0c} & \sigma_0^2 & \sigma_{J0} \\ \sigma_{Jc} & \sigma_{J0} & \sigma_J^2 \end{bmatrix} \qquad [54]$$

Where σ_c^2, σ_0^2 and σ_J^2 are the variances of the error term of the sample selection equation (η_c^k) and are assumed to have a correlation with the error terms of outcome equations (ε_0^k and ε_J^k); σ_{0c} is the covariance between ε_0^k and η_c^k; while σ_{Jc} denotes the covariance between ε_J^k and η_c^k; and σ_{J0} is the covariance between ε_J^k and ε_0^k. According to Maddala (1983) and Greene (2008), σ_0^2 is assumed to be 1 since δ can only be estimated up to the scale factor 1. Meanwhile, it is impossible to observe any given farmer's productivity performance indices in regimes *I* and *J* simultaneously and hence σ_{Jc} and σ_{J0} are not identified.

Since the outcome equations depend on the adoption selection criterion function, the error term of the selection equation is correlated with the error terms in the outcome equations. Following Fuglie and Bosch (1995) the expectations of ε_J^k and ε_0^k are nonzero and are given as:

$$E(\varepsilon_{0i}^k / I_i^k = 1) = E(\sigma_{0c}\eta_{ci}^k / I_i^k = 1) = \sigma_{0c}\frac{\phi\delta F_i^k}{\varphi\delta F_i^k} = \sigma_{0c}\lambda_{0i} \qquad [55a]$$

$$E(\varepsilon_{Ji}^k / I_i^k = 0) = E(\sigma_{Jc}\eta_{ci}^k / I_i^k = 0) = \sigma_{Jc}\frac{\phi\delta F_i^k}{(1-\varphi\delta F_i^k)} = \sigma_{Jc}\lambda_{Ji} \qquad [55b]$$

Where ϕ and φ are standard normal probability density distribution function and cumulative standard normal distribution function respectively. The indices, λ_0 and λ_J evaluated at δF_i^k are known as *IMR*s.

One can use a two stage procedure where the *IMRs* are incorporated into the outcome regime equations, but this provides less efficient estimates. A full information maximum likelihood (*FIML*) method developed by Lokshin and Sajaia (2004) which estimates the selection and outcome equations simultaneously provides more efficient estimates. Therefore, this study used *FIML* multinomial endogenous switching regression method with the outcome equations specified as:

$$\text{Regime } 1: Non-adoption: package\ one: If\ \ I=0;\quad RY_{0i}^k = \rho_0 G_i^k + \sigma_{0c}\lambda_{0i} + \xi_{0i}^k \quad [56a]$$

$$\text{Regime } 2: adoption\ of\ \ package\ \ two: If\ \ I=1;\ \ RY_{1i}^k = \rho_1 G_i^k + \sigma_{1c}\lambda_{1i} + \xi_{1i}^k \qquad [56b]$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$\text{Regime } 4: Adoption\ of\ \ package\ \ J:\ If\ \ I=J;\quad RY_{Ji}^k = \rho_J G_i^k + \sigma_{Jc}\lambda_{Ji} + \xi_{Ji}^k \qquad [56d]$$

Where ξ_0^k, …, ξ_J^k are the error terms with zero expectations.

According to Akpalu (2012), if the covariances σ_{0c} and σ_{Jc} are statistically significant, then the decision not to adopt any of the packages and productivity performance effects are correlated and the null hypothesis of absence of selectivity bias is rejected. This implies endogeneity i.e. endogenous switching is present and the reverse is true indicating exogenous switching. For applicability of *FIML* endogenous switching regression, the restriction criterion requires that there should be identification or valid instrumental variables. This means that at least one variable that affects selection decisions of farmers must not directly affect any of the farmers' productivity performance scores. Following the work of Kabunga *et al.* (2011) and Tambo and Wünscher (2014) and the test for the choice of instrument, access to agricultural information (measured as access to agricultural extension services on rice) is a factor that affects the decision of farmers to choose any of the packages but does not affect the productivity performance scores of farmers directly. As such, access to agricultural information was used as an identification or instrumental variable. Also, endogenous switching regression modelling is applicable when the explanatory variables differ slightly between the two models and this is the case in this study. The conventional inputs, farmer characteristics, institutional and policy variable, environmental factors, agro-ecological dummies and synergy of rice production technologies indicated in appendix I are used in the multinomial endogenous selection and outcome models. For the outcome model, number of extension visits with rice production advice and number of years spent in formal education were not included in the explanatory variables because they were used as intruments.

4.8.2 Estimation and Comparison of Observed and Counterfactual Rice Yield

The MESR model can be used to compare observed and counterfactual productivity performance (*RY*). The yardstick for comparison is the use of unbiased average treatment effects on the treated (*ATT*) for adopters and average treatment effect on the untreated (*ATU*) for non-adopters. It can be used to compare the expected productivity performance (*RY*) of a farmer who adopted any of the packages ($I_I T_0$, $I_0 T_I$ and $I_I T_I$) against a scenario that he/she does not adopt any package ($I_0 T_0$). Conversely, it compares the expected productivity performance (*RY*) of a non-adopter farmer of any of the packages ($I_0 T_0$) to a situation had he/she does adopt any of the packages ($I_I T_0$, $I_0 T_I$ and $I_I T_I$)

4.8.2.1 Adopter with adoption (actual adoption observed)

For adopter *i* in *k*th agro-ecological zone with *G* vector of explanatory variables, the expected value of productivity performance (*RY*) can be expressed as:

$$E\left(RY_{1i}^{k}/I=1\right)=\rho_1 G_i^k+\sigma_{1c}\lambda_{1i} \quad [57a]$$

$$E\left(RY_{2i}^{k}/I=2\right)=\rho_2 G_i^k+\sigma_{2c}\lambda_{2i} \quad [57b]$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$E\left(RY_{Ji}^{k}/I=J\right)=\rho_J G_i^k+\sigma_{Jc}\lambda_{Ji} \quad [57d]$$

4.8.2.2 Adopter without adoption (counterfactual)

For adopter *i* in *k*th agro-ecological zone with *G* vector of explanatory variables, the expected value of productivity performance (*RY*) had he/she not adopted any of the packages can be expressed as:

$$E\left(RY_{0i}^{k}/I=1\right)=\rho_0 G_i^k+\sigma_{0c}\lambda_{1i} \quad [58a]$$

$$E\left(RY_{0i}^{k}/I=2\right)=\rho_0 G_i^k+\sigma_{0c}\lambda_{2i} \quad [58b]$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$E\left(RY_{0i}^{k}/I=J\right)=\rho_0 G_i^k+\sigma_{0c}\lambda_{Ji} \quad [58d]$$

ATT measures the change (impact) in productivity performance (*RY*) of the farmer due to adoption. It is the benefit that an adopter gets if he/she had not adopted and it is expressed as the differences between equations [57a] and [58*a*] or equations [57b] and [58b] etc. Considering equations [57*a*] and [58*a*], *ATT* is expressed as:

$$ATT_i^k=E\left(RY_{1i}^k/I_i=1\right)-E\left(PPI_{0i}^k/I_i=1\right)=G_i^k\left(\rho_1-\rho_0\right)+\lambda_{1i}\left(\sigma_{1c}-\sigma_{0c}\right) \quad [59]$$

4.8.2.3 Non-adopter with no adoption (observed)

Alternatively, for i^{th} non-adopter with *H* vector of explanatory variables who indeed did not adopt any of the technology packages, the expected value of *RY* is specified as:

$$E\left(RY_{0i}^k/I_i=0\right)=\rho_0 H_i^k+\sigma_{0c}\lambda_{0i} \quad [60]$$

4.8.2.4 Non-adopter with adoption (counterfactual)

Similarly, for *i*th farmer in *k*th agro-ecological zone who is not an adopter with *H* vector of explanatory variables, the expected value of *RY* had he/she adopted any of the technology packages is specified as:

$$E\left(RY_{1i}^k/I_i=1\right)=\rho_1 H_i^k+\sigma_{1c}\lambda_{0i} \quad [61]$$

The difference between the expected productivity performance indices of the counterfactuals and the observed is ATU. The change in *RY* of the farmer if he/she had adopted technology is the *ATU* given as:

$$ATU_i^k = E\left(RY_{1i}^k / I_i = 1\right) - E\left(PPI_{0i}^k / I_i = 0\right) = H_i^k\left(\rho_1 - \rho_0\right) + \lambda_{0i}\left(\sigma_{1C} - \sigma_{0c}\right) \quad [62]$$

4.9 Determination of Gender Dynamics in Resource-Use Efficiency in Rice Production

Resource usage among gender differs from one agro-ecological zone to the other. The heterogeneous gender usage of resources in rice production affects allocative efficiency differently. It is important to note that the higher the allocative efficiency, the higher the profit. A research of this nature requires that one determines how efficiently male farmers and female farmers in each of the agro-ecological zones used factor inputs in the production process.

4.9.1 Theoretical Framework of Resource-Use Efficiency

The neoclassical theory of production can be used to derive the resource-use efficiency (allocative efficiency of factor inputs). Farrel (1957) differentiated between technical efficiency and allocative efficiency in his 1957 seminal paper entitled "the measurement of productive efficiency". The concept used in the paper to measure allocative efficiency of factor inputs is traced back to the concept used by Koopmans (1951) and Debreu (1951). Farrel (1957) defined allocative efficiency as the ability of a firm (farmer) to produce at a given level of output using cost minimising input ratios.

Olayide and Heady (1982) opined that allocative efficiency is an important index used in measuring the ability of a firm (farmer) to choose the level of inputs that maximises profit at a given factor cost. It is also the ability of a firm to use factor input optimally given factor prices. At allocative efficiency, it is not possible for a firm (farmer) to increase or maximise the value of factor input through reallocation. Since a shift in the allocative efficiency point will result in the reduction in the welfare of the firm, one can describe allocative effiency as Pareto efficiency. According to Ogundari (2008), a firm is allocatively efficient if it is able to equate the marginal value product (*MVP*) of each input to the respective unit input cost (marginal-factor-cost).

4.9.2 Empirical Estimation of Resource-Use Efficiency

The alternative approach to modelling frontier production function is the cost or profit function approach. This approach is valid based on the duality identity of the production function. Since a production function is self-dual, one can equally model cost as a function of output, output price and inputs prices. Following Kumbhakar and Wang (2006), a cost minimisation problem that defines the minimum cost (*C*) of producing *R* quantity of rice by employing inputs X_j costing P_j. The dual group specific stochastic cost translog model which is a representation of cost (*C*) as a function of price of fertilizer (P_F), price of pesticides (P_{Pc}), price of labour (P_L), price of seed (P_S), farm size (*Fs*) and capital (*K*) is given as:

$$
\ln C_i^k = \begin{Bmatrix}
\beta_0 + +\Omega_1 D_{F_i}^k + \Omega_2 D_{Pc_i}^k + \beta_1 \ln\left\{Max\left(P_{F_i}^k, 1 - D_{F_i}^k\right)\right\} + \\
\beta_2 \ln\left\{Max\left(P_{Pc_i}^k, 1 - D_{Pc_i}^k\right)\right\} + \beta_3 \ln P_{L_i}^k + +\beta_4 \ln P_{S_i}^k + \beta_5 \ln Fs_i^k + \\
\beta_6 \ln K_i^k + \beta_7 \ln R_i^k + \tfrac{1}{2}\beta_{11} \ln\left(NP_{F_i}^k\right)^2 + \tfrac{1}{2}\beta_{22} \ln\left(NP_{Pc_i}^k\right)^2 + \tfrac{1}{2}\beta_{33} \ln\left(P_{L_i}^k\right)^2 + \\
\tfrac{1}{2}\beta_{44} \ln\left(P_{S_i}^k\right)^2 + \tfrac{1}{2}\beta_{55} \ln\left(Fs_i^k\right)^2 + \tfrac{1}{2}\beta_{66} \ln\left(K_i^k\right)^2 + \tfrac{1}{2}\beta_{77} \ln\left(R_i^k\right)^2 + \\
\beta_{12} \ln NP_{F_i}^k \ln NP_{Pc_i}^k + \beta_{13} \ln NP_{F_i}^k \ln P_{L_i}^k + \beta_{14} \ln NP_{F_i}^k \ln P_{S_i}^k + \beta_{15} \ln NP_{F_i}^k \ln Fs_i^k + \\
\beta_{16} \ln NP_{F_i}^k \ln K_i^k + \beta_{17} \ln NP_{F_i}^k \ln R_i^k + \beta_{23} \ln NP_{Pc_i}^k \ln P_{L_i}^k + \beta_{24} \ln NP_{Pc_i}^k \ln P_{S_i}^k + \\
\beta_{25} \ln NP_{Pc_i}^k \ln Fs_i^k + \beta_{26} \ln NP_{Pc_i}^k \ln K_i^k + \beta_{27} \ln NP_{Pc_i}^k \ln R_i^k + \beta_{34} \ln P_{L_i}^k \ln P_{S_i}^k + \\
\beta_{35} \ln P_{L_i}^k \ln Fs_i^k + \beta_{36} \ln P_{L_i}^k \ln K_i^k + \beta_{37} \ln P_{L_i}^k \ln R_i^k + \beta_{45} \ln P_{S_i}^k \ln Fs_i^k + \\
\beta_{46} \ln P_{S_i}^k \ln K_i^k + \beta_{47} \ln P_{S_i}^k \ln R_i^k + \beta_{56} \ln Fs_i^k \ln K_i^k + \beta_{57} \ln Fs_i^k \ln R_i^k + \\
\beta_{67} \ln K_i^k \ln R_i^k + \hbar_i^k - \Psi_i^k
\end{Bmatrix} \quad [63]
$$

Where Ψ_i^k is the group specific economic efficiency which is a function of farmer characteristics (*Age, Sex, HHS, Eduyrs FarmExp*), institutional and policy variables (*ExtVisits, CredAcc, ContFarm, FBO, ImpvSeed, IrrigAcc*), environmental factors' perception (*LodgRice, LowRain)* and rice production technologies (*Adopt_IATs, Adop_FISs, IATs _PC_Index, FISs_PC_Index, IFPs_PC_Index*). These explanatory variables have the same meaning and measurement as indicated earlier in section 4.7.1 and table 4.3. Also, $\hbar_i^k$ is the stochastic error term. Note that the dummy variable of the fertilizer and pesticides as included in equation [38] is to correct for the change in intercept.

Each of the above estimated dual group specific stochastic cost translog models is used to predict production cost which is then used as a dependent variable for the stochastic metafrontier cost translog function (Huang *et al.*, 2014). Therefore, dual stochastic metafrontier cost translog function is given as:

$$\hat{C}_i^* = \left\{ \begin{array}{l} \beta_0 + +\Omega_1 D_{F_i}^* + \Omega_2 D_{Pc_i}^* + \beta_1 \ln\left\{Max\left(P_{F_i}^*, 1 - D_{F_i}^*\right)\right\} + \\ \beta_2 \ln\left\{Max\left(P_{Pc_i}^*, 1 - D_{Pc_i}^*\right)\right\} + \beta_3 \ln P_{L_i}^* + +\beta_4 \ln P_{S_i}^* + \beta_5 \ln Fs_i^* + \\ \beta_6 \ln K_i^* + \beta_7 \ln R_i^* + \frac{1}{2}\beta_{11} \ln\left(NP_{F_i}^*\right)^2 + \frac{1}{2}\beta_{22} \ln\left(NP_{Pc_i}^*\right)^2 + \frac{1}{2}\beta_{33} \ln\left(P_{L_i}^*\right)^2 + \\ \frac{1}{2}\beta_{44} \ln\left(P_{S_i}^*\right)^2 + \frac{1}{2}\beta_{55} \ln\left(Fs_i^*\right)^2 + \frac{1}{2}\beta_{66} \ln\left(K_i^*\right)^2 + \frac{1}{2}\beta_{77} \ln\left(R_i^*\right)^2 + \\ \beta_{12} \ln NP_{F_i}^* \ln NP_{Pc_i}^* + \beta_{13} \ln NP_{F_i}^* \ln P_{L_i}^* + \beta_{14} \ln NP_{F_i}^* \ln P_{S_i}^* + \beta_{15} \ln NP_{F_i}^* \ln Fs_i^* + \\ \beta_{16} \ln NP_{F_i}^* \ln K_i^* + \beta_{17} \ln NP_{F_i}^* \ln R_i^* + \beta_{23} \ln NP_{Pc_i}^* \ln P_{L_i}^* + \beta_{24} \ln NP_{Pc_i}^* \ln P_{S_i}^* + \\ \beta_{25} \ln NP_{Pc_i}^* \ln Fs_i^* + \beta_{26} \ln NP_{Pc_i}^* \ln K_i^* + \beta_{27} \ln NP_{Pc_i}^* \ln R_i^* + \beta_{34} \ln P_{L_i}^* \ln P_{S_i}^* + \\ \beta_{35} \ln P_{L_i}^* \ln Fs_i^* + \beta_{36} \ln P_{L_i}^* \ln K_i^* + \beta_{37} \ln P_{L_i}^* \ln R_i^* + \beta_{45} \ln P_{S_i}^* \ln Fs_i^* + \\ \beta_{46} \ln P_{S_i}^* \ln K_i^* + \beta_{47} \ln P_{S_i}^* \ln R_i^* + \beta_{56} \ln Fs_i^* \ln K_i^* + \beta_{57} \ln Fs_i^* \ln R_i^* + \\ \beta_{67} \ln K_i^* \ln R_i^* + \hbar_i^* - \Psi_i^* \end{array} \right\} \quad [64]$$

Where Ψ_i^* is the metafrontier economic efficiency.

Allocative efficiency is estimated based on the economic and technical efficiencies. To estimate economic efficiency, the Stata econometric software (version 14.0) will be used to run a dual new-two step stochastic metafrontier cost translog function and the economic efficiency scores predicted. From the relationship that economic efficiency is the product of technical and allocative efficiencies (Farrel, 1957), the technical efficiency that will be predicted from the equations [38] and [40] cum the economic efficiency will be used to estimate allocative efficiency. The estimated allocative efficiency estimated using metafrontier can conveniently be called meta-allocative efficiency or meta-resource-use efficiency, whereas the allocative efficieny estimated using group specific frontier is called group allocative efficiency. The interpretation of allocative efficiency is:

- If $AE_i^k = 1$, then factor inputs of ith farmer is efficiently utilised in *k-th* agro-ecological zone and the farmer can neither increase nor decrease rice production by increasing or decreasing the rate of use of factor inputs.
- If $AE_i^k > 1$, then factor inputs of ith farmer is under-utilised in *k-th* agro-ecological zone and increasing the rate of use of factor inputs will increase rice production.
- If $AE_i^k < 1$, then factor inputs of ith farmer is over-utilised in *k-th* agro-ecological zone and therefore it is possible for the farmer to reduce the rate of use of the inputs so as to increase production of rice.

It is possible to calculate the relative percentage change *(Δ%)* that is required to move ith farmer in *k-th* agro-ecological zone to optimum input allocation level. The relative percentage change is the percentage gap that must be filled to enable farmers achieve the optimum input allocation. The relative percentage change necessary for efficient allocation of factor input by ith farmer in *k-th* agro-ecological zone is given as:

$$\Delta_i^k \% = \left(1 - AE_i^k\right) \times 100 \quad [65]$$

4.9.3 Testing Gendered Effects of Resource-Use Efficiencies

To test the gendered effects of resource-use efficiency, a Welch t-test was used. This was done for each of the agro-ecological zones as well as the pool.

4.10 Study Area

The study was conducted in Ghana. Ghana is a tropical country in Africa. It is located in the West African coastline and shares boundary with Burkina Faso to the north, Cote d'Ivoire to the west, Togo to the east and Gulf of Guinea to the south. The country occupies a land area of 238,533km^2 with ten administrative regions. While Greater Accra is the smallest region, Northern is the largest in terms of land area.

Ghana is divided into six agro-ecological zones based on the climatic and environmental conditions. As noted in table 4.5, these agro-ecological zones are SSZ, GSZ, FSTZ, SDRFZ, HRFZ and CSZ. Through stratified sampling technique, GSZ, FSTZ and CSZ were selected for the study. The conditions in these selected agro-ecological zones are good for rice production.

Table 4.5 Agro-ecological zones of Ghana

Agro-ecological zone	Regions	Land area (Km^2)	Average annual rainfall (mm)	Range of rainfall (mm)	Major rainy season	Minor rainy season
SSZ	UE	2200	1000	600-1200	May-Sept. (150- 160adys)	-
GSZ	UE, UW, NR, VR BA	147900	1000	800-1200	May-Sept. (180-100days)	-
FSTZ	BA, ER, V/R, AR	8400	1300	1100-1400	March-July (200-220days)	Sept.-Oct. (60days)
SDRFZ	AR, VR, BA, CR, WR, GA	6600	1500	1200-1600	March-July (150- 160 days)	Sept-Nov. (100 days)
HRFZ	WR	9500	2200	800-2800	March-July (150-160days)	Sept.-Nov. (100days)
CSZ	CR, GA, VR	4500	800	600-1200	March-July (100-110days)	Sept.-Oct. (50days)

UE-Upper East, UW-Upper West, NR-Northern Region, BA-Brong-Ahafo, VR-Volta Region, AR-Ashante Region, ER-Eastern Region, CR-Central Region, WR-Western Region, GA-Greater Accra

Source: Modified from MoFA (2011)

As the name suggests, the CSZ is located in the southernmost part of the country along the coast of Gulf of Guinea. Greater Accra, parts of Volta and central regions are located in CSZ. The zone occupies a total land area of 4500Km^2. CSZ is relatively dry with annual rainfall ranging from 600mm to 1200mm. The zone has a bimodal cropping seasons namely major and minor seasons. It has CSZ shrubs interspersed with grass thickets.

The FSTZ has a total land area of 8400Km^2 and it covers part of Volta, Eastern, Brong Ahafo and Ashanti Regions. It lies in the middle belt of the country. The zone has an annual rainfall ranging from 1100mm to 1400mm with bimodal cropping seasons. The strategic location of the zone made it to have almost all the different types of vegetation in Ghana and hence the name FSTZ. It has the savannah woodlot vegetation in the south, forest in the middle belt and grassland in the north.

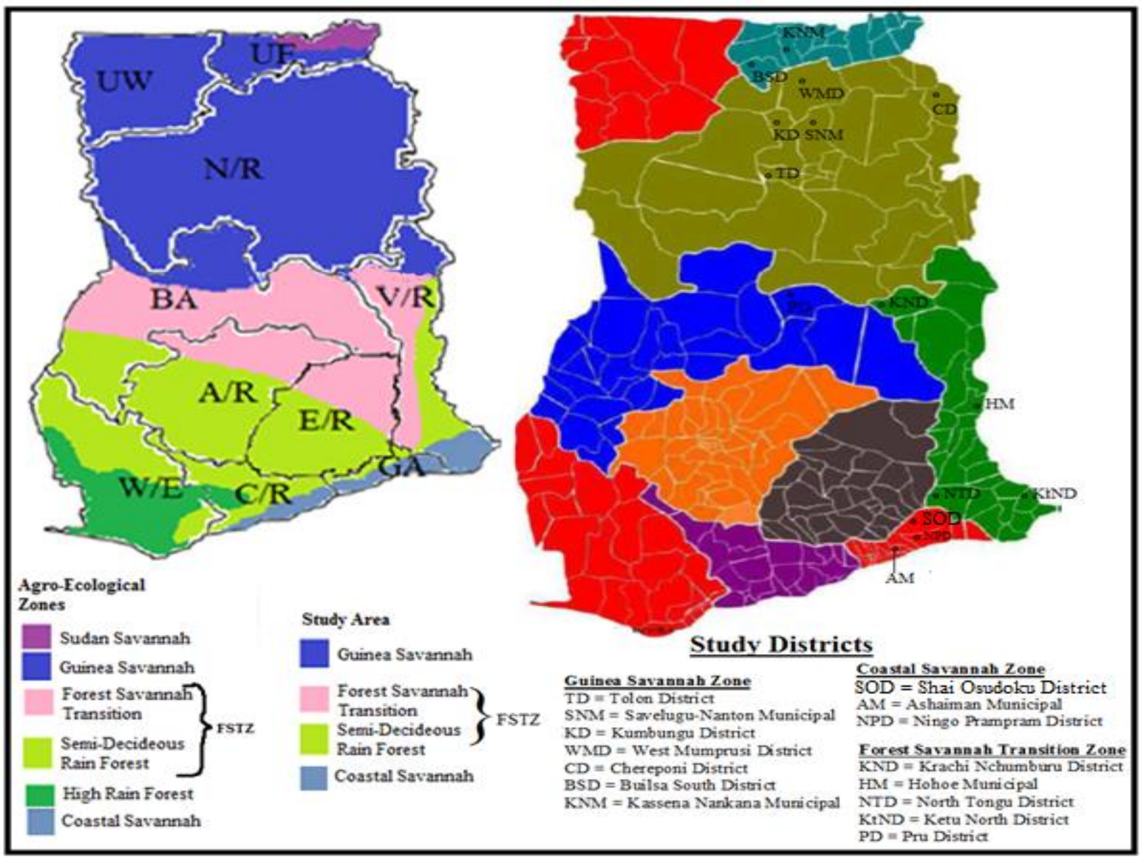


Figure 4.3 Ghana Map Showing the Selected Agro-Ecological Zones and the Study Districts

The half northern part of Ghana is made up of the guinea and sudan savannah. The GSZ stretches from part of Volta, Brong Ahafo, Upper East and the whole of Northern and Upper West regions. Guinea Savannah zone is the largest agro-ecological zone with a total land area of 147900Km^2. It has minimum and maximum annual rainfall amounts of 800mm and 1200mm respectively. The climatic condition in the zone is drier than the southern part of the country. It has unimodal rainy season that begins in May and ends in October. The dry north-east harmattan wind blows from December to early February makes the place dry and dusty. The vegetation consists of large stretches of grasses interspersed with drought-resistant trees.

4.11 Research Design

The study adopted a mixed research design. Both qualitative and quantitative data were collected and analyzed. The design was non-experimental.

4.12 Sources, Type and Method of Data Collection

Data were collected from both primary and secondary sources. The secondary data which included regional rice output and land area were collected and used to calculate regional rice yield. This provided precise information for selecting the research areas. Other secondary data collected are climatic variables (rainfall and temperature) in each of the study districts. The study collected primary cross-section data of rice farmers for 2015/16 cropping season. The data was collected from October 2015 to August 2016.

The data collected from rice farming households included farm characteristics, farmer characteristics, economic factors, institutional factors and geographical locations. The study used semi-structured questionnaire to collect data. The questionnaire contained both closed and open-ended questions.

4.13 Sample Size

In determining the sample size for the study, Slovin's formula used by Visco (2006) and Rivera (2007) was adopted. It is expressed as:

$$n = \frac{N}{1 + Ne^2} \qquad [63]$$

Where *n* is the sample size to be used for the study (total number of farmers to be included in the study). Also, *N* is the population size (in this study, number of potential rice farmers in the agro-ecological zone) and *e* is the percentage of imprecision of sampling that can be tolerated. This study used 8% as the percentage of imprecision.

There is no information on the number of rice farmers in the country except household size. To get the sample size for each of the selected agro-ecological zones, the following analyses were done. From Ghana Statistical Service (GSS) (2014), the national average household size is 4.0 with rural savannah, rural transition and rural coastal recording average household sizes of 5.5, 4.3 and 3.8 respectively.

The proportion of children (less than 15 years) and the elderly (65 years and above) are 38.3% and 4.7% respectively totalling 43% (GSS, 2013). This suggests that 57% of the people in the household are adult and potential farmers. As such, the potential rice farming household sizes in rural savannah, rural transition and rural coastal 3.135 (thus 0.57x5.5), 2.451 (thus 0.57x4.3) and 2.166 (thus 0.57x3.8) respectively. Therefore, the potential rice farmers (sample frame) for GSZ, FSTZ and CSZ were obtained by multiplying the respective potential rice farming household sizes by the rice farming households as shown in table 4.6. As note by GSS (2014), the number of rice farming households in GSZ, FSTZ and CSZ are 296,489, 33,048 and 3,931 respectively.

Table 4.6 Sample Size Estimation

Study area	Study regions	Estimated potential number of rice farmers (N)	Calculated sample size $n = \frac{N}{1+Ne^2}$ (e = 8%)	Actual sample taken		
				Irrigated	Non-irrigated	Total
CSZ	Greater Accra Region	8,515	$\frac{8515}{1+8515\,(0.08)^2} = 153.49$	141	30	171
FSTZ	Volta and Brong Ahafo Regions	81,001	$\frac{81001}{1+81001\,(0.08)^2} = 155.95$	123	236	359
GSZ	Northern and Upper East Regions	929,493	$\frac{929493}{1+929493\,(0.08)^2} = 156.22$	131	246	377
Ghana		**1,019,009**	**245.66**	**395**	**512**	**907**

Source: Author's Analysis (2017)

4.14 Sampling Procedure

A multi-stage sampling technique was used to collect primary data for the study. In the first stage, a stratified random sampling technique was employed. This involved the stratification of the country into northern, middle and southern belts. Rice is better grown in certain agro-ecological zones in the country. Each of the northern, middle and southern belts is made up of specific agro-ecological zones. These agro-ecological zones starting from the north to south are: SSZ, GSZ, FSTZ, semi-deciduous rain forest zone (SDRFZ), high rain forest zone (HRFZ) and CSZ. The northern belt is made up of SSZ and GSZ while the middle belt is made up of FSTZ and SDRFZ. Also, SDRFZ, HRFZ and CSZ are located in southern belt. As a typical of stratified random sampling technique, a simple random sampling method was then used to select one agro-ecological zone from each of the northern, middle and southern belts. Thus, GSZ, FSTZ and CSZ were selected. The selection was also based on the fact that there are wide disparities in rice yields among these regions.

The second stage involved another stratified random sampling. Under this stage, the major rice producing districts in each of the selected agro-ecological zones were grouped into districts with and without irrigation facilities. Considering the proportion of rice production in each of the agro-ecological zones, four districts with irrigation facilities (Tolon District, Kumbungu District, Savelugu Municipal and Kasena-Nankana Municipal) and three districts without irrigation facilities (West Mamprusi District, Chereponi and Builsa South Districts) were randomly selected from GSZ. In FSTZ, North Tongu and Ketu North Districts were all selected whereas Krachi Nchumburu District, Pru Districts and Hohoe Municipal were randomly selected under non-irrigation districts. All the three districts where rice cultivation is evident in the Greater Accra

Region have irrigation facilities. As such all these districts (Shai Osudoku District, Ningo Prampram District and Ashaiman Municipal) were included in the study districts in CSZ.

In the third stage, rice producing communities were stratified into communities with and without irrigation facilities. Two communities each were randomly sampled from each stratum. Systematic sampling technique was then used to select houses and one rice farmer was randomly selected from each house. In some of the communities, the enumerators visited rice farms and the rice farms were systematically selected and the owners interviewed.

4.15 Pre-Testing of Questionnaires

The drafted questionnaire was pre-tested in the Krachi East District in the FSTZ and Tolon District in GSZ. In each of the districts, ten (10) farmers were selected for the pre-testing totalling twenty (20). The districts were stratified into GSZ and FSTZ and simple random sampling technique was used to select one rice farming communities each from each of the districts. Finally, the systematic sampling technique was used to select the individual farmers and data collected through face-to-face interviews. The results of the pre-tested questionnaire led to the modification of some questions to make them clearer for easy data collection. The pre-testing was done in September, 2015.

4.16 Test of Reliability of Survey Instrument

The data from the pre-tested questionnaire was analyzed using SPSS (Statistical Package for Social Sciences). The reliability coefficient of 0.90 was obtained. This value indicated that the survey instrument was good and could be used for the main data collection.

4.17 Econometric Software for Data Analysis

In order to obtain correct estimates, the researcher must use suitable econometric software. Stata (Version 14) and SPSS (Version 20) softwares were used for the data analysis because they gave estimates which were meaningful economically. Each of the estimations were done at least three times to confirm that the results are the same.

CHAPTER FIVE

EMPIRICAL RESULTS OF TECHNOLOGY ADOPTION TYPOLOGY AND RICE YIELD DIFFERENTIALS

5.1 Introduction

This chapter presents the results of the principal component analysis using the empirical model shown in equations [30a] to [30c]. The first section presents the frequency distribution of farmers interviewed in each of the districts in the three agro-ecological zones. The frequency distributions of *IFPs*, *FISs* and *IATs* are presented in the second section of this chapter. With the help of the PCA, farmers were classified into different technology adoption typologies. Differences in rice yields between technology typology adopters were tested and the results presented and discussed in the chapter.

5.2 Frequency Distribution of Farmers in the Study Area

Appendix 3 depicts the frequency distribution of farmers interviewed in each of the districts in the three agro-ecological zones. In GSZ, the largest percentage of farmers (21.5%) were sampled from Kumbungu District. This is as a result of the large number of farmers cultivating rice in the area under both irrigation and rainfed agriculture. The Builsa South District had the lowest percentage of respondents (5.3%), followed by Kasena-Nankana Municipality (8.5%) because only farmers within GSZ of these two districts were included. Farmers located in the sudan savannah zone of these two districts were excluded because the sudan savannah zone is not part of the sampling frame.

In FSTZ, out of 359 farmers sampled, 10.5% came from North Tongu District whereas 6.1% came from Krachi Nchumburu District. The North Tongu district recording the highest number of farmers interviewed is closely followed by Ketu North District with a respondent percentage of 8.9%. The majority of the farmers interviewed in FSTZ came from North Tongu and Ketu North Districts. This is due to the availability of formal irrigation facilities and the large number of farmers engage in rice production in the area.

The largest number of farmers sampled from Shai Ossudoku in CSZ is premised on the large number of farmers engaged in rice production under formal irrigation and rainfed as compared to other districts. Out of 171 farmers, 50.1% came from Shai Ossudoko District. For the pooled data, Shai Ossudoku still recorded the largest number of respondents, whereas Buisa South in GSZ recorded the least. GSZ had the largest number of respondents because of the large number of farmers engaged in rice farming as compared to the two other agro-ecological zones.

5.3 Frequency Distribution of *IFPs*, *FISs* and *IATs*

The total number of farmers used for the analysis was 907. The number of variables or factors used for the PCA was 45. The table shown in appendix 4 presents a frequency distribution of the variables used in PCA. The frequency distribution table shows the frequency and the percentage of adopters and non-adopters of *IFPs*, *FISs* and *IATs*.

From appendix 4, the indigenous farming practice mostly used by farmers (67.1%) is personal scaring of birds using ringing bell, catapult or any noisy object. In rice production, one of the critical stages is the period of tasseling of the rice plant. During this time, birds suck the sugary nector resulting in the inability of the rice plant to bear satisfactory and quality seed. This can result in total crop failure. Almost every rice farmer used this technique to secure their investment. Conversely, haphazard pulverising of soil with hoe is rarely used by farmers. Only 8.7% of the farmers used this farming practice. This indigenous farming practice is losing its importance.

FISs adopted are presented in appendix 4 and it can be observed that the use of wood ash to speed up rice germination had the highest frequency of respondents with a percentage of 27.1%. This is followed by incorporation of rice straw into the soil. The farmer innovation with the lowest proportion of adoption is the use of mulch to suffocate weeds. The changing climatic conditions, especially the reduction in the rainfall amount and duration, may be the main reason why most farmers soak rice seed in wood ash to speed up germination. The removal of rice seed by birds is another likely justification for most farmers adopting wood ash farmer innovation. Due to poor knowledge of farmers on the importance of sustainable agriculture, mulching to suffocate weeds is rarely used by farmers.

The improved agricultural technology that farmers adopted most is the spraying of weeds with chemical pesticides. Out of 907 respondents, 82.8% controlled weeds by spraying chemical pesticides. The plausible reason may be the high cost of labour and the increased promotion of these pesticides by the manufacturers. As such, Horna *et al*. (2008) noted that the use of pesticides by farmers in Ghana to control weeds, increase agricultural productivity and preserve agricultural produce has reached a crescendo thereby calling for urgent attention. The transplanting or dibbling or drilling and planting rice with correct spacing is the least adopted *IATs*. Only 2.2% farmers out of 907 adopted this technology. The labour intensiveness and the low knowledge of farmers on the importance of transplanting or dibbling or drilling and planting with correct spacing might be the reason why few farmers adopt this technology in Ghana. The next least adopted *IAT* is the use of stationary thresher to thresh the paddy from the straw.

5.4 Percentage Distribution of Technology Adoption Typology of Rice Farmers

PCA is an exploratory factor analysis tool which is used to analyse the correlations among larger number of variables. After data entry, cleaning and validation, forty-six variables were analysed using PCA with oblique or oblimin rotation. This was done to typologically and objectively classify the variables under *IFPs*, FISs (*FISs*) and *IAT*. SPSS version 20.0 was used for the analysis and the results shown in appendices 5 to 9.

Since the sample size is 907 and the number of variables considered in this study is forty-six, the sample and the variable adequacy criterion of at least 50 samples and 5 variables was met (Kaiser. 1968). The sample adequacy test for the applicability of PCA tool is validated by Kaiser-Meyer-Olkin (KMO) test. According to Kaiser (1968), KMO value of 0.5 and above is the threshold. As shown in appendix 5, the KMO value of 0.723 was obtained indicating that the sample adequacy is middling[12] and hence that PCA tool is suitable or the sample (Kaiser, 1968). Bartlett's test of sphericity had a Chi-Square value of 10380.675 which is significant at 1% indicating that there are adequate correlations among variables justifying the use of PCA. The Kaiser criterion and the Scree Plot (see appendix 5) tests indicated that factors are loaded and retained under only three components.

[12] Middling means the KMO is greater than 0.5 and hence the sample is adequate for PCA analysis

The communality value for harvesting rice using combine harvesters is 0.820, implying that 82% of the variability in harvesting of rice using combine harvesters is explained by the fourteen components. From the extraction results in appendix 8, fourteen principal components were extracted and they jointly explained 60.13% of the variations in the farming practices, farmer innovations and the IATs (46 variables) used by farmers. The criteria for selecting 14 principal components (PCs) is that each PC should have at least a unit eigenvalue and the total cumulative percentage variance should be at least 50%. The results suggest that the component extraction procedure is accurate and produces results with high integrity as it explained more than half of the variations in the farming practices, farmer innovations and improved technologies (Mohammed *et al*., 2013).

From appendix 8, the eigenvalue of each of the fourteen PCs is greater than one. Out of the fourteen PCs retained, fifteen factors loaded with three PCs. In this study, a factor is loaded when it has factor loading of 0.40 and above. With oblique rotation, factors which are highly inter-correlated are loaded under the same component and they describe the same data clusters (Richman, 1981).

The technology typology extracted are *IFPs*, *FISs* and *IATs*. Under *IFPs*, the loaded factors are the threshing of paddy rice from the straw using wooden or bamboo materials (0.801) and using of cutlass to harvest rice (0.538). From the PCA, threshing of paddy rice from the straw by beating with sticks, slushing and leaving the grasses to decompose, incorporation of rice straw into soil and soaking of rice seed into ash suspension before planting were loaded under *FISs* with the factor loadings of 0.437, 0.472, 0.441 and 0.418 respectively. This implies that threshing of paddy rice from the straw by beating with sticks, slushing and leaving grasses to decompose, incorporation of rice straw into soil and soaking of rice seed into ash suspension before planting are closely interrelated. Hence, they are factors that can be used in the production function to determine their impact on rice production.

Additionally, factors classified and loaded under *IATs* are harvesting of rice with combined harvester, use of certified improved rice varieties, farming rice under formal irrigation, application of chemical fertilizers, rotovation of soil before planting, storage of rice in warehouses, transplanting of seedlings and soaking of seed in water before planting or sowing. The loadings of these factors are not only theoretically correct but also practically consistent. They were loaded under principal component one which this study typologically called *IATs*. The technologies loaded under *IATs* had the highest cumulative variance of 15.3%.

The findings of this study suggest that the greatest variation in the farming activities in Ghana comes from the use of *IATs*, since the extraction was under first principal component. The next variation in farming activities is the use of *FISs* followed by *IFPs*. The IFPs have become part and parcel of farmers thereby resulting least variations among farmers in Ghana. Therefore, the degree of influence of *IATs* on rice production is the highest followed by *FISs* and *IFPs*.

With the help of PCA, farmers were classified into non-adopters (users of *IFPs*), adopters of *FISs*, adopters of *IATs* and adopters of both *FISs* and *IATs*. Figure 5.1 shows the percentage distribution of technology adoption typology of farmers by agro-ecological zones. In terms of percentage distribution of technology adoption typology of farmers, CSZ had the largest proportion adopting *IATs* followed by FSTZ with GSZ having the least. The agro-ecological zone with the largest percentage of farmers adopting *FISs* is FSTZ. In GSZ, majority of the farmers (30.0%) out of 377 still remained users of IFPs. CSZ had the least proportion of farmers using IFPs. This might be the reason why rice farmers in CSZ are having the highest yield as confirmed by MoFA (2015).

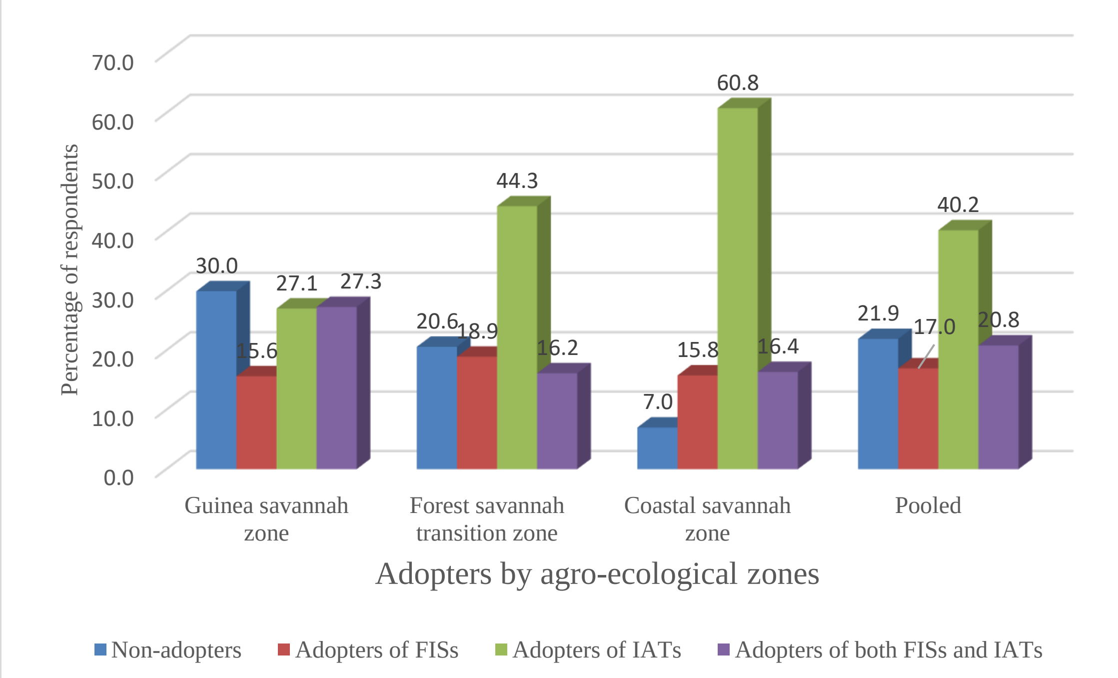


Figure 5.1 Percentage Distribution of Technology Adoption Typology of Farmers

Source: Analysis from the field (2017)

5.5 Differences in Rice Yields between Typology of Technology Adopters

Following the classification of farmers into technology adoption typology using PCA in section 5.4, Welch t-test was used to test for significant differences in rice yields between typology of technology adopters. The results of the Welch t-test are presented in table 5.1. Note that the inherent efficiency and inefficiency of farmers are not taken care off in the Welch t-test results. The Welch t-test was used to statistically test observed mean rice yield values between the above classified technology adoption typology of farmers.

5.5.1 Yield Differential between Adopters of FISs and IATs

From table 5.1, the number of farmers who adopted *IATs* (365) is greater than the number of farmers who adopted FISs (154). The average rice yield of farmers who adopter *IATs* is 3.66 MT/Ha (17.64bags/acre) whereas adopters of *FISs* had the average rice yield of 2.40 MT/Ha (11.57bags/acre). From the Welch t-test results shown in table 5.1, the test is statistically significant at 1%. This implies that there is statistical significant difference between the average rice yields of adopters of *IATs* and adopters of *FISs*. The study revealed that farmers classified as adopters of *IATs* have higher average rice yield than their counterparts who are adopters of *FISs* holding other factors constant. From the results the null hypothesis that there is no statistical significant difference in rice yields between adopters of *IATs* and adopters of *FISs* is rejected in favour of the alternate.

This result is expected since *IATs* are superior to *FISs*. The total adopters of this superior technology had rice yield of 1.26 MT/Ha (6.05bags/acre) more than adopters of *FISs*. Therefore, in comparing rice yields from *IATs* and FISs, it is prudent for farmers to adopt *IATs* which are superior in terms of rice yields.

This not withstanding, the mean rice yield of 3.66 MT/Ha obtained by farmers using superior technology is still below the potential yield of 6.5MT/Ha reported by research institutions and MoFA. On the other hand, the average rice yield of 3.66 MT/Ha obtained by farmers using superior technology (*IATs*) is higher than the actual national average rice yield of 2.69 MT/Ha obtained in Ghana in 2014 (MoFA, 2015).

5.5.2 Yield Differential between Adopters of IATs and Adopters of both FISs and IATs

Out of 907 respondents, 365 farmers adopted *IATs* and 189 jointly adopted *FISs* and *IATs* (see table 5.1). From the table, the average rice yield of adopters of *IATs* is significantly higher than the average rice yield of adopters of both *FISs* and *IATs* at a probability value of 1%. The average rice yields of adopters of *IATs* and adopters of both *FISs* and *IATs* are 3.6595Mt/Ha (17.64bags/acre) and 3.1024Mt/Ha (14.95bags/acre) respectively. The result confirmed the *a priori* expectation that the average rice yield of adopters of both *FISs* and *IATs* is lower than the average rice yield of adopters of *IATs*.

The results suggest that if a farmer wants to adopt superior technologies thus *IATs*, he/she should not mix it with *FISs*. This is because, the combination or mixture of these two technologies will result in a lower rice yield than the adoption of only *IATs* but a higher rice yield than *FISs.* Therefore, adoption of *FISs* in combination with *IATs* helps in making up for the deficit in rice yield that a farmer would have lost by not fully adopting *IATs*.

5.5.3 Yield Disparity between Adopters of IATs and Non-adopters (Users of IFPs only)

The percentage of farmers who did not adopt any technology (either *FISs* or *IATs* or both) but rather concentrated on the use of *IFPs* only is 21.9% (see table 5.1). Statistically, the average rice yield obtained by adopters of *IATs* is 3.6595Mt/Ha (17.64bags/acre) and this figure is significantly higher than the average rice yield obtained by non-adopters (users of *IFPs* only) which is 1.7334Mt/Ha (8.35bags/acre). The P-Value of 0.0000 indicates the test is highly statistically significant at 1%. Therefore, the alternate hypothesis that average rice yield obtained by adopters of *IATs* is higher than average rice yield from non-adopters (users of *IFPs* only) is accepted. This result is confirmed by an earlier research by Wiredu *et al.* (2010) that while adopters of improved rice varieties had average yield of 0.18MT/Ha, non-adopters recorded 0.06MT/Ha. Fertilizer is one of the *IATs* which was found to have increased rice yield by 3.7bags/acre in Northern Ghana (Donkoh and Awuni, 2011).

Table 5.1 Yield Differentials between Technology Adoption Typology of Farmers

Technology Adoption Typology of Farmers	Observation	Mean	Std. Error
Adoption of only *IATs* (I_0T_1)	365	3.6595	0.0759
Adoption of only *FISs* (I_1T_0)	154	2.4049	0.1096
Difference		1.2546***	0.1333
$H_0: \overline{RY}_{I_0T_1} = \overline{RY}_{I_1T_0}$	$H_A: \overline{RY}_{I_0T_1} > \overline{RY}_{I_1T_0}$		
Welch's degrees of freedom = 306.929			
Adoption of *IATs* only (I_0T_1)	365	3.6595	0.0759
Non-adoption (I_0T_0)	199	1.7334	0.0629
Difference		1.9261***	0.0986
$H_0: \overline{RY}_{I_0T_1} = \overline{RY}_{I_0T_0}$	$H_A: \overline{RY}_{I_0T_1} > \overline{RY}_{I_0T_0}$		
Welch's degrees of freedom = 556.813			
Adoption of both FISs and *IATs* (I_1T_1)	189	3.1024	0.0806
Adoption of *IATs* only (I_0T_1)	365	3.6595	0.0759
Difference		-0.5571***	0.1107
$H_0: \overline{RY}_{I_0T_1} = \overline{RY}_{I_1T_1}$	$H_A: \overline{RY}_{I_0T_1} < \overline{RY}_{I_1T_1}$		
Welch's degrees of freedom = 478.208			
Joint Adoption of *FISs* and IATs (I_1T_1)	189	3.1024	0.0806
Adoption of *FISs* only (I_1T_0)	154	2.4049	0.1096
Difference		0.6975***	0.1361
$H_0: \overline{RY}_{I_1T_1} = \overline{RY}_{I_1T_0}$	$H_A: \overline{RY}_{I_1T_1} > \overline{RY}_{I_1T_0}$		
Welch's degrees of freedom = 294.977			
Adoption of *FISs* only (I_1T_0)	154	2.4049	0.1096
Non-Adoption (I_0T_0)	199	1.7334	0.0629
Difference		0.6714***	0.1264
$H_0: \overline{RY}_{I_1T_0} = \overline{RY}_{I_0T_0}$	$H_A: \overline{RY}_{I_1T_0} > \overline{RY}_{I_0T_0}$		
Welch's degrees of freedom = 204.119			
Adoption of both FISs and *IATs* (I_1T_1)	189	3.1024	0.0806
Non-Adoption (I_0T_0)	199	1.7334	0.0629
Difference		1.3690***	0.1022
$H_0: \overline{RY}_{I_1T_1} = \overline{RY}_{I_0T_0}$ $H_A: \overline{RY}_{I_1T_1} > \overline{RY}_{I_0T_0}$			
Welch's degrees of freedom = 361.83			

Source: Analysis from the field (2017)

5.5.4 Yield Variance between Adopters of FISs and Joint Adopters of FISs and IATs

Combined adoption of *FISs* and *IATs* give higher yield than the adoption of only *FISs*. From the results in table 5.1, the Welch t-test is statistically significant at 1% implying the farmers who jointly adopted *FISs* and *IATs* have higher average rice yield (3.1024Mt/Ha or 14.95bags/acre) than their counterparts who adopted only *FISs* with average rice yield of 2.4049Mt/Ha (11.59bags/acre). This result confirms the *a priori* expectation.

5.5.5 Yield Discrepancy between Adopters of FISs and Non-Adopters

Another *a priori* expection is that on average the rice yield of adopters of *FISs* will be higher than average yield of non-adopters (users of *IFPs* only). From table 5.1, the Welch t-test is statistically significant implying rice yield of adopters of *FISs* and non-adopters are unequal. The Welch t-test indicated rice yield of adopters of *FISs* is 0.6714Mt/Ha (3.24bags/acre) more than rice yield of non-adopters. Therefore, the null hypothesis is rejected in favour of the alternate that farmers who adopted *FISs* have significantly higher rice yield than farmers using traditional *IFPs*.

5.5.6 Yield Differential between Adopters of both FISs and IATs and Non-Adopters

The Welch t-test results shown in table 5.1 is statistically significant at 1%. From the results, there is statistical significant difference in average rice yields obtained by joint adoption of *FISs* and *IATs* on one hand and non-adoption of any technology (users of *IFPs*) on the other hand. The joint adoption of *FISs* and *IATs* recorded an average rice yield of 3.1024Mt/Ha (11.59bags/acre) as compared to non-adoption of any technology which recorded average rice yield of 1.7334Mt/Ha (8.35bags/acre). This finding is not surprising since many studies have empirically found out that adoption of *FISs* give higher than non-adoption.

5.5 Summary

Through the use of PCA, farmers have been objectively and typologically classified as non-adopters (users of *IFPs*), adopters of *FISs*, adopters of *IATs* and adopters of both FISs and *IATs*. Out of 907 farmers interviewed across the three agro-ecological zones, 40.2% forming the majority adopted *IATs* while few farmers (17.0%) continued to use their *IFPs*. Comparatively, more proportion of farmers in CSZ adopted *IATs* resulting in them getting higher rice yield. The proportion of farmers who adopted *IATs* in GSZ is the lowest (27.1%).

The study showed that *IATs* are the superior technologies when considering rice productivity and hence should be vigorously pursued by farmers *ceteris paribus*. *FISs*' package is highly adopted by farmers in FSTZ. With the help of Welch t-test, the study demonstrated that adopters of *FISs* also obtained appreciable rice productivity. The joint adoption of *FISs* and *IATs* is better in enhancing farmers' ability of increasing rice yield than sole adoption of *FISs*.

CHAPTER SIX

TECHNOLOGY TYPOLOGY ADOPTION: REASONS AND CONSTRAINTS

6.1 Introduction

This chapter presents the results on the rankings of the reasons why farmers adopt *FISs* or *IATs*. Similarly, the chapter included the analysis of the contraints facing farmers in adopting the superior technology package thus *IATs*. Through literature review and preliminary interview, the reasons and the contraints were identified. During the actual data collection, farmers were asked to rank these reasons and contraints according to their level of importance. Kendall's Coefficient of Concordance was used to analyse the rankings and test farmers' agreements of the rankings. SPSS version 20 was used for this analysis.

6.2 Rankings of the Reasons for the Adoption of *FISs*

People make choices based on certain reasons. This section presents and discusses the rankings of the reasons why farmers use or adopt *FISs*. Table 6.1 shows the results from the rankings and the testing of the agreements of the rankings using Kendall's Coefficient of Concordance. Thirteen reasons were analysed using Kendall's Coefficient of Concordance. Out of these, low production cost was ranked the most important reason why farmers choose to adopt *FISs*. The mean rank for low production cost is 4.45; the lowest thereby making it the principal reasons for the choice of *FISs* by farmers. Closely following the low cost of rice production is drought resistance nature of local rice varieties, which recorded a mean rank of 5.05. The easy understanding of *FISs* is the third reason why farmers adopt *FISs*. Through continual usage of *FISs*, farmers understand all the processes involved in cultivating rice using their own innovations. This is because *FISs* are not externally developed unlike *IATs*.

From Table 6.1, it is possible to discern the decreasing order of importance of the reasons why farmers adopt *FISs.* They are low production cost (4.45), drought resistant of local rice varieties (5.05), easy understanding of *FISs* (6.32), easy availability of local rice varieties (6.37), *FISs'* save water (6.40), *FISs* do not encourage weed growth (6.51), *FISs* maintain soil fertility (6.99), *FISs* are less labour intensive (7.17), *FISs* promote environmental sustainability (7.33), the use of *FISs* make farmers innovative (7.70), quality of paddy from *FISs* (8.76), *FISs* give higher rice yield (8.92) and higher value of paddy produced using *FISs* (9.04). Meanwhile, the least important reason why farmers adopt *FISs* is that paddy produced using *FISs* are highly priced. This implies that rice produced using *FISs* are local varieties which are lowly priced, have lower yield and are of less quality. It is therefore obvious from this research that *FISs* are much preferred by rice farmers principally because of low production cost.

From table 6.1, the test for the agreement of the rankings of the reasons why farmers adopt *FISs* is statistically significant at 1%, even though the estimated 12.8% agreement among farmers' rankings of the reasons is very low. The calculated chi-square value of 520.13 is greater than the critical chi-square value of 23.34, implying the null hypothesis that there is no agreement among farmers' rankings of the reasons is rejected in favour of the alternate.

Table 6.1 Rankings of the Reasons for the Adoption of *FISs*

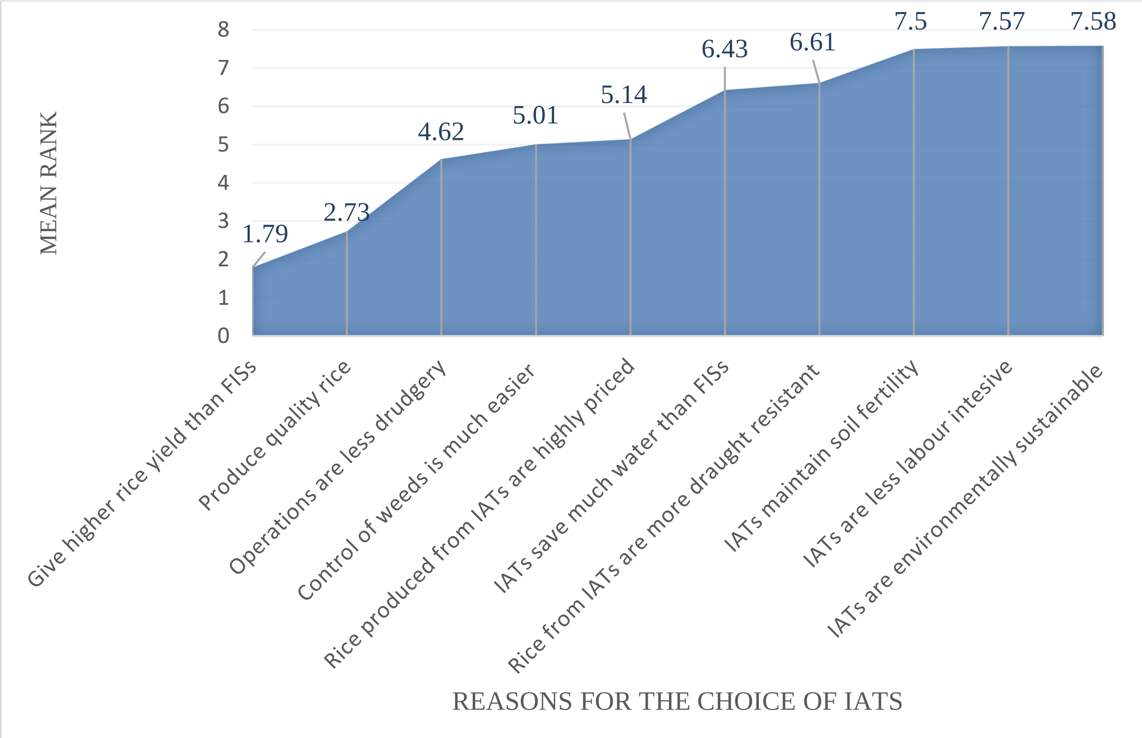
Reasons for the choice of *FISs*	Mean Rank
Low cost of production	4.45
Local rice varieties are draught resistant	5.05
FISs are very easy and simple to understand alike *IATs* which are too complex to understand	6.32
Local rice seeds are readily available unlike improved and certified rice seeds which are not easily available	6.37
FISs are water saving	6.40
FISs reduce weeds unlike *IATs* which encourage weed growth	6.51
FISs maintain soil fertility	6.99
FISs are less labour intensive	7.17
FISs promote environmental sustainability unlike *IATs* which involve uprooting of tree stumps thereby causing soil erosion and desertification	7.33
FISs make farmers innovative and help keep indigenous farming innovations for future generations	7.70
Rice from *FISs* more quality that rice from *IATs*	8.76
FISs give higher rice yield than *IATs*	8.92
Rice from *FISs* are highly priced	9.04
*n=338, Kendall's Coefficient of Concordance = 12.80%, Chi-Square at 12 degrees of freedom = 520.13, P-Value (Asymptotic significance) = 0.000****	

Source: Analysis from the field (2017)

6.3 Rankings of the Reasons for the Adoption of *IATs*

The results of the rankings and testing of the agreements among farmers' rankings of the reasons for adopting *IATs* using Kendall's Coefficient of Concordance are illustrated by the area chart in figure 6.1.

From the figure, it is obvious that the most important reason farmers consider in adopting *IATs* is yield. They have actually realised that producing paddy using *IATs* give higher yield than *FISs*. This is derived from the fact that it has the lowest mean rank values of 1.79. The second, third, fourth and so on reasons for the adoption of *IATs* are quality paddy (2.73), less drudgery farming operations (4.62), easy control of weeds (5.01), high price of paddy from *IATs* (5.14), operations of *IATs* save much water (6.43), drought resistant of improved varieties (6.61), maintenance of soil fertility (7.50), less labour intensity (7.57) and improvement of environmental sustainability (7.58).



*n=498, Kendall's Coefficient of Concordance = 45.2%, Chi-Square at 9 degrees of freedom = 2027.948, P-Value (Asymptotic significance) = 0.000****

Figure 6.1 Reasons for the Adoption of IATs

Source: Analysis from the field (2017)

As depicted in the area chart, farmers do not consider that *IATs* make the environment more sustainable and hence ranked it as the tenth important reason. This is because some of the operations of *IATs* involve uprooting of tree stumps, ploughing, harrowing and levelling of the field before planting. The less labour intensity of *IATs* is ranked nineth, implying it is a minor reason why farmers adopt *IATs*. It seems these findings depict the reality, since *IATs* involve planting in rows, dibbling or transplanting, which is slow and requires more labour.

Since the calculated chi-square value of 2027.948 is greater than the critical chi-square value of 19.02, it suggests that the testing of farmers' ranking of the reasons why they adopt *IATs* is statistically significant at 1% (probability value of 0.000). This implies that the null hypothesis that there is no agreement among farmers' ranking of the reasons for the adoption of *IATs* is rejected in favour of the alternative. The Kendall's Coefficient of Concordance is 45.20% implying there is 45.20% agreement among farmers' ranking of the reasons for the adoption of *IATs*.

6.4 Constraints Preventing Partial or Full Adoption of *IATs*

In farming, one or two factors can prevent a farmer from partial or full adoption of a technology. Some of these factors may be farmer characteristics, farm characteristics, or features of the technology itself. In order to do this analysis, thirteen constraints that prevent farmers from partial or full adoption of *IATs* were identified through literature review and preliminary interview. Farmers were then asked to rank these constraints, with a score from 1 to 13 indicating the most to the least pressing constraint that prevent them from partially or fully adopting *IATs*. The results of the rankings and the testing of the agreement among the rankings are illustrated in the bar chart of figure 6.2.

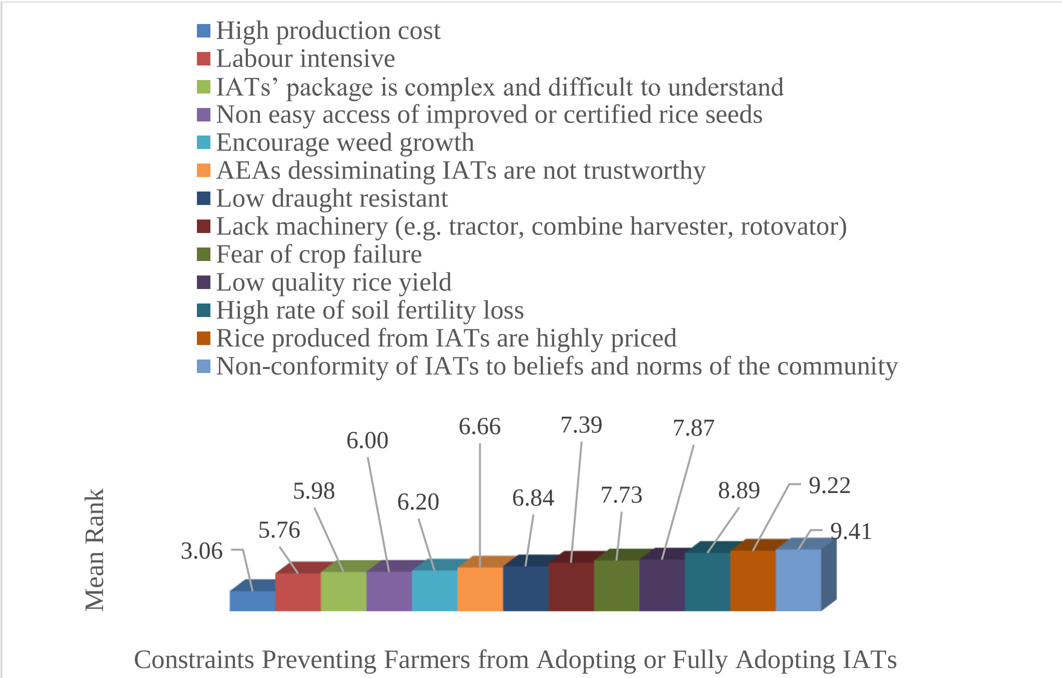
From figure 6.2, farmers unanimously ranked high production cost as the most pressing constraint that prevents them from fully adopting *IATs*. This is because it has the least mean ranked value of 3.06. The adoption of *IATs* require the intensification of farm inputs (using the required and appropriate quantity of improved or certified seeds, fertilizer, pesticides, labour) and hence highly capital intensive (Peterman *et al*., 2010). This suggests that the development of market-facilitated approaches to funding rice production should be intensified.

The second, third, fourth and fifth most pressing constraints limiting partial or full adoption of *IATs* are labour intensity of *IATs'* operations, complexity or uneasy understanding of *IATs*, difficulties in accessing improved and certified rice seeds and the encouragement of weed growth, since the estimated mean ranks are 5.76, 5.98, 6.00 and 6.20 respectively. As noted in the preceding section, the adoption of *IATs* calls for higher labour requirements especially dibbling, planting in rows, transplanting, etc; hence the justification for labour intensity being the second most pressing constraints. Another critical constraint affecting farmers' effectiveness in adopting *IATs* is poor access to improved or certified rice seeds for planting. This finding confirmed the finding of Peterman *et al*. (2010).

Also, farmers indicated that they do not want to adopt or they partially adopt *IATs* because of lack of trust in agricultural extension agents (AEAs), who are the technology disseminating agents. This lack of trust in AEAs is the sixth most pressing constraint, followed by low drought resistant of the improved rice seeds. As noted by Peterman *et al*. (2010), lack of information on *IATs* and neglect of duties by AEAs make it difficult for farmers to understand the intricacies involved in adopting *IATs*. Lack of trust in AEAs stems from the failure of AEAs in honouring their promises or appointments with farmers.

The least constraint that limits the ability of farmers to partially or fully adopt *IATs* is nonconformity of *IATs* to traditional beliefs of their communities. This suggests that nonconformity of *IATs* to traditional beliefs of their communities is less of a problem for them in adopting *IATs*. They also ranked low price of *IATs'* rice and soil fertility loss caused by *IATs* as the second and third lowest pressing contraints preventing them from partially or fully adoption of *IATs*. Lack of farm machinery (tractors, rotovator, planters, combiner harvester etc) and the fear of crop failure were ranked eighth and nineth with mean ranks of 7.39 and 7.73 respectively. The finding of the fear of crop failure is consistent with the work of Adato and Meinzen-Dick (2007), who indicated that production risk discourages the adoption of untried *IATs*.

From the inferential statistics, the calculated chi-square value of 1363.06 is greater than the critical chi-square value of 19.02. From the results, the probability values is 0.000 implying the test is statistically significant at 1% and hence a rejection of the null hypothesis in favour of the alternate that there is an agreement of the farmers' rankings of the constraints. From this result and the Kendall's Coefficient of Concordance value of 19.60%, there is therefore 19.60% agreement in the rankings of the constraints.



n=580, Kendall's Coefficient of Concordance = 19.60%, Chi-Square at 12 degrees of freedom = 1363.06, P-Value (Asymptotic significance) = 0.000***

Figure 6.2 Constraints Preventing Partial or Full Adoption of IATs

Source: Analysis from the field (2017)

6.5 Summary

This chapter analyses the reasons for technology typology adoption and the constraints limiting the ability of farmers to partially or fully adopt *IATs*. From the results, the principal reason for the choice of *FISs* is low production cost. On the other hand, farmers adopt *IATs* because of high rice yield. Meanwhile, the most pressing constraint facing farmers in partially or fully adopting *IATs* is high cost of production. It is therefore recommended that, AEAs, researchers and NGOs should educate farmers for them to know the long run benefits of adopting *IATs*. Credit support system and contract farming concept should be promoted. With these, farmers would be able to afford and be encouraged to adopt IATs to the latter, thereby improving rice productivity.

CHAPTER SEVEN

EMPIRICAL RESULTS OF THE DETERMINANTS OF PRODUCTIVITY PERFORMANCES OF RICE FARMERS IN GHANA

7.1 Introduction

This chapter presents the results on the metafrontier analysis of rice production in Ghana. The empirical results of the estimated productivity performances (technical efficiency, TGR, metatechnical efficiency) are presented and discussed. The empirical results of the determinants of rice output and technical inefficiency, metafrontier technical inefficiency and TGR are also discussed.

7.2 Summary Statistics of Variables in Metafrontier and GLM Models

The variables used in the section are grouped into farmer characteristics, institutional and policy variables, environmental factors, production inputs and output of rice. The summary statistics of continuous and discrete variables used in the new-two step stochastic metafrontier and generalised linear model (GLM) are presented in tables 7.1 and 7.2 respectively. The total number of rice farmers sampled in GSZ, FSTZ and CSZ are 377, 359 and 171 respectively.

The ages of respondents range from 18-71years with an average age of 43.1years for the pooled data. The average age of farmers in the GSZ, FSTZ and CSZ are 39.4years, 45.4years and 46.6years respectively. This follows the national trend of ages of farmers in the country since many young people are involved in agricultural production up north. In the southern Ghana, many youths may attend school due to better understanding of the importance of education. Some are also engaged in commercial activities as a result of a better and relatively large number of business opportunities.

From table 7.1, it can be observed that on average; farmers in GSZ have the largest average household size of 9.4 with low education level, low experience in the cultivation of rice, and few number of extension visits. The distribution of household size is in tandem with Ghana Living Standard Survey Six (GLSS6) which indicates that the three northern regions have relatively high household size (GSS, 2014). In terms of literacy, the 2010 population and housing census revealed that the three northern regions have less than 50 percent of the population aged 11 years and older as literate, while the other regions have at least 69 percent of their population being literate (GSS, 2012). Additionally, farmers in the GSZ received relatively small amount of credit for rice cultivation.

Farmers in the CSZ are better placed in terms of infrastructure which can enhance timely and efficient rice production. The most disadvantage in terms of infrastructure are the farmers located in GSZ. Averagely, farmers in the CSZ are closer to agricultural extension officers, rice output market and Accra, the capital of Ghana, as compared to those in GSZ. Also, FSTZ recorded the highest amount of mean annual rainfall (1150.9mm) followed by GSZ recording 984.7mm with CSZ having the least (800.0mm). The average amount of temperature increases as one moves from southern to northern Ghana.

Continuous Variables	GSZ (n = 377)			FSTZ (n = 359)			CSZ (n = 171)			Pooled (N = 907)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Rice output (Kg)	1966.2	102.0	8862.0	2988.1	336.0	14532.0	5405.5	1008.0	19320.0	3019.1	102.0	19320.0
Farmer characteristics												
Age (years)	39.4	18.0	65.0	45.4	21.0	70.0	46.6	27.0	71.0	43.1	18.0	71.0
Household size	9.4	1.0	30.0	6.8	1.0	17.0	5.6	1.0	12.0	7.7	1.0	30.0
Education years	3.8	0.0	16.0	8.0	0.0	19.0	9.6	0.0	20.0	6.5	0.0	20.0
Rice farming experience (years)	12.8	1.0	41.0	15.6	1.0	50.0	13.7	2.0	36.0	14.1	1.0	50.0
Institutional and policy variables												
Extension visits	2.1	0.0	14.0	2.4	0.0	9.0	3.9	0.0	8.0	2.5	0.0	14.0
Amount of credit (Ghȼ)	120.6	0.0	2000.0	647.2	0.0	5500.0	1433.4	0.0	6500.0	576.5	0.0	6500.0
No. of FBO advice	1.2	0.0	24.0	1.0	0.0	8.0	1.4	0.0	7.0	1.2	0.0	24.0
Infrastructure												
Distance from office of AEAs to community (Km)	11.5	0.0	67.9	5.7	0.0	32.0	2.5	0.1	12	7.5	0.0	67.9
Distance from community to market centres of rice (Km)	11.9	0.0	131.0	4.3	0.0	32.0	2.6	0.0	12	7.1	0.0	131.0

Distance from Accra to Community (Km)	699.8	608	777.0	273.0	95.0	520.0	62.7	29.0	81.0	410.8	29.0	777.0
Distance from farm to the house (Km)	4.3	0.1	80.0	3.7	0.1	22.0	4.6	0.2	18.0	4.1	0.1	80.0
Environmental Shocks												
Actual mean annual rainfall (mm)	984.7	870.0	1050.0	1150.9	1000.0	1270.0	841.3	800.0	870.0	1023.5	800.0	1270.0
Actual mean annual temperature (^{0}C)	28.5	27.8	31.0	26.7	26.0	27.8	24.6	24.0	25.5	27.1	24.0	31.0
Inputs												
Labour (mandays)	40.8	8.0	205.0	44.9	10.0	183.0	52.1	10.0	158.0	44.5	8.0	205.0
Farm size (acres)	2.4	0.5	10.0	2.6	0.5	12.0	2.9	1.0	8.7	2.6	0.5	12.0
Seed (Kg)	76.9	8.0	1000.0	85.5	20.0	1200.0	84.6	20.0	450.0	81.7	8.0	1200.0
Fertilizer (Kg)	144.5	0.0	700.0	218.5	0.0	2300.0	310.4	0.0	1200.0	205.1	0.0	2300.0
Pesticides (Kg)	2.9	0.0	60.0	4.6	0.0	36.0	4.3	0.0	40.0	3.8	0.0	60.0
Capital (Gh₵)	336.3	6.1	3324.0	807.2	7.5	5726.4	1668.0	196.8	6252.9	773.8	6.1	6252.9

Table 7.1 Summary Statistics of Continuous Variables in Metafrontier and GLM Models

Source: Author's analysis from field data and data obtained from Ghana Meteorological Agency (2016)

Farmers in GSZ also produced the smallest quantity of rice compared to farmers in the other two agro-ecological zones. The average quantity of rice produced by farmers in GSZ, FSTZ and CSZ are 1966.2Kg, 2988.1Kg and 5405.5Kg respectively. On average, among all the three agro-ecological zones, farmers in CSZ used the largest quantity of each of the inputs (i.e. labour, seed, fertilizer, pesticides, and capital) followed by farmers in FSTZ, with those in GSZ employing the least quantity. It can therefore be inferred that farmers in CSZ are more productive because they employed higher amount of production inputs.

From the table 7.2, the majority of the farmers interviewed were male. Proportionally, GSZ had the least number of females engage in rice cultivation followed by the CSZ with FSTZ having the highest number. This finding was expected since the land tenure system in the GSZ do not fully support women access to land for the cultivation of rice which is usually classified as a male crop. Farmers in the CSZ have the most opportunities since a higher percentage of them had access to credit, improved seed and irrigation facilities as compared to their counterparts in the other two agro-ecological zones. Similarly, among all the three agro-ecological zones, many farmers are engaged in contract farming, as well as belong to FBOs. More access to these institutional and policy variables may provide better opportunities for farmers in the zone.

It can be observed from table 6.2 that farmers in the GSZ are worst affected by adverse environmental conditions. This is because 35.8% of the farmers in the zone had their rice lodged as a result of strong wind. The percentage of farmers whose rice lodged due to strong wind in FSTZ and CSZ are 31.2% and 31.6% respectively. In the same way, 50.1% of the farmers in GSZ had low rice output due to low amount of rainfall recorded. It is clear from table 6.2 that, 70.2% of the farmers have access to motorable roads in FSTZ. This is the highest among the three agro-ecological zones.

In terms of the technologies, farmers in CSZ were the highest adopters (60.8%) of superior technologies (*IATs*). The GSZ recorded the lowest adopters of *IATs*. On the other hand, the FSTZ recorded the highest percentage (18.9%) of farmers who adopted *FISs* suggesting that farmers in this zone are the most innovative compared to others. GSZ recorded the lowest proportion of farmers (15.7%) adopting *FISs*.

Table 7.2 Summary Statistics of Discrete Variables in Metafrontier and GLM Models

Variables		GSZ (n = 377)		FSTZ (n = 359)		CSZ (n = 171)		Pooled (N = 907)	
		Freq	%	Freq	%	Freq	%	Freq	%
Farmer Characteristics									
Sex:	Female	94	24.93	134	37.33	63	36.84	291	32.08
	Male	283	75.07	225	62.67	108	63.16	616	67.92
Institutional and Policy Variables									
Credit access:	No	299	79.31	229	63.79	76	44.44	604	66.59
	Yes	78	20.69	130	36.21	95	55.56	303	33.41
Contract farming:	No	303	80.37	257	71.59	36	21.05	596	65.71
	Yes	74	19.63	102	28.41	135	78.95	311	34.29
FBO membership:	No	158	41.91	155	43.18	60	35.09	373	41.12
	Yes	219	58.09	204	56.82	111	64.91	534	58.88
Improved seed:	No	242	64.19	215	59.89	75	43.86	532	58.65
	Yes	135	35.81	144	40.11	96	56.14	375	41.35
Input subsidy:	No	291	77.19	274	76.32	164	95.91	729	80.37
	Yes	86	22.81	85	23.68	7	4.09	178	19.63
Access to irrigation:	No	246	65.65	236	65.74	30	17.54	512	56.45
	Yes	131	34.75	123	34.26	141	82.46	395	43.55
Environmental Shock Factors									
Lodging of rice:	No	242	64.19	247	68.80	117	68.42	606	66.81

	Yes	135	35.81	112	31.20	54	31.58	301	33.19
Low rains:	No	188	49.87	195	54.32	140	81.87	523	57.66
	Yes	189	50.13	164	45.68	31	18.13	384	42.34
Affected by diseases:	No	236	62.60	249	69.36	156	91.23	641	70.67
	Yes	141	37.40	110	30.64	15	8.77	266	29.33
Infrastructure									
Motorable road to district capital	No	123	32.63	107	29.81	56	32.75	286	31.53
	Yes	254	67.37	251	70.19	115	67.25	621	68.47
Technologies									
Adopters only *FISs*:	No	318	84.35	291	81.21	144	84.21	753	83.02
	Yes	59	15.65	68	18.94	27	15.79	154	16.98
Adopters only *IATs*:	No	275	72.94	200	55.71	67	39.18	542	59.76
	Yes	102	27.06	159	44.29	104	60.82	365	40.24

Source: Author's analysis from field data (2017)

7.3 Factors Influencing Productivity Performances of Rice Farmers

The tests for metafrontier model specification, the determinants of rice output and technical inefficiency are presented and discussed in this section. The frequency distribution and summary statistics of productivity performances and the drivers of TGR of rice farmers are also presented in this section.

7.3.1 Hypothesis Testing for Appropriateness of Stochastic Metrafrontier Translog Model

For the use of appropriate models, four different hypotheses were tested and the results are presented in tables 7.3. All these hypotheses were tested using the likelihood-ratio statistic. The likelihood-ratio statistic is equivalently distributed as a chi-square or the mixed chi-square (Coelli, 1995).

From table 6.3, the null hypothesis that the Cobb-Douglas functional form is appropriate is rejected for all the zones, since each of the respective calculated Chi-Square values are greater than the critical chi-square values. The alternative hypothesis that the Cobb-Douglas production is inappropriate (but rather translog production) is accepted at significant levels of 1% for all the four models. This is a justification for the use of translog functional form since it better represents the data for all the zones than the Cobb-Douglas production function.

The quantity of rice produced depends on factors which are under the control of the decision maker as well as factors beyond his/her control. As indicated in table 6.3, the null hypothesis that technical inefficiency is absent is rejected, since the test is significant at 1% for all the models. Thus, a significant number of rice farmers operate under the respective group frontiers and hence below the metafrontier. As a result, the used of OLS or average production response model would be inappropriate (Onumah *et al*., 2013).

Table 7.3 Hypotheses for the use of Stochastic Frontier and Metafrontier Models

Null Hypothesis	n	DF	χ^2-cal	LR χ^2-crit	P-Value
Cobb-Douglas functional form is appropriate					
GSZ	377	21	126.45	38.93	0.0000
FSTZ	359	21	43.62	38.93	0.0026
CSZ	171	21	46.20	38.93	0.0012
Metafrontier	907	21	530.73	38.93	0.0000
No inherent inefficiency					
GSZ	377	17	192.16	33.41	0.0000
FSTZ	359	17	173.95	33.41	0.0000
CSZ	171	17	69.77	33.41	0.0009
Metafrontier	907	17	134.55	33.41	0.0000
Homogeneous technologies					
There is no differences in technologies used in GSZ, FSTZ and CSZ	907	49	147.12	74.92	0.0001

Source: Author's analysis from field data (2017)

The last and the principal hypothesis of this study which states that the technologies used by farmers in the three agro-ecological zones are homogenous was rejected. This is because the calculated chi-square value is 147.12 is greater than the critical chi-square value of 74.92. Therefore, the technologies used by farmers in the three agro-ecological zones differ justifying the use of metafrontier model. The rejection of null hypothesis of homogeneity in technologies is grounded on the fact that there are statistically significant differences among the three agro-ecological zones. The use of new-two step stochastic metafrontier translog estimation technique rather than the pooled stochastic frontier would better show the efficiency comparison among farmers in these three agro-ecological zones (Mariano *et al*., 2010; Moreira and Bravo-Ureta, 2010 and Huang *et al*., 2014).

7.3.2 Determinants of Rice Output: The New-Two Step Stochastic Metafrontier translog model

The output of any production activities is heavily dependent on conventional inputs. Table 7.4 shows the maximum likelihood estimates of the agro-ecological zone specific stochastic translog models and the new-two step stochastic metafrontier translog model. These models determine the impact of conventional inputs (fertilizer, pesticides, labour, seed, farm size and capital) on rice output. In order to interpret the first-order parameter estimates as partial production elasticities at the sample mean, the study followed the work of Coelli *et al.* (2005) in which all the inputs and output variables were normalised (divided) by their respective sample means. The monotonicity condition was checked and it was observed that all the models, including the new-two step stochastic metafrontier translog model were monotonic since the respective sums of the estimated first-order coefficients of all the logarithmic inputs were positive. Since the agro-ecological specific production functions were used to estimate the metafrontier, the definition that metafrontier is an envelope of the group frontiers is valid. The convexicity and no free lunch property of all the production functions were met since the use of translog is valid and no farmer indicated that he/she harvested rice from uncultivated field. It is important to note that the relevance of the contribution of each input to quantity of rice produced varies from one agro-ecological zone to the other.

The estimated total variance in GSZ, FSTZ and CSZ are 0.2166, 0.1725 and 0.0813 respectively and they are all statistically significant at 1%. This shows that GSZ has the widest variation across farms, an implication that there is great opportunity on the average for them to raise their technical efficiency levels. The total variance of each of the agro-ecological zone is greater than that of the metafrontier model.

The respective estimated values of the gamma for GSZ, FSTZ and CSZ agro-ecological zones are 0.9299, 0.7546 and 0.8181. Following Sena (2011), this indicates that the variation between frontier and the actual rice outputs are explained by both technical inefficiency and the random error. From the gamma values, the inefficiencies in the usage of the inputs and other farm practices account for 92.99%, 75.46% and 81.81% deviations between actual and frontier rice output in GSZ, FSTZ and CSZ agro-ecological zones respectively. This suggests that GSZ has the highest levels of inefficient usage of inputs and other farm practices accounting for the wide deviations between frontier rice output and the actual rice output. From the above, random shocks outside the control of farmers (e.g. unfavourable weather conditions, floods, bushfires, diseases and measurement errors) account for 7.01%, 24.54%, and 18.19% inefficiencies in the deviations of the actual rice output from the frontier output in GSZ, FSTZ and CSZ agro-ecological zones respectively (Dawson *et al.,* 1991 and Al-hassan, 2008).

Table 7.4 Maximum Likelihood Estimates of Factors Determining Rice Output in the New-Two Step Stochastic Metafrontier Translog Model

Variables	GSZ Model		FSTZ Model		CSZ Model		Metafrontier Model	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Constant	0.0718	0.0596	-0.1358	0.0888	-0.1203	0.0755	0.0948***	0.0192
DF	-0.4143***	0.0985	-0.1460*	0.0749	-0.2462*	0.1366	-0.2555***	0.0216
DPc	0.0011	0.0641	-0.0059	0.0689	0.0448	0.0745	-0.0510***	0.0184
In(F)	0.6449**	0.2864	0.6009***	0.2117	0.6669*	0.3891	0.5352***	0.0617
In(Pc)	0.0449	0.1388	0.0030	0.1931	0.2321	0.1684	0.1505***	0.0411
In(L)	-0.1060	0.1090	0.3456*	0.1970	0.2697*	0.1405	0.0375	0.0346
In(S)	-0.1041	0.0902	-0.4290***	0.1580	-0.5670***	0.1255	-0.2666***	0.0282
In(Fs)	0.7062***	0.1454	0.9552***	0.2721	1.1695***	0.1937	0.8324***	0.0423
In(K)	0.3697***	0.0467	0.0257	0.0485	0.0690	0.1153	0.2204***	0.0121
In(F)In(F)	0.2182	0.3876	0.2158	0.2431	-0.7731	0.5528	0.0387	0.0822
In(Pc)In(Pc)	-0.0942	0.1015	0.1246	0.1660	-0.1255	0.2008	-0.0695*	0.0360
In(L)(In(L)	-0.0751	0.1154	0.5920*	0.3026	0.3195	0.2353	0.0524	0.0461
In(S)In(S)	-0.0411	0.0455	0.1020	0.1093	0.2307	0.1541	0.0044	0.0168
In(Fs)In(Fs)	0.3643*	0.2194	0.6111	0.5546	-0.0685	0.6189	0.5609***	0.0715
In(K)In(K)	0.1617***	0.0255	0.0476**	0.0221	0.1495	0.1746	0.1196***	0.0058
In(F)In(Pc)	0.1817	0.1147	-0.0356	0.1722	0.0274	0.1877	0.0751**	0.0333
In(F)In(L)	0.3085**	0.1507	-0.2360	0.2345	-0.0190	0.1922	0.1365***	0.0480
In(F)In(S)	-0.0272	0.1302	0.5019**	0.2267	0.1901	0.1838	0.2776***	0.0387
In(F)In(Fs)	-0.3209	0.2068	-0.5567	0.3519	-0.1959	0.2837	-0.4369***	0.0618
In(F)In(K)	-0.3129***	0.0653	0.0389	0.0444	-0.0980	0.1101	-0.0921***	0.0154
In(Pc)In(L)	-0.0238	0.1332	-0.2076	0.1958	-0.1242	0.2053	-0.0108	0.0407
In(Pc)In(S)	0.1375	0.0894	0.0975	0.1182	0.2060	0.1742	0.0487**	0.0246
In(Pc)In(Fs)	-0.2097	0.1586	-0.2144	0.1967	-0.2310	0.2743	-0.2150***	0.0422
In(Pc)In(K)	-0.0360	0.0482	0.0475	0.0449	0.2152	0.1310	0.0039	0.0124
In(L)In(S)	0.1480	0.0926	-0.2326	0.1751	-0.2546	0.1661	0.0169	0.0299
In(L)In(Fs)	-0.3459***	0.1109	0.1231	0.2734	0.4254	0.2688	-0.1531***	0.0380
In(L)In(K)	0.0071	0.0570	-0.0766*	0.0422	-0.2080	0.1659	-0.0241*	0.0134
In(S)In(Fs)	0.0406	0.1083	-0.2013	0.2562	-0.1612	0.2721	-0.0779**	0.0347
In(S)In(K)	-0.1189***	0.0418	-0.0522	0.0505	0.0983	0.1089	-0.0627***	0.0106
In(Fs)In(K)	0.0995	0.0702	0.0001	0.0735	-0.2219	0.2448	-0.0070	0.0170
σ_v^2	0.0151		0.0423		0.0148		0.0058	
σ_u^2	0.2015		0.1302		0.0665		0.0224	
σ_s^2	0.2166		0.1725		0.0813		0.0282	
γ_u^2	0.9299		0.7546		0.8181		0.7936	
Log-Lik	40.7859		15.1670		73.5596		735.0145	
Wald χ^2 *(29)*	1679.18***		1400.2***		1336.06***		17389.73***	

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

Source: Author's analysis from field data (2017)

On the average, farmers in Ghana (referring to metafrontier model) have their inefficiencies in the usage of inputs and other farming practices explaining 79.36% deviations of their actual rice output from the metafrontier rice output. These findings suggest that farmers can improve upon their efficiency levels by proper usage of inputs through acquiring managerial skills. From the results shown in table 7.4, the square of the input variables indicates the effect of the continuous usage of that input variable on output. On the other hand, the interaction term indicates the input complementarity or substitutability. The effect of two inputs on output is complementary if the interaction term has significant positive coefficient and the opposite is true for significant negative coefficient of the interaction term.

From the results of the maximum likelihood estimates shown in table 6.4, the intercept coefficient of fertilizer is statistically significant in all the agro-ecological zones' specific frontier models as well as the metafrontier model. The intercept coefficient of pesticide is only significant in the metafrontier model. This revelation means that the estimation of the parameters of the frontier production function would have been biased if the specification of the dummy for fertilizer were eliminated in the models. Principally, the estimation of the new two-stage stochastic translog metafrontier model would have given biased maximum likelihood parameter estimates if the dummies of the fertilizer and the pesticides were not included in the model (Battese, 1997 and Ogundari, 2013).

7.3.2.1 Impacts of factor inputs on rice output in GSZ

The factors which significantly determine rice output in GSZ are fertilizer, farm size and capital. The effects of these three inputs on rice output are consistent with *a priori* expectation (economic theory) since they all have positive influence. The output elasticities of fertilizer, farm size and capital each are significantly different from zero. Fertilizer is significant at 5%, whilst farm size and capital are significant at 1% each. This suggests that fertilizer, farm size and capital increase rice output holding other factors constant. This was expected as Asravor *et al.* (2015) recorded significant positive effects of fertilizer and farm size on rice output in Northern Ghana.

Comparing the impacts, farm size has the highest impact on rice output, followed by fertilizer with capital having the lowest impact. The highest contribution of farm size to rice output and the insignificance of labour were found by Mariano *et al.* (2010) in their study on rice farming in the Philippine. The elasticities of output with respect to fertilizer, farm size and capital are 0.64, 0.71 and 0.37 respectively. This implies that a 100% increase in fertilizer will increase mean rice output by 64% *ceteris paribus*. Similarly, if farm size increases by 100%, mean rice output will increase by 71% holding other factors constant. Also, a farmer who expects to increase mean rice output by 37% must increase the capital used for rice production by 100% *ceteris paribus*. The significance of fertilizer and the fact that it has the second highest impact on rice production in the GSZ is due to the low fertility of the soil.

The sum of first-order elasticities measures the returns to scale. From table 6.4, the sum of first order elasticities is 1.56 implying on average, farmers in GSZ are enjoying increasing returns to scale (IRS). This means that on average the quantity of inputs used by farmers are below the efficient level; hence, a farmer can increase rice output by 156% if all the inputs are jointly increased by 100%. As such, farmers in the study area are under utilizing the inputs since a proportionate increase in all the inputs results in more than a proportionate increase in rice output. Conversely, Asravor *et al.* (2015) observed that rice farmers in Northern Ghana operate at decreasing returns to scale. Meanwhile, it is important to note that the findings of this current study seem to present the realities on the ground, since the majority of the farmers in the study area are operating on small-scale basis without access to the required level of inputs thereby resulting in underutilization of the available inputs.

7.3.2.2 Determinants of rice output in FSTZ

From table 7.4, the first order elasticities of fertilizer, seed and farm size are highly significant at 1% each while labour is lowly significant at 10% in the FSTZ. The findings reveal that pesticides and capital are not significant. The maximum likelihood elasticity estimates of fertilizer, labour and farm size are positive, implying that a 100% increase in fertilizer, labour and farm size each will respectively increase rice output by 60.1%, 34.6% and 95.5% *ceteris paribus*. These significant and positive impact of fertilizer, labour and farm size are in tandem with the findings of Asravor *et al.* (2015) that a percentage increase in labour, farm size and fertilizer each will increase rice output by 14.0%, 58.0% and 23.0% respectively. Also, a 100% increase in the quantity of seed planted will result in a 42.9% decrease in rice output and this negative relationship confirmed a study by Asravor *et al.* (2015).

From the results of the group specific stochastic translog model of FSTZ, the returns to scale is 1.50% indicating that when all the inputs (fertilizer, pesticides, labour, seed, farm size and capital) are jointly increased by 100%, there will be more than proportionate increase in the quantity of rice produced by 50% (150% minus 100%). Therefore, farmers in the FSTZ are also underutilizing inputs as observed in GSZ. This suggests that farmers should increase the quantity of inputs used to enjoy a more than proportionate increase in rice output.

7.3.2.3 Impacts of factor inputs on rice output in CSZ

Rice production in the CSZ depends on fertilizer, labour, seed and farm size. This is because fertilizer and labour significantly affect rice output at significant levels of 10% each whilst seed and farm size significantly influence rice production at significant levels of 1% each. Statistically, pesticides and capital do not influence rice output in the study area. The fertilizer, labour and farm size positively affect rice output whilst seed negatively affect rice output in CSZ. A 100% increase in fertilizer, labour and farm size each will result in an increase the quantity of rice produced of 66.7%, 27.0% and 117.0% respectively. On the contrary, rice output will decline by 0.6% when a farmer increases the quantity of seed planted by 1%. This suggests that whilst fertilizer, labour and farm size are underutilized, seed is over utilized. Farmers overcrowd the rice plot with seed through broadcasting method and should rather reduce the quantity of rice seed they plant on the field since that will result in an increase in rice output.

The total elasticity of output is 1.84% implying that farmers underutilize most of the inputs and hence are operating at increasing returns to scale level. In other words, a 100% increase in all the inputs will result in 184% increase in rice output which is 84% more than the proportionate increase in inputs. This means farmers can still increase rice output by jointly increasing the quantity of all the inputs.

7.3.2.4 Determinants of rice output across the three agro-ecological zones

With the new-two step stochastic metafrontier translog model, after running the zonal stochastic translog models, the rice outputs are predicted for each of the zones which are then pooled together and used to run the metafrontier model. This implies that the regression equation [38] is estimated three times, thus one for each agro-ecological zone. Since the rice output was normalized and linearized, the predicted rice output $\left(\hat{R}_i^*\right)$ is a normalized and linearized dependent variable which is used in running stochastic metafrontier translog model expressed in regression equation [40]. This method, proposed by Huang *et al.* (2014) is relatively new. As noted in the methodology, this estimation procedure has the advantage of providing more and accurate metafrontier technical efficiency estimates than the ones from the two-step mixed model (stochastic-deterministic mixed linear programming) and the pooling stochastic metafrontier approach (Huang *et al.,* 2014).

From the results, all the inputs except labour are significantly different from zero and hence significantly affect the quantity of rice produced. Statistically and coincidentally, fertilizer, pesticides, seed, farm size and capital each are highly significant at the 1% level. The direction of the effects corroborates with the *a priori* expectation since fertilizer, pesticides, farm size and capital have positive whilst seed has a negative relationship with the quantity of rice produced. The partial elasticity values indicated that a 100% increase in the quantity of fertilizer, pesticide, farm size and capital each will result in 53.5%, 15.1%, 83.2% and 22.0% increase in rice output respectively holding other factors constant. On the other hand, rice output will decrease by 26.7% when quantity of rice seed used for planting increases by 100% *ceteris paribus*. The positive relationship between fertilizer and rice output in this study is consistent with the findings of Donkor and Owusu (2014). On the other hand, the negative relationship between seed and rice output in this study did not confirmed the findings of Donkor and Owusu (2014).

On average, farmers involved in rice production in Ghana operate in the first stage of production thus are operating at increasing returns to scale (returns to scale value of 1.51). This means that if all the inputs are jointly increased by 100%, quantity of rice produced in the country will increase by 151%. This increase in rice output is more than a proportionate joint increase in fertilizer, pesticides, labour, seed, farm size and capital. This justifies the need for rice farmers to continue to expand their production activity by increasingly employing more factor inputs until they reach constant returns to scale.

7.3.2.5 Combined cross-term effects on rice output

From the results of the metafrontier model, there are significant input complementary effects between fertilizer and pesticides; fertilizer and labour; fertilizer and seed; and pesticides and seeds. This implies, when the quantities of the pairs of inputs are jointly increased, rice output will increase in Ghana.

Statistically, there is significant input substitution effects on rice output. The inputs that are substitutes are fertilizer and farm size; fertilizer and capital; pesticides and farm size; labour and farm size; labour and capital; seed and farm size; and seed and capital. The findings of these input substitution effects meet the *a priori* expectations. Pesticides and farm size have substitution effects on output because due to high cost of pesticides, farmers prefer to use less of the pesticides and rather increase the farm size so as to increase rice output.

Also, farmers prefer to use money meant for purchasing fertilizer to expand their farms by increasing farm sizes. It is not surprising that fertilizer and capital have substitution effects on output. A plausible reason for this observation could be that when farmers increase the purchase of fertilizer, less amount of capital will be available for the purchase of fixed inputs such hoe, cutlass, pan, baskets, knife, sickle, tractor, etc. Therefore, for farmers to purchase more fixed inputs and still get money for the purchase of fertilizer, they need assistance in the form of credit or grants. The joint effect of seed and capital on rice output is negative because as the farmer increases the investments on fixed inputs, less money will be available for the purchase of improved seeds.

7.3.2.6 Brief comparison of relative impacts of factor inputs on rice output in all the three agro-ecological zones

Rice production in Ghana (all the three agro-ecological zones) exhibited increasing returns to scale suggesting that farmers can increase rice output by employing more inputs. Coincidentally, farm size is the highest contributor to rice output in all the three agro-ecological zones. The input that has the second highest contribution to rice output in all the three agro-ecological zones is fertilizer. The inputs which significantly influence rice production in all the three agro-ecological zones in Ghana are fertilizers and farm size. Pesticides was only significant in the metafrontier model. Labour was positively significant in FSTZ and CSZ models, whilst capital was only positively significant in the GSZ and metafrontier models. Meanwhile, seed does not significantly affect rice output in only GSZ.

The negative contribution of seed on rice output in FSTZ, CSZ and metafrontier models is not surprising, as similar findings were observed by Akongo *et al.* (2016: p. 131) in Northern Uganda. This is due to the fact that the respective actual average seeding rates of rice of 32.88Kg/acre, 29.17Kg/acre and 31.42Kg/acre for FSTZ, CSZ and the pooled data are far above the recommended average seeding rates of 20.00Kg/acre for achieving potential rice yield. As Akongo *et al.* (2016) put it: “the higher seeding rate is not adding to output but rather compensates for those that may not germinate due to drought or buried due to floods as well as poor quality seed which is common among smallholder farmers”.

Labour is insignificant in GSZ and CSZ because perhaps farmers use less quantity of labour in rice production stages as compared to their counterparts in the FSTZ. Since the second highest contributing input to rice output is fertilizer, it can be suggested that more fertilizer should be applied if farmers in the zone want to increase rice productivity.

In terms of returns to scale, CSZ has the highest increasing returns to scale (1.84) followed by GSZ with returns to scale value of 1.56. The FSTZ has the lowest increasing returns to scale value of 1.50. The increasing returns to scale value for the metafrontier is 1.51. All the returns to scales areas significantly different from zero. From the findings of this study, the joint increase in all inputs has more than proportionate effects on rice output in all the three agro-ecological zones. Since the returns to scale value for GSZ and CSZ are higher that of the metafrontier, it means that farmers in these agro-ecological zones operate above the national level of returns to scale. It is only farmers in the FSTZ that had returns to scale value less than that of the national average as deduced from the metafrontier model.

7.3.3 Determinants of Technical Inefficiency Across the Agro-Ecological Zones

As noted by Onumah *et al.* (2013), estimates of the level of technical inefficiency of firms are necessary but not sufficient to provide information for the researcher to make any meaningful policy recommendations. As such, identifying the factors causing the variations in the technical inefficiencies is very important. The variables that were hypothesised to have influence on technical inefficiency of rice farmers were grouped into farmer characteristics (age, sex, household size, years of education, rice farming experience), institutional and policy variables (extension visits, credit access, contract farming, farmer based organisation membership and access to formal irrigation), environmental factors or shocks (lodging of rice, low rainfall amount), and technologies ((FISs (*FISs*) and (IATs (*IATs*)). Also, the principal component indices of *IATs* and *FISs* obtained for each of the farmers from the principal component analysis in chapter 5 were used.

7.3.3.1 Determinants of technical inefficiency in Guinea Savannah Zone

From table 7.5, it is observed that factors which significantly cause technical inefficiency in GSZ are sex, access to irrigation facilities, farmers' perception on lodging of rice, farmers' perception on the amount of rainfall, *IATs'* index and FISs' index. Statistically, the significant levels of the effects of sex, access to irrigation facilities on technical inefficiency are 5% each, whilst perceived low rainfall amount and *FISs* index are significant at 1% each. The perceived lodging of rice and *IATs* index are statistically significant at 1% each.

The direction of the effects of all these significant variables are consistent with the *a priori* expectations except *FISs* index. In terms of the direction of the effects, the findings in GSZ showed that male farmers, farmers who have access to irrigation facilities, farmers who have not experienced lodging of rice, farmers who perceived that they have received high rainfall amount and farmers with well-co-ordinated and more synergised adopted *IATs* are more technically efficient than their counterparts with opposing features holding other factors constant. From table 7.5, farmers who are males, have access to irrigation facilities, have not experienced lodging of rice and perceived high rainfall amount are respectively more efficient than their colleague farmers with contrasting characteristics.

The result of this study shows that male farmers are more efficient than female farmers was confirmed by Abdulai *et al.* (2013) and Ogundari and Awokuse (2016). According to Abdulai *et al.* (2013), women are engaged in unmeasured non-economic activities (such as child care, cooking, cleaning, etc) in the household coupled with some traditional beliefs which reduced their ability to be more efficient. The revelation that farmers who perceived they have received high annual rainfall amount are more technically efficient corroborates with the findings of Miyamoto *et al*. (2012), who indicated that annual rainfall of about 1200mm provides favorable conditions for rice growth in Central Uganda. This finding is also consistent with Rowhani *et al*. (2011) who argued that rice yield increases by 1.7% for a 20% increase in rainfall in Tanzania. In recent times, a research entitled "Effects of Climate and Conflict on Technical Efficiency of Rice Production, Northern Uganda" by Akongo *et al.* (2016) found out that as rainfall increases, the efficiency of farmers producing rice increases.

Table 7.5 Determinats of Technical Inefficiency Across the Agro-Ecological Zones

Variables	GSZ Model		FSTZ Model		CSZ Model		Metafrontier Model	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
ln(σ_v^2)	-3.7636***	0.1669	-3.4287***	0.1215	-4.1166***	0.1919	-5.1947***	0.1330
Farmer Characteristics								
Age	0.0058	0.0167	0.0358	0.0218	0.0569	0.0363	0.0316***	0.0093
Sex	-0.7271**	0.3006	-0.1154	0.2861	-0.0017	0.5031	-0.0221	0.1451
HHS	-0.0190	0.0300	-0.0798*	0.0408	-0.0139	0.1037	-0.0663***	0.0237
Eduyrs	0.0019	0.0366	-0.0699**	0.0338	-0.0390	0.0780	-0.0251	0.0178
FarmExp	-0.0069	0.0206	0.0022	0.0211	-0.0690	0.0503	0.0020	0.0110
Institutional and Policy Variables								
ExtVisits	-0.1120	0.1199	-0.2546**	0.1000	-0.2842	0.1749	0.1468***	0.0392
CredAcc	-0.5862	0.5010	0.7042	0.4520	1.4712	1.0486	-0.2179	0.1689
ContFarm	-0.9801	0.9193	-2.4043*	1.4533	-1.5050**	0.6857	0.2701	0.1908
FBO	-0.3007	0.3042	-0.5991*	0.3360	-0.1611	0.5909	0.0185	0.1500
ImpvSeed	0.2895	0.4806	-1.7176***	0.5123	1.4985**	0.7033	-0.1262	0.1892
IrrigAcc	-0.9617**	0.4194	-2.0761***	0.7297	-0.5482	0.6353	-0.2143	0.1820
Environmental Factors								
LodgRice	1.9192***	0.3317	1.1944***	0.3259	0.7233	0.5790	0.6865***	0.1598
LowRain	0.4737*	0.2766	0.5457*	0.2964	1.0055*	0.5820	-0.2768*	0.1546
Rice Production Technologies								
Adopt_IATs	-0.1833	0.4740	-0.7374*	0.4176	-2.0342***	0.7216	0.0937	0.1883
Adop_FISs	0.3718	0.3523	-0.3205	0.3239	0.3044	0.5234	-0.0760	0.1561
IATs _PC_Index	0.8194***	0.2501	0.7976***	0.2459	0.3941	0.2551	-0.0281	0.0819
FISs_PC_Index	-0.4458*	0.2561	0.4256*	0.2376	-0.4159	0.3670	-0.4694***	0.1050
Constant	-2.4488***	0.7645	-1.9134**	0.9671	-3.6772**	1.7271	-5.2873***	0.4924

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

Source: Author's analysis from field data (2017)

It is important to note that PCA index is a weight which shows the degree of correlation or distribution. When the innovation systems or technologies are more unequally distributed, they have high standard deviations resulting in high PC weight or index (McKenzie, 2003). Therefore, the more the innovation systems or technologies adopted are correlated (uniformly distributed or synergised or well-coordinated), the lower the index of the principal component. From the PCA results, this implies that farmers who uniformly synergise the adoption of *IATs* (adopted the package of *IATs* in a recommended sequence) have respectively lower PC indices. Therefore, as shown in table 7.5, a negative sign of the *IATs*_index suggests that farmers who uniformly synergise the adoption of *IATs* (i.e. have lower PC index) are more technically efficient than their counterparts. Therefore, farmers who well-coordinated and synergised the adopted scientifically improved technologies (harvesting of rice with combined harvester, use of certified improved rice varieties, farming rice under formal irrigation, application of chemical fertilizers, rotovation of soil before planting, storage of rice in warehouses, transplanting of seedlings and soaking of seed in water before planting or sowing) have high technical efficiency scores than those with otherwise features in GSZ *ceteris paribus*. This corroborates with the *a priori* expectations since it pays when a farmer uniformly and synergised the adoption of the superior technology, *IATs*.

On the other hand, farmers who well-coordinated and synergised the adopted *FISs* in GSZ are less technically efficient. This is against the *a priori* expectation. The reason could be that rice farmers in GSZ are not innovative themselves but rather copied or adopted farmer innovations from others and are not able to understand the intricacies or complexities of those innovations.

7.3.3.2 Determinant of technical inefficiency in Forest Savannah Transition Zone

Household size, years of education, number of extension visits, contract farming, FBO membership, the use of improved seed, access to irrigation facilities, perceived lodging of rice, perceived low rainfall amount, adoption of *IATs*, *IATs'* index and *FISs'* index statistically and significantly influence technical inefficiency in FSTZ. The explanatory variables with 1% significant levels of the effects are the use of improved seed, access to irrigation facilities, perceived low rainfall amount and *IATs*' index. The remaining significant explanatory variables have percentage probability levels of 10% each except years of education and number of extension visits which has percentage probability of 5% each.

From the finding of this research, contract farming, FBO membership, the use of improved rice seed, access to irrigation facilities, non-lodging of rice, perceived high rainfall amount, and adoption of *IATs* improve technical efficiency of farmers holding other factors constant. Whilst more uniformly, well-coordinated and synergised adoption of *IATs* increases farmers' technical efficiency, more uniform and synergised adoption of *FISs* decreases technical efficiency ceteris paribus. The direction of effects of all these variables are consistent with economic theory except *FISs' index*. The positive contribution of number of extension visits to technical efficiency is plausible. It confirms the findings of Al-hassan (2008) and Illukpitiya (2005) that farmers who have significant number of advice from agricultural extension agents on IATs are likely to be more efficient. This is because they are able to understand and appropriately adopt modern techniques of rice farming involving land preparation, planting, application of agro-chemicals (pesticides and fertilizer) and harvesting (Al-hassan, 2008). With agricultural extension advice, farmers can acquire knowledge on improved technologies, which in effects, improves their efficiency levels.

The study reveals that it is not enough to adopt *IATs,* the synergy of the adopted *IATs* (the recommended sequential adoption of *IATs*) is also key to improving farmers' technical efficiency. The reason is that a farmer who adopted *IATs* will obtain higher technical efficiency level than his/her counterpart whilst a farmer who synergised and well-coordinated the adopted *IATs* will increase his/her technical efficiency level more than his/her colleagues who did otherwise.

7.3.3.3 Determinants of technical inefficiency in Coastal Savannah Zone

In the CSZ agro-ecological zone, the estimated coefficients of contract farming and adoption of *IATs* are negatively signed and statistically significant at 5% and 1% respectively. The direction of the effects confirms the *a priori* expectations that farmers engaged in contract farming and who adopted *IATs* are more technically efficient than their counterparts who did otherwise. Perceived low rainfall amount is statistically significant at 10% and agrees with the economic theory since it has negative sign. Therefore, farmers who perceived high rainfall amount are more technically efficient than farmers who perceived low amount of rainfall. The reasons for this outcome are the same as explained under technical inefficiency model of GSZ. The use of improved seed is statistically significant at 5% but does not meet the *a priori* expectations.

7.3.3.4 Factors driving metafrontier technical inefficiency

Holding other factors constant, age, household size, extension visits, perceived lodging of rice, perceived low amount of rainfall and uniform and well-coordinated adoption of *FISs* statistically and significantly influence technical inefficiencies of rice farmers in Ghana. It can be deduced from the results (see table 7.5) that farmers who are more technically efficient are younger farmers, farmers who have larger household sizes and farmers who perceived that their rice did not lodge. These factors are statistically significant at 1% and their directions of effects meet the *a priori* expectation.

It is refreshing to find that as farmers grew older, their inefficiencies increased and this outcome is not surprising as similar findings were made by Njeru (2010) among selected wheat farmers in Kenya. This is contingent on the fact that the elderly farmers are so stuck to their old system of farming that they fail to adhere to the advices of the agricultural extension officers on the need to use IATs. Also, most of them do not have access to current information on IATs as compared to younger ones.

As noted by Al-hassan (2008), farmers with larger families have a variety of labour (children, youth, men and women), which leads to division of labour and specialization. Division of labour and specialization result in overall improvement of technical efficiencies of farming operations. Also, farmers with larger household sizes may have enough family labour and hence do not need to spend unproductive time in searching for laborers to hire. The time for supervising hired laborer's may be used in productive activities as well. This may be the reason why farmers with larger household sizes are more technically efficient than their counterparts. In metafrontier model, the number of extension visits, low amount of rainfall received and uniform synergised adoption of *FISs* statistically and significantly influence technical efficiency of rice farmers but do not meet *a priori* expectations.

7.3.4 Technical Efficiency Scores of Farmers

Table 7.6 is a frequency distribution table showing the technical efficiency scores of farmers in the three agro-ecological zones in the study area. The minimum, maximum, and the mean technical efficiency scores in GSZ are 10.0%, 99.0% and 82.2% respectively. In the FSTZ, the minimum technical efficiency score is 23.0% whilst the average is 83.6%. Farmers in CSZ have average technical efficiency score of 89.1% with the minimum score value of 31.0%. The maximum technical efficiency scores for farmers in all the three agro-ecological zones are equal i.e. 99.0%. From the finding of the research, there is no farmer who has technical efficeint score of 100%. It is not surprising since it is practically impossible to have technical efficeincy of 100%.

On average, the farmers in CSZ have the highest technical efficiency score value of 89.1% whilst farmers in GSZ have the lowest technical efficeincy score value of 82.2%. Given the available technologies and managerial skills, rice farmers in GSZ, FSTZ and CSZ respectively produce 17.8%, 16.4% and 10.9% below their potential rice output. On average, farmers in CSZ are 5.5% and 6.9% more productive than farmers in FSTZ and GSZ respectively. This revelation confirms MoFA data on rice yield, which indicates that farmers in Graeter Accra have the highest yield of 6.45Mt/ha followed by Volta Region with yield values of 3.6Mt/Ha (MoFA, 2015).

Table 7.6 Levels and Distrubutions of Group Specific Technical Efficiencies

Technical Efficiency Scores	GSZ		FSTZ		CSZ	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
≤ 0.1	1	0.27	0	0.00	0	0.00
0.11 – 0.20	1	0.27	0	0.00	0	0.00
0.21 – 0.30	7	1.86	2	0.56	0	0.00
0.31 – 0.40	7	1.86	12	3.34	1	0.58
0.41 – 0.50	14	3.71	5	1.39	1	0.58
0.51 – 0.60	22	5.84	18	5.01	2	1.17
0.61 – 0.70	19	5.04	29	8.08	7	4.09
0.71 – 0.80	32	8.49	47	13.09	15	8.77
0.81 – 0.90	95	25.20	66	18.38	32	18.71
0.91 – 100	179	47.48	180	50.14	113	66.08
Total	**377**	**100.00**	**359**	**100.00**	**171**	**100.00**
	Minimum =	0.10	Minimum =	0.23	Minimum =	0.31
	Maximum =	0.99	Maximum =	0.99	Maximum =	0.99
	Mean =	0.8221	Mean =	0.8357	Mean =	0.8910

Source: Author's analysis from field data (2017)

The low level of technical efficiency of rice farmers in Northern Ghana confirmed the findings of Al-hassan (2008). This revelation is plausible, considering the fact that the agricultural extension officer to farmer ratio is low in GSZ coupled with other constraints facing rice farmers as compared to those in agro-ecological zones.

In terms of the distribution, about 92.0% farmers in GSZ obtain more than half technical efficiency scores whereas 94.7% farmers are more than half technically efficient in FSTZ. CSZ has the highest number of farmers whose estimated technical efficiency is more than half. From the table, about 98.8% farmers had more than half technical efficiency scores in CSZ.

7.3.5 Metafrontier Technical Efficiency Scores and TGRs Across Agro-Ecologial Zones

Table 7.7 shows the summary statistics of the metafrontier technical efficiency (MFTE) and the TGR[13]. In this study, agro-ecological zones were used as a to show that technologies are heterogenous. It is important to note that TGR is also called productivity potential. Graphically, it shows the gap between the agro-ecological zone specific frontier and the metafrontier. With TGR, the assumption is that all farmers in any of the agro-ecological zone have the potential access to the best available technology for rice production (rice production industry) in Ghana through innovation diffusion model.

In table 7.7, the average estimated TGRs for farmers in GSZ, FSTZ and CSZ are 92.6%, 91.1% and 84.4% respectively. This TGRs are contingent on the technology available for rice production in Ghana. The maximum TGR values for farmers in GSZ, FSTZ and CSZ are 98.1%, 98.1% and 98.4% respectively. The mean values of the TGRs imply that, on the average, rice farmers in GSZ achieved 92.6% of the potential output given the technology available to the whole rice production subsector. On the other hand, farmers in FSTZ and CSZ produced averagely 91.1% and 83.5% respectively of their potential output given the technology available to the entire rice farming industry. The standard deviation showed that farmers in CSZ have the highest variations in TGRs.

Table 7.7 Summary Statistics of Metafrontier Technical Efficiencies and TGRs

	GSZ		FSTZ		CSZ		Metafrontier	
	MFTE	TGR	MFTE	TGR	MFTE	TGR	MFTE	TGR
Mean	0.7635	0.9262	0.7616	0.9107	0.7511	0.8437	0.7604	0.9045
St. Dev.	0.1747	0.0438	0.1595	0.0445	0.1285	0.1052	0.1608	0.0676
Minimum	0.0870	0.6397	0.2035	0.6879	0.2702	0.5031	0.087	0.5031
Maxmum	0.9655	0.9813	0.9724	0.9807	0.9439	0.9835	0.9724	0.9835
Sample size	377		359		171		907	

Source: Author's analysis from field data (2017)

Since none of the agro-ecological zones had an average TGR of 1, it suggests that none of the group specific frontiers is tangential to the metafrontier. This implies that given the status quo in terms of the available inputs and technology, on average, farmers in the three agro-ecological zones have not been able to produce the potential metafrontier output in Ghana. The reason could be that farmers are not fully using the available technology for rice production. Notwithstanding that, the environmental conditions also prevent them from producing on the metafrontier. As noted by Huang *et al.* (2014), technology gap exists because of the choice of a

[13] Technology gap ratio is a measure of the proportion of the technology differential of each farmer in an agro-ecological zone relative to the best available technology for all the farmers in the rice production subsector.

particular technology which actually depends on the environmental factors. This explains why farmers are not able to achieve potential rice yield in the country as noted by MoFA (2015).

Comparatively, the lowest TGR recorded by farmers in CSZ implies that the zone's specific frontier is farthest away from the metafrontier. As such, rice farming in CSZ tends to be more sensitive to environmental conditions since TGR depends on environmental conditions beyond farmers' control. The estimated TGR for GSZ is the highest among the three agro-ecological zones implying it is less sensitive to environmental stress conditions. This suggests that the effects of environmental factors on rice production in GSZ is minimal as compared to FSTZ and CSZ. Among the three agro-ecological zones, rice production in FSTZ is moderately affected by any changes in environmental conditions. The results of this may be the reason why rice farming in CSZ is mainly under irrigation.

Also, the low amount of rainfall is always recorded in the CSZ (MoFA, 2011) and any slight fluctuations might provide hash or adverse environmental conditions, which in effect might reduce farmers' ability in the zone to achieve potential rice yield as compared to their counterparts. Additionally, the soils in CSZ are slightly saline making the rice output more sensitive to changes in the level of salt in the soil. Rice farming in the FSTZ is also affected by flood due to the high amounts of rainfall coupled with the nearness of most rice farms to big rivers.

The findings of this study imply that an efficient rice producer in CSZ could still increase rice output by 15.6% if he or she were to adopt the most efficient meta-technology in Ghana. Similarly, if an efficient rice farmer in GSZ adopts the most efficient meta-technology in the country, he or she can increase rice output by 7.4%. The rice farmers in FSTZ have the potential of increasing rice output by 8.9% if they adopt meta-technology available in the Ghana. This suggests that farmers in costal savannah zone can be highly productive if they are able to adopt strategies that will minimise the effects of the environmental stress on rice.

On average, farmers in Ghana have TGR of 90.5. This implies that on average, rice farmers in Ghana are able to produce 90.5% of the the local rice industry's possible output given the available and accessible technology of the entire rice industry. Generally, the results imply that no agro-ecological zone frontier was able to reach the meta-technology level.

The estimated technical efficiencies with respect to the metafrontier are quite uniformly spread across the agro-ecological zones. The standard deviations of the metafrontier technical efficiencies (MFTEs) range from 0.1285 to 0.1747. Comparing MFTEs among the three agro-ecological zones, farmers in GSZ outperformed others, recording the highest average metafrontier technical efficiency score of 76.35%, followed by farmers in forest savannah zone and CSZ with average MFTE scores of 76.16% and 75.11% respectively. This finding is in tandem with that of Huang *et al.* (2014) that even though firms in developed countries have higher technical efficiency, their counterparts in developing countries have higher metafrontier technical efficiency. Albeit farmers in CSZ have the highest productivity of rice, they can still increase their productivity levels (they have greater potential) more than farmers in the other two agro-ecological zones.

7.3.6 Drivers of TGR

In order to identify the factors which statistically and significantly influence TGR, a generalised linear model (GLM) was adopted and estimated and the results presented in table 7.8. From the results, the Aikake Information Criterion (AIC) value of -2.8681 implies that the model is fit for that data used for this study. The marginal effect[14] in this model measures the effect of a unit change of the explanatory variable on the TGR. The direction of the effect of the explanatory variables provide the explanation of the factors which can improve climatic and environmental conditions to help farmers bridge the gap between actual output and potential output. Note that a positive sign for any of the explanatory variables suggests an increase in TGR which can be interpreted as measures that favorably improve the production environment for bridging the gap between actual and potential output (Mensah and Brümmer, 2016). The explanatory variables here are the hypothesised factors which are expected to influence the production environment of rice in Ghana (Mensah and Brümmer, 2016).

From the results presented in table 7.8, out of fifteen hypothesized variables, eleven were statistically significant. Distance from Accra to the communities, lodging of rice, mean annual rainfall amount, mean annual temperature, formal irrigation accessibility and closeness of farmers' house to the farm are statistically significant at 1% each. The factors which are statistically significant at 10% are distance from office of AEA to the rice farming communities, contract farming and adoption of *IATs*. Meanwhile, road condition from district capital to the rice farming communities and adoption of *FISs* are significant at 5% each. Out of the eleven significant factors, eight meet their *a priori* expectations. These include contract farming, access to irrigation facilities, condition of road from district capital to farming communities, distance from farm to the house, lodging of rice, actual mean annual rainfall amount within the district, adoption of *IATs* and adoption of *FISs*.

Table 7.8 Generalised Least Square Model Estimates of Drivers of TGR

Variables	Marginal Effects	OIM Std. Err.
Constant	0.47699***	0.05526
Infrastructure		
Condition of road to district capital	0.00785**	0.00419
Distance from office of AEAs to community	0.00081**	0.00039
Distance from community to market centres of rice	0.00007	0.00034
Distance from Accra to Community	0.00005***	0.00001
Distance from farm to the house	-0.00128***	0.00045
Environmental Shocks		
Lodging of rice	-0.02370***	0.00446
Affected by low rainfall amount	0.00429	0.00426
Affected by diseases	-0.00675	0.00449
Actual mean annual rainfall amount	0.00013***	0.00001
Actual mean annual temperature	0.00955***	0.00206

[14] The estimated coefficients of the GLM is the same as the marginal effects.

Government and NGO Programme and Policy Variables		
Irrigation facility	0.01601**	0.00577
Inputs' subsidy	0.00339	0.00374
Contract farming	0.01063*	0.00600
Technology		
Adoption of IATs	0.00850*	0.00470
Adoption of FISs	0.00893**	0.00403
Likelihood = 1320.521399, AIC = -2.876563, BIC = -6064.949		

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

Source: Author's analysis from data obtained from the field and GMA (2017)

The institutional and policy variables which have positive effect on TGR are access to irrigation facilities and contract farming. This suggests that policies should be implemented to engage farmers in contract farming as well as improve farmers' access to irrigation facilities so as to help them bridge the gap between actual and potential rice outputs. Examining the direction of the effects of infrastructural variables, it can be observed that farmers who stay in communities that have good road condition to the district capital and farmers who stay close to their farms have higher TGRs. Under environmental and climatic shocks, farmers who are in districts with high mean annual rainfall and farmers who have not experienced lodging of rice have higher TGRs. This implies that farmers with the above characteristics or features have their group frontier closer to the metafrontier and hence the difference between their actual and potential outputs is small as compared to what their counterparts with contrasting features obtained. Principally, adopters of *IATs* and adopters of *FISs* are able to increase actual rice output closer to the metafrontiar output level. What it means is that, for farmers to catch-up in terms of technology and minimise the effects of environmental and climatic conditions on rice production, they must adopt *IATs* and *FISs* since these technologies bridge the gap between actual and potential rice output.

7.4 Summary

The new-two step stochastic metafrontier was used to empirically estimate the productivity performances (technical efficiency, metafrontier technical efficiency and TGR) of rice farmers across GSZ, FSTZ and CSZ. All the estimated models (GSZ model, FSTZ model, CSZ model and metafrontier model) exhibited increasing returns to scale suggesting joint underutilization of the inputs.

Seed reduces rice output, suggesting a possible overcrowding of rice plant in Ghana. Fertilizer and farm size are very important inputs in rice production since each of them had statistical significant positive impact on rice output in all the three agro-ecological zones not excluding metafrontier model. While labour is an important input that increases rice output in FSTZ and CSZ, capital is a key input that propel the expansion of rice farms and hence increases rice output in GSZ and Ghana at large.

Also, the factors affecting farmers' technical efficiencies differ across agro-ecological zones. In general, the study identified age, sex, household size, education years, number of extension visits, contract farming, access to and appropriate use of improved seeds, access to irrigation, perceived low rainfall amount, lodging of rice, type of technology adopted and the coordinated or synergized adoption of the technologies as factors significantly influencing technical efficiency of rice farmers in Ghana.

Farmers in CSZ are more technically efficient in rice production than their counterparts in the other two agro-ecological zones. While the technical efficiency of farmers in CSZ is 89.10%, farmers in FSTZ and GSZ recorded technical efficiency scores of 83.57% and 82.21% respectively. Albeit farmers in CSZ are doing well in terms of rice yield, they still have the highest potential of increasing rice yield than their counterparts in FSTZ and GSZ. This is premised to the fact that they have the lowest mean TGR of 90.45% followed by farmers in FSTZ (91.07%) and GSZ (92.62%).

Factors which increase TGR are contract farming, access to irrigation facilities, good condition of road from district capital to farming communities, nearness of rice farm to the farmers' houses, non-lodging of rice, high actual mean annual rainfall amount within the district, adoption of *IATs* and adoption of *FISs*. Lastly, good infrastructure, favorable environmental conditions, favourable government and NGO policy supports and IATs and farmer innovations can enhance the potential of farmers to increase rice productivity in Ghana.

CHAPTER EIGHT

EMPIRICAL RESULTS OF IMPACTS OF TECHNOLOGY ADOPTION TYPOLOGY ON RICE YIELD IN GHANA

8.1 Introduction

This chapter presents and discusses the empirical results of the analysis of the impacts of technology adoption on rice yield. This was done by using STATA 14.0 to run the multinomial endogenous switching regression and predict the treatment effects. With the help of t-test, the difference average treatment effect for the treated and average treatment effect for the untreated were statistically tested. The first section of this chapter presents the descriptive statistics of the variables used in the multinomial endogenous switching regression. The empirical results for the analysis of the impacts of technology adoption on rice yield are presented and discussed in this chapter. Lastly, the statistical test for the treatment effects is presented and discussed in this chapter.

8.2 Descriptive Statistics of Socioeconomic Characteristics

In this section, the summary statistics of both the continuous and discrete variables used in multinomial endogenous switching regression model are presented. It must be recalled that, these variables are summarised in terms of technology adoption typology classified in chapter five. These technology adoption typologies are non-adopters, adopters of *FISs*, adopters of *IATs* and adopters of both *FISs* and *IATs*.

8.2.1 Summary Statistics of Continuous Variables in MESRMs

Table 8.1 shows the summary statistics of continuous variables used in MESRM. From the table, adopters of *IATs* had the highest average rice yield of 3.66Mt/Ha (17.64bags/acre) followed by adopters of both *FISs* and *IATs* obtaining average rice yield of 3.10Mt/Ha (14.94bags/acre). The non-adopters obtained the lowest rice yield of 1.73Mt/Ha (8.34bags/acre).

It is clear from table 8.1 that adopters of *FISs* had the largest average farm size (2.8acres) whereas non-adopters had the smallest average farm size (2.4acres) albeit no wide variations in average farm size. Also, there are no wide variations in the average total labour employed among non-adopters and adopters of the various technology adoption typologies even though adopters of *FISs* employed the highest average mandays of labour of 47.1. As expected, the adopters of *IATs* applied the highest average quantity of fertilizer (295.7Kg) as compared to their counterparts (51.0Kg for non-adopters, 143.2Kg for adopters of *FISs* and 242.6Kg for adopters of both *FISs* and *IATs*). Adopters of FISs applied more pesticides than other technology typologically classified farmers. The farmers who invested the highest average amount of capital in rice production are adopters of *IATs*. This is due to the cost requirements of *IATs* as noted by Donkoh and Awuni (2011).

Table 8.1 Summary Statistics of Continuous Variables in MESRM

Variable	Non-Adopters (n = 199)			Adopters of *FISs* (n = 154)			Adopters of *IATs* (n = 365)			Adopters of both *FISs* and *IATs* (n = 189)		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Yield (Mt/Ha)	1.73	0.38	5.12	2.40	0.60	8.09	3.66	0.78	10.27	3.10	0.25	6.22
Production Inputs												
Farm size (acres)	2.4	0.5	10.0	2.8	1.0	12.0	2.6	0.5	8.7	2.7	0.5	10.0
Labour (man-days)	38.2	8.0	156.0	47.1	10.0	183.0	45.3	11.0	205.0	47.7	11.0	144.0
Fertilizer (Kg)	51.0	0.0	450.0	143.2	0.0	925.0	295.7	0.0	2300.0	242.6	0.0	900.0
Seed (Kg)	94.3	20.0	1200.0	97.7	16.8	650.0	72.2	10.0	800.0	73.9	8.0	360.0
Pesticides (liters)	3.0	0.0	24.0	4.5	0.0	36.0	3.8	0.0	60.0	4.3	0.0	36.0
Capital (Gh₵)	285.5	6.1	4177.1	646.2	8.5	6252.9	1081.2	12.1	5787.4	797.9	25.9	4687.4
Farmer Characteristics												
Age (years)	43.7	18.0	65.0	42.6	20.0	71.0	44.0	21.0	71.0	41.4	21.0	64.0
Household size	8.9	1.0	25.0	8.2	1.0	30.0	6.7	1.0	25.0	7.7	1.0	25.0
Education years	4.2	0.0	14.0	5.3	0.0	15.0	7.9	0.0	19.0	7.3	0.0	20.0
Rice farming experience (years)	15.8	1.0	35.0	15.2	2.0	50.0	13.8	1.0	40.0	11.9	2.0	41.0
Institutional and Policy Variables												
Extension visits	0.9	0.0	7.0	2.0	0.0	9.0	3.2	0.0	8.0	3.4	0.0	14.0
No. of FBO advice	0.4	0.0	5.0	1.0	0.0	7.0	1.4	0.0	24.0	1.6	0.0	8.0
Infrastructure												
Distance from office of AEAs to community (Km)	12.1	0.0	67.9	7.9	0.0	38.0	4.5	0.0	38.0	7.9	0.0	38.0
Distance from community to rice marketing centre (Km)	11.5	0.0	67.9	9.3	0.0	38.0	3.9	0.2	38.0	7.2	1.0	38.0
Distance from Accra to rice farming community (Km)	514.3	29.0	777.0	441.4	29.0	777.0	298.0	29.0	777.0	494.6	29.0	777.0
Environmental Shocks												
Actual mean annual rainfall (mm)	1036.5	800.0	1270.0	1035.6	800.0	1270.0	1010.8	800.0	1270.0	1024.2	800.0	1270.0
Actual mean annual temperature (^0C)	27.8	24.0	31.0	27.3	24.0	31.0	26.5	24.0	31.0	27.5	24.0	31.0

Source: Author's analysis from field data and data obtained from Ghana Meteorological Agency (2017)

The mean age of adopters of *IATs* (44.0years) is however higher than the mean age of adopters of *FISs* (42.6years) whereas non-adopters have the highest mean household size of 8.9. The mean number of years of education of adopters is 7.9 years compared to 4.2 years of non-adopters. This observation reflects the fact that understanding and adopting *IATS* requires a high level of education or training to appreciate the science behind the technology. The non-adopters represent farmers with very little education and training and therefore are unable to appreciate modern technology. Thus, they stick to the familiar *IFPs* which they have been accustomed to over generations. Farmers in this category have the highest number of years of farming experience extending back into the past 43.7 years.

As shown in table 8.1, farmers who had the highest mean number of agricultural extension officers visiting and advising them on rice production are joint adopters of *FISs* and *IATs*. Adopters of both *FISs* and *IATs* received the highest number of advice on rice cultivation from farmer-based organization. In terms of distance, non-adopters stayed farthest away (averagely 12.1Km) from offices of agricultural extension officers, rice marketing centers (11.5Km) and Accra (514.3Km) than their adopting counterparts. Similarly, non-adopters stay in the area where mean annual rainfall and temperature are the highest.

8.2.2 Summary Statistics of Discrete Variables used in MESRM

In table 8.2, the technology adoption typology which had the highest percentage of males (71.4%) is adopters of both *FISs* and *IATs.* In this study, the proportion of female adopters is lower than the proportion of male adopters for each of the technologies. Most of the farmers who cultivate rice as a business are those adopting *FISs*. The majority of adopters of *IATs* (54.5%) had access to credit for rice cultivation and are also involved in contract farming (45.8%). On the other hand, the lowest percentage of farmers having access to credit and engaging in contract farming are farmers who stick to their traditional IFPs without adopting any technology. This is because *IFPs* are not highly expensive. Also, farm credit lending institutions and companies or individuals providing farmers with credit or engaging farmers in contract farming are not ready to work with *IFPs'* users.

Comparatively, it can be observed in table 8.2 that a greater percentage of joint adopters of *FISs* and *IATs* (75.13%) belongs to FBOs. They are the majority who as well receive input subsidy from government and NGOs. Additionally, technology adoption typology of farmers who perceived lodging of rice and low annual amount of rainfall are those who did not adopt any technology.

Table 8.2 Summary Statistics of Discrete Variables in MESRMs

Variables		Non-Adopters (n = 199)		Adopters of *FISs* (n = 154)		Adopters of *IATs* (n = 365)		Adopters of both *FISs* and *IATs* (n = 189)	
		Freq	%	Freq	%	Freq	%	Freq	%
Farmer Characteristics									
Sex:	*Female*	62	31.16	51	33.12	124	33.97	54	28.57
	Male	137	68.84	103	66.88	241	66.03	135	71.43
Business purpose	*No*	42	21.11	34	22.08	73	20.00	37	19.58
of farming rice:	*Yes*	157	78.89	120	77.92	292	80.00	152	80.42
Institutional and Policy Variables									
Credit access:	*No*	174	87.44	121	78.57	199	54.52	110	58.20
	Yes	25	12.56	33	21.43	166	45.48	79	41.80
Contract farming:	*No*	187	93.97	121	78.57	167	45.75	121	64.02
	Yes	12	6.03	33	21.43	198	54.25	68	35.98
FBO membership:	*No*	135	67.84	80	51.95	111	30.41	47	24.87
	Yes	64	32.16	74	48.05	254	69.59	142	75.13
Input subsidy:	*No*	184	92.46	127	82.47	291	79.73	127	67.20
	Yes	15	7.54	27	17.53	74	20.27	62	32.80
Environmental Shock Factors									
Lodging of rice:	*No*	77	38.69	87	56.49	286	78.36	156	82.54
	Yes	122	61.31	67	43.51	79	21.64	33	17.46

Low rains:	*No*	63	31.66	80	51.95	252	69.04	128	67.72
	Yes	136	68.34	74	48.05	113	30.96	61	32.28
Agro-Ecological Zone Dummies									
GSZ:	*No*	86	43.22	95	61.69	263	72.05	86	45.50
	Yes	113	56.78	59	38.31	102	27.95	103	54.50
FSTZ:	*No*	125	62.81	86	55.84	206	56.44	131	69.31
	Yes	74	37.19	68	44.16	159	43.56	58	30.69

Source: Author's analysis from field data (2017)

8.3 Empirical Econometric Analysis of Impacts of Technology Adoption Package on Rice Yield

The impacts of technology adoption package on rice yield was analysed using MESR. The study used full information maximum likelihood approach for the estimation and the results are presented in tables 8.3 and 8.4. For proper identification, Lokshin and Sajaia (2004) indicated that the selection equation should contain all the variables in the regime equations except that the selection equation should have at least one instrument. From the MESRM results as shown in table 8.4, the model used fits well for the data since the Wald test is statistically significant at 1% for each of the technology adoption packages. The significance of the Wald Chi-Square test implies that the null hypothesis that all regression coefficients are jointly equal to zero is rejected in favour of the alternate hypothesis.

8.3.1 Factors Explaining Technology Adoption Package in Rice Yield MESRM

The results of the multinomial endogenous switching regression explaining the technology adoption packages (I_1T_0, I_0T_1 *and* I_1T_1) are presented in table 8.3. From the table, the base category with which the technology adoption packages were compared is non-adoption (I_0T_0). The selection equation explains the factors determining technology adoption package. As noted by Donkor *et al.* (2016), the coefficients of the adoption equation are normal probit coefficients which can be interpreted as probabilities.

The probability of farmers adopting *FISs* significantly increases with rice farming experience, number of rice farming advices received from FBOs and distance from farmers' community to input markets. On the other hand, an increase in farmers' age, *IFPs_PC_Index* and *IATs_PC_Index*, decreases the probability of farmers adopting *FISs*. Note that the *PC_Index* measures the level of coordination's in the adoption of the technologies or level of sequential adoption of the package of each technology. Also, farmers who are not located in GSZ have higher probability of adopting

FISs than their counterparts located in the area. The directions of the effects of all these significant factors on farmers' adoption of *FISs* meet the *a priori* expectations except farmers' age, GSZ dummy, and *IFPs_PC_Index*. Farmers who have well-co-ordinated and had synergised the adoption of *IATs* have low probability of adopting *FISs* only.

The factors which have significant positive impacts on the adoption of *IATs* are number of extension visits, farmers located in GSZ and FSTZ. Conversely, farmers who stay closer to rice marketing centres, farmers who are located in areas with high amount of annual rainfall and average annual temperature have lower probability of adopting *IATs*. Farmers who have less coordinated and synergised adoption of *IFPs* are more adopters of *IATs*. The effects of all these factors on farmers' adoption decisions of *IATs* confirm the expected results except temperature.

Number of visits by agricultural extension officers' increases farmers' probability of adopting *IATs* because with extension officers visiting the farmers, it is expected that farmers will be well informed on the impacts of *IATs* on rice productivity. As noted by Diagne and Demont (2007), a farmer cannot adopt a technology without being aware of it.

The factors determining the decision of farmers to jointly adopt *FISs* and *IATs* are age and purpose of farming. From the results, the probability of farmers jointly adopting *FISs* and *IATs* increases with farmers' age, which is consistent with the *a priori* expectation. Farmers who cultivate rice as a business venture have lower probability of jointly adopting *FISs* and *IATs* and this is also in line with the *a priori* expectation. Perhaps farmers who cultivate rice as a business adopt the superior technology like *IATs* only. They may not like to combine *IATs* with *FISs*.

Table 8.3 Full Information Maximum Likelihood Estmation of Determinants of Technology Adoption in MESRM

Variables	***FISs*** **(I_1T_0)**		***IATs*** **(I_0T_1)**		***FISs*** **and** ***IATs*** **(I_1T_1)**	
	Coef.	**Robust SE**	**Coef.**	**Robust SE**	**Coef.**	**Robust SE**
Conventional inputs						
Labour	0.1510	0.1048	-0.4549*	0.2425	0.1438	0.2317
Fertlizer	-0.0646	0.0897	0.2022*	0.1063	-0.0486	0.1773
Seed	-0.0061	0.0373	-0.0912	0.0987	-0.1172	0.1254
Pesticides	0.0575	0.0465	-0.0208	0.0634	0.0200	0.0443
Capital	0.0166	0.0623	0.1853	0.0789**	-0.0275	0.0714
Farmer Characteristics						
Age	-0.0204***	0.0053	-0.0043	0.0070	0.0196**	0.0081
Sex	0.0468	0.1129	-0.1433	0.1086	0.1271	0.1336
HHS	0.0209	0.0154	0.0068	0.0143	-0.0061	0.0141
BusFm	-0.0810	0.1170	0.1376	0.1212	-0.2436*	0.1367
Eduyrs	-0.0020	0.0062	0.0069	0.0094	0.0075	0.0134
FmExp	0.0162***	0.0037	-0.0003	0.0065	-0.0188	0.0074
Institutional and Policy Variables						
CredAcc	-0.1436	0.1286	-0.0997	0.1191	-0.2459	0.1820
ContFarm	-0.0903	0.1580	0.1822	0.1403	-0.1725	0.1988
FBO	0.0207	0.1079	-0.0257	0.1231	-0.0604	0.1236
InpSub	0.0122	0.1308	-0.0536	0.1208	0.2510	0.2039
ExtVisits	-0.0533***	0.0187	0.0879**	0.0345	0.1461	0.0980
FBO_Adv	0.0514***	0.0198	0.0130	0.0281	-0.0019	0.0312
DistAEAs	-0.0052	0.0058	-0.0070	0.0070	-0.0094	0.0072
DistInpMkt	0.0176***	0.0059	-0.0265*	0.0128	0.0009	0.0134
DistAccraCom	0.0003	0.0004	-0.0002	0.0008	0.0016	0.0022
Environmental Factors						
LodgRice	0.1222	0.1027	-0.2159	0.1400	-0.0612	0.1888
LowRain	-0.1141	0.1048	-0.0021	0.0999	0.0483	0.1474
RainAmt	-0.0002	0.0009	-0.0022**	0.0009	0.0013	0.0030
Temp	0.0983	0.0807	-0.2349***	0.0871	0.0991	0.2440
Agro-Ecological Zone Dumies						
GSZ	-1.2362***	0.3994	1.0358**	0.5261	-0.8006	0.7810
FSTZ	-0.4046	0.4458	1.1295***	0.4188	-0.5983	0.6245
Rice Production Technologies						
IFPs_PC_Index	-0.0631**	0.0269	0.1571*	0.0806	0.0762	0.0610
FISs_PC_Index			-0.0956	0.0831	0.4188	0.3202
IATs_PC_Index	-0.1415***	0.0367				
Constant	-2.4767	2.5493	7.8466***	2.6907	-5.6418	8.0650

***, **, * represent 1%, 5%, and 10% significance level, respectively. Also, SE represent satandard error.

Source: Author's analysis from field data and data (2017)

8.3.2 Determinants of Rice Yield in the Regime Equations of MESRM

Table 8.4 presents the second-stage of the FIML estimates of MESRMs for each of the technology packages (I_1T_0, I_0T_1 *and* I_1T_1). As noted by Tambo (2013), the rho is the correlation coefficients between the error terms of the selection and outcome equations and it indicates the presence or absence of selection bias. From the results shown in table 8.4, the rho for non-adopters of *IATs* is statistically significant, suggesting that self-selection is present, meaning both observed and unobserved factors influence the adoption decisions and the yield outcomes. Also, it implied that selectivity bias was present and that if it was not corrected, the coefficients would not have shown the true effects of the explanatory variables on rice yield.

The Wald Chi-Square (likelihood ratio) test of independent equations is statistically significant for *FISs* and *IATs* indicating evidence of joint dependence between the technology adoption selection and the rice yield outcome equations for both adopters and non-adopters. This suggests that the selection and outcome equations cannot be estimated separately, confirming the findings of Donkor *et al.* (2016). The insignificance of the Wald Chi-Square (likelihood ratio) test of independent equations for I_1T_1 package implies that there is no joint dependence between the selection and the outcome equations for adopters of both *FISs* and *IATs*.

There are differences between factors determining rice yield for adopters and non-adopters of the three technology packages (I_1T_0, I_0T_1 *and* I_1T_1). From table 7.4, for adopters of *FISs*, quantity of fertilizer applied, capital, purpose of rice farming, contract farming, perception about lodging of rice and GSZ dummy variable significantly influence rice yield, holding other factors constant. Rice yield for adopters of *FISs* will increase when the quantity of fertilizer applied increases, but the reverse is true for amount of capital invested in rice production. Contract farming also increases rice yield of adopters of *FISs*. From the results, rice yield of adopters of *FISs* is lower for farmers who cultivate rice as a business venture, farmers who experienced lodging of rice and farmers who are located in the GSZ. The effects of all these factors are consistent with the *a priori* expectations, except amount of capital. The reason could be that farmers who cultivate rice as a business are not innovative enough but rather rely on externally developed technologies like *IATs*. Unlike their counterparts who are subsistent farmers, their farm sizes are so large that they cannot implement their own innovation effectively.

The factors which have positive significant impacts on rice yield for non-adopters of *FISs* are fertilizer, business purpose of rice farming, credit access, contract farming and FBO membership holding other factors constant. On the contrary, an increase in the amount of labour employed, quantity of rice seed planted, farmers' age, household size, annual amount of rainfall and temperature results in a significant decline in rice yield for non-adopters of *FISs*. Non-adopters of *FISs* who experienced lodging of rice, low rainfall amount, are not located in GSZ, have access to credit, do contract farming, are members of FBOs as well as apply recommended quantity of fertilizer have higher rice yield than their counterparts. The directions of the effects of these factors confirmed the *a priori* expectation.

Table 8.4 Full Information Maximum Likelihood Estimation of Factors affecting Rice Yield in MESRM

Variables	*FISs (I_1T_0)*		*IATs (I_0T_1)*		*FISs and IATs (I_1T_1)*	
	Adopters	**Non-adopters**	**Adopters**	**Non-adopters**	**Adopters**	**Non-adopters**
Conventional Inputs						
Labour	0.1664	-0.1876*	0.1081	-0.2125	-0.3150	-0.2194**
	(0.1697)	(0.0989)	(0.1508)	(0.1377)	(0.2484)	(0.1036)
Fertilizer	0.2805*	0.3216***	0.1795**	0.3489***	0.2346	0.3326***
	(0.1687)	(0.0599)	(0.0698)	(0.1041)	(0.1689)	(0.0644)
Seed	-0.0841	-0.1247**	-0.1317*	-0.0966*	-0.4666***	-0.0914**
	(0.0554)	(0.0507)	(0.0765)	(0.0569)	(0.1595)	(0.0428)
Pesticides	-0.0553	0.0599*	0.0895	-0.0194	-0.0402	0.0315
	(0.0734)	(0.0307)	(0.0715)	(0.0445)	(0.0570)	(0.0299)
Capital	-0.2666**	0.0160	-0.0764	-0.0037	0.1670**	-0.0115
	(0.1143)	(0.0419)	(0.0562)	(0.0764)	(0.0666)	(0.0449)
Farmer Characteristics						
Age	-0.0104	-0.0073**	-0.0062	-0.0028	-0.0124	-0.0054
	(0.0082)	(0.0036)	(0.0053)	(0.0040)	(0.0095)	(0.0037)
Sex	0.0093	0.0188	0.0578	0.0856	-0.0136	-0.0309
	(0.1671)	(0.0743)	(0.1019)	(0.0937)	(0.1637)	(0.0945)
HHS	0.0178	-0.0145*	-0.0351***	-0.0020	0.0038	-0.0089
	(0.0262)	(0.0082)	(0.0129)	(0.0101)	(0.0193)	(0.0087)
BusFm	-0.3195*	0.1582**	0.2508*	-0.0978	0.2440	0.1767**
	(0.1768)	(0.0776)	(0.1290)	(0.0918)	(0.1962)	(0.0844)
Institutional and Policy Variables						
CredAcc	-0.2554	0.2570***	0.3772***	0.1698*	-0.0174	0.2716**
	(0.2280)	(0.0730)	(0.0998)	(0.1006)	(0.1802)	(0.1141)
ContFarm	0.8390***	0.5668***	0.3176**	0.6246***	0.7599***	0.7028***
	(0.2748)	(0.0963)	(0.1320)	(0.2054)	(0.1714)	(0.1328)
FBO	0.0090	0.1461**	0.0191*	0.1637*	0.2542	0.0340
	(0.1548)	(0.0664)	(0.0971)	(0.0855)	(0.1743)	(0.0928)
InpSub	-0.1618	-0.0592	0.0039	-0.1329	-0.3443*	-0.2002
	(0.1839)	(0.0810)	(0.1266)	(0.1036)	(0.1855)	(0.1444)
Environmental Factors						
LodgRice	-0.7459***	-0.5854***	-0.4003***	-0.5605***	-0.3462	-0.5624***
	(0.1474)	(0.0693)	(0.1224)	(0.0894)	(0.2694)	(0.0784)
LowRain	-0.1429	-0.4283***	-0.4572***	-0.2404***	-0.2634*	-0.2957***
	(0.1443)	(0.0654)	(0.0966)	(0.0789)	(0.1494)	(0.0783)
RainAmt	-0.0013	-0.0027***	-0.0031***	-0.0004	-0.0023	-0.0035***
	(0.0012)	(0.0005)	(0.0007)	(0.0009)	(0.0025)	(0.0006)
Temp	0.0084	-0.1296***	-0.0677	0.0600	-0.1561	-0.2228***
	(0.1237)	(0.0491)	(0.0778)	(0.0829)	(0.1822)	(0.0691)
Agro-Ecological Zone Dummies						
GSZ	-1.2950*	-0.9606***	-1.0165**	-1.0811***	-1.1956**	-0.4606
	(0.6598)	(0.2605)	(0.3997)	(0.3353)	(0.5643)	(0.3516)
FSTZ	-0.0128	-0.1197	-0.2563	-0.4341	-0.1174	0.4630
	(0.6788)	(0.2699)	(0.4064)	(0.4466)	(0.8291)	(0.3886)
Constant	3.1239	10.0883***	9.3808***	1.9415	11.6251	12.4836***
	(3.6435)	(1.5417)	(2.4002)	(2.9677)	(7.8391)	(2.0875)
Rho	0.9941	0.2900	-0.5143	-0.8563**	-0.7418	-0.9028
Wald chi^2 (19)	127.76***		571.63***		205.58***	
Wald chi^2 (1) test of indep. eqns.	9.87***		7.06***		1.07	

***, **, * represent 1%, 5%, and 10% significance level, respectively. Values in parentheses are standard errors *Source: Analysis from field data (2017)*

From table 8.4, rice yield of adopters of *IATs* is positively affected by quantity of fertilizer applied, business purpose of rice cultivation, credit access, contract farming and FBO membership. For adopters of *IATs*, quantity of rice seed planted, household size, lodging of rice, perceived low amount of rainfall and the actual total annual rainfall amount decrease rice yield. In all, the *a priori* expectation is met except total annual amount of rainfall. The results for the non-adopters of *IATs* have the same significant factors influencing rice yield except household size and amount of annual rainfall, which are not significant. The direction of the effects of the significant factors for both adopters and non-adopters of *IATs* is the same.

For adopters of both *FISs* and *IATs*, the factors which significantly and positively affect rice yield are capital and contract farming, as opposed to quantity of rice seed, input subsidy, perception of experiencing low rainfall amount and GSZ dummy which have significant and negative effects on rice yield. Among these significant variables, it was only access to input subsidy that did not conforme to the *a priori* expectation. On the other hand, quantity of fertilizer, business purpose of rice farming, credit access and contract farming have positive significant impact on rice yield of non-adopters of joint adoption of *FISs* and *IATs*. Also, from the last column of table 8.4, labour, seed, lodging of rice, perceived low rainfall amount, actual average annual rainfall in the area and actual average annual temperature in the area have negative significant effects on rice yield for farmers who do not jointly adopted *FISs* and *IATs*. The direction of effects of the above significant factors affirms the *a priori* expectations, except actual average annual rainfall amount within the farming area.

8.3.3 Rice Yield Treatment Effects of Technology Adoption Packages

From the full information maximum likelihood estimates of the MESRM, the mispredict command in Stata was used to predict observed and the counterfactual rice yields of farmers' technology adoption package decision. The use of MESRM to predict the observed and the counterfactual rice yields is grounded on the observation of Maddala (1983) and Di Falco and Veronesi (2013) that a simple comparison between the observed mean yield values of rice between adopters and non-adopters is misleading and does not tell the true impact of adoption. The predicted rice yields for the observed and the counterfactuals were used to estimate average treatment effect for the treated (ATT) and average treatment effects for the untreated (ATU). The t-test was used to test whether or not there is significant difference between the observed and counterfactual mean rice yields and the results presented in table 8.5. Note that ATT is the difference between the mean values of actual rice yield obtained by adopters of a given technology package and the mean rice yield that they would have obtained if they had decided not to adopt the said technology package. On the other hand, ATU is the mean difference between the actual rice yield of non-adopters and the yield they would have obtained if they had adopted the technology package.

From table 8.5, ATT and ATU for all the technology adoption package are significant. All the directions of the impacts of technology adoption packages on rice yield confirmed the *a priori* expectations and economic theory except ATU for non-adopters of *FISs*. There is general positive impact of adoption of any of the three technology packages on rice yield with the exception of counterfactual adoption decision of non-adopters of *FISs*. The ATT and ATU for *FISs* are 0.4404Mt/Ha (2.12bags/acre) and -2.2157Mt/Ha (-10.67bags/acre) respectively. This implies that adopters of *FISs* will be better off if they continue to adopt the technology holding other factors constant. What it means is that if adopters of *FISs* decided to be non-adopters they are going to lose rice yield of 0.4404Mt/Ha (2.12bags/acre). This suggests that there is a justification for adopters of *FISs* to maintain and even improve upon the adoption of *FISs*.

On the other hand, if non-adopters of *FISs* decide to adopt *FISs*, their rice yields will decrease from 3.0069Mt/Ha (14.49bags/acre) to 0.912Mt/Ha (4.39Mt/acre). This finding is against the *a priori* expectation.

Table 8.5 Treatment Effects of Impact of Technology Adoption on Rice Yield

Technology Adoption Package	**Sample**	**Adoption Decision**		**Treatment Effects**	**% Change in TE**	**Transitional Heterogeneity (ATT - ATU)**
		Adopting	**Not Adopting**			
I_1T_0	Adopters *FISs*	1.2754 (0.0507)	0.8349 (0.0153)	ATT = 0.4404*** (0.0471)	52.75	2.2157
	Non-Adopters of FISs	0.7912 (0.0308)	3.0069 (0.0405)	ATU = -2.2157*** (0.0208)	73.69	
I_0T_1	Adopters *IATs*	3.3862 (0.0432)	1.8532 (0.0530)	ATT = 1.5330*** (0.0866)	82.72	0.3401
	Non-Adopters of *IATs*	3.5246 (0.0355)	2.3317 (0.0290)	ATU = 1.1929*** (0.0161)	51.16	
I_1T_1	Adopters of *FISs* and *IATs*	5.7672 (0.1111)	0.9852 (0.0288)	ATT = 4.7820*** (0.1239)	485.38	3.6431
	Non-Adopters of *FISs* and *IATs*	3.7871 (0.0439)	2.6482 (0.0401)	ATU = 1.1389*** (0.0137)	43.01	

I_1T_0 =154, I_0T_1 = 365, I_1T_1=189, I_0T_0=199,
***, **, * represent 1%, 5%, and 10% significance level, respectively. Values in parentheses are standard errors

Source: Analysis from field data (2017)

Also, the estimated ATT and ATU values for adoption and non-adoption of *IATs* are 1.5330Mt/Ha and -1.1929Mt/Ha respectively suggesting that there is benefit in adopting *IATs*. If an adopter of *IATs* decides not to adopt, his or her rice yield is expected to decrease by 1.5330Mt/Ha (7.39bags per acre). Conversely, if non-adopters of *IATs* decided to adopt, their rice yield will increase by 1.1929Mt/Ha (5.75bags/acre). Row planting is one of the *IATs*. The positive impact of *IATs* on rice yield is a confirmation of the empirical studies conducted by Donkor *et al*. (2016), who found that row planting improves rice productivity. A study by Wiredu *et al.* (2010) observed that the adoption of New Rice for Africa (NERICA) and National Agricultural Research Stations (NARS) rice varieties which are *IATs* increases rice yield by 0.024Mt/Ha in Ghana. Furthermore, the findings by Kijima *et al.* (2008) that improved crop variety increases rice yield are confirmed in this study, since improved rice yield is associated with the adoption. A similar finding was made by Awotide *et al.* (2012).

From the t-test results in table 8.5, adopters of both *IATs* and *FISs* would have significantly reduced rice yield from 5.7672Mt/Ha (27.80bags/acre) to 0.9852Mt/Ha (4.75bags/acre) if they had not jointly adopted both technologies. This implies if the adopters of both *FISs* and *IATs* had decided not to adopt, they would have lost rice yield of 4.7820Mt/Ha (23.05bags per acre). This quantity is colossal enough to motivate farmers to continue joint adoption of *FISs* and *IATs*. In the same vein, non-adopters of both *FISs* and *IATs* will obtain rice yield of 1.1389Mt/Ha (ATT=5.49bags/acre) more if they decided to adopt both technologies.

8.4 Summary

The econometric estimation of the impact of technology adoption packages on rice yield was done using multinomial endogenous switching regression models. This model was used to account for the possible occurrence of selection bias and disentangle the potential hidden self-selection biases affecting farmers' decisions to adopt any of the technology packages. The base category to which all adoption of *FISs*, adoption of *IATs* and joint adoption of *FISs* and *IATs* were compared with is non-adoption.

The adoption of *FISs* is positively determined by the number of advice farmers receive from FBOs, rice farming experience and distance from farming communities to input markets. Conversely, farmers who have well-co-ordinated and synergised the adoption of *IATs* have low probability of adopting *FISs* only. This implies that farmers who sequentially adopted all the technology units of *IATs'* package (from planting to harvesting) have low probability of adopting *FISs.* The cost that comes with co-ordinated adoption of *IATs* is high and hence farmers might not be ready to incur addition additional cost by adopting *FISs* which even gives lower yield.

This study has revealed that probability of adoption of *IATs* increases with number of extension visits, credit access, contract farming and closeness of the farmers to input markets as well as Accra. The results also show that farmers located in areas with high amount of rainfall, high amount of temperature and farmers who are closer to rice markets have low incentive of adopting *IATs*. Farmers located in CSZ have higher probability of adopting *IATs* than their counterparts living in other agro-ecological zones. Also, farmers who have higher probability of jointly adopting *FISs* and *IATs* are the older farmers and farmers who have access to input subsidy. They are ready to blend their innovations with improved technologies introduced by AEAs.

The results from this study made us understand that *FISs* and *IATs* have heterogeneous impact on rice yield. If non-adopters of *FISs* decide to adopt them, their rice yield will decrease by 2.2157Mt/Ha (10.68bags/acre). Conversely, if non-adopters of *IATs* decide to adopt *IATs*, their rice yield will increase by 1.1929Mt/Ha (5.57bags/acre). Also, joint adoption of *FISs* and *IATs* are better off in terms of rice yield as compared to the non-adoption option of both technologies.

CHAPTER NINE

GENDERED EFFECTS OF ALLOCATIVE EFFICIENCY IN RICE PRODUCTION

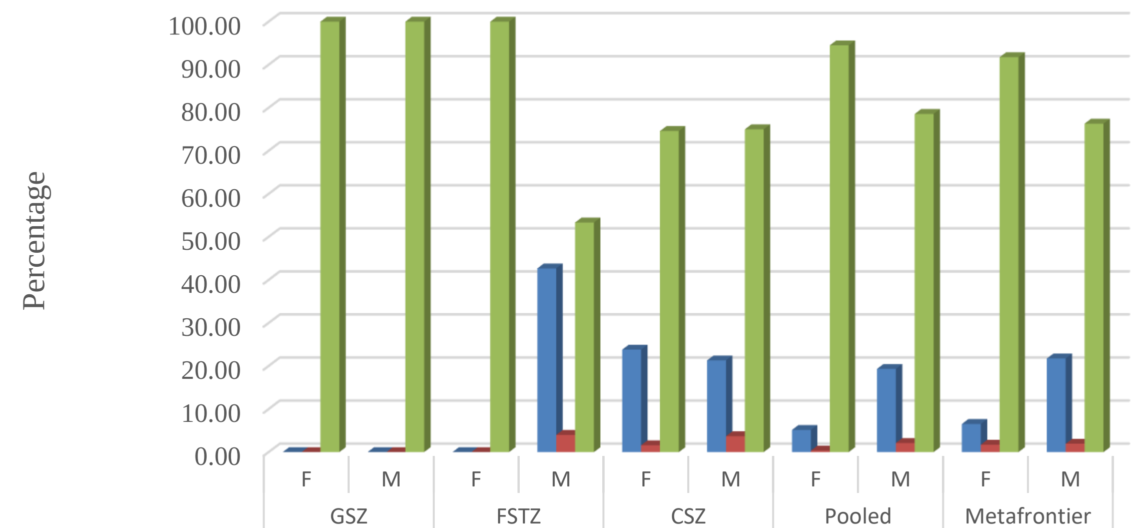
9.1 Introduction

This chapter assesses gender dimensions of allocative efficiency of factor inputs (labour, fertilizer, pesticides, seeds, land and capital) used in rice production. Allocative efficiency can be estimated using the economic and technical efficacies. To estimate economic efficiency, Stata econometric software (version 14.0) was used to run a dual new-two step stochastic metafrontier cost translog function (see appendix 12 and 13) and the economic efficiency scores predicted. The predicted economic efficiency scores (see appendix 14) cum the predicted technical efficiency scores obtained in chapter seven were used to estimate allocative efficiency scores. According to Farrel (1957), allocative efficiency is the ratio of economic efficiency to the technical efficiency scores.

9.2 Frequency Distribution of Allocative Efficiency

Figure 9.1 shows the frequency distribution of the allocative efficiencies of farmers in each of the agro-ecological zones. It is clear from the bar charts that none of the female farmers is input allocative efficient or over-utilizing factor inputs in GSZ and FSTZ, except CSZ. Most female farmers in GSZ and FSTZ use family or communal labour, cultivate rice on already developed lands of their husbands and hence the costs of production are low as compared to their counterparts in CSZ. On average, all the female farmers have under-utilised factor inputs in GSZ and FSTZ. Also, all the male farmers (283) have under-utilized factor inputs in GSZ. This suggests that farmers in GSZ pay less additional cost than the value of the additional input employed. Therefore, given input prices, farmers are under-utilising inputs. This is because, GSZ is a place where most farmers use family and communal labour, get a lot of agricultural interventions (input subsidy) from MoFA and NGOs. Some of the social support services that they get from government and NGOs are also channelled into the purchase of inputs. Owing to these interventions, farmers in GSZ are encouraged to employ more inputs to take advantage of the low cost of employing additional input.

In CSZ, out of 63 female farmers, 1.59% have the allocative efficiency scores of 1 implying they are allocatively efficient whilst 23.81% have allocative efficiency scores less than one meaning they over-used factor inputs (capital, labour, seeds, fertilizer, land and pesticides). Given factor prices, majority of the females (74.60%) have allocative efficiency scores greater than 1 suggesting they under-utilised factor inputs. The possible reasons why highest percentage of females under-utilised factor inputs are that they are good managers of resources and hence they are able to get the higher marginal value of the inputs used in rice production than the marginal cost of inputs. From figure 9.1, on average, the majority of the farmers have under-utilised factor inputs implying they are paying less additional cost of inputs than marginal value product.



	GSZ F	GSZ M	FSTZ F	FSTZ M	CSZ F	CSZ M	Pooled F	Pooled M	Metafrontier F	Metafrontier M
Over-utilization	0.00	0.00	0.00	42.67	23.81	21.30	5.15	19.32	6.53	21.75
Allocative efficient	0.00	0.00	0.00	4.00	1.59	3.70	0.34	2.11	1.72	1.95
Under-utilization	100.00	100.00	100.00	53.33	74.60	75.00	94.50	78.57	91.75	76.30

Figure 9.1 Frequency Distribution of Allocative Efficiency

Source: Analysis from field data (2017)

9.3 Gendered Effects of Allocative Efficiency

The average allocative efficiency is greater than one implying that rice farmers are not achieving cost minimizing combination of inputs. Cost minimising combination of inputs implies that farmers produce at a point where marginal cost of inputs equate marginal value product (allocative efficiency condition). Rice farmers do not on average choose optimal combination of inputs. This finding as explained by Farrell (1957) suggests that rice farmers are under investing in rice production (short-run period) and hence there is still more window for them to increase the level of input employed (Badunenko *et al.,* 2008). The under investment in rice production might be because of lack of financial support to expand production so as to take advantage of their ability to get higher marginal value from the factor inputs.

The statistical difference between the estimated allocative efficiency scores were tested using Welch t-test which is an appropriate test for unequal variance. From table 9.1, results from the Welch t-test showed that there is statistical significant difference between allocative efficiencies of female and male rice farmers across the agro-ecological zones except CSZ. The Welch t-test of GSZ and FSTZ recorded statistical significant levels of 1% and 5% respectively. The test confirmed the *a priori* expectations that, given factor prices, female rice farmers have higher input allocative efficiency than their male counterparts. For the pooled data, the test is 1% statistically significant confirming null hypothesis that with given prices of inputs, female rice farmers have higher input allocative efficiency than their counterpart male farmers. As noted earlier, females are good at managing resources and hence are able to efficiently use factor inputs that their male counterparts. When females had the opportunity to take part in farmer trainings, they take the skills acquired more seriously and thereby apply them to the latter than their male counterparts.

These findings confirmed the work of Davis *et al.* (2010) who found out in East Africa that females are ever ready to participate in farmer trainings just as males and when they do, they get higher productivity and incomes.

Table 9.1 Gendered Effects of Allocative Efficiency

Sex	Observation	Mean	Std. Error	P-Value
Guinea Savannah Zone				
Females	94	2.7017	0.3005	
Males	283	1.4152	0.0257	
Difference		1.2865***	0.3016	0.0000
$H_0 : \overline{AE}_F = \overline{AE}_M \quad H_A : \overline{AE}_F > \overline{AE}_M$				
Welch's degrees of freedom = 94.3951				
Forest Savannah Transition Zone				
Females	134	1.2804	0.0372	
Males	225	1.1725	0.0288	
Difference		0.1078**	0.0470	0.0113
$H_0 : \overline{AE}_F = \overline{AE}_M \quad H_A : \overline{AE}_F > \overline{AE}_M$				
Welch's degrees of freedom = 281.773				
Coastal Savannah Zone				
Females	63	1.1167	0.0450	
Males	108	1.0626	0.0149	
Difference		0.0541	0.0474	0.1287
$H_0 : \overline{AE}_F = \overline{AE}_M \quad H_A : \overline{AE}_F > \overline{AE}_M$				
Welch's degrees of freedom = 76.1986				
Pooled				
Females	291	1.7041	0.1067	
Males	616	1.2647	0.0170	
Difference		0.4393***	0.1081	0.0000
$H_0 : \overline{AE}_F = \overline{AE}_M \quad H_A : \overline{AE}_F > \overline{AE}_M$				
Welch's degrees of freedom = 303.946				
Metafrontier				
Females	291	1.4199	0.0458	
Males	616	1.2148	0.0153	
Difference		0.2052***	0.0483	0.0000
$H_0 : \overline{AE}_F = \overline{AE}_M \quad H_A : \overline{AE}_F > \overline{AE}_M$				
Welch's degrees of freedom = 356.988				

Source: Analysis from the field (2017)

As noted by Isik and Hassan (2001), allocative efficiency is the ability of a firm to choose proper input mix. Therefore, per the findings of this study, given factor cost, female farmers are better in managing and combining factor inputs for rice production. The finding of this study that female rice farmers have higher allocative efficiency than their male counterpart is contrary to the findings of Sena (2011). In a similar study, Sena (2011) observed that male NERICA rice farmers are more efficient in the combination of inputs given their respective prices than female NERICA rice farmers in the Volta Region (part of FSTZ). The current findings can be attributed to the fact that female rice farmers make sure that they reap maximum benefit from any factor inputs that they employ more than their counterpart male farmers. Female farmers are better in managing resources as compared to their male counterparts who can divert factors inputs (fertilizer, pesticides) from rice farms to other crops or sell the inputs and use the money for different thing.

9.4 Relative Percentage Change Necessary for Efficient Allocation of Inputs

Table 9.2 shows the relative percentage change necessary for efficient allocation of factor inputs. From the table, on average and given input prices, all categories of rice farmers (both males and females) in each of the agro-ecological zones and Ghana at large need to increase the usage of factor inputs to achieve he input minimizing cost condition. Since female rice farmers in GSZ are the category of farmers who spent lowest amount of money in employing factor inputs, they are expected to increase the usage of factor inputs by 170.20%. This is followed by their counterpart male farmers who are expected to increase the usage of factor inputs by 41.51%.

In the same vein, female and male rice farmers in FSTZ can achieve optimal rice production level by increasing the usage of factor inputs by 28.03% and 17.27% respectively. Not only that but also, it is prudent for female and male farmers in CSZ to increase the usage of factor inputs by 11.74% and 6.30% respectively to achieve efficient resource allocation condition. In a nut shell, male farmers in CSZ have the lowest level of percentage of inputs they must increase to reach the cost minimizing level. The findings of this research follow the national trend in the cost of producing rice (as one moves from the south to the north, price of factor inputs used in rice farming especially labour and land decreases).

Table 9.2 Relative Percentage Change Necessary for Efficient Allocation of Inputs

	Relative Percentage Change Necessary for Efficient Allocation of Inputs		
Agro-ecological zones	**Female**	**Male**	**Pooled**
Guinea savannah zone	-170.2011	-41.5100	-105.8556
Forest savannah transition zone	-28.0304	-17.2678	-22.6491
Coastal savannah zone	-11.7398	-6.3024	-9.0211
Pooled	-69.9904	-21.6934	-45.8419

Source: Analysis from field data (2017)

9.5 Summary

Resource allocative efficiency as noted by Badunenko (2008) has important implications for firms. However, allocative efficiency which looks at the cost minimisation condition of firms is rarely researched into due to the difficulties in getting input prices. The gender dimension of the findings of this research suggest that female rice farmers appear to use less of the factor inputs given factor prices than their male counterparts. Relatively, female farmers are better at utilising all factor inputs given the prices. Due to the relatively small farm size of rice cultivated by females, they are able to choose proper input mix given the available price.

As one moves from the south to the north, one needs to increase the usage of factor inputs more as this is evidenced from the increasing allocative efficiencies. The relatively high allocative efficiency recorded in the GSZ might be the low cost of factors of production in the area.

CHAPTER TEN

SUMMARY, CONCLUSIONS AND POLICY RECOMMENDATIONS

10.1 Introduction
This is the concluding chapter of the study. The chapter presents the summary, key findings, conclusions and the policy recommendations.

10.2 Summary
Rice production in Ghana is spread across the country but the main agro-ecological areas were rice are produced much are GSZ, FSTZ and CSZ. Rice production supports both the rural economy and the national economy. Ghana spends significant amount of foreign exchange on rice imports. Over the years, rice production has increased but the actual rice yields in Ghana are still below the potential level. Also, rice yields among agro-ecological zones are heterogenous. Farmers, researchers and policy makers are making frantic efforts not to only bridge the gap between the agro-ecological zones but to close the import and domestic production gap. To deal with this, researchers, NGOs and policy makers are playing diverse role in promoting *IATs*. Some of the farmers have also modified these *IATs* and *IFPs* through their own innovativeness form *FISs*.

In order to come out with evidence-based policy directions, this study analyses rice productivity heterogeneity among agro-ecological zones and policy implications for the adoption of *FISs* and *IATs* to enhance yield in Ghana.

Key empirical models and methodologies were used to estimate key socio-economic and ecological factors which influence rice output. These include principal component analysis, Welch t-test, Kendall's Coefficient of Concordance, the new-two step stochastic metafrontier model, the generalised linear model, multinomial endogenous switching regression and the dual new-two step stochastic cost metafrontier model. The study used both primary and secondary data. The findings of theses analyses are presented in section 10.3 below

10.3 Key Findings of the Study
From the study, farmers were classified as non-adopters, adopters of *FISs*, adopters of *IATs* as well as adopters of both. The most adopted technology typology in Ghana is *IATs*. Adopters of *IATs* have the highest rice yield whereas non-adopters (users of *IFPs*) have the lowest rice yield. From the results, farmers adopt *FISs* because of the low cost of production whereas adoption of *IATs* is principally based on high yield.

Rice production in Ghana exhibits increasing returns to scale. All the factors of production namely fertilizer, pesticides, labour, seed, farm size and capital significantly determine rice output. Fertilizer and farm size are the only inputs that significantly determine rice output in all the three agro-ecological zones as well as metafrontier model.

In general, the factors which significantly influence technical efficiency of farmers are age, sex, household size, education years, number of extension visits, contract farming, access to improved seeds, access to irrigation, perceived low rainfall amount, lodging of rice, type of technology adopted and the coordinated or consistent adoption of the technologies. Farmers in CSZ (Greater Accra Region) are more technically efficient in rice production than their counterparts in the other two agro-ecological zones. This could be due to the fact that access to technology are closer to Accra and distance to market being is shorter.

While farmers in GSZ have the highest TGR, they have the lowest potential of increasing rice output. The determining factors of TGR are contract farming, access to irrigation facilities, good condition of road from district capital to farming communities, nearness of rice farm to the farmers' houses, non-lodging of rice, high actual mean annual rainfall amount within the district, adoption of *IATs* and adoption of *FISs*.

The adoption of *FISs* is positively determined by the number of advice farmers receive from FBOs, rice farming experience and distance from farming communities to input markets. Conversely, farmers who have well-co-ordinated and consistent adoption of *IATs* have low probability of adopting *FISs* only.

This study established that probability of adoption of *IATs* increases with number of extension visits, credit access, contract farming and closeness of the farmers to input markets as well as Accra. On the other hand, farmers located in areas with high amount of rainfall, high amount of temperature and closer to rice markets have low incentive of adopting *IATs*. Farmers located in CSZ have higher probability of adopting *IATs* than their counterparts living in other agro-ecological zones. Also, farmers who have higher probability of jointly adopting *FISs* and *IATs* are the older farmers and farmers who have access to input subsidy.

Additionally, adopters of *IATs* are better off if they continue to adopt *IATs* than otherwise. This is because the treatment effect of *IATs* on the treated and untreated are 1.53Mt/Ha and 1.19Mt/Ha respectively. On the other hand, non-adopters of *FISs* are better off staying in their comfort zone than deciding to adopt *FISs*. This is because if non-adopters of *FISs* decide to adopt, their rice yield will reduce from 3.0Mt/Ha to 0.8Mt/Ha. It should be noted that the findings of the impacts of technology adoption typology on metafrontier technical efficiency are similar to the findings of the impact of technology adoption typology on rice yield. Gender has effect on allocative efficiency. Female farmers have higher allocative efficiency than their counterpart male farmers.

10.4 Conclusions

This study analyses rice productivity heterogeneity and policy implications for *FISs* and *IATs* in Ghana. The study has shown that rice farmers are typological grouped into users of *IFPs* (non-adopters) (I_0T_0), adopters of *FISs* (I_1T_0), adopters of *IATs* (I_0T_1) and adopters of both *FISs* and *IATs* (I_1T_1). Farmers in CSZ have the highest rice yield because of the high rate of adoption of *IATs* and contract farming. It can be deduced from the findings that while adoption of *IATs* has the highest impact on rice yield, a joint adoption of *FISs* and *IATs* also provide significant impact on rice yield than sole adoption of *FISs*. Adoption of *FISs* and *IATs* are based on cost of production and yield.

With all returns to scale values greater than 1, rice producers in each of the agro-ecological zones and Ghana at large operate at increasing returns to scale, which implies that inputs are jointly underutilized. Meanwhile, individually, farmers overcrowd rice plants due to the common broadcasting method of seeding. It can be concluded from the study that while labour is an important input that increases rice output in FSTZ and CSZ, capital is a key input that propel the increase in rice output in GSZ and Ghana at large. Technical inefficiency is evident among rice producers in Ghana. For intra-group comparison, rice farmers in CSZ are the most technically efficient. On the other hand, rice farmers in GSZ have the highest metafrontier technical efficiency.

The study concludes that in all the agro-ecological zones, good infrastructure, favorable environmental conditions, favourable government and NGO policy supports systems and policies as well as *IATs* and farmer innovations improve rice productivity performances of farmers in Ghana. The adoption of superior technology package thus *IATs* is the best technology option in all the three agro-ecological zones. In terms of gender, female farmers are better at utilising all factor inputs in all the agro-ecological zones than their male counterparts except in CSZ. Due to the relatively small farm size of rice cultivated by females, they are able to choose proper input mix given the available price.

10.5 Policy Implications and Recommendations

This study provided empirical evidence that rice farmers especially those in GSZ still continue to use *IFPs* which stifle their ability to increase rice yield. Given that *IATs* have the highest impact on rice yield, group specific technical efficiency and metafrontier technical efficiency, stakeholders (i.e. the government, through MoFA, development partners and individual private companies) should not only seek to promote the adoption of *IATs* but also, they should educate farmers on how to coordinate and synergise the adoption of the whole package. The designed policy for the promotion of this superior technology should be intensified and farmer targeted in the whole country, especially GSZ, considering the high percentage of non-adopters of the superior technology package. In the short term, private rice processing companies, rice marketing companies, financial institutions etc. should engage farmers in contract farming to help them get access to improved farming inputs which in effect will enhance their productivity performances. Agricultural extension agents should also intensify the extension activities to farmers by advising them on good agronomic practices in rice production. It is important to note that all these efforts should incorporate the needs of farmers in the respective agro-ecological zones but not just a holistic approach.

The long-term policy for government and NGOs are that good road infrastructure and construction of irrigation facilities should be pursued to the latter so as to enhance farmers' potential to increase rice productivity closer to potential level in Ghana. Another long term policy intervention is that concerted and co-ordinated efforts should be made for researchers in national agricultural research institutions (e.g. Savannah Agricultural Research Institute and Crop Research Institute) and academic agricultural research centres (agricultural research centres in the various universities) to vigorously research into rice production *FISs and* improve upon them and make them available to farmers.

It is recommended for female rice farmers to increase the usage of factor inputs to take advantage of relatively low input mix cost and their skills in managing cost of production. This can be effectively done through female targeted credit support system, input subsidy, land allocation among by government, NGOs and development partners.

10.6 Unique Contributions of the Study

This study is holistic and comprehensive in nature, it tries to ascertain the factors promoting rice productivity heterogeneity in Ghana and prescribes policy recommendations for the adoption of *FISs* and *IATs* to bridge the gap between actual and potential yields. The study is unique in the sense that, it used PCA to typologically classify rice production technologies in Ghana. Also, by adapting the new two-step metafrontier model proposed by Huang *et al* (2014) and Battese's (1997) model for estimating production function with some explanatory variables having zero observations, the study is unique in Ghana, and Africa in general to the best of the researcher's knowledge.

Another area of uniqueness of this study is the use of GLM to empirically model the drivers of TGR which have always been estimated using the ordinary least squares (OLS) (with its attendant biases). The study also included farmer perceptions in the determinants of efficiency and productivity which is uncommon in may studies, again to the best of the researcher's knowledge.

10.7 Suggestions for Future Research

While this study analyses rice productivity heterogeneity and policy implications for *FISs* and *IATs* in Ghana, it fell short of the analysis of the marketing efficiency of local rice. Meanwhile, a comprehensive analysis of the production and marketing efficiency of rice in Ghana is needed for government and development agencies to implement policies that can be holistic in dealing with the inefficiencies in the local rice industry. It is therefore suggested that further studies should be carried out on marketing efficiency of local rice in Ghana.

Also, a critical examination of rice yield over time shows that yield for some of the years are much high than others. It is important for researchers to examine productivity performances especially the use of stochastic frontier to examine the inefficiencies in rice production over the years in Ghana. With information on the causes of inefficiencies in rice production over the past years, policy recommendations can be suggested for government and development partners to implement so as to enhance future productivity performances of rice farmers in the country. Lastly, it is suggested that researchers should investigate the factors influencing gender dichotomy of allocative efficiency in rice production.

REFERENCES

Abdulai, A. and Huffman, W. E. (2000). Structural adjustment and efficiency of rice farmers in Northern Ghana. *Economic Development and Cultural Change,* 48(3): 503-521.

Abdulai, A. and Huffman, W. E. (2014). Adoption and impact of soil and water conservation technology: an endogenous switching regression application. *Land Economics,* 90: 26-43.

Abdulai, S., Nkegbe, P. K. and Donkoh, S. A. (2013). Technical efficiency of maize production in Northern Ghana. *African Journal of Agricultural Research*, 8(43): 5251-5259, doi: 10.5897/AJAR2013.7753.

Adato, M. and Meinzen-Dick, R. (2007). Agricultural research, livelihood and poverty: studies of the economic and social impacts in six countries. Baltimore: Johns Hopkins University Press.

Agbanyo, A. D. A. (2012). Rice production and marketing: a comparative study of Weta (Afife) and Avatime traditional areas. Thesis Submitted to the University of Ghana, Legon in partial fulfilment of the requirement for the award of MPhil Degree in African Studies.

Ahmad, M. and Bravo-Ureta, B. (1996). Technical efficiency measures for dairy farms using panel data: a comparison of alternative model specifications. *Journal of Prod. Analysis,* 7: 399-416.

Aigner, D., Lovell, C. A. K. and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models, *Journal of Econometrics,* 6: 21-37.

Akongo, G. O., Gombya-Ssembajjwe, W., Buyinza, M. and Bua, A. (2016). Effects of climate and conflict on technical efficiency of rice production, Northern Uganda. *Journal of Economics and Sustainable Development,* 7(11): 126-136.

Akpalu, W. and Normanyo, A. K. (2012). Illegal fishing and catch potentials among small scale fishers: application of endogenous switching regression model. Center for Environmental Economics Research and Consultancy (CEERAC), *CEERAC Working Papers No. 001*.

Al-hassan, S. (2012). Technical efficiency in smallholder paddy farms in Ghana: an analysis based on different farming systems and gender. *Journal of Economics and Sustainable Development,* 3 (5): 91-106

Al-hassan, S. (2008). Technical efficiency of rice farmers in Northern Ghana. The African Economic Research Consortium, Research Paper 178, Nairobi, Kenya

Altieri, M.A. (1995). *Agroecology: The Science of Sustainable Agriculture,* Westview Press, Boulder.

Angelucci F., Asante-Poku A. and Anaadumba P., (2013). Analysis of incentives and disincentives for rice in Ghana. Technical notes series, MAFAP, FAO, Rome.

Ansah, I. G. K. and Tetteh, B. K. D. (2015). Determinants of yam postharvest management in the Zabzugu District of Northern Ghana. *Advances in Agriculture*. 2016: 1-9. doi: 10.1155/2016/9274017.

Asravor, J., Onumah, E. E., Wiredu, A. N. and Siddig, K. (2015). Rice productivity and technical efficiency: a meta-frontier analysis of rice farms in Northern Ghana. Conference on International Research on Food Security, Natural Resource Management and Rural Development organized by the Humboldt-Universität zu Berlin and the Leibniz Centre for Agricultural Landscape Research (ZALF), September 16-18, 2015; Tropentag 2015, Berlin, Germany

Asuming-Brempong, S., Gyasi, K. O., Marfo, K. A., Diagne, A., Wiredu, A. N., Asuming-Boakye, A., Haleegoah, J. and Frimpong, B. N. (2011). The exposure and adoption of New Rice for Africa (NERICAs) among Ghanaian rice farmers: What is the evidence? *African Journal of Agricultural Research*, 6(27): 5911-5917, DOI: 10.5897/AJAR11.882

Awotide, A. B., Diagne, A. and Omonona, T. B. (2012). Impact of improved agricultural technology adoption on sustainable rice productivity and rural farmers' welfare in Nigeria: A Local Average Treatment Effect (LATE) technique. A Paper presented at the African Economic Conference, Kigali, Rwanda, October 30- November 2, 2012.

Badunenko, O., Fritsch, M. and Stephan, A. (2008). Allocative efficiency measurement revisited. Do we really need input prices? *Economic Modelling* 25(2008): 1093-1109. doi:10.1016/j.econmod.2008.02.001

Banker, R. D., Charnes, R. R. and Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 30: 1078-1092

Barnes, A. and Revoredo-Giha, C. (2011). A metafrontier analysis of technical efficiency of selected European Agricultures. Paper prepared for presentation at the EAAE 2011 Congress on Change and Uncertainty, Challenges for Agriculture, Food and Natural Resources, ETH Zurich, Zurich, Switzerland, August 30 to September 2, 2011.

Battese, G. E. (1997). A note on the estimation of Cobb-Douglas production functions when some explanatory variables have zero values. *Journal of Agricultural Economics*, 48(2): 250-252.

Battese, G. E. and Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2): 325-332.

Battese, G. E. and Rao, D. S. P. (2002). Technology gap, efficiency, and a stochastic metafrontier function. *International Journal of Business and Economics*, 1: 87-93.

Battese, G. E., Rao, D. S. P. and O'Donnell, C. J. (2004). A metafrontier production function for estimation of technical efficiencies and technology potentials for firms operating under different technologies. *Journal of Productivity Analysis*, 21: 91-103

Biggs, S. D. (1981). Sources of innovation in agricultural technology. *World Development,* 9: 321-336.

Binam, J. N., Gockowski, J. and Nkamleu, G. B. (2008). Technical efficiency and productivity potential of cocoa farmers in West African countries. International Institute of Tropical Agriculture. The Sustainable Tree Crops Program (STCP) Working Paper Series, Issue 7. (Version: February 2008)

Blein, R., Bwalya, M., Chimatiro, S., Faivre-Dupaigre, S., Kisira, S., Leturque, H., Wambo-Yamdjeu, A. (2013). African agriculture, transformation and outlook. New Partnership for African Development (NEPAD).

Bloom, A., Duffy, C., Iyer M., Jacobs-Smith A., and Moy, L., (2009). *Transnational Corporations and the Right to Food.* www.chrgj.org/publications/docs/TNCsandR.TF.pdf. Accessed 08, July, 2016.

Boansi, D. and Favour, R. M. (2015). Why the persistent increase in Ghana's Rice imports? Prescriptions for future rice policy. *Asian Journal of Agricultural Extension, Economics & Sociology,* 7(4): 1-21, SCIENCEDOMAIN *international,* www.sciencedomain.org

Bobko, P., Roth, P. L., and Buster, M. A. (2007). The usefulness of unit weights in creating composite scores a literature review, application to content validity, and meta-analysis. Organizational Research Methods. *SAGE,* 10(4): 689-709.

Booysen, F., van der Berg, S., Burger, R., von Maltitz, M. and du Rand, G. (2008). Using an asset index to assess trends in poverty in seven sub-saharan African countries, *World Development*, 36(6): 1113-1130.

Boshrabadi, H. M., Villano, R. and Fleming, E. (2008). Technical efficiency and environmental technological gaps in wheat production in Kerman province of Iran, *Agricultural Economics,* 38: 67-76.

Bravo-ureta, B. E. and Pinheiro, A. E. (1993). Efficiency analysis of developing country agriculture: a review of the frontier function literature. Department of Agricultural and Resource Economics, University of Connecticut, Storrs, CT.

Brockhoff, K. (1970). On the qualification of the marginal productivity of industrial research by estimating a production function for a single firm. *Germany Economic Review*, 8: 202 – 229.

Brown, M. (1966). *On the Theory and Measurement of Technological Change*, Cambridge University Press.

Buckland, J. (2004). *Neoliberalism, Modern Technology and the State of the World's Farmers*. Fernwood Publishing, Zed Books.

Chambers, R., Pacey, A. and Thrupp, L. A. (1989). Farmers first: farmer innovation and agricultural research. Intermediate Technology Publications, London, pp. 218.

Charnes, A., Cooper, W. W. and Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operation Research*, 2: 429-44.

Chen, C-M., Tzu-Chun, Sheng, T-C., and Yang, Y-L. (2014). Cost efficiency analysis of Taiwan biotech and pharmaceutical industry: The application of stochastic meta frontier model. *International Journal of Economics and Finance*, 6(11): 1916-9728, URL: http://dx.doi.org/10.5539/ijef.v6n11p131

Coalition for African Rice Development (CARD) (2010). Mapping of Poverty Reduction Strategy Papers (PRSPs), Sector Strategies and Policies related to rice development in Ghana.

Coelli, T. J. (1995). Estimators and hypothesis tests for a stochastic frontier function: a Monte Carlo analysis. *Journal of Productivity Analysis,* 6: 247-268.

Coelli, T. J., Prasada, R. and Battese, G. E. (1998). An introduction to efficiency and productivity analysis. Kluwer Academic Publishers. Boston. http://dx.doi.org/10.1007/978-1-4615-5493-6.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. and Battese, G. E. (2005). An introduction to efficiency and productivity analysis, 2nd ed., Springer, New York, NY.

Conen, F., Smith, K. A. and Yagi, K. (2010). Rice cultivation. In D. Reay, P. Smith, and A. van Amstel, eds. *Methane and Climate Change*. London, UK: Earthscan Publications, p. 261.

Cook, W. D., Tone, K. and Zhu, J. (2014). Data Envelopment Analysis: Prior to Choosing a Model, OMEGA, 44: 1-4

Davis, F. D., Bagozzi, R. and Warshaw, P. (1989), User acceptance of computer technology: A comparison of two theoretical models, *Management Science*, 35(8): 982-1003.

Davis, K., Nkonya, E., Kato, E., Mekonnen, D. A., Odendo, M., Mirro, R. and Nkuba, J. (2010). Ipact of farmer field school on agricultural productivity and poverty in East Africa. International Food Policy Research Institute (FPRI) Discussion Paper 992. Washington DC.

Dawson, P. J., Lingard, J. and Woodford, C. H. (1991). A generalized measure of farm-specific technical efficiency. *American Journal of Agricultural Economics*, 73(4): 1099-104.

Debreu, G. (1951). The coefficient of resource utilization. *Econometrica* 19(3): 273-292.

Del Gatto, M., Di Liberto, A. and Petraglia, C. (2011). Measuring Productivity. *Journal of Economic Surveys*. 25 (5): 952-1008. DOI: 10.1111/j.1467-6419.2009.00620.x.

Di Falco, S. (2014). Adaptation to climate change in Sub-Saharan agriculture: assessing the evidence and rethinking the drivers. *European Review of Agricultural Economics.* 41(3): 405-430. doi:10.1093/erae/jbu014.

Di Falco, S. and Veronesi, M. (2013). How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia. *Land Economics*, 89:743-766.

Diagne, A. and Demont, M. (2007). Taking a new look at empirical model of adoption: average treatment effect estimation of adoption rates and their determinants. *Agricultural Economics,* 37:201-221.

Diako, C., Sakyi-Dawson, E., Bediako-Amoa, B., Saalia, F. K. and Manful, J.T. (2010). Consumer perceptions, knowledge and preferences for aromatic rice types in Ghana. *Nature and Science*, 8(12)

Diao, X., Hazell, P., Resnick, D. and Thurlow, J. (2007). The role of agriculture in development: *Implications for Sub-Saharan Africa.* International Food Policy Research (IPRI), Washington, D.C., doi: 10.2499/9780896291614RR153.

Dong, F., Mitchel, D. P. and Colquhoun, J. (2015). Measuring farm sustainability using data envelope analysis with principal components: The case of Wisconsin cranberry. *Journal of Environmental Management*, Elsevier, 147(2015): 175-183

Donkoh, A. S. and Awuni, A. J. (2011). Adoption of farm management practices in lowland rice production in Northern Ghana. *Journal of Agriculture and Bilogical Sciences*, 2(6): 183-192.

Donkor, E. and Owusu, V. (2014). Effects of land tenure systems on resource-use productivity and

efficiency in Ghana's rice industry. *African Journal of Agricultural and Resource Economics,* 9(4): 286-299.

Donkor, E., Owusu-Sekyere, E., Owusu, V. and Jordaan, H. (2016). Impact of row-planting adoption on productivity of rice farming in Northern Ghana. *Review of Agricultural and Applied Economics*, 19(2): 19-28. doi: 10.15414/raae.2016.19.02.19-28

Doss, C. R. and Morris, M. L. (2001). How does gender affect the adption of agricultural innovations? The case of improved maize technology in Ghana. *Agricultural Economics*, 25 (2001): 27-39

Dowling, E. T. (2012). *Introduction to Mathematical Economics*, Third Edition, McGraw-Hill Companies. New York.

Dubin, J. and McFadden, D. (1984). An econometric analysis of residential electric appliance holdings and consumption. *Econometrica.* 52: 345-362.

Duong, T. and Duong, V. (2008). Non-negative sparse principal component analysis for multidimensional constrained optimization. In: Ho, T.-B., Zhou, Z.-H. (Eds.), Lecture Notes in Artificial Intelligence, Springer-Verlag, Berlin, 5351: 103-114.

Food and Agriculture Organisation (FAO) (2012). Agricultural productivity growth and bridging the gap for small-family farms, Food and Agricultural Organisation. *Interagency Report to the Mexican G20 Presidency.*

FAO (2006). Briefs on import surges-countries. No. 5, Ghana: rice, poultry and tomato paste.

Fare, R. and Primont, D. (1995). Multi-output production and duality: theory and applications, Kluwer Academic Publishers, Boston.

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A. General* 120(3): 253-290.

Feder, G., Just, R. J. and Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A Survey. *Economic Development and Cultural Change,* 33(2): 255-98.

Fermont, A. and Benson, T. (2011). Estimating Yield of Food Crops grown by Smallholder Farmers. A Review in the Uganda Context. *International Food Policy Research Institute (IFPRI)*. Discussion Paper 01097.

Ferrari, S. L. and Cribari-Neto, F. (2004). Beta regression for modelling rates and proportions. *Journal of Applied Statistics*, 31(7): 799-815.

Filmer, D. and Pritchett, L. H. (2001). Estimating wealth effects without expenditure data or tears: an application to educational enrollments in states of India. *Demography,* 38(1): 115-132.

Frisvold, G. B., and Lomax, E. (1991). Differences in agricultural research and productivity among 26 countries, U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report Number 644.

Fuglie, K. O. and Bosch, D. J. (1995). Economic and environmental implications of soil nitrogen testing: A switching-regression analysis. *American Journal of Agricultural Economics.* 77: 891-900.

Ghana Statistical Service (GSS) (2014). Ghana Living Standards Survey Round 6 (GLSS 6), Main Report, Ghana Statistical Service, Accra

Ghana Statistical Service, GSS (2013).2010 Population and Housing Census. Analytical Report, Volta Region. GSS, Accra

Ghana Statistical Service, GSS (2012). 2010 Population and Housing Census. Summary Report of Final Results. GSS, Accra.

Gilbert, E. H., Norman, D. W. and Winch, F. E. (1980). Farming Systems Research: A Critical Appraisal. MSU Rural Development Paper No. 6; Department of Agricultural Economics, Michigan State University, East Lansing, Michigan, USA.

Greene, W. H. (2008). *Econometric Analysis*. Prentice Hall, Englewood Cliffs.

Grigoriou, C., Guillaumont, P. and Yang, W. (2005). Child mortality under Chinese reforms. *China Economic Review,* 16: 441-464

Han, H. (2010). Nonnegative principal component analysis for mass spectral serum profiles and biomarker discovery. BMC Bioinform. 11 (Suppl. 1), S1.

Hayami, Y. (1969). Sources of agricultural productivity gap among selected countries. *American Journal of Agricultural Economics*, 51, 564-575.

Hayami, Y. and Ruttan V. W. (1971), Agricultural development: An international perspective, Baltimore, Johns Hopkins University Press.

Hayami, Y. and Ruttan V. W. (1970), Agricultural productivity differences among Countries. *American Economic Review*, 60: 895-911.

Hazell, P. and Bernstein, J. (2013). Feed the Future Learning Agenda Literature Review: Improved Agricultural Productivity, Rockville, MD: Westat

Heckman, J., Ichimura, H., Smith, J. and Todd, P. (1998). Characterizing selection bias using experimental data. Econometrica 66 (5): 1017-1098.

Horna, D., Smale M., Al-Hassan, Falck-Zepeda, R., J., and Timpo, S. E. (2008). Insecticides use on vegetables in Ghana: would GM seed benefit farmers? IFPRI Discussion Paper 007855.

Howe, L. D. and Hargreaves, J. R. (2008). Issues in the construction of wealth indices for the measurement of socio-economic position in low-income countries. *Emerg Themes Epidemiol* 5:3.

Huang, C. J., Huang, T-H. and Liu, N-H. (2014). A new approach to estimating the metafrontier production function based on a stochastic frontier framework. *Journal of Productivity Analysis*. 42: 241-254. doi: 10.1007/s11123-014-0402-2

Illukpitiya, P. (2005). Technical efficiency in agriculture and dependency on forest resources: An economic analysis of rural households and the conservation of natural forests in Sri Lanka. Economy and Environment Program for Southeast Asia, EEPSEA, Technical Report. Retrieved from: www.idrc.ca/en/ev-99958-201-1-Do-TOPIC.html.

Institute of Statistical, Social and Economic Research (ISSER) (2014). State of the Ghanaian economy. Institute of Statistical, Social and Economic Research, University of Ghana, Legon.

Isik, I. and Hassan, M. K. (2002). Technical, scale and allocative efficiencies of Turkish banking industry. *Journal of Banking & Finance.* 26(200): 719-766

Jolliffe, I. T. (2002). Principal Component Analysis, second ed. *Springer*, New York.

Kabunga, N. S., Dubois, T. and Qaim, M. (2011). Impact of tissue culture banana technology on farm household income and food security in Kenya. Courant Research Centre Discussion paper no. 8, Göttingen, Germany

Kaiser, H. F. (1968). A measure of the average intercorrelation. Educational and psychological measurement, 28: 245-247.

Kendall, M. G. (1939). The geographical distribution of crop productivity in England. *J. R. Stat. Soc.*, 21: 102.

Kiatpathomchai, S. (2008). Assessing Economic and Environmental Efficiency of Rice Production Systems in Southern Thailand: An Application of Data Envelopment Analysis. A thesis submitted for the degree of Doktor des Agrarwissenschaften (Dr. agr.) Faculty of Agricultural Sciences, Nutritional Sciences and Environmental Management, Justus-Liebig University Giessen.

Kijima, Y., Otsuka, K. and Sserunkuuma, D. (2008). Assessing the impact of NERICA on income and poverty in central and western Uganda. *Journal of Agricultural Economics*, 38: 327-337. doi: http://dx.doi.org/10.1111/j.1574-0862.2008.00303.x

Kijima, Y, Sserunkuuma, D. and Otsuka, K. (2006). How revolutionary is the "NERICA revolution"? Evidence from Uganda. *The Developing Economies,* XLIV-2: 252-267.

Koopmans, T. C., (1951). An analysis of production as an efficient combination of activities. In: Koopmans, T.C. (Ed.), Activity Analysis of Production and Allocation. *Wiley*, New York.

Kopp, R. J. and Smith. V. K. (1980). Frontier production function estimates for steam electric generation: A comparative analysis." *Southern Economic Journal 47: 1049-59.*

Kramol, P., Villano, R.., Fleming, E. and Kristiansen, P. (2010): Technical efficiency and technology gaps on 'clean and safe' vegetable farms in Northern Thailand: A comparison of different technologies. In: 54th Annual Conference of the Australian Agricultural and Resource Economics Society (AARES), Adelaide, South Australia, 8–12 February 2010.

Kudaligama, V. P. and Yanagida, J. F. (2000). A Comparison of Intercountry Agricultural Production Functions: A Frontier Function Approach, *Journal of Economic Development*, 25 (1).

Kumbhakar, S. C., and Lovell, C. A. K. (2000). *Stochastic Frontier Analysis*. New York, NY: Cambridge University Press.

Lokshin, M. and Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *Stata Journal,* 4: 282-289.

Lovell, C. A. K. (1993). Production Frontiers and Productive Efficiency. In Fried, H. O. and Schmidt, S. S. (eds) The Measurement of Productivity: Techniques and Applications. Oxford U.K.: 3-67

Mabe, F. N., Sarpong, D. B. and Osei-Asare, Y. (2014). Empirical evidence of climate change: effects on rice production in the Northern Region of Ghana*, British Journal of Economics, Management & Trade,* SCIENCEDOMAIN*,* 4(4): 551-562.

Macmillan Reference (2006). "Agriculture, Modern" from *Macmillan Science Library: Plant Sciences* Copyright, Macmillan Reference USA, An imprint of the Gale Group.

Maddala, G. S. (1983). Limited-dependent and qualitative variables in econometrics. Cambridge University Press.

Maggino, F., and Ruviglioni, E. (2011). Obtaining weights: from objective to subjective approaches in view of more participative methods in the construction of composite indicators. *Proceedings of new techniques and technologies for statistics.* Brussels, Belgium: Eurostat.

Mansur, E. T., Mendelsohn, R. and Morrison, W. (2008). Climate change adaptation: a study of fuel choice and consumption in the US energy sector. *Journal of Environmental Economics and Management*, 55:175–193.

Mariano, M. J., Villano, R., Fleming, F. and Acda, R. (2010). Metafrontier analysis of farm-level efficiencies and environmental-technology gaps in Philippine rice farming. Australian Agricultural and Resource Economics Society (AARES), 54th Annual Conference, 10-12 February 2010, Adelaide, Australia.

McFadden, D. (1973). Conditional logit analysis of qualitative choice behaviour; In: Zarembka, P. (Ed), Frontiers in Econometrics. Academic Press, New York.

Mckenzie, D. J. (2003). Measuring inequality with asset indicators. *Journal of Population Economics*, 18: 229-260.

Meeusen, W. and van den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review,* 18(2): 435-444.

Mendola, M. (2007). Farm household production theories: A review of institutional and behavioral response. *Asian Develop. Rev.,* 24: 49-68

Mensah, A. and Brümmer, B. (2016). Drivers of technical efficiency and technology gaps in

Ghana's mango production sector: A stochastic metafrontier approach. *African Journal of Agricultural and Resource Economics*. 11(2): 101-117

Michelsen, C. C. and Madlener, R. (2013). Homeowners' motivation to adopt residential heating system: a principal component analysis. Institute for Future Energy Consumer Needs and Behavior (FCN), FCN Working Paper No. 17, School of Business and Economics, RWTH Aachen University, Germany

Millennium Development Authority (MiDA) (2010). Investment opportunity in Ghana: maize, rice, and soybean. Accra, Ghana.

Miyamoto, K., Maruyama, A., Haneishi, Y., Matsumoto, S., Tsuboi, T., Asea, G., Okello, S., Takagaki, M. and Kikuchi, M. (2012). NERICA cultivation and its yield determinants: the case of upland rice farmers in Namulonge, Central Uganda. *Journal of Agricultural Science*, 4(6): 1916-9760.

MoFA (2015). Statistics, Research and Information Directorate (SRID), Ministry of Food and Agriculture, Accra, Ghana

MoFA (2014). 2013 Agric. Sector Annual Progress Report, Ministry of Food and Agriculture, Accra.

MoFA (2011). Facts and Figures for 2010, Statistics Research and Information Directorate (SRID), Ministry of Food and Agriculture (MoFA), Accra, Ghana.

MoFA (2010). Medium Term Agriculture Sector Investment Plan (METASIP), Ministry of Food and Agriculture (MoFA), Accra, Ghana

MoFA (2009). National Rice Development Strategy (NRDS). Accra, Ghana

MoFA (2007). Food and Agriculture Sector Development Policy (FASDEP II), Ministry of Food and Agriculture, Accra, Ghana

Mohammed, S., Egyir, S. I. and Amegashie, D. P.K. (2013). Social capital and access to credit by farmer based organizations in the Karaga District of Northern Ghana. *Journal of Economics and Sustainable Development*, www.iiste.org, 4(16): 146-155.

Moreira V. H. and Bravo-Ureta B. E. (2010). Technical efficiency and metatechnology ratios for dairy farms in three southern cone countries: a stochastic metafrontier model. *Journal of Productivity Analysis*, 33: 33–45.

Njeru, J. (2010). Factors influencing technical efficiencies among selected wheat farmers in Uasin Gishu District, Kenya. The African Economic Research Consortium, Research Paper 206, Nairobi, Kenya

Nkamleu, G. B., Nyemeck, J. and Gockowski, J. (2010). Technology gap and efficiency in cocoa production in West and Central Africa: implications for cocoa sector development. Working paper series, Africain Development Bank

Noltze, M., Schwarze, S. and Qaim, M. (2012). Farm diversity and heterogeneous impacts of system technologies on yield, income and poverty: the system of rice intensification in Timor Leste, Department of Agricultural Economics and Rural Development, Georg-August-University of Goettingen, *Selected Poster prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.*

O'Donnell, C. J, Rao, D. S. P. and Battese, G. E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios, Empirical Economics, Springer, 34:231–255: DOI 10.1007/s00181-007-0119-4

Ogundari, K. (2013). Crop diversification and technical efficiency in food crop production. *International Journal of Social Economics*. 40(3): 267-287.

Ogundari, K. and Awokuse, T. (2016). Land tenure and technical efficiency of rice farms in Thailand. Paper prepared for presentation at the "2016 World Bank Conference on Land and Poverty" The World Bank - Washington DC, March 14-18, 2016

Onumah, J. A., Onumah, E. E., Alhassan, R. M. and Brümmer, B. (2013). Meta-frontier analysis

of organic and conventional cocoa production in Ghana, *Agric. Econ. Czech*, 59(6): 271–280.

Papke, L. E. and Wooldridge, J. M. (1996). Econometric Methods for Fractional Response Variables with an Application to 401(K) Plan Participation Rates. *Journal of Applied Econometrics,* 11(6): 619-32.

Peterman, A., Behrman, J. and Quisumbing, A. (2010). A review of empirical evidence on gender differences in nonland agricultural inputs, technology and services in developing countries. International Food Policy Research Institute (FPRI) Discussion Paper 00975. Washington DC.

Prolinnova (2004). Proceeding of the First International PROLINNOVA Workshop, 8-12, March

2004, Yirgalem, Ethiopia. Addis Ababa: ASE/Silang, Philippines: International Institute of Rural Reconstruction

Pryce, G. and Mason, P. (2006). Controlling for transactions bias in regional house price indices. Working Paper as at 23 June 2006. Presented at the Conference in Honour of Patric Hendershott. (Columbus Ohio, July) Department of Urban Studies. University of Glasgow

Rahman, S. (2010). Women's labour contribution to productivity and efficiency in agriculture:

empirical evidence from Bangladesh. *Journal of Agricultural Economics*. 61: 318-342.

Richman, M. B. (1981). Obliquely rotated principal components: an improved meteorological map typing techniques? *Journal of Applied Meteorology*. 1145-1159.

Rivera, M. M. (2007). Practical and Guide to Thesis and Dissertation Writing (Revised Edition). Katha Publishing Inc.: Quezon City.

Rogers, E. M. (2003), *Diffusion of Innovations*, 5th Ed., New York: The Free Press.

Rogers, E. M. (1983). *Diffusion of Innovation* (Second ed.). New York: Free Press.

Rogers, E. M. (1962). *Diffusion of Innovations* (First ed.). London: The Free Press.

Rowhani, P., Lobell, D.B., Linderman, M., and Ramankutty, N. (2011). Climate variability and crop production in Tanzania. *Agricultural and Forest Meteorology*. 151 (2011): 449-460.

Sahin, I. (2006). Detailed Review of Rogers' Diffusion of Innovations Theory and Educational Technology-Related Studies Based on Rogers' Theory, *The Turkish Online Journal of Educational Technology (TOJET)*. 5(2)

Salter, W. E. G. (1960). *Productivity and Technical Change*, Cambridge University Press.

Schmidt, P. (1976). On the statistical estimation of parametric frontier production functions. *The Review of Economics and Statistics,* 58: 238-239.

Sena, A. (2011). Economic efficiency analyses of NERICA rice farms in the Volta Region of Ghana. Thesis Submitted to the University of Ghana, Legon in partial fulfilment of the requirement for the award of M.Phil. in Agricultural Economics.

Shiferaw, B., Kassie, M., Jaleta, M. and, Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia, *Food Policy,* 44(2014): 272-284

Smyth, R. (2004). Exploring the usefulness of a conceptual framework as a research tool: a researcher's reflections of Issues in educational research, 14, Online: http://education.curtin.edu.au/iier/iier14/smyth.html

Tabachnick, B. G. and Fidell, L. S. (2007). *Using Multivariate Statistics*, 5th ed., Upper Saddle River, NJ: Pearson Allyn and Bacon.

Tambo, J. A. (2013). Farmer Innovation in Rural Ghana Determinants, Impacts and Identification, Inaugural Ph.D Thesis, University of Bonn, Germany.

Tambo, J. A. and Wünscher, T. (2014). Building farmers' capacity for innovation generation: what are the determining factors? Center for Development Research (ZEF), University of Bonn

Teeken, B., Nuijten, E., Temudo, P. M., Okry, F., Mokuwa, A., Struik, C. P. and Richards, P. (2012). Maintaining or Abandoning African Rice: Lessons for Understanding Processes of Seed Innovation, *Hum Ecol*. Springer Science+Business Media, LLC. DOI: 10.1007/s10745-012-9528-x

Teklewold, H., Kassie, M., Shiferaw, B and Kohlin, G. (2013). Cropping System Diversification, Conservation tillage and modern seed adoption in Ethiopia: impacts on hosehold income, agrochemical use and demand for labour. *Ecological Economics, Elsevier*, 93(2013): 85-93.

Thiam, A., Bravo-Ureta, B. E. and Rivas T. (2001). Technical Efficiency in Developing CountryAgriculture: a meta-analysis. *Agricultural Economics*. 25: 235-243.

Tzouvelekas, V., Pantzios C. J. and Yotopoulos, C. (2001). Economic efficiency in organic farming: Evidence from cotton farms in Viotia, Greece. *Journal of Agricultural and Applied Economics*, 33: 35-48.

Umeh, C. J. (1990). An econometric choice for extension-teaching methods: the Ilorin and Oyo North Agricultural Development Projects' experience. *Agricultural Economics,* Elsevier Science Publishers B.V. 4: 229-238

Villano, R., Boshrabadi, H. M, and Fleming, E. (2010). When Is Metafrontier Analysis Appropriate? An Example of Varietal Differences in Pistachio Production in Iran. *Journal of Agricultural Science Technology*. Vol. 12: 379-389

Visco, E. S. (2006). Dynamics of conflict of cooperation of group stability among selected government-assisted cooperatives I region IV, Philippines. *International Journal of Social Sciences* 1: 222–232.

Vyas, S. and L. Kumaranayake (2006). Constructing socio-economic status indices: how to use principal components analysis. *Health Policy Plan* 21(6): 459-468.

Wagner, J. (2002). Unobserved Firm Heterogeneity and the Size – Exports Nexus: Evidence from German Panel Data, *HWWA Discussion Paper 194*, Hamburg Institute of International Economics.

Welch, B. L. (1947). "The generalization of "Student's" problem when several different population variances are involved". *Biometrika*. 34 (1–2): 28–35. *doi:10.1093/biomet/34.1-2.28*. *MR 19277*.

West Africa Rice Development Association (WARDA) (2009). NERICA: origin, nomenclature and identification characteristics. http://www.africarice.org/publications/nerica-comp/module2_Low.pdf. (Accessed 30/08/2015).

Williams, L. J., Abdi, H., French, R. and Orange, J. B. (2010). A tutorial on multi-block discriminant correspondence analysis (MUDICA): a new method for analyzing discourse data from clinical populations. *J Speech Lang Hear Res*. 53:1372-1393

Wills, O. (2012). Recognising the unrecognised: farmer innovation In Northern Malawi, A Report By Find Your Feet, United Kingdom.

Wiredu, A. N., Gyasi, K. O., Marfo, K. A., Asuming-Brempong, S., Haleegoah, J. Asuming-Boakye, A. and Nsiah, B. F. (2010). Impact of improved varieties on the yield of rice producing households in Ghana. *Second Africa Rice Congress*, Bamako, Mali, 22-26 March 2010: Innovation and Partnerships to Realize Africa's Rice Potential.

Wooldridge, J.M. (2005). Instrumental estimation of the average treatment effect in the correlated random coefficient model. Department of Economics, Michigan State University, Michigan.

World Bank (2011). *Agricultural Innovation Systems: An Investment Source Book.* Washington DC:

Ghana@www.mofa.gov.gh/site/?page_id=4626 (accessed: 29/09/2015)

APPENDICES

Appendix 1: Definitions and measurements of *IFPs*, *FISs* and *IATs*

Variables	Definition and Measurements
IFPs=P	
P_1	Use of previous years seed without selection (1 if yes and 0 otherwise)
P_2	Farmer-to-farmer seed exchange (1 if yes and 0 otherwise)
P_3	Purchasing of ordinary seed from market (1 if yes and 0 otherwise)
P_4	Slush and burn (1 if yes and 0 otherwise)
P_5	Haphazard cutting and turning of soil with hoe (1 if yes and 0 otherwise)
P_6	Broadcasting seed haphazardly (1 if yes and 0 otherwise)
P_7	Handpicking of weeds (1 if yes and 0 otherwise)
P_8	Use of hoe and cutlasses to control weeds (1 if yes and 0 otherwise)
P_9	Mixed cropping (1 if yes and 0 otherwise)
P_{10}	Use of scare crow to sack birds on the field (1 if yes and 0 otherwise)
P_{11}	Setting of trap to catch birds on the field (1 if yes and 0 otherwise)
P_{12}	Personal bird scaring through shouting, ringing of bell, use of catapult etc (1 if yes and 0 otherwise)
P_{13}	Use of knife to harvest rice (1 if yes and 0 otherwise)
P_{14}	Use of sickle/cuttlas to harvest rice (1 if yes and 0 otherwise)
P_{15}	Threshing by beating rice straw and paddy with sticks (1 if yes and 0 otherwise)
P_{16}	Threshing by beating rice straw and paddy with sticks (1 if yes and 0 otherwise)
FISs=I	
I_{17}	Selection of seed for next season from healthy and good plants (1 if yes and 0 otherwise)
I_{18}	Selection of fertile land, planting rice on it and using the rice from the plot as foundation seed (1 if yes and 0 otherwise)
I_{19}	Slash and leave crop residue to decompose (1 if yes and 0 otherwise)
I_{20}	Zero or minimal tillage (1 if yes and 0 otherwise)
I_{21}	Use of wood ash to speed-up germination (1 if yes and 0 otherwise)
I_{22}	Transplanting of seedlings with approximate spacing (1 if yes and 0 otherwise)
I_{23}	Broadcasting in rows with approximate spacing (1 if yes and 0 otherwise)
I_{24}	Dibbling/drilling with approximate spacing (1 if yes and 0 otherwise)
I_{25}	Mulching with plants parts to keep moisture (1 if yes and 0 otherwise)
I_{26}	Use of mulch to suffocate weeds (1 if yes and 0 otherwise)
I_{27}	Incorporation of rice straw into soil (1 if yes and 0 otherwise)
I_{28}	Colouring of rice seed to prevent identification by rodents or bird after seeding (1 if yes and 0 otherwise)
I_{29}	Use of cassette magnetic ribbon to scare birds (1 if yes and 0 otherwise)
I_{30}	Use of net to prevent birds from sucking nector (1 if yes and 0 otherwise)
I_{31}	Threshing by holding rice sheaves and thrashing against wooden or slated bamboo container (1 if yes and 0 otherwise)

Continuation of appendix 1: Definitions and measurements of *IFPs*, *FISs* and *IATs*

Variables	Definition and Measurements
IATs =T	
T_{32}	Rouging (1 if yes and 0 otherwise)
T_{33}	Use of certified seed (1 if yes and 0 otherwise)
T_{34}	Clear the land before plough and harrow with tractor (1 if yes and 0 otherwise)
T_{35}	Plough and harrow the land directly without clearing (1 if yes and 0 otherwise)
T_{36}	Rotovation of the land (*Tilling and crossing*) (1 if yes and 0 otherwise)
T_{37}	Puddling the field 3 to 4 days before seeding (1 if yes and 0 otherwise)
T_{38}	Soaking of seed in water to speed-up germination (1 if yes and 0 otherwise)
T_{39}	Dibbling/drilling with correct spacing (1 if yes and 0 otherwise)
T_{40}	Adoption of formal irrigation (1 if yes and 0 otherwise)
T_{41}	Construction of water bunds and puddling the field with water (1 if yes and 0 otherwise)
T_{42}	Spraying the weeds and pests with herbicides or pesticides (1 if yes and 0 otherwise)
T_{42}	Application of fertilizer (1 if yes and 0 otherwise)
T_{43}	Green manuring (1 if yes and 0 otherwise)
T_{44}	Scientific composting (1 if yes and 0 otherwise)
T_{45}	Biological control of pest on the field (1 if yes and 0 otherwise)

Source: Analysis from field data (2017)

Appendix 2: Definition and Measurements of Explanatory in MESRMs

Explanatory Variables	**Definitions and Measurements**
Conventional inputs	
L	Quantity of labour (mandays)
F	Quantity of fertilizer (Kg)
S	Quantity of rice seed (Kg)
Pc	Quantity of pesticides (lit)
K	Ghana Cedis (GH₵)
Fs	Farm size (acres)
Farmer Characteristics	
Age	Age (years)
Sex	Sex (1 if male, 0 otherwise)
HHS	Household size (numbers)
Eduyrs	Number of years in formal education (years)
FarmExp	Rice farming experience (years)
BusFm	Business purpose of farm rice (1 if yes, 0 otherwise)
Institutional and Policy Variables	
ExtVisits	Number of extension contacts with advioce on rice farming (number)
CredAcc	Credit access ((1 if access, 0 otherwise)
ContFarm	Contract farming (1 if yes, 0 otherwise)
FBO	Farmer-based organisation membership (1 if member, 0 otherwise)
FBO_Adv	FBO advice on rice production (numbers)
InpSub	Inputs' subsidy (1 if access, 0 otherwise)
DistAEAs	Distance from office of AEAs to community (Km)
DistInpMkt	Distance from community to market centres of rice (Km)
DistAccraCom	Distance from Accra to Community (Km)
Environmental Factors or Shocks	
LodgRice	Lodging of rice (1 if rice lodged, 0 otherwise)
LowRain	Affected by low rainfall amount (1 if experienced low rainfall amount, 0 otherwise)
RainAmt	Actual mean annual rainfall amount within the district (mm)
Temp	Actual mean annual temperature within the district (^{0}C)
Agro-Ecological Zone Dumies	
GSZ	Guinea savannah zone (1 if a farmer is located in guinea savannah zone, 0 otherwise)
FSTZ	Forest savannah transition zone (1 if a farmer is located in forest savannah transition zone, 0 otherwise)
Rice Production Technologies	
IATs_PC_Index	Principal component index of *IATs* (indices)
FISs_PC_Index	Principal component index of *FISs* (indices)
FISs_PC_Index	Principal component index of *IFPs* (indices)

Source: Analysis from field data (2017)

Appendix 3: Frequency Distribution of Farmers in the Study Area

Districts	Frequency	Percentage (%) out of sample size in agro-ecological zone	Percentage (%) out of total sample size
Guinea savannah zone	**377**	**100.0**	**41.57**
Tolon District	65	17.24	7.17
Kumbungu District	81	21.49	8.93
Savelugu Municipal	63	16.71	6.95
West Mamprusi District	77	20.42	8.49
Chereponi District	39	10.34	4.30
Builsa South District	20	5.31	2.21
Kassena Nankana Municipal	32	8.49	3.53
Forest savannah transition zone	**359**	**39.58**	**39.58**
Krachi Nchumburu District	55	15.32	6.06
Hohoe Municipal	58	16.16	6.39
North Tongu District	95	26.46	10.47
Ketu North District	80	22.28	8.82
Pru District	71	19.78	7.83
	171	18.85	18.85
Coastal savannah zone			
Shai Osudoku District	101	59.06	11.14
Ningo Prampram District	30	17.54	3.31
Ashaiman Municipal	40	23.39	4.41
Total	**907**	**100.0**	**100.0**

Source: Analysis from field data (2017)

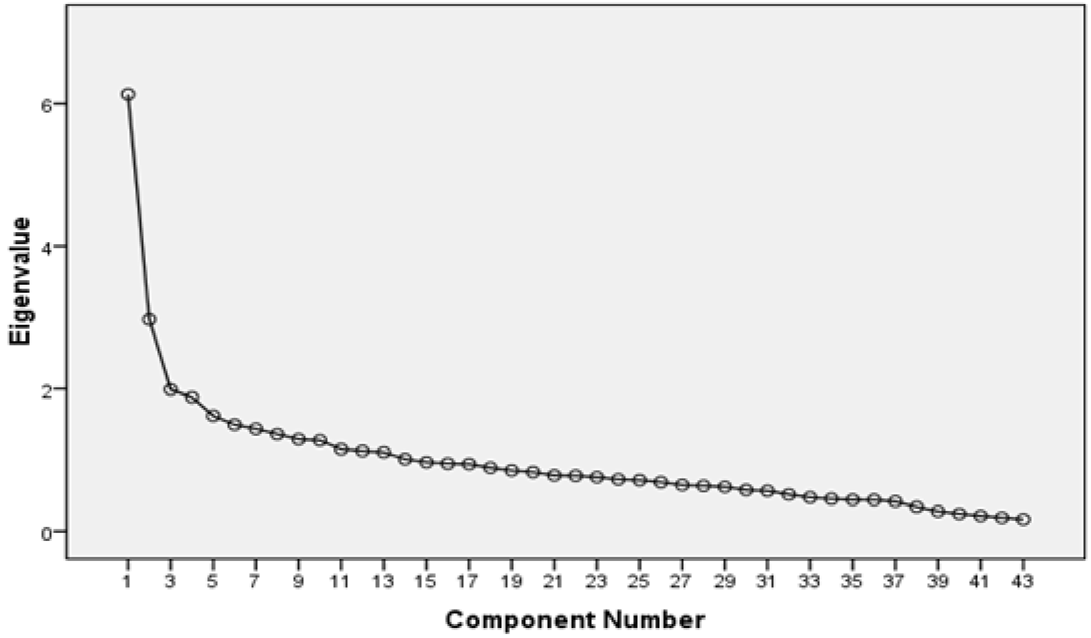
Appendix 4: Frequency table of *IFPs*, *FISs* and *IATs* for PCA

Indigenous Farming Practices, Farmer Innovations and Scientifically Improved Agricultural Technologies	Frequency		Percentage	
	No	**Yes**	**No**	**Yes**
Hypothesised Indigenous farming practises (*IFPs*)				
Use of previous years rice as seed without selection	714	193	78.70	21.30
Farmer-to-farmer seed exchange	814	93	89.70	10.30
Purchasing of ordinary seed from market	771	136	85.00	15.00
Slush and burn	730	176	80.60	19.40
Haphazard cutting and turning (pulverising) of soil with hoe	828	79	91.30	8.70
Broadcasting seed haphazardly	456	451	50.30	49.70
Handpicking of weeds	609	291	67.10	32.90
Use of hoe and cutlasses to control weeds	597	310	65.80	34.20
Mixed cropping	771	136	85.00	15.00
Use of scare crow to sack birds on the field	478	429	52.70	47.30

Setting of trap to catch birds on the field	805	102	88.80	11.20
Personal bird scaring through shouting, ringing of bell, use of catapult etc	298	609	32.90	67.10
Use of sickle to harvest rice	450	457	49.60	50.40
Use of knife or cutlass to harvest rice	691	216	76.19	23.81
Threshing by beating rice straw and paddy with sticks	546	361	60.20	39.80
Storage of rice in bags	347	560	38.30	61.70
<u>Hypothesised Farmer Innovation Systems (*FISs*)</u>				
Selection of seed for next season from healthy and good rice plants	708	199	78.60	21.40
Planting of rice on selected fertile land, planting rice on it and using the rice from the plot as foundation seed	771	136	85.00	15.00
Slash and leave crop residue to decompose	704	203	77.60	22.40
Zero or minimal tillage	888	19	97.90	2.10
Use of wood ash to speed-up germination	660	247	72.80	27.20
Transplanting of seedlings with approximate spacing	709	198	78.20	21.80
Broadcasting in rows with approximate spacing	712	195	78.50	21.50
Dibbling/drilling with approximate spacing	768	139	84.70	15.30
Mulching with plants parts to keep moisture	811	96	89.40	10.60
Use of mulch to suffocate weeds	799	108	88.09	11.91
Incorporation of rice straw into soil	699	208	77.10	22.90
Colouring of rice seed to prevent identification by rodents or bird after seeding	816	91	90.00	10.00
Use of cassette magnetic ribbon to scare birds	696	211	76.74	23.26
Threshing by holding rice sheaves and thrashing against wooden or slated bamboo container	750	157	82.69	17.31

Hypothesised Improved agricultural technologies (*IATs*)				
Rouging	794	113	87.50	12.50
Use of certified seed	561	346	61.90	38.10
Clear the land before plough and harrow with tractor	652	255	71.90	28.10
Plough and harrow the land directly without clearing	738	169	81.40	18.60
Rotovation of the land (*Tilling and crossing*)	669	238	73.80	26.20
Puddling the field 3 to 4 days before seeding	758	149	83.57	16.43
Soaking of seed in water to speed-up germination	501	406	55.20	44.80
Transplanting or dibbling or drilling and planting with correct spacing	887	20	97.80	2.20
Adoption of formal irrigation	513	394	56.60	43.40
Construction of water bunds and puddling the field with water	536	371	59.10	40.90
Spraying the weeds with chemical pesticides	156	751	17.20	82.80
Application of fertilizer	611	296	67.36	32.64
Use of stationary thresher to thresh rice	872	35	96.10	3.90
Use of combine haverster	600	307	66.20	33.80
Storage of rice in warehouses	772	135	85.10	14.90
Control of storage and field pests using chemical pesticides	182	725	20.10	79.90

Source: Analysis from field data (2017)



Appendix 5: Scree Plot

Source: Analysis from field data (2017)

Appendix 6: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.723
Bartlett's Test of Sphericity	Approx. Chi-Square	10380.675
	df	903
	Sig.	0.000***

Source: Analysis from field data (2017)

Appendix 7: Dimensional Indices of Factors Loaded under *IFPs*, *FISs* and *IATs*

Source: Analysis from field data (2016)

Class of farming practices, innovations and improved technologies	Factor Loadings	Initial Total Eigen Values	Loaded Eigen Values	Variance Explained (%)	Cumulative Percentage (%)	Communalities
PC1: *IATs*						
Harvesting of rice with combine harvesters	0.657					0.820
Use of certified improved rice seed	0.642					0.649
Farming rice under irrigation	0.639					0.622
Application of chemical fertilizers	0.596					0.590
Rotovation of the soil	0.592	6.131	5.088	14.258	14.258	0.711
Storage of rice in warehouses	0.582					0.591
Transplanting of seedlings	0.491					0.519
Soaking of seed in water before planting or sowing	0.451					0.572
Puddling rice field before planting or sowing	0.438					0.443
PC2: *FISs*						
Threshing of paddy rice from the straw by beating with sticks	0.437					0.702
Slush the grasses and leave to decompose	0.472	2.972	1.768	6.912	21.171	0.456
Incorporation of rice straw into soil	0.441					0.542
Soaking of rice seed into ash suspension before planting	0.418					0.401
PC3		1.991		4.630	25.800	
PC4: *IFPs*						
Bamboo for threshing	0.801					0.725
Using cutlass to harvest rice	0.538	1.880	1.346	4.372	30.173	0.670
PC5		1.619		3.766	33.939	
PC6		1.495		3.478	37.416	

PC7		1.436		3.340	40.757	
<u>PC8: Undefined component</u>						
Dibbling and planting with approximate spacing	0.524	1.362	0.524	3.167	43.924	0.733
<u>PC9</u>		1.291		3.003	46.927	
<u>PC10: Undefined component</u>						
Scare crow	0.423	1.276	0.423	2.967	49.894	0.513
<u>PC11: Undefined component</u>						
Exchange of foundation seed with other farmers	0.499	1.153	0.499	2.681	52.575	0.587
<u>PC12: Undefined component</u>						
Mulching to suffocate weeds	0.543	1.127	0.543	2.621	55.196	0.517
<u>PC13: Undefined component</u>						
<u>PC14: Undefined component</u>						
Colouring of seed before planting	0.409	1.013	0.409	2.356	60.129	0.617

Appendix 8: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.13	14.26	14.26	6.13	14.26	14.26	3.41
2	2.97	6.91	21.17	2.97	6.91	21.17	2.98
3	1.99	4.63	25.80	1.99	4.63	25.80	2.69
4	1.88	4.37	30.17	1.88	4.37	30.17	2.02
5	1.62	3.77	33.94	1.62	3.77	33.94	1.66
6	1.50	3.48	37.42	1.50	3.48	37.42	2.62
7	1.44	3.34	40.76	1.44	3.34	40.76	2.41
8	1.36	3.17	43.92	1.36	3.17	43.92	2.02
9	1.29	3.00	46.93	1.29	3.00	46.93	2.12
10	1.28	2.97	49.89	1.28	2.97	49.89	2.16
11	1.15	2.68	52.58	1.15	2.68	52.58	1.68
12	1.13	2.62	55.20	1.13	2.62	55.20	2.28
13	1.11	2.58	57.77	1.11	2.58	57.77	1.71
14	1.01	2.36	60.13	1.01	2.36	60.13	1.42
15	0.97	2.26	62.39				

16	0.95	2.21	64.59					
17	0.94	2.20	66.79					
18	0.89	2.07	68.86					
19	0.85	1.99	70.85					
20	0.83	1.93	72.78					
21	0.78	1.82	74.61					
22	0.78	1.81	76.42					
23	0.76	1.77	78.18					
24	0.73	1.69	79.88					
25	0.72	1.67	81.55					
26	0.69	1.60	83.15					
27	0.65	1.51	84.66					
28	0.64	1.48	86.14					
29	0.62	1.45	87.59					
30	0.58	1.35	88.93					
31	0.57	1.32	90.25					
32	0.52	1.20	91.45					
33	0.48	1.11	92.56					
34	0.46	1.06	93.62					
35	0.44	1.03	94.65					
36	0.44	1.03	95.68					
37	0.42	0.98	96.65					
38	0.34	0.80	97.45					
39	0.28	0.65	98.10					
40	0.25	0.57	98.67					
41	0.22	0.50	99.17					
42	0.19	0.44	99.61					
43	0.17	0.39	100.00					

Extraction Method: Principal Component Analysis.

a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

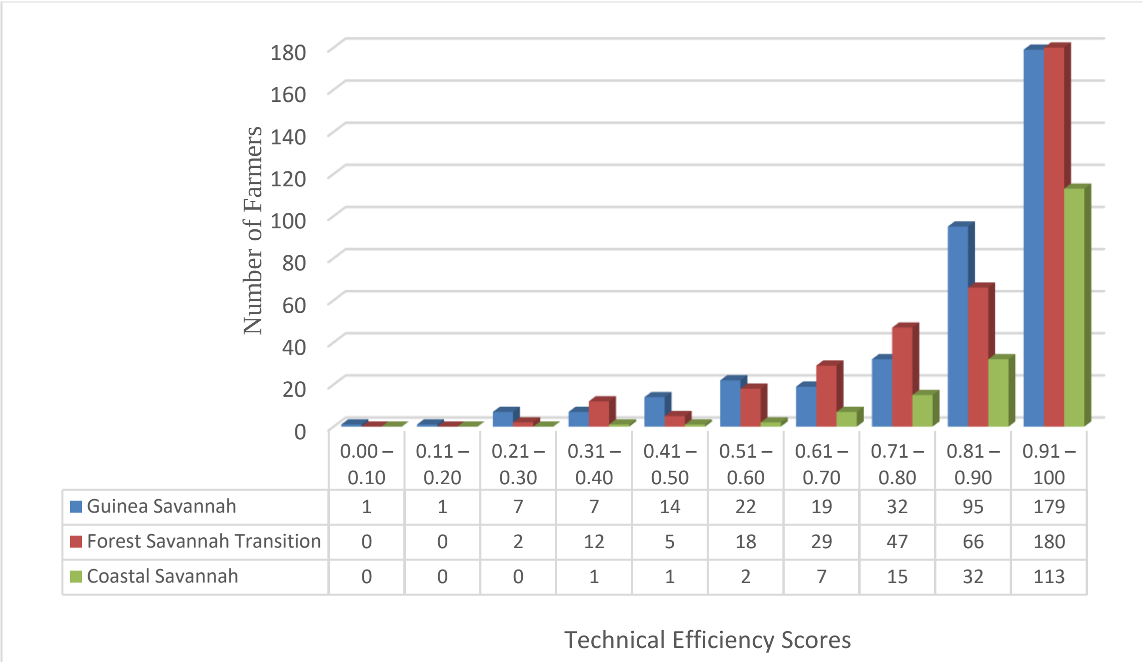
Source: Analysis from field data (2017)

Appendix 9: Communalities

Indigenous Farming Practices, Farmer Innovations and Scientifically Improved Agricultural Technologies	Initial	Extraction
Use of previous years rice as seed without selection	1	0.616
Farmer-to-farmer foundation seed exchange	1	0.587
Purchasing of ordinary seed from market	1	0.476
Slush and burn	1	0.427
Haphazard cutting and turning (pulverising) of soil with hoe	1	0.53
Broadcasting seed haphazardly	1	0.65
Handpicking of weeds	1	0.566
Use of hoe and cutlasses to control weeds	1	0.62
Mixed cropping	1	0.494
Use of scare crow to sack birds on the field	1	0.513
Setting of trap to catch birds on the field	1	0.459
Personal bird scaring through shouting, ringing of bell, use of catapult etc	1	0.672
Use of knife or cutlass to harvest rice	1	0.67
Use of sickle to harvest rice	1	0.762
Threshing by beating rice straw and paddy with sticks	1	0.702
Storage of rice in bags	1	0.677
Selection of seed for next season from healthy and good rice plants	1	0.668
Planting of rice on selected fertile land, planting rice on it and using the rice from the plot as foundation seed	1	0.481
Slash and leave crop residue to decompose	1	0.456

Use of wood ash to speed-up germination	1	0.401
Transplanting of seedlings with approximate spacing	1	0.572
Broadcasting in rows with approximate spacing	1	0.506
Dibbling/drilling with approximate spacing	1	0.733
Use of mulch to suffocate weeds	1	0.517
Incorporation of rice straw into soil	1	0.542
Colouring of rice seed to prevent identification by rodents or bird after seeding	1	0.617
Use of cassette magnetic ribbon to scare birds	1	0.438
Hiring of labourers to scare birds by shouting, ringing of bell, use of catapult etc	1	0.53
Threshing by holding rice sheaves and thrashing against wooden or slated bamboo container	1	0.725
Rouging	1	0.618
Use of certified seed	1	0.649
Clear the land before plough and harrow with tractor	1	0.759
Clear the land before plough and harrow with tractor	1	0.722
Rotovation of the land (*Tilling and crossing*	1	0.711
Puddling the field 3 to 4 days before seeding	1	0.519
Soaking of seed in water to speed-up germination	1	0.443
Adoption of formal irrigation	1	0.622
Spraying the weeds with chemical pesticides	1	0.757
Application of fertilizer	1	0.59
Control of storage and field pests using chemical pesticides	1	0.717
Use of combine haverster	1	0.82
Use of stationary thresher to thresh rice	1	0.729
Storage of rice in warehouses	1	0.591
Extraction Method: Principal Component Analysis.		

Source: Analysis from field data (2017)



Appendix 10: Frequency Distribution of Technical Efficiencies

Source: Analysis from field data (2017)

Appendix 11: Maximum Likelihood Estimates of the New-Two Step Stochastic Metafrontier Cost Translog Model

Variables	Guinea savannah Model		Forest savannah transition Model		Coastal savannah Model		Metafrontier Model	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
DF	0.0114	0.0878	-0.2083	0.1700	0.0363*	0.0197	-0.0432**	0.0198
DPc	0.1343	0.1158	-0.0179	0.1442	0.0100	0.0905	0.0510	0.0437
In(R)	0.3662***	0.0955	0.1449	0.0894	0.5169***	0.1843	0.2992***	0.0388
$In(P_F)$	0.2153	0.3331	0.5444	0.5981	-0.0010	0.3755	0.2666***	0.0948

In(P_{Pc})	-0.4761	0.3144	0.3686	0.3717	-0.0112	0.1272	0.0679	0.1161
In(P_L)	0.4708***	0.1357	0.2142	0.1756	-0.2019	0.3117	0.3229***	0.0684
In(P_S)	-0.1690*	0.1008	0.4450***	0.1397	0.4236***	0.1545	0.1502***	0.0467
In(Fs)	-0.0678	0.0722	0.3853***	0.0727	-0.0744	0.1978	0.1483***	0.0341
In(K)	0.5115***	0.0569	0.4085***	0.0353	0.4830***	0.1259	0.4171***	0.0171
In(R)In(R)	0.1142**	0.0460	0.0522	0.0436	0.2134**	0.0924	0.0578***	0.0188
I In(P_F)In(P_F)	0.2114	0.2638	0.0132	0.4907	0.3342	0.3638	0.1090	0.0935
In(P_{Pc})In(P_{Pc})	0.3365	0.2082	-0.2038	0.2428	0.0199	0.0870	-0.0542	0.0798
In(P_L)In(P_L)	0.2257*	0.1237	0.1098	0.1545	0.2346	0.1518	-0.0065	0.0527
In(P_S)In(P_S)	0.0102	0.0196	0.1368***	0.0349	0.1247***	0.0310	0.0605***	0.0130
In(Fs)In(Fs)	0.1528***	0.0306	0.0317	0.0294	-0.2016	0.2301	0.0782***	0.0142
In(K)In(K)	0.0837***	0.0107	0.0527***	0.0077	0.1720**	0.0814	0.0583***	0.0041
In(P_R)InR	-0.0868	0.1317	0.0907	0.1268	0.4396	0.4447	-0.1353**	0.0537
In(R)In(P_F)	-0.0474	0.1004	0.0248	0.0957	-0.2863	0.2858	-0.0240	0.0486
In(R)In(P_{Pc})	-0.0350	0.0793	0.2000**	0.0966	-0.1700	0.2006	0.0440	0.0386
In(R)In(P_L)	-0.0209	0.1286	0.0284	0.1261	0.2712	0.2348	0.2350***	0.0549
In(R)In(P_s)	-0.0752	0.0761	-0.0539	0.0852	0.2871*	0.1491	-0.0278	0.0354
In(R)In(Fs)	-0.1108*	0.0616	-0.0468	0.0507	0.0493	0.2817	-0.0774***	0.0234
In(R)In(K)	-0.0683*	0.0390	-0.0492**	0.0238	-0.2885*	0.1688	-0.0552***	0.0134
In(P_F)In(P_{Pc})	-0.1603	0.6452	2.9558***	0.7624	0.0425	1.1462	1.3155***	0.3374
In(P_F)In(P_L)	-0.1718	0.5511	-2.2578***	0.5951	0.4585	1.1784	-1.1360***	0.2726
In(P_F)In(P_S)	0.1123	0.0815	-0.3885***	0.1352	-0.0654	0.1870	-0.1376**	0.0533
In(P_F)In(Fs)	0.1243	0.0814	-0.1580**	0.0703	0.2681	0.2979	-0.0804**	0.0354
In(P_F)In(K)	-0.0987**	0.0501	-0.0311	0.0344	-0.1668	0.1383	-0.0660***	0.0189
In(P_{Pc})In(P_L)	0.0263	0.1170	0.0481	0.2250	0.3660	0.2364	0.0778	0.0742
In(P_{Pc})In(P_S)	0.1268	0.1004	-0.0375	0.1945	-0.2312*	0.1341	0.0650	0.0577
In(P_{Pc})In(Fs)	0.0689	0.0607	-0.1019	0.0730	0.2911	0.3009	0.0310	0.0290
In(P_{Pc})In(K)	-0.0678*	0.0380	-0.1095***	0.0335	-0.0986	0.1569	-0.0976***	0.0164
In(P_L)In(P_S)	0.0188	0.1062	0.1820	0.2261	0.2567	0.2039	0.0876	0.0584
In(P_L)In(Fs)	0.1518**	0.0656	0.0748	0.0915	-0.4576**	0.2234	0.0134	0.0372
In(P_L)In(K)	-0.1139*	0.0681	-0.2009***	0.0425	0.0939	0.1721	-0.1625***	0.0231
In(P_S)In(Fs)	0.0743	0.0512	0.1021	0.0638	-0.1442	0.1418	0.0629	0.0232
In(P_S)In(K)	-0.0889**	0.0439	0.0101	0.0375	-0.1470*	0.0766	-0.0599***	0.0174
In(Fs)In(K)	-0.1316***	0.0354	-0.0052	0.0178	0.0298	0.2363	-0.0316***	0.0097
Constans	-0.4590***	0.0668	0.3715***	0.0554	-0.1622**	0.0775	-0.2416***	0.0269
σ_v^2 σ_u^2 σ_s^2 γ_u^2								
Log-Lik Wald χ^2 (29)	169.3678 6193.72***		133.2276 5208.80***		183.5732 6239.30***		572.5869 16602.90***	

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

DF=dummy of fertilizer usage, DPc=dummy of pesticide usage, P_R=unit price of rice (Gh¢), R=quantity of rice (Kg), P_F=price of fertilizer (Gh¢), P_{Pc}= price of pesticides (Gh¢), P_L=price of labour (Gh¢), P_S=price of seed (Gh¢), Fs=farm size (acres), K=capital (Gh¢)

Source: Analysis from field data (2017)

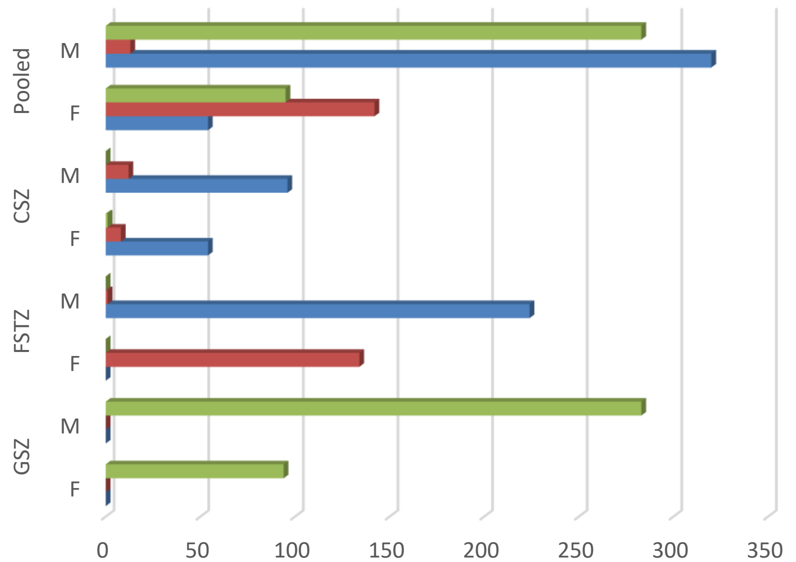
Appendix 12: Determinats of Economic Inefficiency

Variables	Guinea savannah Model		Forest savannah transition Model		Coastal savannah Model		Metafrontier Model	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
In(σ_v^2)	-4.7643***	0.2208	-3.6784***	0.0896	-5.4434***	0.2266	-4.5628***	0.1016
Farmer Characteristics								
Age	0.0079	0.0133	-0.0753	0.0531	-0.0928*	0.0505	-0.0415***	0.0114

Sex	-1.2962***	0.2906	31.6789	1534.8130	-0.4479	0.6642	0.0928	0.2495
HHS	-0.0499*	0.0279	-0.1582	0.1054	0.0358	0.1021	0.0994***	0.0237
Eduyrs	-0.0191	0.0282	-0.0716	0.0663	-0.0194	0.0926	-0.1243***	0.0225
FarmExp	-0.0038	0.0161	0.1448*	0.0754	0.1484***	0.0551	-0.0055	0.0139
Institutional and Policy Variables								
ExtVisits	0.0935	0.0679	0.2139	0.2259	-0.4216*	0.2163	0.0682	0.0560
CredAcc	-0.0814	0.2776	-1.9530	1.3198	-0.4582	0.6662	-0.0737	0.2327
ContFarm	-0.9378**	0.4107	-1.0793	1.1416	1.1538	0.9021	-0.7920**	0.3179
FBO	-0.2308	0.2507	0.3565	0.6001	-0.2211	0.6521	0.2376	0.1881
ImpvSeed	0.8490**	0.3455	0.3141	0.7180	-1.0264	0.6371	-0.4569*	0.2446
IrrigAcc	0.2543	0.3186	1.8156*	0.9527	2.4553**	1.1580	-0.5793**	0.2444
Environmental Factors' Perception								
LodgRice	1.1772***	0.2861	-1.1546*	0.6539	0.9647	0.6439	0.0665	0.1937
LowRain	0.0070	0.2296	-0.3470	0.6445	-1.4382	2.3606	0.0900	0.1752
Adopt_IATs	-0.4768*	0.2787	-0.4451	0.7698	-0.9197	0.7607	-0.1076	0.2149
Rice Production Technologies								
Adop_FISs	-0.4340	0.3209	-0.3179	0.9863	0.2940	0.9259	-0.6972***	0.2251
IATs _PC_Index	-0.2775	0.2093	-0.6356	0.3860	-1.5223***	0.4003	-0.5028***	0.1409
FISs_PC_Index	-0.3101*	0.1609	*NA*	*NA*	0.3543	0.3539	0.3357***	0.1122
IFPs_PC_Index	*NA*	*NA*	0.5324**	0.2700	*NA*	*NA*	*NA*	*NA*
Constant	-2.5104***	0.6639	-33.6234	1534.8140	-3.3749	3.3166	-2.1808***	0.5622
sigma_v	0.0924	0.0102	0.1589	0.0071	0.0658	0.0075	0.1021	0.0052

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

Source: Analysis from field data (2017)



	GSZ		FSTZ		CSZ		Pooled	
	F	M	F	M	F	M	F	M
Over economic efficient	94	283	0	0	1	0	95	283
Economic efficient	0	0	134	1	8	12	142	13
Less economic efficient	0	0	0	224	54	96	54	320

Appendix 13 Frequency Distribution of Economic Efficiency

Source: Analysis from field data (2017)

Appendix 14: Research Questionnaire

University for Development Studies
Faculty of Agribusiness and Communication Sciences
Department of Agricultural and Resource Economics

University for Development Studies

USAID | GHANA FROM THE AMERICAN PEOPLE

FEED THE FUTURE The U.S. Government's Global Hunger & Food Security Initiative

Agriculture Policy Support Project

United States Agency for International Development (USAID)/Ghana Feed the Future (FtF) Agriculture Policy Support Project (APSP)
Research Studies to Support Evidence-Based Policymaking

Research Topic: Productivity Heterogeneity of Rice Production in Ghana: Policy Implications for Farmer Innovations and Improved Agricultural Technologies

Serial number of questionnaire …………………..

Please introduce yourself to respondent: My name is_________________ . I am an enumerator collecting data on behalf of Mr. Franklin N. Mabe, a PhD student and principal researcher of University for Development Studies, Tamale who is on USAID project "**Research Studies to Support Evidence-Based Policymaking"**

The research aims at examining Indigenous Farming Practices (IFPs), Farmer Innovation Systems (FISs) and Scientifically Improved Agricultural Technologies (SIATs) used for rice production, their effects and policy implications for improvement in rice productivity. The research has a strong link with the key policy intervention areas of METASIP especially "The Science and Technology in Food and Agricultural Development", Food Security and Emergency Preparedness" and Increased Income Growth" which USAID's Ghana Feed the Future (FtF) Agriculture Policy Support Project (APSP) is promoting.

Before I begin, I would like to assure you that your responses will be strictly used for academic research and will be treated absolutely anonymously and confidential. Your name would not be mentioned anywhere in the research work. Therefore, try as much as possible to be accurate and objective in your responses. If you have any concern, you can contact the principal researcher Franklin N. Mabe, University for Development Studies, on the mobile number 0242760053/0206783104.

A. REFERENCE INFORMATION

Enumerator's code	Name of community	Name of region
Date of interview: ……./………/…………….	Name of district	Name of agro-ecological zone

B. HOUSEHOLD DEMOGRAPHIC CHACRATERISTICS AND FARMING ACTIVITIES

- ***Respondent's basic characteristics***

1.1 Age of respondent (number)	…………..
1.2 Sex of respondent	(1) Male [ ] (2) Female [ ]
1.3 Marital status of respondent	(1) Single/unmarried [ ] (2) Married [ ] (3) Widow or widower [ ] (4) Divorced/Separated [ ]
1.4 Household size (number)	……………….
1.5 Household composition by sex	(1) Number of males:……. (2) Number of females:………..
1.6 Tick the highest level of education completed you	(1) No education [ ] (2) Non-formal/only Islamic education [ ] (3) Primary school [ ] (4) Middle school/JSS/JHS [ ] (5) Voc/Sec. Tech/SSS/SHS [ ] (6) Teacher/Nursing Colleges [ ] (7) Polytechnic/University [ ]

1.7 Number of years of schooling by respondent	…………………..

Note: Household size includes all people, who usually eat from the same pot and sleep under the same roof. Include also members who are absent for less than six months!

2 *Household's income generated from on-farm and off-farm activities in 2014/15 cropping season*

2.1 Tick the main source of household's cash income (1) Agricultural activities [ ] (2) Non-agricultural activities [ ]
2.2 State the percentage proportion of household's cash income from agricultural activities: …………. %
2.3 State the percentage proportion of household's cash income from non-agricultural activities: …………. %
2.4 If you tick non-agricultural activities in 2.1 above, tick the actual main (major) source of household cash income (*Tick only one*)
(1) Trading [ ] (2) Full-time/part time salary employment [ ] (3) Craftsmanship [ ] (4) Remittances [ ]
(5) Other sources [ ] (please specify)………………………..

3 *Access to basic social amenities*

Basic social amenity/facility	Do you have access to the following facilities? [1] Yes [2] No	How far is the facility from your house? (km)	How long does it take to get to the facility? Days Hrs Mins
3.1 At least primary school			
3.2 Health centers			
3.3 Portable water			
3.4 National electricity grid			
3.5 Public toilet/privately own toilet (at least pit latrine)			
3.6 Bank (rural & commercial)			

4 *Access to agricultural extension services and information in 2014/15 cropping season*

4.1 Fill in table below

Have you ever sought any assistance/advice from an agric. extension worker? Yes [1] No [2]	If No, please state reasons [1] Not interested [2] Too far [3] Don't know where extension office is [4] Not enough time [5] AEAs are not trustworthy [6] Others, please specify	If yes, how many times did an agric. extension worker visit you in 2014/15 farming season and advice you on rice farming?	Did you adopt (at least) any one of the recommended practices? [1] Yes, fully [2] Partly [3] No, not at all [4] Others please specify	Did you find the advice useful? Yes [1] No [2]

4.2 Where do you often get/hear information about **new rice production technology** (e.g. new variety, new chemicals, new farming practices etc)? Tick as many as applicable.

(1) Mass media (TV, radio, newspapers) [ ] (2) Agric. extension officers [ ] (3) Other farmers [ ] (4) Input dealers [ ]
(5) Farmer based organisations [ ] (6) Output aggregators/buyers [ ] (7) NGOs [ ]

(8) Others (specify) [ ]…………………………………………………………….

5 *Credit access, amount and use in 2014/15 cropping season*

5.1 Fill in the table below

Did you obtain any credit during the last years' farming season (2014/2015)? (1) Yes [ ] (2) No [ ]	If yes, please state credit source (1) Commercial banks [ ] (2) Rural banks [ ] (3) Credit unions (*susu* groups) [ ] (4) Governmental credit programme [ ] (5) NGO credit programme [ ] (6) Shopkeeper/traders in the village/town [ ] (7) Relatives [ ] (8) Friends [ ] (9) Money lenders [ ] (9) Contract credit providers [ ]	Did you get the full amount you applied for? (credit con-strained) (1) Yes [ ] (2) No [ ]	If you did not get full amount, state the reasons (1) lack of collateral [ ] (2) could not repay last loan [ ] (3) political [ ] (4) religious [ ] (5) ethnic [ ]	What was the total amount applied for? (Ghȼ)	What was the total amount received? (Ghȼ)	How much of the credit was used for rice farming? (Ghȼ)	How much of the credit was used for other agricultural purposes? (Ghȼ)	How much of the credit was used for non-agricultural purposes? (Ghȼ)	How much do you have to pay back? i.e. (loan + interest) (Ghȼ)	How many months did you use in paying the loan?
				………		……....	………..	………….	……….	……

……

5.2 Are you member of any credit or savings' and loans' group? (1) Yes [ ]   (2) No [ ]

5.3 If yes to 5.2, please mention the nature of the organization/institution ………….

6 Social capital of the farmer

Types of organization	Member-ship: [1] Yes [2] No	If yes, give number of times you attended association meetings in 2014/2015 cropping season	If yes, give number of times you got advice on rice production in 2014/2015 cropping season
6.1 Farmer-based organization			
6.2 Credit and savings' group			
6.3 Community-based organization			
6.4 Any other (Specicy) ……………			

7. Land ownership, usage and land rent

7.1 Ownership status of land used for farming rice in 2014/15 season: (1) Owned [ ] (2) Leased/rent [ ] (3) family/communal land [ ]

7.2 If the land was rented, how much did you pay per an acre as rent? Gh¢ ………..

8. ***Farming experience and rice cultivation decisions***

8.1 How many years have you been farming? ………..

8.2 Mention the crops you normally cultivate:

……….

8.3 Which of the crops mentioned above is the main? …………………………….

8.4 How many years have been engaged in rice production? ………..

8.5 State the reasons why you cultivate rice: 1. ………………………………………………. 2. ……………………………………………………

3. ……………………………….. 4. ……………………………………………. 5. ……………………………………………………

9. Access to agricultural policy interventions and other things

9.1 Did you apply subsidized fertilizer on your rice farm in 2014/2015 cropping season? (1) Yes [ ] (2) No [ ]

9.2 Did you apply subsidized pesticides on your rice farm in 2014/2015 cropping season? (1) Yes [ ] (2) No [ ]

9.3 Did you use subsidized certified planting materials (rice seeds) in 2014/2015 cropping season? (1) Yes [ ] (2) No [ ]

9.4 How far is your rice farm from the house? …………………Km

9.5 How long will it take to walk to your farm? …………..hours …………..minutes ………….seconds

9.6 Fill in the table below

Community to	**District capital**	**Product market (rice selling market)**	**Input market**	**Agricultural extension office**
Distance				
Means of transport	(1) Foot [ ] (2) Bicycle [ ] (3) Motor cycle [ ] (4) Car [ ] (5) Canoe/engine boat [ ] (6) Other [ ] (specify)……….	(1) Foot [ ] (2) Bicycle [ ] (3) Motor cycle [ ] (4) Car [ ] (5) Canoe/engine boat [ ] (6) Other [ ] (specify)……….	(1) Foot [ ] (2) Bicycle [ ] (3) Motor cycle [ ] (4) Car [ ] (5) Canoe/engine boat [ ] (6) Other [ ] (specify)……….	(1) Foot [ ] (2) Bicycle [ ] (3) Motor cycle [ ] (4) Car [ ] (5) Canoe/engine boat [ ] (6) Other [ ] (specify)……….
Time of travel	……..hrs ………minutes	……..hrs ………minutes	……..hrs ………minutes	……..hrs ………minutes
Nature of roads	(1) Path [ ] (2) Untarred road [ ] (3) Tarred road [ ]	1) Path [ ] (2) Untarred road [ ] (3) Tarred road [ ]	1) Path [ ] (2) Untarred road [ ] (3) Tarred road [ ]	1) Path [ ] (2) Untarred road [ ] (3) Tarred road [ ]
Motorallability	(1) Motorable [ ] (2) Unmotorallable [ ]	(1) Motorable [ ] (2) Unmotorallable [ ]	(1) Motorable [ ] (2) Unmotorallable [ ]	(1) Motorable [ ] (2) Unmotorallable [ ]

10. Labour Input Requirements

10.1 Family labour for rice production in 2014/15 cropping season *(Note this: one manday is 8hrs)*

Farming activity	No. of adult family labourers		Number of days worked		Average number of hours worked per day		Wage per person per day		Total mandays ***(one manday is 8hrs)***	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Preparation of nursery bed										
Planting on nursery bed										
Manual clearing of the land										
Mechanical or animal power clearing of land										
Ploughing										
Harrowing										
Transplanting of seedlings										
Direct seeding/planting										
1st Fertilizer application										
1st Application of manure										
Spraying of pre-emergence weedicides										
Irrigation/watering/construction of bounds										
Rogging (removal of unsown variety of rice)										
Manual weed control (with hoe and cutlasses)										
Mechanical or animal power weed control										
Spraying of selective weedicides										

2nd fertilizer application				
2nd Application of manure				
On-field pest control				
Harvesting				
Threshing, drying and bagging				
Transportation				
Postharvest pest control				
TOTAL	……	….....	…….	……….

10.2 On average, how much mandays of communal labour was provided by males for rice production in 2014/15 cropping season? .... *(Note this: one manday is 8hrs)*
10.3 On average, how much mandays of communal labour was provided by females for rice production in 2014/15 cropping season? .... *(Note this: one manday is 8hrs)*

10.4 Hired labour for rice production in 2014/15 cropping season *(Note this:* *one manday is 8hrs*)

Farming activity	No. of adult hired labourers		Number of days worked		Average number of hours worked per day		Wage per person per day (Gh¢)		Total mandays ***(one manday is 8hrs)***	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Preparation of nursery bed										
Planting on nursery bed										
Manual clearing of the land										
Mechanical or animal power clearing of land										

Ploughing
Harrowing
Transplanting of seedlings
Direct seeding/planting
1st Fertilizer application
1st Application of manure
Spraying of pre-emergence weedicides
Irrigation/watering/construction of bounds
Rogging (removal of unsown variety of rice)
Manual weed control (with hoe and cutlasses)
Mechanical or animal power weed control
Spraying of selective weedicides
2nd fertilizer application
2nd Application of manure
On-field pest control
Harvesting
Threshing, drying and bagging
Transportation

Postharvest pest control				
TOTAL	…….	………	………	……

*11. Cost of machinery operations and animal traction for rice production in **2014/15 cropping season***

Number of acres of rice cultivated in 2014/2015: …………..								
Rice farming activity	Tractor ploughing	Tractor harrowing	Animal ploughing	Animal harrowing	Mechanical weed control	Combined harvesting and threshing	Transportation	Irrigation
Number of acres								
Cost per acre								
Total cost (Gh¢)	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Overall total cots (Gh¢) (a)+(b)+(c)+(d)+(e)+(f)+(g)+(h)								

*12. Input usage and cost of rice production in **2014/15 cropping season***

12.1 Cost of variable inputs

Name of variable inputs	Name of variety of rice seed	Chemical fertilizer			Pest control agrochemicals				Total cost of variable inputs
		Ammonia	NPK	Liquid fertilizer	Weedicides	Insecticides	Water for irrigation	Organic fertilizer (compost and FYM)	(Gh¢)
Units									

Quantity	
Unit price (Gh¢)	
Total cost (Gh¢)	

12.2 Cost of fixed inputs

Name of fixed inputs	Sickle	Knife	Cutlass	Small hoe	Big hoe	Pan/Basket	Knapsack sprayer	Watering can	Other fixed inputs (specify)		Total cost of fixed inputs
Units											
Useful life (No of years it can be used)											
Quantity (a)											
Unit price (b) (Gh¢)											

Total cost of fixed inputs (a) X (b)	

13. Farm practices: indigenous farming practices, farmer innovation systems and scientifically improved agricultural technologies

13.1 Indicate agro-ecological system that you use in cultivating rice.

(1) Valley bottom/lowland rainfed [ ] (2) Irrigation [ ] (3) Controlled flooding [ ] (4) Upland [ ]
(5) Other [ ] (specify)……………………….

13.2 Tick all the methods of farming you use in cultivating rice. (you can tick more than one)

[ ] Indigenous farming practices: They are relatively unimproved older farming practices handed over to you by your parents, grandparents or any other older family members or friends).

[ ] Farmer innovation systems: They are relatively improved farming systems which are ingeniously developed by you or any other farmer(s) within your community or outside your community. They include extensively modified or uniquely combined indigenous farming systems and/or scientifically improved agricultural technologies. It is also defined as the combination of existing techniques or technologies in new ways in order to enhance their impact (Wills, 2012).

[ ] Scientifically improved agricultural technologies: They are highly improved externally developed technology by research institutions within Ghana (MoFA, CSIR-SARI, CSIR-SRI, CSIR-WRI, etc.) or outside Ghana (FAO, IRRI etc.)

13.3 Fill in the table below concerning 2014/2015 rice production activities.

Rice farming activity	**Indigenous Farming Practices (IFPs)** Tick the method(s) of indigenous farming practice(s) you use for each of the rice production activities stated in the first column of this table	**Farmer Innovation Systems (FISs)** Tick the method(s) of farmer innovation system(s) you use for each of the rice production activities stated in the first column of this table	**Scientifically Improved Agricultural Technologies (SIATs)** Tick the method(s) of scientifically improved agricultural technology (ies) you use for each of the rice production activities stated in the first column of this table

Seed selection	[ ] Use of rice seed from previous year without any selection	[ ] Farmer own pollination	[ ] Rouging: removing unintended rice variety plant from the field
	[ ] Farmer-to-farmer seed exchange	[ ] Selection of seed from healthy and good rice plant	[ ] Buying certified seeds
	[ ] Buying of ordinary seeds from other farmers	[ ] Selection of healthy plot and planting rice to be used next season	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Land preparation	[ ] Slash and burn	[ ] Slash and leave the crop and other plant residual (organic plant parts) on the field to decomposed	[ ] Clear and plough directly
	[ ] Making of ridges	[ ] Spray weeds on the field with plant extracts (pepper, neem, hot water or others	[ ] Plough the field without clearing
	[ ] Raising of mounds and subsequently pulverizing the soil	[ ] Spray weeds on the field with hot water	[ ] Zero ploughing/tillage
	[ ] Haphazardly cutting, turning and pulverizing the soil	[ ] Spray field with soap and oil	[ ] Distumping
	[ ] Use of animal plough	[ ] Other	[ ] Other
	[ ] Other	[ ] other	[ ] other
	[ ] Other	[ ] other	[ ] other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Seeding (nursery managemen t and seedling transplantin	[ ] Broadcasting haphazardly	[ ] Use of wood ash to speed up germination	[ ] Keep puddle of water for a while (3 to 4 days)
	[ ] Other	[ ] Transplanting seedlings without a definite distance or space between plants	[ ] Soaking seeds in water before planting
	[ ] Other	[ ] Broadcasting in rows with approximate spacing	[ ] Setting planting guides using wire, twine, wood

g and direct seeding)	[ ] Other	[ ] Dibbling with approximate spacing	[ ] Using mechanical transplanter
	[ ] Other	[ ] Other	[ ] Dibbling (hill planting)method with correct spacing (at least 20cm x 20cm)
	[ ] Other	[ ] Other	[ ] Use of planter with correct spacing (at least 20cm x 20cm)
	[ ] Other	[ ] Other	[ ] drilling with correct spacing (at least 20cm x 20cm)
	[ ] Other	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Soil moisture managemen t	[ ] Traditional mulching with other plant parts	[ ] Rain harvesting	[ ] Rotary of soil
	[ ] Other	[ ] Rice straw as mulch/synthetic mulch	[ ] Formal irrigation concrete irrigation channel
	[ ] Other	[ ] Improvised irrigation	[ ] Other
	[ ] Other	[ ] Farming in valleys or closer to rivers	[ ] Other
	[ ] Other	[ ] Water control bunds	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Weed control or	[ ] Handpicking of weeds	[ ] Spraying of home-made vinegar	[ ] Spaying with chemical herbicides
	[ ] Use of hoes and cutlasses	[ ] Spraying field with plant extracts (pepper, neem or others) or hot water/soap/salt/oil	[ ] Use of industrial vinegar

management	[ ] Use of animal power for weeding	[ ] Use of mulching material to suffocate weeds	[ ] Rotary weeding
	[ ] Other	[ ] Pudding/maintaining water in the rice field	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Soil fertility management	[ ] Fallowing through land rotation and shifting cultivation	[ ] Minimum or zero tillage, avoiding inversion of surface soil	[ ] Chemical fertilizer application (solid and liquid)
	[ ] Integration of crops and livestock	[ ] Application of self-prepared organic manure (compost) or farm yard manure	[ ] Scientific composting
	[ ] Mixed cropping	[ ] Rice straws are incorporated in rice field after threshing	[ ] Green manuring
	[ ] Other	[ ] Using plant extracts mixed with molasses, vinegar, alcohol or charcoal	[ ] Alley cropping
	[ ] Other	[ ] Other	[ ] Cover cropping
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Field pests management	[ ] Using scare crow	[ ] Colouring of rice seed with charcoal to prevent birds and rodents from recognising and picking the seeds	[ ] Application of pesticides
	[ ] Traps	[ ] Use of magnetic ribbon or strips of tape cassette	[ ] Biological control (Use of other animal)
	[ ] Personal bird scaring/shouting	[ ] Use of bell or shaking of containers with pebbles	[ ] Other
	[ ] Other	[ ] Spraying of plant extracts	[ ] Other

	[ ] Other	[ ] Net	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Method of rice harvesting and threshing	[ ] use of cutlass to cut the stem close to the ground	[ ] Threshing by holding the sheaves and thrashes against wooden or metal or slatted bamboo container	[ ] Use of combined harvester and thresher
	[ ] use of sickle to cut the stem close to the ground or just the panicle	[ ] Threshing by using tractor to tread on the grain	[ ] Use of stationary thresher
	[ ] use of knife	[ ] Other	[ ] Pedal or treadle thresher (threshing drum, foot crank)
	[ ] Threshing by beating with sticks or tread with feet and winnowing	[ ] Other	[ ] Other
	[ ] Threshing by using animals to trample on the grain	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs
Method of storage and storage pests'	[ ] storing paddy rice in traditional ban	[ ] Storing paddy rice in airtight rubber or metal containers placed in ordinary room	[ ] Storing paddy rice in airtight rubber or metal containers placed in warehouse or silo
	[ ] Storing paddy rice in non-airtight pots	[ ]Storing rice with wood ash or paddy husk ash mixed with cinnamon leaves	[ ] Storage of paddy rice in bags placed in warehouse or silo

managemen t	[ ] Storage of paddy rice in bags	[ ] Storing paddy rice with neem (*Azdirachta indica)*extract or driedchopped leaves of wild tobacco (*Lobella nicotionifolia)*	[ ] Spraying of pesticides
	[ ] Setting of traps	[ ] Mixing red pepper (*Capsicum Sp)* with paddy rice for pests prevention	[ ] Other
	[ ] Other	[ ] Use of granules of salt to prevent pests	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Other	[ ] Other	[ ] Other
	[ ] Did not use any of IFPs	[ ] Did not use any of FISs	[ ] Did not use any of SIATs

- ***In the first row, tick between FISs and SIATs, the one you prefer and have been adopting most. For the one you have ticked, rank the reasons why you use/adopt from a scale of 1 to n (1=most important reason and n=least important reason). Also, rank the constraints that prevent you from adopting/using SIATs fully by using a scale of 1 to n (1=most severe constraint and n=least severe constraint).***

[ ] Farmer Innovation Systems (FISs) (If tick this, answer 15.1 and 15.3 but do not answer 15.2)	**[ ] Scientifically Improved Agricultural Technologies (SIATs) (If tick this, answer 15.2 and 15.3 but do not answer 15.1)**	
15.1 Rank the reasons why you prefer FISs to SIATs	**15.2 Rank the reasons why you prefer SIATs to FISs**	**15.3 Rank cosntraints preventing you from fully or not adoption/using SIATs**
Higher yield [ ]	Higher yield [ ]	Higher production cost (capital intensive) [ ]
Less labour intensive [ ]	Less labour intensive [ ]	More Labour intensive [ ]
Quality output [ ]	Quality output [ ]	Low output quality [ ]
Draught resistance [ ]	Draught resistance	Low draught resistance [ ]
Maintenance of soil fertility [ ]	Maintenance of soil fertility [ ]	Higher rate of soil fertility loss [ ]
Higher market value of produce (higher income) [ ]	Higher market value of produce (higher income) [ ]	Low market value of produce (higher income) [ ]
Environmentally sustainable (reduce erosion, environmental and resource cost [ ]	Environmentally sustainable (reduce erosion, environmental and resource cost [ ]	Fear of crop failure (Lack of trust in SIATs) [ ]
Water saving [ ]	Water saving [ ]	Unavailability of certified seeds [ ]
Reduce weed growth [ ]	Reduce weed growth/easy to control weeds [ ]	Increase weed growth [ ]
For own innovations [ ]	Reduces drudgery [ ]	Low understanding (complexity) of technology [ ]
Low production cost [ ]		Lack of thrust in extension service delivery [ ]
		No conformity to my beliefs [ ]
		Unavailability of machinery (tractor etc) [ ]

- ***Please fill in the table by writing the names of varieties of rice cultivated, quantity sold, consumed, offered as gift, lost as well as the unit price per 50kg bag of paddy rice sold from 2014/15 cropping season.***

Varieties of rice cultivated in 2013/14 cropping season	Acres of land cultivated	Quantity sold (No. of 84kg bags)	Quantity consumed (No. of 84kg bags)	Quantity given as gift (No. of 84kg bags)	Quantity lost due to post harvest losses as gift (No. of 84kg bags)	Total quantity harvested (No. of 84kg bags)	Unit price of 84kg bag (Gh¢)	Total income (Gh¢)
Total								
							Total income (Gh¢)	

- ***Shocks, disasters and constraints***

17.1 Fill in the table below

In the 2013/14 cropping season, did any of these adverse events affect your production of rice? [1] Yes [2] No	Low temperature	High temperature	Strong winds	Low rainfall	Heavy rainfall or flooding or waterlogging	Drought	Fire	Soil erosion	Pest or diseases infestation

.4 Mention the main constraints facing rice production in your community. 1……………………………………………………………………………
2. ……………………………………………………………….. 3. ………………………………………………………………………………
4. ……………………………………………………………….. 5. ……………………………………………………………………………..

16. Respondent's household ID/House No:………………. Telephone no of respondent (if any) **……………………………..**

Thank you

Appendix 15: Matrix for Objectives, Methods, Key Findings, Conclusions, Implications and Policy Recommendations

Objectives	**Method of analysis**	**Key findings**	**Conclusions and policy implications**	**Policy recommendations**
To classify farmers into technology adoption typology and descriptively estimate the impact of each typology on rice yield	i. Principal Component Analysis (PCA) ii. Welch t-test.	i. Farmers were objectively and typologically classified as non-adopters e.i. users of indigenous farming practices (*IFPs*), adopters of farmer innovation systems (*FISs*), adopters of improved agricultural technologies (*IATs*) and adopters of both adopters of farmer innovation systems (*FISs*) and improved agricultural technologies (*IATs*). ii. *IATs* are more adopted in coastal savannah zone. iii. Rice yield of non-adopters, adopters of FISs, adopters of *IATs* and adopters of both FISs and IATs are 1.73Mt/Ha, 2.40Mt/Ha, 3.66Mt/Ha and 3.10Mt/Ha respectively.	Technology typology used in rice production are *IFPs*, *FISs* and *IATs*. Adopters of *IATs* have highest rice yield than any of the typologically classified adoption technologies. Superior technology for rice production in Ghana are *IATs*.	*IATs* should be highly promoted among farmers in the whole country but more emphasis ahould be given to its promotion among farmers in coastal savannah zone
To identify reasons for the choice of each technology typology and the constraints face in adopting superior technology	Kendall's Coefficient of Concordance	i. Farmers prefer to adopt *FISs* because of low production cost ii. Farmers adopt *IATs* because of high productivity iii. High rice production cost is the most pressing constraint preventing farmers from fully adopting *IATs*.	i. The superior rice production technology typology is *IATs* ii. The adoption of *IATs* is more expensive than *FISs*	AEAs, researchers and NGOs should educate farmers for them to know the long run benefits of adopting *IATs*. Credit support system and contract farming concept should be promoted

Continuation of **Appendix 15: Matrix for Objectives, Methods, Key Findings, Conclusions, Implications and Policy Recommendations**

Objectives	**Method of analysis**	**Key findings**	**Conclusions and policy implications**	**Policy recommendations**
To model the determinants of rice output and estimate agro-ecological zone specific technical efficiency and metafrontier technical efficiency of rice farmers in Ghana.	New-Two Step Stochastic Metafrontier Translog Model	i. The total elasticity of rice output for farmers in each of the agro-ecological zones as well as metafrontier is greater than 1. ii. While addition of each of capital, labour, farm size, pesticides and fertilizer increase rice output, addition of seed decreases rice output iii. The average technical efficiencies of farmers in guinea savannah, forest savannah and coastal savannah zones are 82.21%, 83.57% and 89.10% respectively whereas the metafrontier technical efficiency of farmers in guinea savannah, forest savannah transition and and coastal savannah zones are 76.35%, 76.16% and 75.11% respectively.	i. Rice farmers are operating at increasing returns to scale. When inputs are jointly increased, rice output will increase more than the proportionate increase in the inputs. ii. Farmers are overcrowding rice plants iii. Technical inefficiency is evident in rice production. iv. Within groups, farmers in coastal savannah zone are more technically efficient in rice production than their counterparts. Farmers in guinea savannah zone have the highest metafrontier technical efficiency	i. Farmers ahould jointly increase capital, labour, farm size, pesticides and fertilizer except auantity of seed as a unit a percentage increase in them results in more that a proportionate in in rice output ii. Farmers are urged to reduce seeding rate
To identify the determinants of agro-ecological zone specific technical efficiency and metafrontier technical efficiency of rice farmers in Ghana.	New-Two Step Stochastic Metafrontier Translog Model	Technical inefficiency of farmers are negatively influence by age, sex, household size, education years, extension visits, contract farming, access to improved seeds, access to irrigation, high rainfall amount, less lodging of rice, and well-coordinated and synergised adoption of technologies.	Farmers can improve their technical efficiencies through access to improved seeds, access to irrigation facilities, extension service, engagement in contract farming, well coordination of the adoption of *FISs* and *IATs*.	i. Contract farming concept, provision of improved rice seeds, intensification of agricultural extension services should be vigorously pursued to the latter ii. The longterm policy of govenrnement and any development partner should be the construction of irrigation facilities in major rice production communities.

				iii. Ministry of food and agriculture, development partners and individual private companies should educate farmers to coordinate and synergise the adoption of the FISs and *IATs*

Continuation of **Appendix 15: Matrix for Objectives, Methods, Key Findings, Conclusions, Implications and Policy Recommendations**

Objectives	**Method of analysis**	**Key findings**	**Conclusions and policy implications**	**Policy recommendations**
To estimate technology gap ratio (TGR) and identify the influencing factors	New-Two Step Stochastic Metafrontier Translog Model and Generalised Linear Model (GLM)	i. Farmers in guinea savannah have the highest TGR (92.62%) followed by farmers in forest savannah transition (91.07%) with coastal savannah zone having the lowest (90.45%). ii. Technology gap ratio is positively influenced by contract farming, access to irrigation, good road conditions, nearness of farms from the house, non-lodging of rice, high actual rainfall amount, adoptions of FISs and adoption of IATs.	i. Farmers in coastal savannah have the highest potential of increasing rice yield. ii. Good infrastructure, favorable environmental conditions, favourable government and NGO policy supports and improved agricultural technologies and farmer innovations can enhance potential of farmers to increase rice productivity closer to potential productivity level in Ghana	i. Good road infrastructure and irrigation facilities should be provided for in rice farming communities ii. FISs and IATs should be highly promoted for farmers to adopt. iii. Farmers whose rice fields are far away from their houses are hornestly urged to build farm houses and move to stay in them to do work at the peak periods.
To identify the drivers of farmers' decision to adopt particular technology packages.	Multinomial Endogenous Switching Model	i. Factors motivating the adoption of *FISs* are high number of FBOs advice, many years of rice farming experience and farness of input market whereas probability of adoption *IATs* increases with many extension visits, credit access, contract farming, location of farmers in coastal savannah zone, closeness of the farmers to input markets as well as Accra.	Farmers will be motivated to adopt *IATs* when they have access to extension advice, credit, engaged in contract farming, have easy access to the improved inputs.	Contract farming concept, provision of improved rice seeds, intensification of agricultural extension services should be vigorously pursued to the latter

		ii. Older farmers and farmers who have access to input subsidy have higher probability of jointly adopting both FISs and *IATs*		

***<u>Continuation of</u>* Appendix 15: Matrix for Objectives, Methods, Key Findings, Conclusions, Implications and Policy Recommendations**

Objectives	**Method of analysis**	**Key findings**	**Conclusions and policy implications**	**Policy recommendations**
To econometrically assess the impacts of each technology adoption package on rice rice yield	Multinomial Endogenous Switching Model (MESM)	i. While adopters of FISs would have lost 0.4404Mt/Ha (2.12bags/acre) if they had decided not to adopt, non-adopters of FISs would have lost 2.2157Mt/Ha (10.68bags/acre) if they decided to adopt. ii. Adoption of IATs by non-adopters can increase rice yield by 1.1929Mt/Ha (5.75bags/acre). iii. Joint adoption of FISs and IATs can increase rice yield by 1.1389Mt/Ha (5.49bags/acre)	i. Adhoc adoption of *FISs* by non-adopters reduces rice yield. Wholesome recommendation of *FISs* to all farmers is not justifiable. ii. The superior technology that can increase rice yield of farmers is *IATs*	i. Farmers should always modify any *FISs* that they adopt to suit their situations ii. *IATs* should be highly promoted among farmers in the whole country but more emphasis ahould be given to its promotion among farmers in coastal savannah zone iii. Concerted and co-ordinated efforts should be made for researchers in national agricultural research and academic agricultural research institutions centres to research into rice production farmer innovation systems and improved upon and made available to farmers for adoption
To analyse gendered effects of resource-use efficiency of farmers across agro-ecological zones	i. New-Two Step Stochastic Metafrontier Cost Translog Model ii. Welch t-test	i. Female rice farmers have relatively high allocative efficiency than their counterpart male farmers	Factors of production are more under-utilised by female than male rice farmer. Female farmers have better managerial skills and hence are able to choose proper input mix given the available input prices than males	It is recommended for female rice farmers to increase the usage of factor inputs to take advantage of relatively low input mix cost. This can be effectively done through female targeted credit support system, input subsidy, land allocation etc by government, NGOs and development partners.