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FARMER INNOVATIONS, IMPROVED AGRICULTURAL TECHNOLOGIES AND PRODUCTIVITY HETEROGENEITY OF RICE PRODUCTION IN GHANA

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(M.PHIL. AGRICULTURAL ECONOMICS)

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS, FACULTY OF AGRIBUSINESS AND COMMUNICATION SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE (PhD) IN AGRICULTURAL ECONOMICS

JANUARY, 2018

DECLARATION

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

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(Name of Student)	Signature	Date

We hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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ABSTRACT

In recent times, rice production can be said to be receiving some attention in Ghana. This notwithstanding, 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 draws policy implications for the 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 classify farmers into non-adopters, adopters of *FISs*, adopters of *IATs,* and adopters of both *FISs* and *IATs*. The study used the theory of production and the theory of utility maximisation as the theoretical foundations. The new-two step stochastic metafrontier model was used to estimate productivity performances of rice farmers and identify the determinants of such performances because of agro-ecological differences and its ability to provide exact and accurate metafrontier technical efficiency estimates. The generalised linear model (GLM) was used to analyse the drivers of technology gap ratio. In order to estimate the impacts of technology adoption typology on rice yield, this study used multinomial endogenous switching regression model. Farmers in CSZ had the highest rice yield. The adoption of IATs has the highest impact on rice yield 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 recorded the highest potential of increasing rice yield since they had the lowest technology gap ratio (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 should 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. GSZ should be highly considered due to high percentage of non-adopters of the superior technology package. Contract farming should be vigorously pursued. In the long term, government and development partners should provide good road infrastructure and irrigation facilities in rice production communities. Lastly, 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) should vigorously research into rice production *FISs* and improved upon and made available to farmers to adopt. All these efforts should incorporate the needs of farmers in the respective agro-ecological zones.

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DEDICATION

I dedicate this thesis to my lovely wife, Mrs. Esther Mabe, my children, Humphrey S. Mabe, Mathias B. Mabe and Ithiel W. Mabe and dear mother, Mrs. Faustina Tiboriwo Mabe.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AE	Allocative Efficiency
AEAs	Agricultural Extension Agents
AM	Ashaiman Municipal
AR	Ashanti Region
ASRP	Agricultural Services Habitation Project
ATT	Average Treatment Effects on the Treated
ATU	Average Treatment Effects on the Untreated
BAR	Brong-Ahafo Region
BSD	Builsa South District
CARD	Coalition for African Rice Development
CCR	Charnes, Cooper and Rhodes
CD	Chereponi District
CR	Central Region
CRI	Crop Research Institute
CSZ	Coastal Savannah Zone
DEA	Data Envelopment Analysis
DIM	Diffusion of Innovation Model
DMU	Decision Making Units
SOD	Shai Osudoku District
EE	Economic Efficiency
ER	Eastern Region
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FASDEP	Food and Agriculture Sector Development Policy
FIML	Full Information Maximum Likelihood
FISs	Farmer Innovation Systems
FSTZ	Forest Savannah Transition Zone
GAR	Greater Accra Region
GADCO	Global Agricultural Development Company
GCAP	Ghana Commercial Agricultural Project
GDP	Gross Domestic Product
GF	Group Frontier
GLM	Generalised Linear Model
GLSS6	Ghana Living Standard Survey Six
GPRS	Ghana poverty Reduction Strategy
GSGDA	Ghana Shared Growth Development Agenda
GSZ	Guinea Savannah Zone
HM	Hohoe Municipal
HRFZ	High Rain Forest Zone
IATs	Improved Agricultural Technologies

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
KD	Kumbungu District
KND	Krachi Nchumburu District
KNM	Kasena Nankana Municipal
KtND	Ketu North District
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
NDPC	National Development Planning Commision
NERICA	New Rice for Africa
NGOs	Non-Governmental Organisations
NPD	Ningo Prampram District
NR	Northern Region
NRDP	NERICA Rice Development Project
NRDP	NERICA Rice Dissemination Project
NRDS	National Rice Development Strategy
NTD	North Tongu District
PD	Pru District
Ph.D	Doctor of Philosophy
PPI	Productivity Performance Indices
PSM	Propensity Score Matching
RER	Random Error Ratio
RY	Rice Yield
SAP	Structural Adjustment Programme
SARI	Savannah Agricultural Research Institute
SDGs	Sustainable Development Goals
SDRFZ	Semi-Deciduous Rain Forest Zone
SE	Standard Error

SNM	Savelugu-Nanton Municipal
SRI	Soil Research Institute
SRID	Statistics Research Information Directorate
SSA	Sub-Sahara Africa
TD	Tolon District
TE	Technical Efficiency
TER	Technical Efficiency Ratio
TGR	Technology Gap Ratio
UER	Upper East Region
USA	United States of America
USAID	United States Agency for International Development
UWR	Upper West Region
VR	Volta Region
WARDA	West African Rice Development Association
WMD	West Mamprusi District
WR	Western Region

CONVERSIONS OF UNITS

Standard Metric Units

1Kg	0.001T
1T	1000Kg
1ha	2.471acres
1acre	0.404Ha

Standard Metric Units

1bag of pady rice	84Kg (From the field and hence this is non-standard)

CHAPTER ONE

INTRODUCTION

1.1 Background

Agriculture has remained the cornerstone of many African economies, employing 48%, and contributing significantly to Gross Domestic Product (GDP) in most of the countries (Blein *et al.*, 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. Out of 51 mllion farms in Africa, 80% (or 41 million) are smaller than 2 ha in size (Lowder *et al.*, 2016). This smallholder farms supply 30% of total agricultural output (Herrero, et al., 2017). In the current decade, people especially policy makers and scientists are very conscious of helping farmers increase agricultural productivity in Africa of which Ghana is not exception.

The general population in Ghana has over the years been fed with the help of farmers especially the industrious contributions of smallholder 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) (2017), the agricultural sector recorded a growth rate of 3.6% in 2016 thereby contributing 18.9% to the overall GDP of Ghana. It is important to note that in 2016, the sector contributed 29% to the foreign exchange earnings of the economy (ISSER, 2017).

In Ghana, agriculture is often regarded as the engine of growth because it plays a critical role through the provision of food for the populace and raw materials for the industrial sector. The sector also provides avenue for the absorption of majority of Ghanaian labour force. Most rural folks in Ghana are engaged in agricultural production in one way or the other. The rural economy predominantly depends on agricultural activities. Agricultural production has become a livelihood support sector for a great number of people in the rural areas. Many rural folks are directly or indirectly involved in agricultural production and marketing. Many people are also engaged in the agricultural product value addition.

At least, five of the Sustainable Development Goals (SDGs) are strongly linked to agricultural because agricultural sector has direct impact on their attainment. They are end poverty in all its forms everywhere; end hunger, achieve food security and improved nutrition and promote sustainable agriculture; achieve gender equality and empower all women and girls; ensure sustainable consumption and production patterns; and protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. The Ministry of Food and Agriculture (MoFA) (2015) noted that these goals can be achieved sustainably through increasing agricultural productivity. Therefore, improving agricultural productivity in the crop subsector is cardinal.

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 noted in Table 1. 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 very high. 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, 2017).

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 homes, Ghanaian hospitality industries, during official functions, funerals and traditional durbars. Also, the urbanisation and the engagement of most Ghanaians in full time employment 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 compounded 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 gro 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)] that MoFA rolled out in the rice sector across the country, rice production deficit has been 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 hectares 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.

Despite 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).

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 produced most are Volta, Northern and Upper East regions. In 2015, Volta, Northern and Upper East regions respective produced 31.71%, 27.74% and 18.87% of the national rice output (MoFA, 2016). Greater Region which crontributed just 3.49% of the national rice output in 2015 is cardinal since it solely produces irrigated rice. 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 (Sudan 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, which have bimodal rainfall distributions in a year.

As a result of 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, there have been wide differences in rice yields. *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* (Tambo and Wuscher, 2014). 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, drought 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 processing 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 Centre for Scientific and Industrial Research [Savannah Agricultural Research Institute (SARI); Soil Research Institute (SRI); and Crop Research Institute (CRI)], International Rice Research Institute (IRRI) among others. Unlike FISs which are equally improved ways of increasing rice yield, vigorous 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 plan framework, the Medium Term Agricultural Sector Investment Plan (METASIP) enumerated six strategic programmes for the improvement and modernisation of 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, the application of science and technology in agricultural production and improved institutional coordination (MoFA, 2007 and MoFA, 2010). The two documents aim at improving agricultural productivity of priority staple food crops including maize, rice, yam, cassava and cowpea.

FASDEP II identified rice as one of the important food crops that need special attention for the country to attain food self-sufficiency. This is premised on the high demand for rice 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 decade has witnessed heavy investments in irrigation facilities and the 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, Dawhenya, Tankase, Koori are currently under construction and rehabilitation. According to Mabe (2014), 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. The construction of Avnash, a rice processing factory in the Northern Region of Ghana is another huge investment in the rice subsector.

Investement in land development of rice production is also on the increase. Large hectares of land have 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. 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 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, 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 agriculture. 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 investment priorities indicated in the preceding paragraphs aimed at increasing rice productivity and production levels. This is to help farmers increase their income levels and reduce importation of foreign rice. 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. 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 2.8Mt/ha

(MoFA, 2016). Many researchers have ascribed this low yield to rudimentary technologies used by farmers, incidence of diseases and pests as well as unavailability of certified seeds. Rice productivity is not only low; there is wide variationin in productivity levels across the agro-ecological zones (regions). The regional productivity differences are attributed to the heterogeneity in production systems of the cereal.

Characteristically, the soil and climatic conditions of the entire country differ slightly across agro-ecological. 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 in 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. The contributions of farmer innovation rice production systems or improved rice production technologies as well as differences in environmental (soil and climatic) conditions to heterogeneous rice yield across agro-ecological zones cannot be eliminated. Over the years, rice productivity among agro-ecological zones has been highly heterogeneous and the drivers of this heterogeneity still remain a misery.

Evidently, rice yields differ across the agro-ecological zones in Ghana. Table 1.1 shows output, area cultivated and yields of rice in the ten administrative regions in Ghana for 2014 and 2015 cropping seasons. Whilst farmers in Greater Accra Region (CSZ) always obtained rice yield above 6Mt/ha, their counterparts in Northern (GSZ), Upper East (Sudan

Savannah and GSZ) and Volta (Transitional Savannah) Regions where the much rice is produced always struggled to obtain 4Mt/ha. In 2015, farmers in Greater Accra obtained rice yield of 6.95Mt/ha whilst those in Northern, Upper East and Volta Regions obtained 2.23Mt/ha, 2.78Mt/ha and 4.56Mt/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 and this may be attributed to the fact that rice production in Greater Accra is largely done under irrigation. As can be seen in Table 1.1, rice yield among regions are highly heterogeneous.

Table 1.1 Production Output, Area Cropped and Yield of Rice in 2014 and 2015

Region	Quantity (Mt)		Area (ha)		Yield (Mt/ha)	
	2014	**2015**	**2014**	**2015**	**2014**	**2015**
Western	33,080	33,741	25,914	27,677	1.28	1.22
Central	2,846	2,561	1,645	1,645	1.73	1.56
Greater Accra	21,528	22,389	3,219	3,219	6.69	6.95
Volta	188,952	203,419	42,873	44,635	4.41	4.56
Eastern	33,205	33,869	9,572	9,572	3.47	3.54
Ashanti	34,614	31,153	11,449	13,212	3.02	2.36
Brong Ahafo	7,435	7,064	4,448	4,448	1.67	1.59
Northern	164,979	177,946	77,961	79,724	2.12	2.23
Upper East	109,394	121,075	41,788	43,551	2.62	2.78
Upper West	8,008	8,275	5,587	5,587	1.43	1.48
TOTAL	**604,041**	**641,492**	**224,457**	**233,270**	**2.69**	**2.75**

Source: Statistics, Research and Info. Directorate (SRID), Min. of Food & Agric.-March, 2016

As noted by Abdulai and Huffman (2014) that it is possible for farmers to increase the productivities of crops through adoption of modern farming practices, the same may be said specifically to 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 levels. Regional (agro-ecological) heterogeneity in rice yield (land productivity) can be bridged or improved through adoption of *IATs* or *FISs*.

Low productivity is critical to farmers and hence it is important for them to adopt innovations[1]. 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 to 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

[1] Wills (2012) stated that "while invention often concerns a single technique or technology, innovation frequently involves the combination of existing techniques or technologies in new ways in order to enhance their impact".

of assessing whether they are demand driven or not. Many of the farmers feel that their own farmer innovations are better and therefore, they fail to adopt the externally developed *IATs*.

Irrespective of many rice productivities enhancing agricultural technologies developed over the years, the actual rice yield is still below the potential yield and varies across agro-ecological zones. This might be that there is always a disconnection between what farmers require and what MoFA, research institutions and other stakeholders in the agricultural sector provide.

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 innovations in 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 of farmers' innovations is not analysed 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 following: differences in *IFPs*, *FISs* and *IATs;* efficiencies of farmers in the production process; climatic and soil conditions; 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 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 unravelled the drivers of efficiency performances of rice farmers but none of these did a country-wide 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. Since there are no empirical studies, to the best of the researcher's knowledge, on the causes of rice productivity heterogeneity among the agro-ecological zones in Ghana, the attributable factors at the national level can only be guessed and hence the need for this research.

Methodologically, none of the above-mentioned studies has examined the impact of rice farmers' adoption of *FISs* and *IATs* on productivity performance especially rice yield (RY) using instrumental variables especially multinomial endogenous switching regression model.

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 factors that determine rice output and what are the levels of technical inefficiencies of farmers in GSZ, FSTZ and CSZ in Ghana?

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

4. What are the drivers of technology gap ratios of rice farmers in Ghana?

5. What factors influence rice farmers' decision to adopt a particular technology typology?

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

1.3 Objectives of the Study

The principal objective of this study is to analyse the impacts of farmer innovation systems (*FISs*), improved agricultural technologies (*IATs*) on productivity heterogeneity of rice farmers among agro-ecological zones in Ghana. In order to achieve this prime objective, the specific objectives of the study are to:

1. classify farmers into technology adoption typology and statistically test the differences in rice yields among the typology;

2. identify the determinants of rice output and estimate agro-ecological zone specific technical efficiency and metafrontier technical efficiency of rice farmers in Ghana;

3. investigate the determinants of agro-ecological zone specific technical efficiency and metafrontier technical efficiency of rice farmers in Ghana;

4. estimate technology gap ratio (*TGR*) and identify the influencing factors;

5. identify the drivers of farmers' decision to adopt a particular technology package;

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

1.4 Hypotheses of the study

Hypotheses are tentative statements about the relation between two or more variables. The principal hypothesis to be tested in this research is that *IFPs*, *FISs* and *IATs* are major causes of yield and efficiency heterogeneity among rice farmers in and across the various agro-ecological zones in Ghana. It is also hypothesized that adoption of appropriate *FISs* and scientifically *IATs* is a viable option for low efficient rice farmers in one agro-ecological zone to improve upon their efficiencies so as to catch up with highly efficient rice farmers in another agro-ecological zone. Additionally, favourable institutional factors, policy variables and environment conditions increase the ability of farmers to bridge TGR.

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 formulation and implementation, farming and agricultural extension delivery and advocacy. Notable among them are briefly explained below.

In Ghana, the typology, the impacts and policy implications of rice production *FISs* and *IATs* need to be researched into. Full knowledge on 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 guide policy directions for rice productivity enhancement in the country. To make innovations demand driven and widely acceptable, research of this nature is critical as it aims at identifying, classifying and documenting farmer based-innovations in rice production. 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

In conducting this empirical study, the researcher will be able to determine the actual gap between the group frontier output and the group 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 *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 *FISs* and *IATs* on technical efficiency and technology gap ratio is deficient. Therefore, this study will assist policy makers to know whether *FISs* or *IATs* or a combination of them have the potential of improving upon productivity performances of rice farmers. This will help us know which of these produce the best results for farmers.

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.

It is imperative to note that, many researchers both local and international have used stochastic frontier analysis to determine technical and allocative efficiencies and prescribed 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, there has not been enough methodological analysis of productivity heterogeneity among groups with different characteristics. In academia, the research will contribute immensely 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 Thesis

The thesis is organised into eight 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 analyse 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. The empirical results on the determinants of rice output and productivity performances of rice farmers in Ghana are presented and discussed in chapter six. Chapter seven presents and discusses the impacts of technology adoption on rice rice yield in Ghana. The conclusions, policy recommendations and suggestions for future research are presented in chapter eight.

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 the ability of stochastic metafrontrier 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. However, the 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 CSZ) could improve their technical efficiency. Also, the study fails to incorporate marketing efficiencies, which are very vital in determining the 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 the objective of achieving desirable results. 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 district 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, district policy or local policy just to mention few.

Over the years, Ghana's agricultural sector has had many policy documents which specify the investment direction of government and development partners. In Ghana, most rice policies are embedded in the agricultural policy documents. Considering the importance of rice to 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), 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 oriented policies (1957-1982). That policy document was strategically designed to help the country achieve self-sufficiency status in priority staple crops including rice. The policy was successful at the country averagely achieved rice self-sufficiency rate of 63.3% with the highest rate of 99.2% achieved in 1976 (Bozza, 1994). During the pre-trade liberalization period (1957-1982) 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 off tax on other agricultural inputs such as tractor and its implements (Mercer-Quarshie, 2000).

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 (Brooks *et al*., 2007). This policy document was comprehensive because it included ways of improving agricultural research for enhancing rice, maize and cassava productivities. Eventhough, the policy objectives were good, the implementation was difficult due to weak institution capacity (Brooks *et al*., 2007).

The "Agricultural Services Rehabilitation Project (ASRP)" 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. It generally aimed at strengthening the institutional framework for formulating and implementing agricultural policies and programmes and improve private sector participation in the procurement and distribution of agricultural inputs (Brooks *et al*., 2007). Even though, other thematic areas of ASRP targeted the rice subsector, the investment in irrigation development was mainly directed to modernizing production (Asuming-Brempong, 1998). Another principal 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 (Kranjac-Berisavljevic, 2000 and Asuming-Brempong, 1998). 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. This was to be done through achieving food security, poverty reduction and supplying of raw materials to industries ((Brooks *et al.*, 2007). It is important to note that FASDEP I was developed based on the tenets of Accelerated Agricultural Growth and Development Strategy. The rice production sector was also a component of FASDEP I. FASDEP I was developed to fit into national policy document, Ghana poverty Reduction Strategy (GPRSI) (2003-2005) (MoFA (2007).

This revised policy (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 (MoFA, 2014). 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. It emphasises on the sustainable utilization of all resources for agricultural commercialisation, food security and income diversification of resource poor farmers (MoFA, 2007). Empirically, the development of rice value chain saw high boost under the implementation of FASDEP II.

Because FASDEP II is an intention policy document, the realisation of its objectives was done through the development and implementation of a Medium-Term Agriculture Sector Investment Plan (METASIP) (MoFA, 2010). The years of its implementation spanned the period 2011-2015. METASIP has the objective 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 done through investment in agricultural production, application of scientific methods etc.

The "National Rice Development Strategy (NRDS)" which aims at doubling domestic production of rice by the end of the 10-year period starting from 2009 to 2018 (Angelucci *et al.*, 2013). With the NRDS, the government continues to invest in improving the quality of domestically produced rice through the development of quality rice varieties, promote its consumption and increase information sharing among stakehlders in the rice value chain. As part of the efforts to increase and improve the quality of 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, establishement of rice milling centres, feeder road construction to create market access, block farm promotion, and marketing.

The medium-term national development policy framework, Ghana Shared Growth and Development Agenda (GSGDA) II is another policy document which contains the specific strategies to be implemented for the modernisation of agricultural sector. The third thematic area of GSGDA II is accelerated agricultural modernisation and natural resource management [National Development Planning Commission (NDPC), 2015]. Under this thematic area, the development of the three selected cash crops (Cocoa, Oil Palm, Cotton) and horticultural products for export and processing, as well as food crops (rice and maize) to ensure food security is one of the cardinal specific interventions (NDPC, 2015).

According to Angelucci *et al.* (2013), the underlisted are some of the on-going and completed rice-related development projects implemented by MoFA and some development partners.

1. Food Security and Rice Producers Organization Project (2003-2008)
2. Special Programme for Food Security in Ghana (2002-2007)
3. Project for Promotion of Farmers' Participation in Irrigation Management (FAPIM) (2004-2006)
4. The Study on the Promotion of Domestic Rice in the Republic of Ghana (2006-2008)
5. Small Scale Irrigation Development Project (2001-2009)
6. Inland Valleys Rice Development Project (2004-2009). May be extended to 2011
7. Improvement of Drought Tolerance of Rice through Within-Species Gene Transfer (2007-2009)
8. Small Farms Irrigation Project (2003-2009)
9. NERICA Rice Dissemination Project (2005-2010)
10. Rice Seed Production (2008-2010)
11. Ghana Rice Inter-Professional Body (2008-2012)
12. Rice Sector Support Project (2008-2014)

13. Project for Sustainable Development of Rain-fed Lowland Rice Production (2009-2014)
14. Development of low-input rice cultivation system in wetland in Africa (2009-2015)
15. Development of rice varieties with enhanced nitrogen use efficiency and salt tolerance (2010-??)
16. Improving yield, quality and adaptability of upland and rain-fed lowland rice varieties in Ghana to reduce dependency on imported rice (2010-2012)
17. An Emergency Initiative to Boost Rice Production (USAID – SARI) (2008-2010)
18. Improving Organic Matter content of soil for increased yield of NERICA (2006-2011)
19. Development of Rice Varieties with Enhanced Nitrogen-Use Efficiency and Salt Tolerance (NUE EST-AATF) (2010-2015)
20. Improving Yield, Quality and Adaptability of Upland and Rain fed Lowland Rice Varieties in Ghana to Reduce Dependency on Imported Rice (CRI-AGRA) (2009-2012)
21. Expanded Rice Programme (2008-on-going)
22. Dissemination of Improved Rice Production Systems with Emphasis on Nerica to Reduce Food Deficit and Improve Farmers Income in Ghana (2011-2014)

2.2 Types of Rice Production Systems in Ghana

Agro-ecological names are used to classify rice production systems in Ghana. The source of water used for the production of 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 (FAO, 2006). Of all these systems, lowland rainfed system of rice production is the main type followed by irrigated system.

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 the 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.

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).

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 • SwampsIrrigated
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)

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 are able to 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. In general, 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). Table 2.2 shows features/characteristics and the percentages of farmers with those characteristics in Ghana (MoFA, 2009).

Table 2.2 Percentages Distribution of Rice Farmers by Typology

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 are able to 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

The efforts of government of Ghana and other stakeholders in rice subsector cannot be under stated. Irrespective of the fact that Ghana as a country is improving and making headway in rice production, the country is still facing numerous challenges in rice subsector. 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 (MoFA, 2014) affects their ability to access and own land for rice cultivation. Rice production is 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 farming communities, women are part of farming households but their roles in decision making on agricultural production is often relegated. This is common in the northern part of the country where women are often downgraded in rice production decision making. Base on the mistrust between husband and wives, a woman cannot unilaterally meet a male agricultural extension agent for advice on farming activities. These affect their ability to have access to improved technology for adoption and productivity enhancement (Quaye *et al.*, 2014).

As a country, there a number of traditional rice festivals. Most of these festivals are celebrated by the people of Volta Region. During these festivals, different rice cuisines displayed. Many traditionalists use rice as food for the goddesses. This presents a great opportunity for rice production in Ghana. In spite of these opportunities, many farmers still do not have the incentive to enter into rice production in commercial quantities. Due to low literacy rate, farmers do not have the capacity to quickly and adequately adopt improved rice production technologies (Akongo, 2016). Farmers are adamant in changing their indigenous methods of rice production. The indigenous method of cultivating rice is still the norm of the day.

There is also a notion in some villages in Ghana that families who eat rice are food insecure and hence such families are often ridiculed. This tends to affect the production of rice in large scale as compared to maize which is a major staple food in Ghana (MoFA, 2015). Due to the fact that farmers regard maize as an important food security crop than rice, Amanor-Boadu *et al*. (2015) found out that the average household land allocated to maize production in 2012 in Northern Ghana was 1.2 ha as compared to 0.8ha for rice. The trickle-down effects of rice consumption which should stimulate production are not felt. The above-mentioned factors create disincentives for some farmers especially in some traditional areas in northern Ghana.

2.4.2 Land Tenure System

The landownership 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 concern and approval. Any member of the family cannot also sell any piece of land without all the family members' concern and approval. For a piece of land to be sold for agricultural investments, all the people in the family need to be convinced and this takes time. Therefore, land acquisition in Ghana takes a longer time and it is also cumbersome thereby discouraging domestic and foreign investors. Business people who conscious of time value of money will not have the patience to wait for one to three years just to acquire land for agricultural production. Therefore, agricultural production including the cultivation of rice stands the risk of note receiving the necessary investment.

As a monoculture crop, many land owners are not willing to lease land for rice production. Many of the leasors lament that rice farmers tend to cultivate rice on the same piece of land from year to year thereby rendering the land infertile in the shortest possible time. With that, they do not get good deals when the land is to be lease to another prospective farmer since the next leasee would have to apply heavy amount of fertility to regain the soil fertility. Therefore, land acquisition for rice production is a huge challenge in Ghana.

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 their 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 compare to cultivating lands which are adjoining.

2.4.3 Changes in Environmental and Climatic Condition

As it stands now, rice is the most important staple crop on this globe since it is the most widely consumed food in the world. It is worth noting that the human population in the world feeds on 532 million tonnes of rice food (Angelucci *et al.*, 2013). One cannot underscore the fact that rice is a global food security crop. Meanwhile, in Ghana especially northen Ghana, 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). Since rainfed upland and rainfed lowland system of rice cultivation is preeminent in Ghana and the evidence that rainfall amount is decreasing over the years, Ghana domestic rice sector is going to be affected in the future. It is important to note that the changing climatic and environmental conditions will worsen the already on-farm low productivity of rice being experienced in the country.

In order to overcome this challenge, different water saving rice production technologies 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 "Green Revolution" that introduced new technologies like high yielding rice varieties, inorganic fertilizer and pesticides during the 1960s. Assuming-Brempong *et al*. (2011) posited that adoption of improved varieties of rice especially NERICA variety 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. In order 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.

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), 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. 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) Rogers (1983).

Psychologists regard decision making as a cognitive process which involves the brain (Barry and Halfmann, 2016). The rationality of an individual decision making requires that the decision maker has significant, if not full or explicit knowledge about the possible outcome of each of the options available. For technology to be adopted, decision 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 behavior 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).

In order 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 (Rogers, 2003). 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 an innovation spreads through social communication processes (factors extrinsically controlled but not intrinsically controlled).

Rogers' DIM 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 where farmers are being sensitized on the innovations. After the creation of the awareness, data is colletcted from the farmers and evaluated to know their perception about the expected benefits 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 benefits of the innovation outweigh their indigenous way of farming, they adopt the innovation.

After a while, other people within the social structure learn from the innovators (early adopters) and adopt the said innovation. Over time, the number of adopters increases to the maximum and begins to decrease as some of the adopters stop adoption by going back to their old ways (Rogers, 2003).

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 of time. 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 period. The innovation needs to be communicated to the target group through channels like the mass media or face-to-face interaction. The choice of an appropriate channel is crucial. The characteristics of the target group help in selecting the appropriate channel of communication and this 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 the innovation.

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 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 (Tambo, 2013).

The improvement in the management of any organization in this 21st century is hinged on the ability of the organization to develop innovations which the organization uses to carve a niche for itself. Similarly, farmers can improve on their farming practices to form innovations which are unique to them. Not only that but also, the enhancement of the agricultural sector in every country depends greatly on the innovativeness of farmers and policy makers. Innovations provide the hedge for an organisation or firm to allocate resources efficiently given the constraints so as to increase productivity.

Farmer innovations, which according to World Bank (2011), are critical to improving agricultural productivity, have not been fully harnessed in developing countries including Ghana. Indigenous farmers have over the years modified indigenous farming systems and practices with the aim of improving agricultural productivity. 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 are non-scientific, they cannot be verified using scientific methods. Meanwhile, they are important to local farmers. This is because farmers' innovations are easily accepted and adopted by other farmers than externally developed improved farming technologies.

Even though, Rogers (2003) used the word "technology" and "innovation" as synonyms, there are differences between them. The succeeding subsections provide vivid description of *IFPs*, farmer innovations and improved farming technologies. The quest for higher agricultural productivity led to the modernization of agricultural production activities through scientific research. Scientific research resulted in the identification of *IATs* which are described in this research as *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 beliefs have been handed over to local farmers in specific geographical zones. Indigenous farming knowledge or practices are not scientific technologies, rather they are practices developed based on beliefs and experiences, and used by farmers and they change over time (Chambers *et al.*, 1989; Gilbert *et al.*, 1980). It is important to note that an indigenous farming knowledge or practice is not owned by a tribal group or the original inhabitants of an area because it is not patented. This indigenous knowledge can be traditional beliefs or farming practices. Despite the onset of the Green Revolution, *IFPs* still exist. Some of the *IFPs* are mixed cropping, shifting cultivation, mono-cropping, farm yard manure, closer planting, use of hoe and cutlasses, setting of traps, using of scare crow among others.

3.4.2 Farmer Innovations Systems

According to Rogers (2003, p. 12), “an innovation is an idea, practice, or project that is perceived as new by an individual or other unit of adoption” (Rogers, 2003, p. 12). From Rogers’ definition, one can have different types of innovation. In this research, farmer innovations are the focus. A practice or knowledge is classified as an innovation when it is perceived to be new irrespective of whether it was discovered, invented, developed or existed long ago (Hahnke (2007). The saying that “experience is the best teacher” can be used to explain the development of farmer innovations. Through constant and continuous involvements of farmers in agricultural production over the years, farmers have become well experienced. They have over the years changed or modified the manner in which they farm and handle agricultural foodstuffs. In an attempt to adapt to the changing environmental conditions and increase agriculture productivity, they have become innovators in agricultural production.

Over the years, farmers have single-handedly and innovatively selected rice varieties which are high yielding. Some of the farmers have also developed storage technologies which do not require heavy expenditure or the use of fungicides or insecticides. According to Tambo and Wunscher (2014), some of the farmers store seeds of crops in bicycle tubes, some use pepper and *neem*[2] (*Azadirachta indica*) extract to treat seed before storage. Despite the development or discovery of farmer innovations as well as its contribution to improving agricultural productivity, these farmer innovations have not been fully documented and improved upon.

Farmers in different agro-ecological zones are likely to have different localized *FISs* which are unique. Irrespective of this, farmers from different agro-ecological zones in Ghana share certain things in common. These include socio-economic factors, farming practices, crop varieties, history of farming etc. As such, it is possible that some of the innovations used by farmers will be common across agro-ecological zones in Ghana. Farmer innovations, which are farmer-specific have not also received intellectual property right. Some farmer innovations are agro-ecological zone specific while others are farmer specific. It is necessary for researchers to estimate the impact of innovations and make recommendations for further improvement by agronomists and promoted by all stakeholders. Also, the improvements of identified farmer innovations as well as modification of modern scientific innovations are critical to productivity enhancement.

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

[2] Neem is a medicinal tree which is very bitter

generation. It also includes internalization of external knowledge into local settings. Famer innovations include techniques or practices or process 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 in order to enhance their impact". They can be applied in everyday life of farming households.

Indigenous and local farmers are not only adopters of externally developed innovations but 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 materials 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.

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 which is "the information base for the tool". 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 also be merchanical, biological or chemical. *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 development reflects 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 already known objective of firms, namely 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. Irrigation as an improved agricultural technology aims at providing optimum quality water for crops all year round. Irrigation technology also supplement inadequate rainfall water for improved crop yield. Pesticides are applied to minimize crop damage by pest to economic threshold level.

It is important to note that all is not rosy about the emergence of *IATs*. The affordability of *IATs* to smallholder farmers is critical. Farmers sometimes mix the *IFPs*, *FISs* and *IATs*. To classify these farmers ino the adopters of a particular technology, one needs an appropriate tool or metthod such as principal component analysis (PCA). Section 3.5 below gives a brief description and history of PCA.

3.5 Principal Component Analysis (PCA)

PCA is a statistical estimation procedure in which a large number of 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 few composite variables called principal components. As such, the number of principal components after the analysis is less than the number of correlated or uncorrelated variables that were 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 PCA 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 test. The components of strongly correlated variables can also be extracted. Two variables are non-collinear when they have zero or perfect correlation thereby making them non-factorable.

The 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).

3.6 Meaning of Efficiency and Productivity

More often than not, efficiency, efficacy, and effectiveness are not clearly distinguished. 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 inputs while 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 inputs at a certain period of time.

Sometimes, 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 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, and effectiveness is the use of labour (either small or large quantity of labour) to produce the expected 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 some people. Lovell (1993) defined productivity as the ratio of output to input. This definition does not incorporate the quality of the output. In actual 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 used only quantity of consumable or salable (marketable) output. Output can generate positive or negative externality. 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 single output or multiple outputs. 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.

Farell (1957) distiinguihsed among three types of efficiency-technical, allocative and economic efficiency. Figure 3.1 shows the input oriented approach to measuring technical and allocative efficiency measures. A firm employing two inputs, X_1 and X_2 to produce a single output Y has an isoquant represented by II' as shown in Figure 3.1. The isoquant shows the combinations of inputs, X_1 and X_2 to produce output Y. The input price ratios are represented by the isocost line CC'. Any firm operating at point K is technically efficient whiles a firm operating at point L is allocatively efficient. This implies that firms operating along the isoquant and isocost are technically and allocatively efficient respectively. The technical efficiency measure of a firm operating at point M is $^{OK}/_{OM}$. Given input prices and cost minimizing objective of firms, a firm located at point M has an allocative efficiency of $^{OL}/_{OK}$. The economic efficiency of a firm operating at point M is $(^{OK}/_{OM})*(^{OL}/_{OK})$ which is equal to OL/OM. From the above explanation, a firm located at point K' is technically and allocatively efficient implying economic efficiency. The above mentioned three types of efficiency can be measuring using the ouput oriented approach which is explained in the next section.

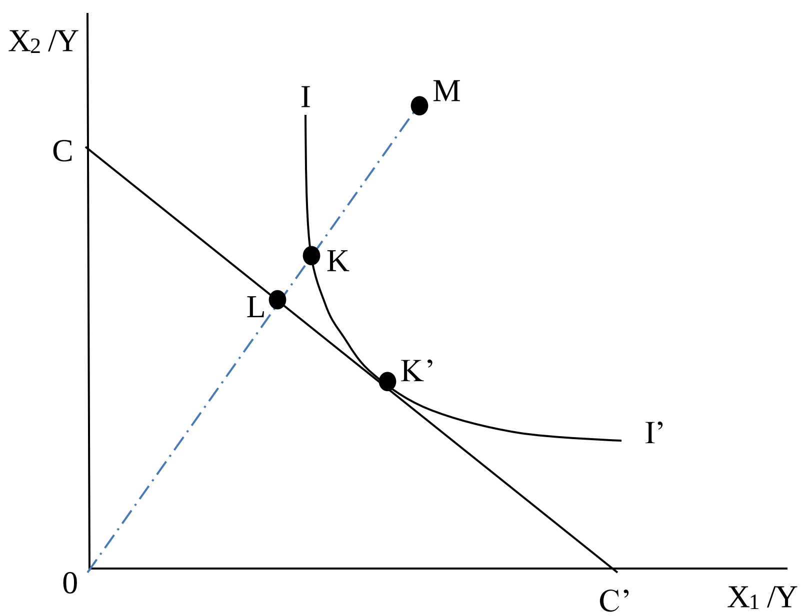

Figure 3.1 Input Oriented Technical and Allocative Efficiency Measure

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 an 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. In order to measure efficiency of firms, one needs to use the appropriate approaches.

There are three approaches to measuring or analyzing 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 are able to 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 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 the 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). According to Meeusen and Van den Broeck (1977), a stochastic frontier model for cross sectional data for ith farmer using x input to produce output y is given as:

$$y_i = f(x_i, \beta)\exp(\varepsilon_i) \qquad [1]$$

This approach is more appropriate as it indicates that inefficiencies ($\mathcal{E}_i$) of farmers are not only determined by factors under their control but also factors beyond their control. According to Farrell (1957), the composite error term ε_i , is made up of two independent elements $\varepsilon_i = (v_i - u_i)$, where the v_i is a symmetric random error term that accounts for exogenous factors beyond the control of the farmer e.g. measurement error, extreme weather, poaching etc. and the u_i is a non-negative inefficiency error term. Note that β is a vector of unknown parameters. The procedure involved in this approach is vividly explained in the methodology chapter.

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.

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

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 (CCR) are credited for its development. In a seminar 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. This is usually done by comparing relative efficiencies of firms in a particular industry. DEA cannot be used to calculate absolute efficiency but rather relative efficiency.

As a linear programming technique, DEA uses 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 cost minimization procedure and this is based on the fact that firms reduce the quantity of inputs given certain level of output. For output orientated model, output maximizing is used and this involves increasing output given a combination of some level of inputs. Following Cook *et al.* (2014), the

[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.

output maximisation version of DEA is given by equations [2] and [3]. 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 other DMU within the sample that has greater unit efficiency weights.

$$Max \frac{\sum_{j=1}^{j=n} v_j y_j}{\sum_{i=1}^{i=m} u_i x_i} \qquad [2]$$

$$Subject\ to \quad \frac{\sum_{j=1}^{j=s} v_j y_j}{\sum_{i=1}^{i=m} u_i x_i} \leq 1 \qquad [3]$$

Where v_j is the weight assigned to output j and u_i is the weight assigned to input i. 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 was appropriate when the inputs are in constant returns to scale. This was a major limitation of DEA model developed by these trios. In order to deal with this limitation Banker *et al.* (1984) developed model with variable returns to scale. As a nonparametric approach, DEA assumes that variations in productivity performance of firms are as a result 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 technique, the parameters are both finite and infinite. The use of productivity indices, growth accounting and index theory principles are semi-parametric techniques. 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 the study to determine the sources of agricultural productivity gap among selected countries, Hayami (1969) first mentioned metaproduction function. Two years later, Hayami and Rutta (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 of time. A 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 particular time period.

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 based on the fact that 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 performance defined in the seminal paper of Farrel (1957) are technical efficiency, allocative efficiency and economic efficiency. According to Farrel (1957), productivity performance of firms can be obtained by determining a single 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 group of firms operating with different inputs, technologies and under different environmental conditions define metatechnology set. A metafrontier is an overarching benchmark function that incorporates different group 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 have the potential to access and use the same technology or inputs or to work under similar environmental conditions. The contributions of earlier researchers to the development of metafrontier analysis cannot be under estimated. After the use and modification of 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 there is frontier production function and frontier cost function, there is also metafrontier production function and metafrontier cost function.

3.8.1 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 stochastic metafrontier cost model, 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, metafrontier production function is shown in Figure 3.2.

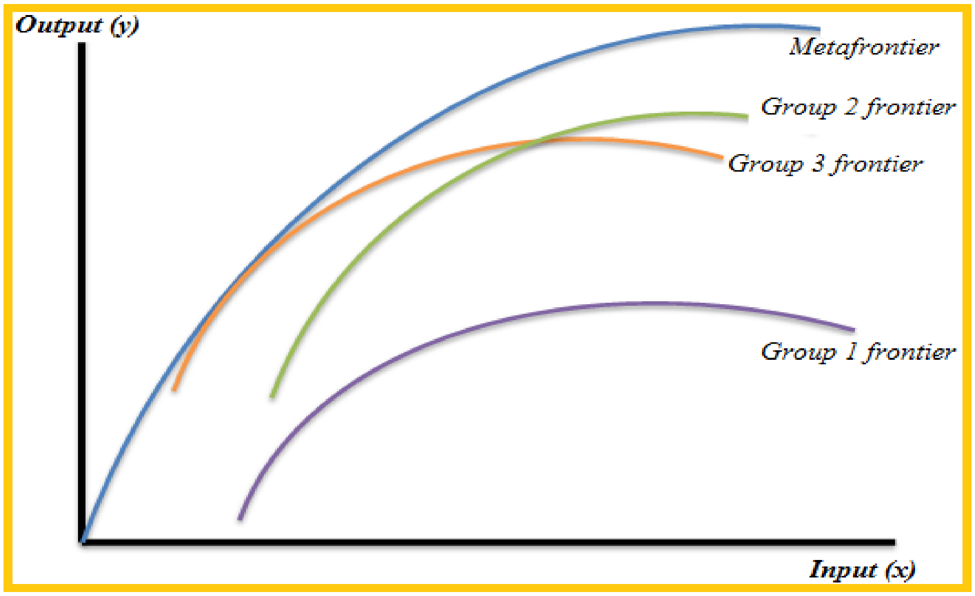

Figure 3.2 Illustration of Metafrontier

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 [4] and [5] below.

$$y_i^k = f^k(x_i, \beta^k)e^{v_i^k - u_i^k} = e^{x_i\beta^k + v_i^k - u_i^k} \qquad [4]$$

$$y_i* = f*(x_i, \beta*)e^{v_i* - u_i*} = e^{x_i\beta* + v_i* - u_i*} \qquad [5]$$

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 [4], 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.

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

$$TE_A^1 = \frac{\text{Observed output of firm A}}{\text{Frontier output of group1 firms}} = \frac{y_A^1}{y^1} = \frac{f_A^1(x,\beta^1)e^{v^1-u^1}}{f^1(x,\beta)e^{v^1}} = -u^1 \qquad [6]$$

Also, with output-oriented efficiency, the technology gap ratio of firms in group 1 cluster (TGR^1) can be estimated as:

$$TGR^1 = \frac{\text{Frontier output of firms in group1}}{\text{Metafrontier output}} = \frac{y^1}{y^*} \qquad [7]$$

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

$$TE^* = MFTE = \frac{\text{Observed output of firm A in group1}}{\text{Metafrontier output}} = \frac{y_A^1}{y^*} \qquad [8]$$

From the above, 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 models are discussed in the next subsections of this chapter while the latter is discussed in the methodology.

[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.

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:

$$y_i{*} = f\left(x_i, \beta_i{*}\right)\ell^{V_i{*}-U_i{*}} = \ell^{x_i\beta_i{*}+V_i{*}-U_i{*}} \quad [9]$$

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:

$$y_i^k = f\left(x_i, \beta_i^k\right)\ell^{V_i^k-U_i^k} = \ell^{x_i\beta_i^k+V_i^k-U_i^k} \quad [10]$$

Where y_i^k denotes the quantity (kg) of rice produce 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:

$$\mu_i^k = 1 - U_i^k = \varphi_0^k + \sum_{m=1}^{m=M} \varphi_i^k Z_{mi}^k + \omega_i^k \qquad [11]$$

Where φ_i^k and ω_i^k respectively denote a $\left(L \times 1\right)$ 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 $\left(1 \times L\right)$ 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:

$$TE_i^k = \ell^{-U_i^k} = \ell^{-Z_m \varphi_i^k - \omega_i^k} \qquad [12]$$

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 from taking the ratio of certain terms in the group specific stochastic frontier to the stochastic metafrontier. These indices are technology gap ratio (*TGR*), random error ratio (*RER*) and technical efficiency ratio (*TER*). The technology gap ratio (*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, technical efficiency ratio (*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 (10) and (11), the indices technology gap ratio (*TGR*), random error ratio (*RER*) and technical efficiency ratio (*TER* are derived as:

$$TGR_i^k = \frac{y_i^k}{y_i *} = \frac{\ell^{x_i \beta_i^k}}{\ell^{x_i \beta_i *}} = \ell^{-x_i(\beta_i^k - \beta_i *)} = \frac{D_i * (x, y)}{D_i^k (x, y)} = \frac{TE_i *}{TE_i^k} \qquad [13]$$

$$RER_i^k = \ell^{V_i^k} \big/ \ell^{Vi*} = \ell^{V_i^k - V_i *} \qquad [14]$$

$$TER_i^k = \ell^{-U_i^k} \Big/ \ell^{-U_i *} = \ell^{-U_i^k + U_i *} = \frac{TE_i^k}{TE_i *} \qquad [15]$$

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

$$TGR_i^k \times RER_i^k \times TER_i^k = \ell^{x_i\beta_i^k} \Big/ \ell^{x_i\beta_i *} \times \ell^{V_i^k} \Big/ \ell^{V_i *} \times \ell^{-U_i^k} \Big/ \ell^{-U_i *} = 1 \qquad [16]$$

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

$$MFTE_i^k = \ell^{x_i\beta_i^k} \Big/ \ell^{x_i\beta_i *} \times \ell^{-U_i^k} \times \ell^{V_i^k} \Big/ \ell^{V_i *} = \mathrm{TGR}_i^k \times \mathrm{TE}_i^k \times \ell^{V_i^k} \Big/ \ell^{V_i *} \qquad [17]$$

Due to the presence of $\ell^{V_i^k} / \ell^{V_i *}$ in equation [17], the metafrontier technical efficiency estimated using 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)

A two-step mixed approach to estimating metafrontier production model has the advantage of dealing with the limitations of 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 [10] 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:

$$y_i^k = f\left(x_i, \beta_i^k\right)\ell^{V_i^k - U_i^k} = \ell^{x_i \beta_i^k + V_i^k - U_i^k} \qquad [18]$$

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:

$$\min \sum_{k=1}^{K}\sum_{i=1}^{N_k}\left(\ell^{x_i \beta_i * - U_i *} - \ell^{x_i \hat{\beta}_i^k}\right)^2 = \min \sum_{k=1}^{K}\sum_{i=1}^{N_k}(U_i *)^2 \qquad [19]$$

$$subject\ to\ \ \ell^{x_i \beta_i * - U_i *} \geq \ell^{x_i \hat{\beta}_i^k} \qquad [20]$$

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 lost 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

It is possible to evaluate group specific firm performance in terms of cost relative to all the group cost performance. 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:

$$c_i = f^M(y_i, w_i, \beta^c)e^{v_i^c + u_i^c} \quad [21]$$

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 (eg. 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 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 from 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 set is represented by *MT*. The metfrontier has a non-negativity property which can be expressed mathematically as:

$$MT = \{(x, y): y \geq 0; x \geq 0\} \quad [22]$$

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

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

$$P(x) = \{y : (x, y) \in MT\} \quad [23]$$

Similarly, the input technology set which is the transformation (Q) between the output and input vector is given as:

$$Q(y) = \{x : (x, y) \in MT\} \quad [24]$$

Note that the boundary of output technology set and the boundary of 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 (homogenous of degree one in output).

3.10 Properties of Group Frontiers

It is possible to conceptualise the same idea used in theorising 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:

$$T^k = \{(x, y) : y \geq 0; x \geq 0\} \qquad [25]$$

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)

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 [26] and [27].

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

$$Q^k(y) = \{x : (x, y) \in T^k\} \qquad [27]$$

Since the metatechnology (*MT*) is an envelope of the group specific technologies, the metatechnology is a union of all the individual group specific technologies ($T^1, T^2, \ldots, T^K$) and it is expressed in mathematical symbols as:

$$MT \supseteq (T^1 \cup T^2 \cup T^3) \qquad [28]$$

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

$$D_y^k(x, y) = \inf_\theta \left\{ \theta > 0 : \left(y/\theta \right) \in P^k(x) \right\} \quad [29]$$

Where θ is the inverse of the proportion by which a firm may expand output while still using its given level of input. 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.

$$D_x^k(x, y) = \sup_\rho \left\{ \rho > 0 : \left(x/\rho \right) \in Q(y) \right\} \quad [30]$$

Where ρ is the inverse of the proportion by which a firm may contract input while still producing a given level of output. 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 output distance function is meritorious in this study as 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

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

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, $$P(x):(x,0)\in MT \qquad [31a]$$

$$P^k(x):(x,0)\in T^k \qquad [31b]$$

For the origin, $$P(x):(0,0)\in MT \qquad [32a]$$

$$P^k(x):(0,0)\in T^k \qquad [32b]$$

For output intercept, $P(x):(0, y) \notin MT$ [33a]

$$P^k(x):(0, y) \notin T^k \quad [33b]$$

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 inputs 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 suggests 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 are lacking in each of the factors thereby resulting in 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 than developing countries. Frisvold and Lomax (1991) 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 stochastic frontier metaproduction function. To avoid the estimation bias inherent in two-step estimation procedure, Binam *et al.* (2008) used 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 fruit industry in Ghana. With the study, both the technology gap ratio (which is outside the control of the farmer) and the technical inefficiency (which is under farmers 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 technology gap ratio.

On the other hand, Mensah and Brümmer (2016) identified technical inefficiency to be responsible for low fruit output by farmers in 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 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 influenced technical efficiency. However, the positive impacts of these factors, considering the estimated coefficients, were not strong enough to provide a competitive edge for local banana producers in the international market.

"Metafrontier analysis of organic and conventional cocoa production in Ghana" was studied by Onumah *et al.* (2013). 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 technology gap ratios 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 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 the Northern Ghana still lack the necessary farm inputs.

3.13 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 welfare 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 counterfactual situation (control group) 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 Hekcman sample correction model, propensity score matching (PSM), generalised propensity score (GPS) matching in continuous treatment framework and instrumental variables (treatment effect and endogenous switching regression models). Heckman sample correction model is the foundation of all other models.

3.13.1 The Heckman Sample Correction Model

The Heckman sample correction model was developed by the 2000 Economics Nobel Prize winner, James Heckman (Heckman, 1979). It is a model which has the ability to correct for selection bias which until then was a critical problem in econometric modeling (Gronau, 1974). The Heckman sample correction model is also called the Heckman sample selectivity model or the Heckman's lambda method or the Heckit method.

The Heckman correction method is a two-step statistical analysis which can correct biases resulting from non-random selection of samples. It is able to deal with the biases that emanate from the fact that selected sample may have similar characteristics making them to be automatically clustered into certain groups. The sample selection bias means the selection of the sample to form a group was not done randomly so as for the group to have different characteristics.

Considering a model to determine the impacts of participation in a project on welfare, one need to model the decision to participate in the project by specifying a probit model as:

$$Prob(P = 1, or\ 0/Z) = f(Z\alpha) = \alpha_0 + \sum_{j=1}^{j=J} \alpha_j Z_{ji} + \mu_i \qquad [34]$$

Where P denotes participation (P=1 for participation and P=0 fo non-participation), Z denotes a vector of explanatory variables, f denotes a standard normal cumulative distribution function and α denotes a vector of unknown parametres. From this probit model, the probabilities of project participation of each individual can be predicted and used in the second model to examine the impact of participation on welfare. This involves the correction of the sample selection bias by modeling the welfare on explanatory variables including the predicted probabilities of participation. The second model is given as:

$$E(W/X\,,\,P=1\,or\;\;0)=X\beta+\rho\delta_{\mu\varepsilon}\lambda_1+\varepsilon \qquad [35]$$

Where ρ is the correction between unobserved determinants of propensity to participate; $\delta_{\mu\varepsilon}$ is the standard deviation of µ and Ɛ; λ is the inverse Mills ratio which measures the impact of participation on welfare. X denotes the explanatory variables that can affect welfare but not necessarily affecting participation and denotes a vector of those variables' coefficients. In Heckman sample correction model, the testing of sample selectivity bias is just testing the null hypothesis that the coefficient on λ is zero (i.e. ρ =0).

Despite the strengths of Heckman sample correction model, it is a limited information maximum likelihood (LIML) estimator which does not exhibit better statistical properties as full information maximum likelihood (FIML) estimator (Puhani, 2000). Also, the assumption that the error terms are jointly normal can fail resulting in inconsistent estimates. Lastly, the model cannot correct for sample selection bias if there is no appropriate instrument. An instrument is a variable that affects the decision variable but does not affect the outcome variable (welfare or yield). The other impact assessment models which can solve some of the limiting problems of Heckman sample correction model are propensity score matching (PSM), generalised propensity score matching (GPSM) 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 on characteristics of adopters or participants and non-adopters or non-participants are matched and according to the propensities predicted from adopting or participating (Rosenbaum and Rubin 1983, Heckman *et al*., 1998 and Wooldridge, 2005).

GPSM is a continuous treatement effect model which Hirano and Imbens (2004) extended from the binary treatement effect model. It uses parametric approach. GPSM is used to establish causal inferences in observational data and it has the advantage of reducing bias caused by non-random treatement assignment (Rosebaum and Rubin 1983). Its limitation is that it does not require joint independence of all potential outcomes. It is important to note that this is not always the case.

More importantly, instrumental variables (treatment effect and endogenous switching regression models) have advantage over PSM since 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, 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 treatement 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 multinomial endogenous switching regression model. Due to the advantages of endogenous switching regression and appropriateness of the data, this study used multinomial endogenous switching regression model (MESRM).

3.13.2 Theoretical Review of Multinomial Endogenous Switching Regression Model

As noted above, MESRM is used when one wants to evaluate the impact of three or more decisions taken 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 (Kassie *et al.* (2014). 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 adopts 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 (Teklewold *et al.*, 2013). 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 probit model which is based on random utility model. On the contrary, the outcome models are estimated using ordinary least squares (OLS).

3.13.3 Empirical Review of Multinomial Endogenous Switching Regression Model

Multinomial endogenous switching regression model can be used 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 household maize income, agrochemical use and family labor 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 of farm household in Sub-Saharan Africa, Di Falco (2014) used 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.

Another by Mutenje *et al.* (2016), used multinomial endogenous switching regression model, to find impacts of innovations on crop yield and food security in Malawi. The study revealed that joint adoption of improved storage facilities and improved maize varieties significantly to maize yield in Malawi, compared with other combination of technologies. Kankwamba and Mangisoni (2015) estimated impact of sustainable agricultural practices on maize output and household incomes of smallholder farmers in Malawi using multinomial endogenous switching regression model. In the study, adoption of sustainable agricultural practices such as improved seed and soil and water conservation have increases output and household incomes. Also, with thw use of multinomial endogenous switching regression model, Kassie *et al.* (2014) found out that simultaneous adoption of both crop diversification (maize–legume intercropping and rotations) and minimum tillage enhances greater food security and larger reduction in downside risk in Malawi.

3.14 Factors Influencing Adoption Agricultural Technologies

Adoption of agricultural innovations or technologies is a decision which is determined by certain factors. Alemaw (2014) indicated that household's personal and demographic variables are some of the factors that affect farmer's adoption behaviour. These factors can be grouped into farmer characteristics, environmental factors and institutional and policy factors. Under farmer specific characteristics, researchers such as Nchinda *et al.* (2010), Asfaw and Shiferaw (2010), Donkor *et al.* (2016), have modelled age, sex, household size, farming experience and education as the determinants of agricultural technology adoption.

Agricultural extension contacts, credit access or amount, contract farming, access to input subsidy and membership of farmer based organisations are some of the institutional and policy factors which have extensively been modelled as the determinants of adoption of agricultural innovations or technologies (Diagne and Demont, 2007; Donkor et al., 2016; Azumah et al., 2016 and Mekonnen, 2007). Legesse *et al.* (2001) demonstrated that distance to market is a determining factor of adoption and intensity of use of technologies. The environmental conditions such as rainfall, temperature, wind and topography of the farm land have been used as factors influencing technology adoption. Shiferaw *et al.* (2014) included an environmental factor such as moist mid highlands as a determinant of adoption of improved wheat variety and realised that it was statistically significant.

3.14 Conclusion

The preceeding sections of this chapter reviewed literature on the thematic areas of the study. From the literature review, it is clear that there are three types of farming systems or technologies (*IFPs*, *FISs* and *IATs*). Out of these three, the superior technology in terms of rice yield is the *IATs* but the most environmentally sustainable one is *FISs*. Each technology typology is a package with respective individual farming systems or technologies. As noted in this chapter, the technologies can best typologically be classified by using PCA with oblique rotation. This is because, PCA with oblique rotation has the ability to reduce the technologies into few components by extracting those which are much consistent or correlate with one another.

Also, the chapter pointed out that the most appropriate model for estimating group specific TE and MFTE of a study of this nature (a study involving three different agro-ecolgical zones) is the new two-step stochastic metafrontier model proposed by Huang *et al.* (2014). This is because the estimates of the model satisfy all the statistical conditions, unlike the two-step mixed approach and the pooling stochastic metafrontier approach which underestimates the inefficiency emanating from the environement.

The impact assessment models which are used to solve selection bias problem emanating from observational cross-sectional data are PSM, GPSM, instrumental variables (treatment effect and endogenous switching regression models). Out of these, the treatment effect and endogenous switching regression models are superior since they have the ability to account for both observable and unobservable heterogeneity. Estimators from endogenous switching regression and treatment effect models are consistent because the models have the ability to deal with any hidden biases, unlike PSM and GPSM. Meanwhile, whether or not a researcher uses endogenous switching regression model or treatment effect model depends on the appropriateness of the data collected.

From the chapter, it is observed that many studies on rice productivity heterogenieity have not comprehensively analysed any cross agro-ecological zone differences especially in the major rice producing areas in the country. Also, there is no study which has classified technologies and examined the impact of the classified technologies on productivity performances of farmers. The next chapter describes the methodology used for this research.

CHAPTER FOUR

METHODOLOGY

4.1 Introduction

This chapter outlines the methods used in achieving each of the objectives of the research. 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 sample size, the sources and type of data collected and the econometric softwares used for data analysis are also described in the chapter. The last section presents a description of the study area.

4.2 Conceptual Framework

Figure 4.1 represents a conceptual framework for the study. 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 complex model.

The conceptual framework shown in figure 4.1 is adapted from the works of Kiatpathomchai (2008) and Alemaw (2014). The conceptual framework used by Alemaw (2014) schematically showed how farmer specific characteristics, institutional and policy factors and psychological factors affect adoption of new maize technology (improved maize variety). Also, conceptual framework designed and used by Kiatpathomchai (2008) examined the effects of farm household characteristics and rice farming practices on efficiency. This current study combined the conceptual framework of Kiatpathomchai

(2008) and Alemaw (2014). In order to take care of the effect of heterogenous agro-ecological zone factors on adoption and productivity or efficiency, this study added agro-ecological zone-specific characteristics which Shiferaw *et al.* (2014) termed as environmental factors.

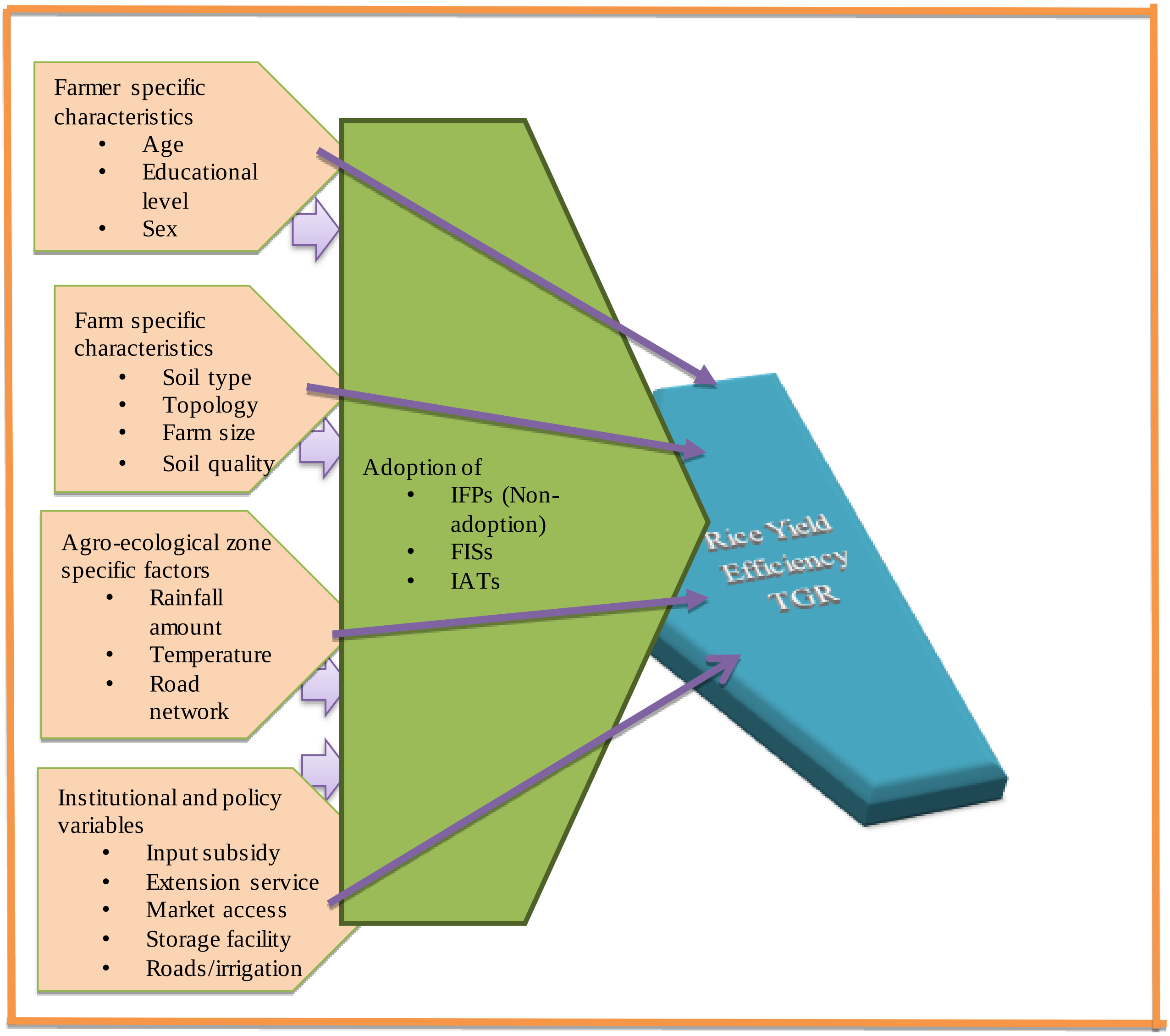

Figure 4.1 Conceptual Framework of the Study

Source: Modified from Kiatpathomchai (2008) and Alemaw (2014).

A farmer has some specifc characteristics which influence his or her decision on whether to adopt technologies or not. These characteristics are age, sex, management skills, household size, education among others. Aside these farmer specific factors, 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 amon others) and above all, profit maximizing objectives (Foster and Rosenzweig, 2010), a farmer will decide 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 and aimed at maximizing utility or profit from agricultural technology adoption which the changing prices for agricultural products is a key determinant (Kijima *et al*, 2011). Utility maximization depends on the farmer's ability to make the best alternative choice(s).

A farmer cultivating 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 diffrences and institutional and policy factors.

Taking into account the the four categories of factors depicted in Figure 4.1, the country will possess a metaproduction frontier which Hayami (1969) noted that it measures 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 has three aspects. These are how resources are allocated efficiently (allocative efficiency) and how the technologies are adopted to obtain the highest yield (technical efficiency) as well as the product of the two (economic efficiency). Against the background that farmer specific and farm chracteristics 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 *IATs*).

Conversely, economically efficient farmers have relatively high technology gap ratio or high productivity potentials and hence will not have to struggle so much to catch up 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 secure 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*[7] 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 productivity 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 productivity since each input's magnitude of contribution 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 and hence there is no need for using subject matter experts to generate

[7] 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.

weights to show the intensity of adoption or contribution of technologies. Meanwhile, the 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 *IATs* (*T*), principal component analysis (PCA) was used. The principal component analysis model transforms the technology variables into a linear equation simply by allocating relative weights to each 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 to 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 Principal Component Analysis

In determining the correlation among variables with common properties, one needs to estimate eigenvalue using PCA with oblique rotation. An eigenvalue has a standardised variance with a mean of zero and a standard deviation of 1. Hence, any component (indigenous farming practice or farmer innovation system or scientifically improved agricultural technology) 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 selecting 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 variable. Multiple correspondence analysis (MCA) is designed for categorical or discrete variables. In a curiosity to determine the significant difference between PCA and MCA, Howe and Hargreaves (2008) used multiple correspondent analysis (MCA) and principal component analysis (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 quartimax) rotation. The results of PCA using oblique rotation is 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 is 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 of *f* number of random *IFPs* (P), *g* number of random *FISs* (*I*) and *h* number of random *IATs* (*T*) can be expressed as:

$$PC_1 = \sum_{f=1}^{f=F} a_{1f}^{P} P_{fi} + \sum_{g=F+1}^{g=G} a_{1g}^{I} I_{gi} + \sum_{h=G+1}^{h=H} a_{1h}^{T} T_{hi} \quad [36a]$$

$$PC_2 = \sum_{f=1}^{f=F} a_{2f}^{P} P_{fi} + \sum_{g=F+1}^{g=G} a_{2g}^{I} I_{gi} + \sum_{h=G+1}^{h=H} a_{2h}^{T} T_{hi} \quad [36b]$$

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

$$PC_{43} = \sum_{f=1}^{f=F} a_{43f}^{P} P_{fi} + \sum_{g=F+1}^{g=G} a_{43g}^{I} I_{gi} + \sum_{h=G+1}^{h=H} a_{43h}^{T} T_{hi} \quad [36aq]$$

Where a_{1f}^{P} , a_{1g}^{I} , a_{1h}^{T} represent coefficients (weights/factor loadings) for first principal component of f^{th} number of random *IFPs* (*P*), g^{th} number of random *FISs* (*I*) and h^{th} number of random *IATs* (*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 original data and so on. In all, forty-three variables were used and their definitions and mode of measurements are shown in appendix 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.

It is important to note that the following assumptions as noted by Filmer and Pritchett (2001) need to be valid for one to use PCA.

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 so as to reduce heterogeneous influence on the results.

4.4 Estimation of 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 as yield, 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 *FISs* or *IATs* or combinations of any of them. Mathematically, the average rice yield for l^{th} technology adopters ($\overline{RY}_l$) is given as:

$$\overline{RY}_l = = \frac{\sum_{i=1}^{i=k} R_i^l}{\sum_{i=1}^{i=k} FS_i^l} \qquad [37]$$

Where R_i^l and FS_i^l are the quantity of rice produced (Mt) and the farm size (Ha) cultivated by the *ith* farmer who adopts the l^{th} 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:

$$Welch's\,t-test = = \frac{\overline{RY}_1 - \overline{RY}_2}{\sqrt{S_1^2/n_1 + S_2^2/n_2}} \qquad [38]$$

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 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 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 samples 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 localities, 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.

4.5.1 Graphical Representation of Group Frontiers and Metafrontier

Generally, it is hypothesized that there is a metatechnology set which envelopes 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 environemental 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[8].

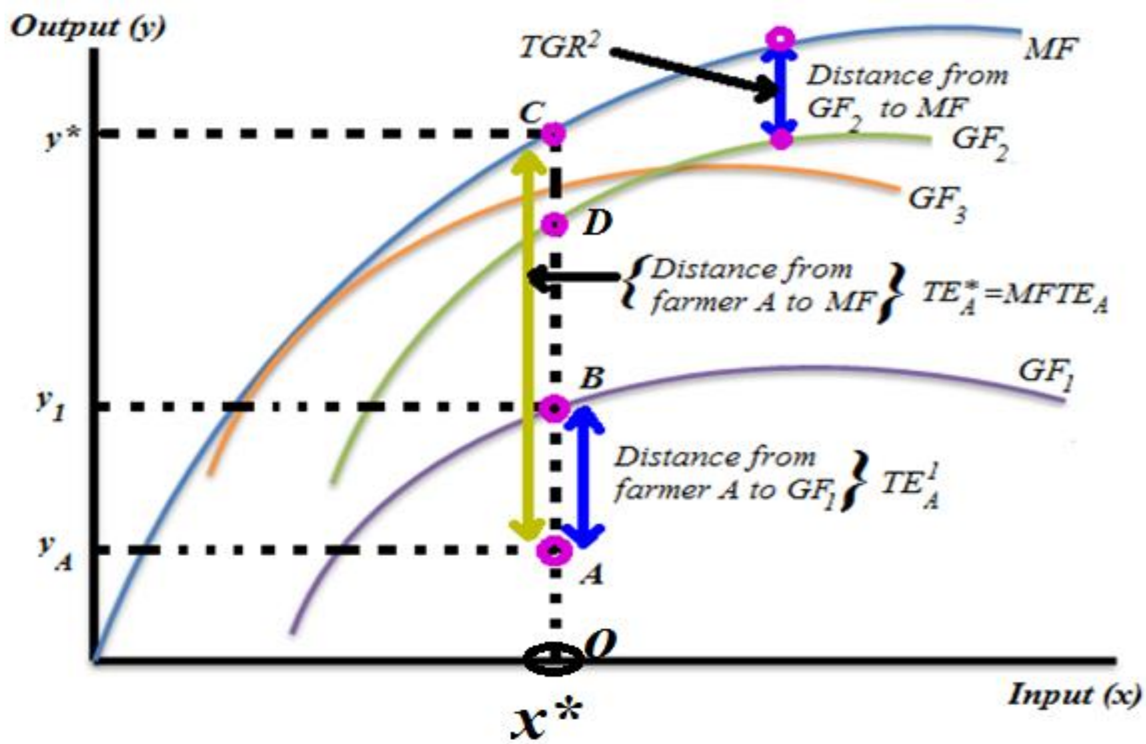

Figure 4.2: Graphical Representation of Metafrontier

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

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 concepts 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

[8] 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.

for group one is measured as the distance between GF_1 and MF. 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:

$$TE_A^1 = \frac{OA}{OB} = \frac{y_A}{y_1} \qquad [39]$$

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 technology gap ratio (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 technology gap ratio (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 (36).

$$TGR^1 = \frac{TE_1^*}{TE_A^1} = \frac{OA/OC}{OA/OB} = \frac{y_A/y^*}{y_A/y_1} = \frac{OB}{OC} = \frac{GF\ output}{MF\ output} = \frac{y_1}{y^*} \qquad [40]$$

Assuming that a farmer at point A could use the joint technology, thus the metafrontier technical efficiency (MFTE) score or the technical efficiency relative to the metafrontier (TE_1^*) can be determined by using the index:

$$TE_1^* = MFTE = MTR^1 \times TE_A^1 = \frac{OB}{OC} \times \frac{OA}{OB} = \frac{OA}{OC} = \frac{y_A}{y^*} \qquad [41]$$

From equation [41] above, the technical efficiency relative to the metafrontier (TE_1^*) is the product of the technical efficiency relative to the group and the environmental-technology gap ratio (MTR) between the metatechnology and the technology gap ratio.

4.5.2 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 technology gap ratio 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. It is important to note that 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, it is important to note that, $MFTE^k > TE^k$. 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 real world is questionable.

4.5.3 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). However, while the estimated metafrontier technical efficiencies using the pooling stochastic metafrontier model are not exact, the two-step mixed approach violates the standard regularity property. The superiority of the new two-step approach lies in the fact that its estimated metafrontier technical efficiencies are accurate and exact and also meet all the standard regularity conditions. Therefore, this study employs the new two-step approach in estimating metafrontier technical efficiencies of rice farmers in the three agro-ecological zones in Ghana.

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 [10] under section 3.8.1.1 in chapter three, the group specific stochastic frontier regression is specified as:

$$y_i^k = f\left(x_i, \beta_i^k\right)\ell^{V_i^k - U_i^k} = \ell^{x_i\beta_i^k + V_i^k - U_i^k} \qquad [10]$$

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 [42] below:

$$\hat{y}_i^k = f\left(x_i, \hat{\beta}_i^k\right)\ell^{\hat{V}_i^k - \hat{U}_i^k} = f\left(x_i,\ \beta_i *\right)\ell^{V_i * - U_i *} = \ell^{x_i\beta_i * + V_i * - U_i *} \qquad [42]$$

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

$$M\hat{FTE}_i^k = T\hat{GR}_i^k \times T\hat{E}_i^k \qquad [43]$$

Note that $0 \leq M\hat{FTE}_1^k \leq 1$, $0 \leq T\hat{E}_i^k \leq 1$, and $0 \leq T\hat{GR}_i^k \leq 1$. Meanwhile, $M\hat{FTE}_i^k$, $T\hat{E}_i^k$ and $T\hat{GR}_i^k$ are all predicted.

4.6 Empirical Group Stochastic Frontier and Stochastic Metafrontier Models

Under this section, the empirical models used for estimating technical efficiency, metafrontier technical efficiency and technology gap ratio as well as their determinants are stated and explained.

4.6.1 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 very 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 very 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 returns to scale of the farm-firm. The traditional Cobb-Douglas production function assumes that the elasticities of substitution between inputs are constant. Also, Sena (2011) indicated that the Cobb-Douglas production function imposes functional form restriction. It is inflexible in estimation eventhough its parameters are easy to calculate. Many researchers have resorted to the use of transcendental logarithmic (translog) functional form. The limitations of the Cobb-Douglas production function mentioned above are all dealt with by the translog specification.

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 stochastic translog production frontier model, the parameters to be estimated are many. Also, the estimated parameters of the interaction terms of the stochastic translog production frontier model are always difficult to interprete economically. For a better and meaningful economic interpretation of the parameters, one needs to calculate elasticities by normalising the variables. These limitations notwithstanding, the stochastic translog production frontier model is flexible and enables the researcher 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:

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

Where:

Ω_1^k, Ω_2^k and are the coefficients for the dummy variables fertilizer (F_i^k) and pesticides (Pc_i^k) 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, β_{12}^k, ..., β_{17}^k; β_{23}^k,..., β_{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

$\ln\{Max(F_i^k, 1-D_{F_i}^k)\}$ and $\ln\{Max(Pc_i^k, 1-D_{Pc_i}^k)\}$ 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, $\ln\{Max(F_i^k, 1-D_{F_i}^k)\}$ and $\ln\{Max(Pc_i^k, 1-D_{Pc_i}^k)\}$ 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, $\ln\{Max(F_i^k, 1-D_{F_i}^k)\}$ and $\ln\{Max(P_i^k, 1-D_{Pc_i}^k)\}$ 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 $\ln\{Max(F_i^k, 1-D_{F_i}^k)\}$ and $\ln\{Max(Pc_i^k, 1-D_{Pc_i}^k)\}$. This is for simplification.

Whether a farmer is technically efficient or not depends on farmer-specific, farm-specific, location-specific and 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:

$$TI_i^k = U_i^k = \left\{\varphi_0^k + \sum_{m=1}^{m=5}\varphi_m^k FC_{mi}^k + \sum_{m=6}^{m=11}\varphi_m^k IPV_{mi}^k + \sum_{m=12}^{m=13}\varphi_m^k EF_{mi}^k + \sum_{m=14}^{m=17}\varphi_{14}^k RPT_i^k + \omega_i^k\right\} \quad [45a]$$

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 N(0, 1).

4.6.2 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.

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:

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

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:

$$U_i^* = \left\{ \varphi_0^k + \sum_{m=1}^{m=5} \varphi_m^* FC_{mi}^* + \sum_{m=6}^{m=11} \varphi_m^* IPV_{mi}^* + \sum_{m=12}^{m=13} \varphi_m^* EF_{mi}^* + \sum_{m=14}^{m=17} \varphi_{14}^* RPT_i^* + \omega_i^* \right\} \quad [45b]$$

The metafrontier technical efficiency ($M\hat{F}TE_i$ or $T\hat{E}_i*$) is obtained by subtracting the metafrontier technical inefficiency component from one by using the formula given below:

$$M\hat{F}TE = T\hat{E}_i * = 1 - U_i^* \quad [46]$$

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). Technology gap ratio (*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 zone (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 technology gap ratio, 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), technology gap ratio (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 $\left(1-\hat{TGR}_i^k\right)$.

The technology gap ratio 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.

$$\hat{TGR}_i^k = \frac{GF\ output}{MF\ output} = \frac{R_i^k}{\hat{R}_i} = \ell^{x_i\beta_i^k} \Big/ \ell^{x_i\beta_i*} = \frac{\hat{MFTE}_i}{\hat{TE}_i^k} = \frac{1-\hat{U}_i^*}{\hat{TE}_i^k} \qquad [47]$$

4.6.3 Testing the Hypotheses for Appropriateness of Models

In order to choose the appropriate model, the study tested and validated four null hypotheses as 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: $\gamma = \varphi_0 = \varphi_1 = \ldots = \varphi_{12} = 0$

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: $\varphi_0 = \varphi_1 = \ldots = \varphi_{12} = 0$

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 explains 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:

$$LR = -2\frac{\{\ln L(H_0)\}}{\{\ln L(H_1)\}} = -2[\{\ln L(H_0)\} - \{\ln L(H_1)\}] \sim \chi^2 \quad [48]$$

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 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 exits or not. Therefore, uniformity in technological gap ratios (*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 the 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

4.6.4 Empirical Fractional Regression Model: Determinants of TGR

As noted in the objectives of this research, it is important for the researcher to model and unravel the determinants of TGR. This provides the necessary information for recommending appropriate policy interventions which aim at bridging the actual and potential rice outputs across agro-ecological zones in Ghana. Such policy directions will be demand driven.

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:

$$E\left(T\hat{G}R_i / X\right) = g(Xb) \qquad [49]$$

Where $E\left(T\hat{G}R_i / X\right)$ is the expected technology gap ratio 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 [50]

$$E\left(\hat{TGR}_i / X\right) = \ln\left(\frac{\hat{TGR}_i}{1-\hat{TGR}_i}\right) \qquad [50]$$

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. Meanwhile, 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 these assumptive approximations, 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 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:

$$E\left(\hat{TGR}_i / X\right) = \frac{\exp(Xb)}{[1+\exp(Xb)]} \quad [51]$$

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.

$$\ln L(b) = \hat{TGR}_i \ln\left[E(\hat{TGR}_i / X)\right] + \left(1-\hat{TGR}_i\right)\ln\left[1-E(\hat{TGR}_i / X)\right] \quad [52]$$

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

$$E\left(\hat{TGR}_i\right) = \begin{pmatrix} b_0 + b_1 IrrigAcc_i + b_2 InpSub_i + b_3 ContFm_i + b_4 Road_i + \\ b_5 DistAEA_i + b_6 DistMkt_i + b_7 DistAccra_i + b_8 DistFarm_i + \\ b_9 LodgRice_i + b_{10} LowRain_i + b_{11} Disease_i + b_{12} RainAmt_i + \\ b_{13} Temp_i + b_{14} AdoptFISs_i + b_{15} AdoptIATs_i + \omega_i \end{pmatrix} \quad [53]$$

The explanatory variables are defined in Table 4.2. Since technology gap ratio (*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.

4.6.5 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	Value 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 technology gap ratio 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)	NA	NA	-
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

4.7 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) especially random utility theory (Shiferaw, 2014). 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 productivity performance indices (*TE* and *TGR*). 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 productivity performance scores (*TE* and *TGR*) 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 performance (rice yield) 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 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 productivity performance indices (*TE* and *TGR*) and also solves the problem of self-selection bias (Mansur *et al.*, 2008).

4.7.1 Multinomial Endogenous Switching Regression Model (MESR)

This study used 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 productivity performance (rice yield) (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 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:

$$I_i^{*k} = \begin{cases} 1 & iff \quad U_{1i}^* > U_{mi}^* \quad or \quad U_{1i}^* - U_{mi}^* > 0 \\ \vdots & \vdots \quad \vdots \qquad\qquad\qquad \vdots \\ J & iff \quad U_{ji}^* > U_{mi}^* \quad or \quad U_{ji}^* - U_{mi}^* > 0 \end{cases} \qquad j \neq m \qquad [54]$$

A farmer will choose jth combination of adoption option over that of m if the utility or benefit he/she will derive from choosing jth adoption option is greater than adopting mth package. The sample selection criterion models expressing the utility for adopting jth 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:

$$U_{ji}^{*k} = F_i^k \delta_j + \eta_{ci}^k \quad [55a]$$

$$U_{mi}^{*k} = F_i^k \delta_m + \eta_{ci}^k \quad [55b]$$

Where F_i^k is a vector of exogenous variables explaining the choice decision of ith farmer in kth agro-ecological zone, δ_j and δ_m are vectors of parameters, η_{ci}^k is the error term for ith farmer in kth 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; $N(0, \sigma_c^2)$ with the the multinomial logit model indicating the probability that farmer i chooses jth package ((i.e. choosing any of these: I_0T_0, I_1T_0, I_0T_1 and I_1T_1) given as:

$$P\left(U_{j1i}^{*} - U_{mi}^{*} > 0 / F_i^k\right) = \frac{\exp\left(F_i^k \delta_j\right)}{\sum_{m=1}^{m=J} \exp\left(F_i^k \delta_m\right)} \quad [56]$$

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) or MFTE)] 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:

$$\text{Regime } 1: Non-adoption: package\ one(I_oT_o) \Rightarrow I=0: RY_{0i}^k = \rho_0 G_i^k + \varepsilon_{0i}^k \qquad [57a]$$

$$\text{Regime } 2: adoption\ of\ package\ two(I_1T_o) \Rightarrow I=1: \quad RY_{1i}^k = \rho_1 G_i^k + \varepsilon_{1i}^k \qquad [57b]$$

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

$$\text{Regime } J: Adoption\ of\ package\ J \quad \Rightarrow I=J: \quad RY_{Ji}^k = \rho_J G_i^k + \varepsilon_{Ji}^k \qquad [57d]$$

Where RY_{Ji}^k represents the outcome variable measuring rice yield of the ith farmers adopting jth 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 1 and J respectively. Also, ε_0^k and ε_J^k denote the error terms for regimes 1 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:

$$Cov\left(\eta_c^k, \varepsilon_0^k, \varepsilon_J^k\right) = \begin{bmatrix} \sigma_c^2 & \sigma_{0c} & \sigma_{Jc} \\ \sigma_{0c} & \sigma_0^2 & \sigma_{J0} \\ \sigma_{Jc} & \sigma_{J0} & \sigma_J^2 \end{bmatrix} \quad [58]$$

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 *1* and *J* simultaneously and hence σ_{Jc} and σ_{J0} are not defined.

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 in regimes. Following Fuglie and Bosch (1995) the expectations of ε_J^k and ε_0^k are nonzero and are given as:

$$E\left(\varepsilon_{0i}^k / I_i^k = 1\right) = E\left(\sigma_{0c}\eta_{ci}^k / I_i^k = 1\right) = \sigma_{0c}\frac{\phi\delta F_i^k}{\varphi\delta F_i^k} = \sigma_{0c}\lambda_{0i} \quad [59a]$$

$$E\left(\varepsilon_{Ji}^k / I_i^k = 0\right) = E\left(\sigma_{Jc}\eta_{ci}^k / I_i^k = 0\right) = \sigma_{Jc}\frac{\phi\delta F_i^k}{\left(1-\varphi\delta F_i^k\right)} = \sigma_{Jc}\lambda_{Ji} \quad [59b]$$

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:

$$\text{Regime 1}: Non-adoption: package\ one: If\ \ I=0;\quad RY_{0i}^k=\rho_0 G_i^k+\sigma_{0c}\lambda_{0i}+\xi_{0i}^k \qquad [60a]$$

$$\text{Regime 2}: adoption\ of\ \ package\ two: If\ \ I=1;\quad RY_{1i}^k=\rho_1 G_i^k+\sigma_{1c}\lambda_{1i}+\xi_{1i}^k \qquad [60b]$$

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

$$\text{Regime 4}: Adoption\ of\ \ package\ \ J: If\ \ I=J;\quad RY_{Ji}^k=\rho_J G_i^k+\sigma_{Jc}\lambda_{Ji}+\xi_{Ji}^k \qquad [60d]$$

Where λ_0, …, λ_J evaluated at δF_i^k are known as *IMR*s and 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 instrumental variable. 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), 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. Access to agricultural information will be 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 1 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.

4.7.2 Conditional Expectations and Average Treatment Effects

The multinomial endogenous switching regression 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_1T_0, I_0T_1 and I_1T_1) against a scenario that he/she does not adopt any package (I_0T_0). Conversely, it compares the expected productivity performance (*RY*) of a non-adopter farmer of any of the packages (I_0T_0) to a situation had he/she does adopt any of the packages (I_1T_0, I_0T_1 and I_1T_1)

4.7.2.1 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:

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

$$E\left(RY_{2i}^{k}/I=2\right)=\rho_2 G_i^k+\sigma_{2c}\lambda_{2i} \quad [61b]$$

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

$$E\left(RY_{Ji}^{k}/I=J\right)=\rho_J G_i^k+\sigma_{Jc}\lambda_{Ji} \quad [61d]$$

4.7.2.2 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:

$$E\left(RY_{0i}^{k}/I=1\right)=\rho_0 G_i^k+\sigma_{0c}\lambda_{1i} \quad [62a]$$

$$E\left(RY_{0i}^{k}/I=2\right)=\rho_0 G_i^k+\sigma_{0c}\lambda_{2i} \quad [62b]$$

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

$$E\left(RY_{0i}^{k}/I=J\right)=\rho_0 G_i^k+\sigma_{0c}\lambda_{Ji} \quad [62d]$$

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 [61*a*] and [62*a*] or equations [61b] and [62b] etc. Considering equations [57*a*] and [58*a*], *ATT* is expressed as:

$$ATT_i^k = E\left(RY_{1i}^k / I_i = 1\right) - E\left(PPI_{0i}^k / I_i = 1\right) = G_i^k\left(\rho_1 - \rho_0\right) + \lambda_{1i}\left(\sigma_{1c} - \sigma_{0c}\right) \quad [63]$$

5.7.2.3 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:

$$E\left(RY_{0i}^k / I_i = 0\right) = \rho_0 H_i^k + \sigma_{0c}\lambda_{0i} \quad [64]$$

5.7.2.4 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:

$$E\left(RY_{1i}^k / I_i = 1\right) = \rho_1 H_i^k + \sigma_{1c}\lambda_{0i} \quad [65]$$

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:

$$ATU_i^k = E\left(RY_{1i}^k / I_i = 1\right) - E\left(PPI_{0i}^k / I_i = 0\right) = H_i^k\left(\rho_1 - \rho_0\right) + \lambda_{0i}\left(\sigma_{1C} - \sigma_{0c}\right) \quad [66]$$

4.8 Study Area

The study was conducted in Ghana, located on 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	UER	2200	1000	600-1200	May-Sept. (150- 160adys)	-
GSZ	UER, UWR, NR, VR BAR	147900	1000	800-1200	May-Sept. (180-100days)	-
FSTZ	BA, ER, VR, AR	8400	1300	1100-1400	March-July (200-220days)	Sept.-Oct. (60days)
SDRFZ	AR, VR, BAR, CR, WR, GAR	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, GAR, VR	4500	800	600-1200	March-July (100-110days)	Sept.-Oct. (50days)
UER-Upper East Region, UWR-Upper West Region, NR-Northern Region, BAR-Brong-Ahafo Region, VR-Volta Region, AR-Ashante Region, ER-Eastern Region, CR-Central Region, WR-Western Region, GAR-Greater Accra Region						

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 Ashante 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.

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 Savavannah zone is the largest agro-ecological zone with a total land area of 147900Km^2

(MoFA, 2011). It has minimum and maximum annual rainfall amounts of 800mm and 1200mm respectively (MoFA, 2011). 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.

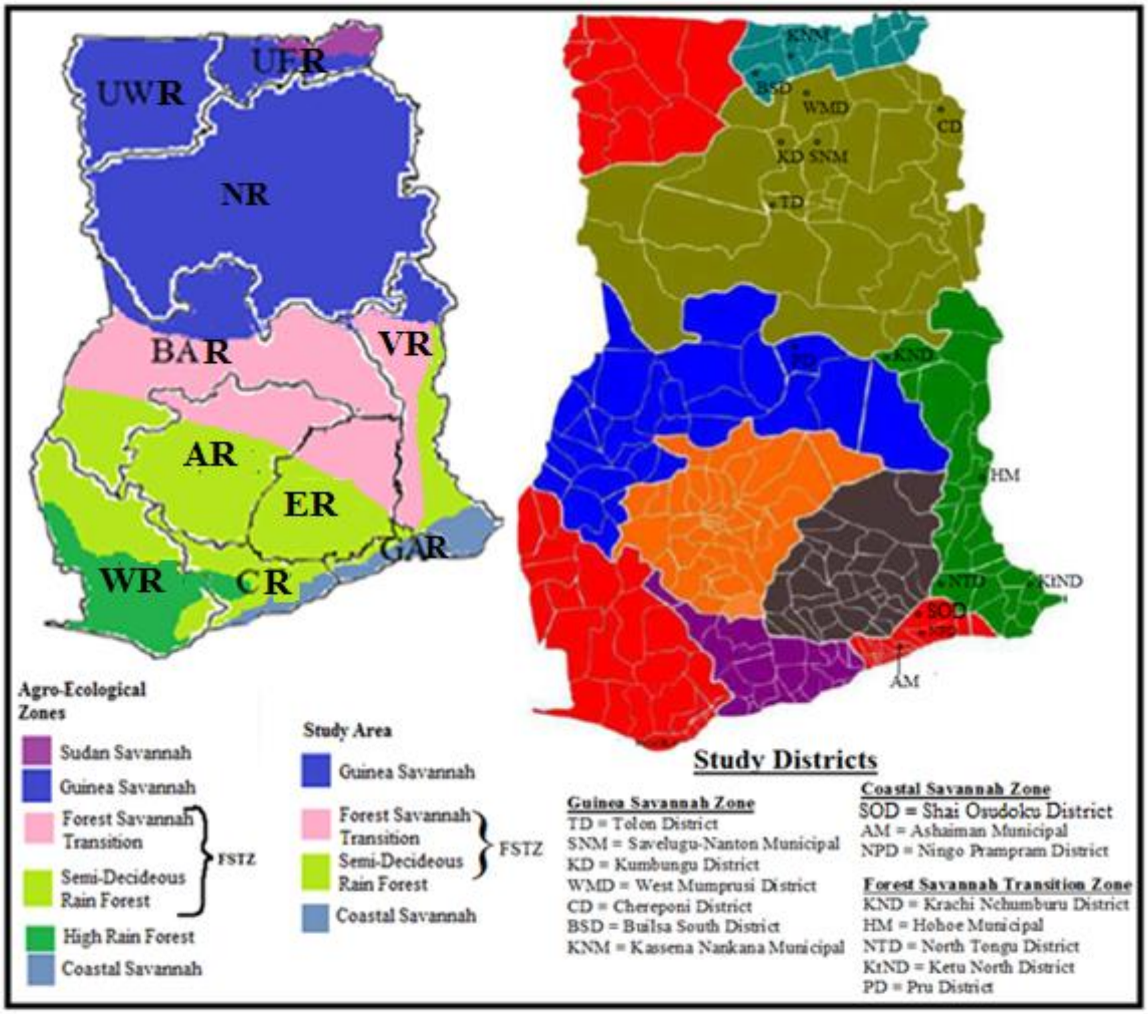

Figure 4.3 Ghana Map Showing the Selected Agro-Ecological Zones and the Study Districts

4.9 Research Design

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

4.10 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.

4.11 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:

$$n = \frac{N}{1 + Ne^2} \qquad [67]$$

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 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 are 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 noted by GSS (2014), the number of rice farming households in GSZ, FSTZ and CSZ are 296,489, 33,048 and 3,931 respectively. The wide variations in the actual sample size among the three agro-ecological zones (GSZ, FSTZ and CSZ) are due to the fact that the land area of the agro-ecological zones differ widely. While, GSZ has the largest land area followed by FSTZ, CSZ has the smallest land area.

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)

4.12 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 and hence there is the need to factor this in sampling. 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.

4.13 Pre-Testing of Questionnaires

The drafted questionnaire was pre-tested in the Krachi East District in the FSTZ and Tolon District in GSZ in September, 2015. 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 techniques 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.

4.14 Test of Reliability of Survey Instrument

The data from the pre-tested questionnaire were 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 can be used for the main data collection.

4.15 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 to analyse the data because they gave estimates which were economically meaningful.

4.16 Conclusion

Chapter four has discussed the method used in this study. The conceptual framework has shown how socio-economic factors influence technology adoption decisions which subsequently affect productivity performances (TE, MFTE, TGR) of farmers. It was also observed that PCA can be used to classify farmers into different adoption typologies. To test the differences between adopters of any two technology typologies, where the sample sizes and variances are unequl, the Welch's t-test is appropriate. It was also noted that the new two-step stochastic metafrontier model is the best for estimating TE, MFTE and TGRs. To determine the drivers of TGR, the GLM is appropriate due to fractional nature of the scores of TGR. Similarly, for ATT and ATU to be estimated econometrically, the MESRM was proposed.

Furthermore, given that the sampling involves different stages, the chapter established that multi-stage sampling procedure is appropriate. Lastly, the sample size for the study was eatimated to be 907 across the three agro-ecological zones (GSZ, FSTZ and CSZ) where rice is grown principally in Ghana.

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 [36*a*] to [30*a*q]. The first section presents the frequency distribution of farmers interviewed in each of the districts in the three agro-ecological zones. The frequency distribution of the *IFPs, FISs* and *IATs* is presented in the second section of the chapter. With the help of the principal component analysis, farmers were classified into different technology adoption typology. Differences in rice yields between technology adoption typologies 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.

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%. 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 Osudoku District in CSZ is premised on the large numbers 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 Osudoku District. For the pooled data, Shai Osudoku District 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 principal component analysis (PCA) was 44. The table shown in Appendix 4 presents a frequency distribution of the variables used in PCA. The frequency distribution table (Table 5.1) shows the frequency and the percentage of adopters and non-adopters of *IFPs*, *FISs* and *IATs*. From Table 5.1, the *IFPs* mostly used by farmers (67.1%) is personal scaring of birds by ringing bell, catapult or any noisy object. In rice production, one of the critical stage is the period of tasseling of the rice plant. During this time, birds suck the sugary nectar 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.

In Table 5.1, 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 *IATs* that farmers adopted most is the spraying of weeds with chemical weedicides. Out of 907 respondents, 82.8% controlled weeds by spraying chemical weedicides. 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 agrochemicals by farmers in Ghana to control weeds, increase agricultural productivity and preserve agricultural produce has reached a crescendo thereby calling for urgent attention. The next least adopted *IAT* is the use of stationary thresher to thresh the paddy from the straw.

Table 5.1 Frequency Table of *IFPs, FISs* and *IATs* for PCA

Indigenous farming practises, Farmer Innovations and Improved Agricultural Technologies	Frequency		Percentage	
	Non adopters	Adopters	Non adopters	Adopters
Hypothesised Indigenous farming practises (*IFPs*)				
Use of previous years rice as seed without selection	714.0	193.0	78.7	21.3
Farmer-to-farmer seed exchange	814.0	93.0	89.7	10.3
Purchasing of ordinary seed from market	771.0	136.0	85.0	15.0
Slash and burn	730.0	176.0	80.6	19.4
Haphazard cutting and turning (pulverising) of soil with hoe	828.0	79.0	91.3	8.7
Broadcasting seed haphazardly	456.0	451.0	50.3	49.7
Handpicking of weeds	609.0	291.0	67.1	32.9
Use of hoe and cutlasses to control weeds	597.0	310.0	65.8	34.2
Mixed cropping	771.0	136.0	85.0	15.0
Use of scare crow to scare birds off the field	478.0	429.0	52.7	47.3
Setting of traps to catch birds on the field	805.0	102.0	88.8	11.2
Personal bird scaring through shouting, ringing of bell, use of catapult etc	298.0	609.0	32.9	67.1
Use of sickle to harvest rice	450.0	457.0	49.6	50.4
Use of knife or cutlass to harvest rice	691.0	216.0	76.2	23.8
Threshing by beating rice straw and paddy with sticks	546.0	361.0	60.2	39.8
Storage of rice in bags	347.0	560.0	38.3	61.7
Hypothesised Farmer Innovation Systems (*FISs*)				
Selection of seed for next season from healthy and good rice plants	708.0	199.0	78.6	21.4
Selection of fertile land, planting rice on it and using the rice from the plot as foundation seed	771.0	136.0	85.0	15.0
Slash and leave crop residue to decompose	704.0	203.0	77.6	22.4
Use of wood ash to speed-up germination	660.0	247.0	72.8	27.2
Transplanting of seedlings with approximate spacing	709.0	198.0	78.2	21.8
Broadcasting in rows with approximate spacing	712.0	195.0	78.5	21.5
Dibbling/drilling with approximate spacing	768.0	139.0	84.7	15.3
Mulching with plants parts to suffocate weed and keep moisture	771.0	136.0	85.0	15.0
Incorporation of rice straw into soil	699.0	208.0	77.1	22.9
Colouring of rice seed to prevent identification by rodents or bird after seeding	816.0	91.0	90.0	10.0
Use of cassette magnetic ribbon to scare birds	696.0	211.0	76.7	23.3
Threshing by holding rice sheaves and thrashing against wooden or slated bamboo container	750.0	157.0	82.7	17.3
Hypothesised Improved Agricultural Technologies (*IATs*)				
Rouging	794.0	113.0	87.5	12.5
Use of certified seed	561.0	346.0	61.9	38.1
Clear the land before plough and harrow with tractor	652.0	255.0	71.9	28.1
Plough and harrow the land directly without clearing	738.0	169.0	81.4	18.6
Rotovation of the land (*Tilling and crossing*)	669.0	238.0	73.8	26.2
Puddling the field 3 to 4 days before seeding	758.0	149.0	83.6	16.4
Soaking of seed in water to speed-up germination	501.0	406.0	55.2	44.8
Adoption of formal irrigation	513.0	394.0	56.6	43.4
Construction of water bunds to allow water to stay on the field	536.0	371.0	59.1	40.9
Spraying the weeds with chemical weedicides	156.0	751.0	17.2	82.8
Application of fertilizer	611.0	296.0	67.4	32.6
Use of stationary thresher to thresh rice	872.0	35.0	96.1	3.9
Use of combine haverster	600.0	307.0	66.2	33.8
Storage of rice in warehouses	772.0	135.0	85.1	14.9
Control of storage and field pests using chemical pesticides	182.0	725.0	20.1	79.9

Source: *Analysis from field data (2017)*

5.4 Classification of Farmers into *IFPs*, *FISs* and *IATs* Adopters

PCA was used to typologically and objectively classify the variables under *IFPs*, *FISs* and *IATs*. SPSS version 20.0 was used for the analysis. Since the sample size is 907 and the number of variables considered in this study is forty-three, 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 Table 5.2, the KMO value of 0.723 was obtained indicating that the sample adequacy is middling[9] and hence PCA tool is perfect for 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 Figure 5.1) tests indicated that factors are loaded and retained under only three components.

Table 5.2 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	907
	Sig.	0.000***

Source: *Analysis from field data (2017)*

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

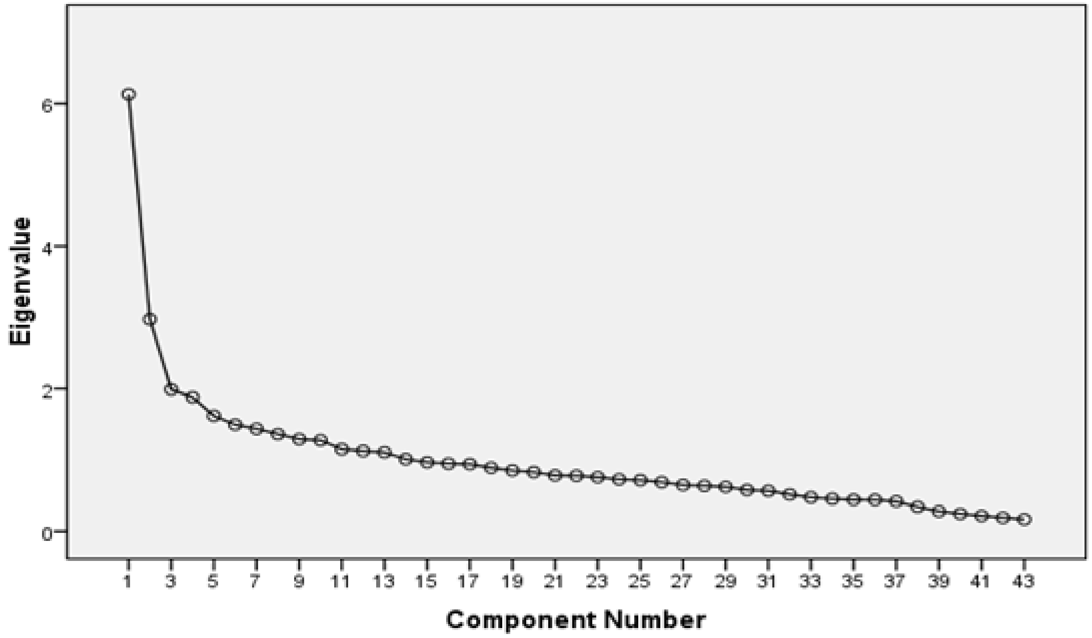

Figure 5.1 Scree Plot

Source: *Analysis from field data (2017)*

Table 5.3 shows the dimensional indices of factors loaded under *IFPs, FISs* and *IATs*. 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 4, fourteen principal components were extracted and they jointly explained 60.13% of the variations in the *IFPs, FISs* and *IATs* (44 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).

Table 5.3 Dimensional Indices of Factors Loaded under *IFPs*, *FISs* and *IATs*

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 using 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 (tilling and crossing)	0.592	6.131	5.088	14.258	14.258	0.711
Storage of rice in warehouses	0.582					0.591
Transplanting of seedlings with approximated spacing	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
Slash 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	
PC8: Undefined component						
Dibbling and planting with approximate spacing	0.524	1.362	0.524	3.167	43.924	0.733
PC9		1.291		3.003	46.927	
PC10: Undefined component						
Scare crow	0.423	1.276	0.423	2.967	49.894	0.513
PC11: Undefined component						
Exchange of foundation seed with other farmers	0.499	1.153	0.499	2.681	52.575	0.587
PC12: Undefined component						
Mulching to suffocate weeds	0.543	1.127	0.543	2.621	55.196	0.517
PC13: Undefined component						
Rouging	0.473	1.108	0.473	2.577	57.773	0.618
PC14: Undefined component						
Colouring of seed before planting	0.409	1.013	0.409	2.356	60.129	0.617

Source: *Analysis from field data (2017)*

From the Appendix 4, 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 principal component analysis, threshing of paddy rice from the straw by beating with sticks, slashing 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, slashing and leaving grasses to decompose, incorporation of rice straw into soil and soaking of rice seed into ash suspension before planting are closely interrelated since they are all loaded under component two. 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 variations 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*.

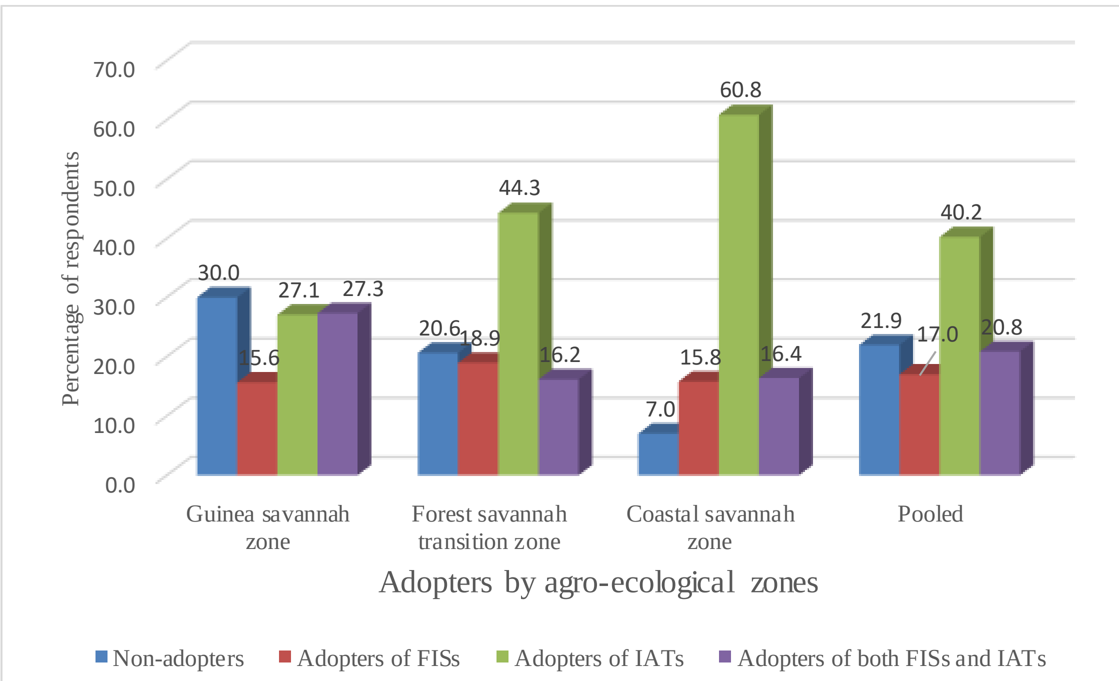

Figure 5.2 Percentage Distribution of Technology Adoption Typology of Farmers

Source: Analysis from the field (2017)

With the help of principal component analysis, farmers were classified into non-adopters (users of *IFPs*), adopters of *FISs*, adopters of *IATs* and adopters of both *FISs* and *IATs*.

Figure 5.2 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 (2016).

5.5 Descriptive Analysis of the Impacts of Technology Adoption on Rice Yield

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 5.4. 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 5.4, 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 3.6595Mt/Ha (17.64bags/acre) whereas adopters of *FISs* had the average rice yield of 2.40Mt/Ha (11.57bags/acre). From the Welch t-test results shown in Table 5.2, there is statistically 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 was expected since *IATs* are superior to *FISs*. The total adopters of this superior technology had rice yield of 1.2546MT/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 notwithstanding, the mean rice yield of 3.6595Mt/Ha obtained by farmers using superior technology is still below the potential yield of 6.5Mt/Ha reported by research institutions and MoFA (MoFA, 2011). On the other hand, the average rice yield of 3.6595Mt/Ha obtained from data collected for 2015 farming season from farmers using superior technology (*IATs*) is higher than the actual national average rice yield of 2.75Mt/Ha obtained in Ghana in 2015 (MoFA, 2016).

Table 5.4 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)

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

Out of 907 respondents, 40.2% farmers adopted *IATs* and 20.8% jointly adopted *FISs* and *IATs* (see Table 5.4). 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 like *IATs,* he/she should not mix it with *FISs*. This is because, the combination of these two set of technologies will result in a lower rice yield than the adoption of only *IATs* but a higher rice yield than *FISs*. Thus, adoption of *FISs* in combination with *IATs* helps in making up for the deficit in rice yield that a farmer would have lost for not fully adopting *IATs*.

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

The number of farmers who did not adopt any technology (either *FISs* or *IATs* or both) but rather concentrated on the use of *IFPs* only is 199 (see Table 5.4). 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 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. Wiredu *et al.* (2010) also found 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).

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

Combined adoption of *FISs* and *IATs* pays more than the adoption of only *FISs*. From the results in Table 5.4, 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 revelation confirms the *a priori* expectation.

5.5.5 Yield Discrepancy between Adopters of FISs and Non-Adopters

Another *a priori* expection was that averagely the rice yield of adopters of *FISs* would be higher than average yield of non-adopters (users of *IFPs* only). From Table 5.4, 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 that 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 5.4 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 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). Therefore, it is better for farmers to adopt their own innovations if they cannot afford the cost requirements of *IATs* than using *IFPs*. This finding is not surprising since many studies have empirically found out that adoption of *FISs* give higher than non-adoption. Therefore, *FISs* should be incorporated in the development of *IATs* by technocrats or scientists.

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* obtained appreciable rice productivity but their productivity is lower than farmers who have jointly adopted *FISs* and *IATs.*

CHAPTER SIX

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

6.1 Introduction

This chapter presents the metafrontier estimation results of rice production in Ghana. The empirical results of the estimated productivity performance indicators (technical efficiency, technology gap ratio, metatechnical efficiency) are presented and discussed. The empirical results of the determinants of rice output and technical inefficiency, metafrontier technical inefficiency and technology gap ratio are also discussed.

6.2 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 Table 6.1 and 6.2 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 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 6.1, 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 credits for rice cultivation.

Farmers in the CSZ are better placed in terms of infrastructure which can enhance timely and efficient rice production. The most disadvantaged 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.

Table 6 … mary Statistics of Continuous Variables in Metafrontier and GLM Models

	GSZ (n = 377)			FSTZ (n = 359)			CSZ (n = 171)			Pooled (N = 907)		
Continuou … les	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Rice outpu	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 c … stics												
Age (year	39.4	18.0	65.0	45.4	21.0	70.0	46.6	27.0	71.0	43.1	18.0	71.0
Househol	9.4	1.0	30.0	6.8	1.0	17.0	5.6	1.0	12.0	7.7	1.0	30.0
Educatior	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 farmi … ence (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
Institutio … licy variables												
Extension	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 o … h¢)	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 FB	1.2	0.0	24.0	1.0	0.0	8.0	1.4	0.0	7.0	1.2	0.0	24.0
Infrastruc												
Distance … of AEAs to communit	11.5	0.0	67.9	5.7	0.0	32.0	2.5	0.1	12	7.5	0.0	67.9
Distance … unity to market centres of	11.9	0.0	131.0	4.3	0.0	32.0	2.6	0.0	12	7.1	0.0	131.0
Distance … a 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 … 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
Environm … ocks												
Actual me … l 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 me … l 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 (n	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	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

Source: Author's analysis from field secondary data (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. Averagely, 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 6.2, 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 mototorable 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 6.2 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)

6.3 Determinants of Productivity Performances: The New-Two Step Stochastic Metafrontier Translog and GLM Model

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 technology gap ratio of rice farmers are also presented in this section.

6.3.1 Hypothesis Testing for Appropriateness of Stochastic Metafrontier Translog Model

For the use of appropriate models, four different hypotheses were tested and the results are presented in Table 6.3. 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 alternate 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 accurately and 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 6.3 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. The test revealed that the model for GSZ is nested into FSTZ and CSZ models. Also, FSTZ model is nested into GSZ and CSZ models. 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 the stochastic translog model of the FSTZ is nested in the stochastic translog model of the CSZ and the GSZ as well as the new-two step stochastic metafrontier translog model. The use of new-two step stochastic metafrontier translog estimation technique rather than the pooled stochastic frontier 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).

6.3.2 Determinants of Rice Output: The New-Two Step Stochastic Metafrontier Translog Model

The output of any production activity is dependent on the conventional inputs used. Table 6.4 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 envelop 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 technical efficiencies 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 accounts 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).

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. The revelations above suggest that farmers can improve upon their efficiency levels by proper usage of inputs through acquiring managerial skills. From the results shown in Table 6.4, 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 bias maximum likelihood parameter estimates if the dummies of the fertilizer and the pesticides were not included in the model (Battese, 1997 and Ogundari, 2013).

Table 6.4 Maximum Likelihood Estimates of 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
ln(F)	0.6449**	0.2864	0.6009***	0.2117	0.6669*	0.3891	0.5352***	0.0617
ln(Pc)	0.0449	0.1388	0.0030	0.1931	0.2321	0.1684	0.1505***	0.0411
ln(L)	-0.1060	0.1090	0.3456*	0.1970	0.2697*	0.1405	0.0375	0.0346
ln(S)	-0.1041	0.0902	-0.4290***	0.1580	-0.5670***	0.1255	-0.2666***	0.0282
ln(Fs)	0.7062***	0.1454	0.9552***	0.2721	1.1695***	0.1937	0.8324***	0.0423
ln(K)	0.3697***	0.0467	0.0257	0.0485	0.0690	0.1153	0.2204***	0.0121
ln(F)ln(F)	0.2182	0.3876	0.2158	0.2431	-0.7731	0.5528	0.0387	0.0822
ln(Pc)ln(Pc)	-0.0942	0.1015	0.1246	0.1660	-0.1255	0.2008	-0.0695*	0.0360
ln(L)(ln(L)	-0.0751	0.1154	0.5920*	0.3026	0.3195	0.2353	0.0524	0.0461
ln(S)ln(S)	-0.0411	0.0455	0.1020	0.1093	0.2307	0.1541	0.0044	0.0168
ln(Fs)ln(Fs)	0.3643*	0.2194	0.6111	0.5546	-0.0685	0.6189	0.5609***	0.0715
ln(K)ln(K)	0.1617***	0.0255	0.0476**	0.0221	0.1495	0.1746	0.1196***	0.0058
ln(F)ln(Pc)	0.1817	0.1147	-0.0356	0.1722	0.0274	0.1877	0.0751**	0.0333
ln(F)ln(L)	0.3085**	0.1507	-0.2360	0.2345	-0.0190	0.1922	0.1365***	0.0480
ln(F)ln(S)	-0.0272	0.1302	0.5019**	0.2267	0.1901	0.1838	0.2776***	0.0387
ln(F)ln(Fs)	-0.3209	0.2068	-0.5567	0.3519	-0.1959	0.2837	-0.4369***	0.0618
ln(F)ln(K)	-0.3129***	0.0653	0.0389	0.0444	-0.0980	0.1101	-0.0921***	0.0154
ln(Pc)ln(L)	-0.0238	0.1332	-0.2076	0.1958	-0.1242	0.2053	-0.0108	0.0407
ln(Pc)ln(S)	0.1375	0.0894	0.0975	0.1182	0.2060	0.1742	0.0487**	0.0246
ln(Pc)ln(Fs)	-0.2097	0.1586	-0.2144	0.1967	-0.2310	0.2743	-0.2150***	0.0422
ln(Pc)ln(K)	-0.0360	0.0482	0.0475	0.0449	0.2152	0.1310	0.0039	0.0124
ln(L)ln(S)	0.1480	0.0926	-0.2326	0.1751	-0.2546	0.1661	0.0169	0.0299
ln(L)ln(Fs)	-0.3459***	0.1109	0.1231	0.2734	0.4254	0.2688	-0.1531***	0.0380
ln(L)ln(K)	0.0071	0.0570	-0.0766*	0.0422	-0.2080	0.1659	-0.0241*	0.0134
ln(S)ln(Fs)	0.0406	0.1083	-0.2013	0.2562	-0.1612	0.2721	-0.0779**	0.0347
ln(S)ln(K)	-0.1189***	0.0418	-0.0522	0.0505	0.0983	0.1089	-0.0627***	0.0106
ln(Fs)ln(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)

6.3.2.1 Determinants of rice output in Guinea Savannah Zone

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 insignificant 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 0.6449, 0.7062 and 0.3697 respectively. This implies that a 100% increase in fertilizer will increase mean rice output by 64.5%, *ceteris paribus*. Similarly, if farm size increases by 100%, mean rice output will increase by 70.6% holding other factors constant. Also, a farmer who expects to increase mean rice output by 37.0% 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 1.5556 implying on average, farmers in GSZ are enjoying increasing returns to scale (IRS). This means that averagely the quantity of inputs used by farmers are below the efficient level and hence a farmer can increase rice output by 155.6% 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 seems to present the realities on the ground since 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.

6.3.2.2 Determinants of rice output in Forest Savannah Transition Zone

From Table 6.4, 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 quantity of seed planted will result in a 42.9% decrease in rice output and this negative relationship confirmes a study by Asravor *et al.* (2015).

From the results of the group specific stochastic translog model of FSTZ, the returns to scale is 1.5014% 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 50.1% (150.14% 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 so as to enjoy a more than proportionate increase in rice output.

6.3.2.3 Determinants of rice output in Coastal Savannah Zone

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. 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 by 66.7%, 27.0% and 117.0% respectively. On the contrary, rice output will decline by 0.5670% 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 1.8402% 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 184.0% increase in rice output which is 84.0% more than the proportionate increase in inputs. This means farmers can still increase rice output by jointly increasing the quantity of all the inputs.

6.3.2.4 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 linearised, 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 1% each. 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 contradicts the findings of Donkor and Owusu (2014).

Averagely, the sampled farmers involved in rice production in Ghana operate in the first stage of production function, i.e. they are operating at increasing returns to scale (returns to scale value of 1.5094). This means that if all the inputs are jointly increased by 100%, quantity of rice produced will increase by 151.0%. 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.

6.3.2.5 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.

6.3.2.6 Comparison of results of the frontiers

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 (1.8402) followed by GSZ with returns to scale value of 1.5556. The FSTZ has the lowest increasing returns to scale value of 1.5014. The increasing returns to scale value for the metafrontier is 1.5094. From the findings of this study, the joint increase in all inputs have 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.

6.3.3 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* and *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.

6.3.3.1 Determinants of technical inefficiency in Guinea Savannah Zone

From Table 6.5, 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.

Table 6.5 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
$ln(\sigma_v^2)$	-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.*
The a priori expectaions are shown in the parenthesis against variable names

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

The result of this study which 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) which 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.

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* have respectively lower PC indices. Therefore, as shown in Table 6.5, 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 feature 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.

6.3.3.2 Determinants 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 are able to 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* 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.

6.3.3.3 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 negative 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 is consistent wth economic theory, given its negative sign. Thus, 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.

6.3.3.4 Determinants of 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 6.5) 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 not surprising to find that as farmers grow older, their inefficiencies increased. 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. Another important reason that might result in inefficiencies of older farmers is that their physical strength reduces which affect their ability to provide manual labour. Similar findings were made by Njeru (2010) among selected wheat farmers in Kenya.

As noted by Al-hassan (2008), farmers with larger families have a variety of labour (children, youth, men and women) which makes division of labour and specialization possible. Division of labour and specialization result in overall improvement of technical efficiencies of farming operations. Household labour supply is very crucial in situations where hired labour is non-existing or difficult to find. In the metafrontier model, the number of extension visits, low amount of rainfall received and uniform synergised adoption of *FISs* statistically and significantly influenced technical efficiency of rice farmers but did not meet the *a priori* expectations.

6.3.4 Summary Statistics and Frequency Distributions of Technical Efficiencies

Table 6.6 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 finiding of the research, there is no farmer who has technical efficient 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 farmerrs in Graeter Accra have the highest yield of 6.45Mt/ha followed by Volta Region with yield values of 3.6Mt/Ha (MoFA, 2016).

Table 6.6 Levels and Distrubutions of Group Specific Technical Efficiencies

Technical Efficiency Scores	GSZ Frequency	GSZ Percentage	FSTZ Frequency	FSTZ Percentage	CSZ Frequency	CSZ 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 confirms 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.

6.3.5 Summary Statistics of Metafrontier Technical Efficiencies and TGRs

Table 6.7 shows the summary statistics of the metafrontier technical efficiency (MFTE) and the technology gap ratio (TGR[10]). In this study, agro-ecological zones were used as a yardstick for defining technology heterogeneity. TGR is also called productivity potential and it graphically 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.

Table 6.7 Summary Statistics of Metafrontier Technical Efficiencies and Technology Gap Ratios

	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)

In Table 6.7, 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

[10] 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.

given the technology available to the entire rice farming industry. The standard deviation showed that farmers in CSZ have the highest variations in TGRs.

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 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 (2016).

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 harsh 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 CSZ can be highly productive if they are able to adopt strategies that will minimise the effects of the environmental stress on rice.

Averagely, farmers in Ghana have technology gap ratio 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.

6.3.6 Drivers of Technology Gap Ratio

In order to identify the factors which statistically and significantly influence technology gap ratio, a generalised linear model (GLM) was estimated and the results presented in Table 6.8. From the results, the Aikake Information Criterion (AIC) value of -2.8681 implies that the model is fit for the data used for this study. The marginal effect[11] 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 so as 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 favourably improve the production environment for bridging the gap between actual and potential output (Mensah and Brümmer, 2016). The explanatory variables here are the

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

factors which are expected to influence the production environment of rice in Ghana (Mensah and Brümmer, 2016).

Table 6.8 Generalised Linear 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
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*
The a priori expectations are shown in the parenthesis

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

From the results presented in Table 6.8, out of fifteen hypothesied 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*.

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 technology gap ratios. 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 technology gap ratios. 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 rice actual 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.

6.4 Summary

The new-two step stochastic metafrontier was used to empirically estimate the productivity performances (technical efficiency, metafrontier technical efficiency and technology gap ratio) 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 decreases rice output suggesting a possible overcrowding of rice plants in the study area. 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 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 on the fact that they have the lowest mean technology gap ratio of 84.37% 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 SEVEN

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

7.1 Introduction

This chapter presents and discusses the results of the multinomial endogenous switching regression. STATA 14.0 was used to run the multinomial endogenous switching regression and the treatment effects predicted. With the help of t-test, the difference between 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 is presented and discussed in this chapter. Lastly, the statistical test for the treatment effects is presented and discussed in the chapter.

7.2 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*.

7.2.1 Summary Statistics of Continuous Variables in MESRM

Table 7.1 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). These findings provide clues on the expected magnitude of the impacts of the various technology adoption typology to rice yield.

It is clear from Table 7.1 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. Unsurprisingly, 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).

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 of *IATs* 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 thay 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 7.1, 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 centres (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.

Table 7 … mary Statistics of Continuous Variables in MESRM

Variabl…	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 (M…	1.73	0.38	5.12	2.40	0.60	8.09	3.66	0.78	10.27	3.10	0.25	6.22
Product… ts												
Farm si…)	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 … s)	38.2	8.0	156.0	47.1	10.0	183.0	45.3	11.0	205.0	47.7	11.0	144.0
Fertiliz…	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 (K…	94.3	20.0	1200.0	97.7	16.8	650.0	72.2	10.0	800.0	73.9	8.0	360.0
Pestici…)	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…	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 … eristics												
Age (ye…	43.7	18.0	65.0	42.6	20.0	71.0	44.0	21.0	71.0	41.4	21.0	64.0
Househ…	8.9	1.0	25.0	8.2	1.0	30.0	6.7	1.0	25.0	7.7	1.0	25.0
Educati…	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 far… erience (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
Institut… l Policy Variables												
Extensi…	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 F… ce	0.4	0.0	5.0	1.0	0.0	7.0	1.4	0.0	24.0	1.6	0.0	8.0
Infrastr…												
Distanc… fice of AEAs to commu…	12.1	0.0	67.9	7.9	0.0	38.0	4.5	0.0	38.0	7.9	0.0	38.0
Distanc… mmunity to rice marketi… (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
Distanc… ccra 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 and secondary data (2017)

7.2.2 Summary Statistics of Discrete Variables used in MESRM

In Table 7.2, 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*. 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 advancement 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 7.2 that a greater percentage of joint adopters of *FISs* and *IATs* (75.13%) belong 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 7.2 Summary Statistics of Discrete Variables in MESRM

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 of farming rice:	*No*	42	21.11	34	22.08	73	20.00	37	19.58
	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)

7.3 Econometric Analysis of Impacts of Technology Adoption Package on Rice Yield

The impacts of technology adoption package on rice yield was analysed using multinomial endogenous switching regression. The study used full information maximum likelihood approach for the estimation and the results are presented in Tables 7.3 and 7.4. 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 7.4, the model used fits well for the data since the Wald Chi-Square test is statistically significant at 1% for each of the technology adoption package. 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. A simple falsification test suggested by Di Falco (2014) was used to test for the appropriateness of the instruments. After the test, years of education, extension contacts and advice from FBO were selected as the appropriate instruments because they significantly affected adoption but not rice yield.

7.3.1 Factors Explaining Technology Adoption Package in Rice Yield of 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 7.3. 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 are 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*. Also, farmers who are not located in GSZ have higher probability of adopting *FISs* than their counterpart 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 unaware 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; and this 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 7.3 Full Information Maximum Likelihood Estimation of Determinants of Technology Adoption in MESRM

	FISs **(I_1T_0)**		***IATs*** **(I_0T_1)**		***FISs*** **and** ***IATs*** **(I_1T_1)**	
Variables	**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.

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

7.3.2 Determinants of Rice Yield in the Regime Equations of MESRM

Table 7.4 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 7.4, 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 implies 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*.

Table 7.4 Full Information Maximum Likelihood Estimation of Determinants of Rice Yield in MESRM

	FISs **(I_1T_0)**		***IATs*** **(I_0T_1)**		***FISs*** **and** ***IATs*** **(I_1T_1)**	
Variables	**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 and secondary data (2017)

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 corroborates with the *a priori* expectation 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 except lodging of rice and low rainfall amount. This is not suprising as Sena (2011) confirmed the positive impact of FBO membership on rice productivity. It has also been noted by Azumah *et al.* (2016) that contract farming is viable policy instrument to consider in climate change adaptation because it has significant impact on agricultural productivity.

From Table 7.4, rice yield of adopters of *IATs* are 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 conform 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 7.4, 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.

7.3.3 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 7.5. 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 7.5, ATT and ATU for all the technology adoption packages are significant. All the directions of the impacts of technology adoption packages on rice yield confirm 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 further 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*.

Table 7.5 Impact of Technology Adoption on Rice Yield (Treatment Effects)

Technology Adoption Package	Sample	Adoption Decision: Adopting	Adoption Decision: Not Adopting	Treatment Effects	% Change in TE	Transitional Heterogeneity (ATT - ATU)
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)

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 0.7912Mt/Ha (3.81bags/acre). This finding is against the *a priori* expectation. *FISs* are farmer and location specific. The innovation a farmer develops or learn from his/her colleague farmer is continuously changing and non-adopter of that innovation cannot ad-hocly adopt the package with the aim of increasing rice productivity. Innovation is inherent and some farmers might not have that trait and hence are bound to be worst off if they copy the innovation wrongly.

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 would 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 findings by Donkor *et al.* (2016) to the effect 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 is 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 7.5, 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) implying they would have lost 4.7820Mt/Ha (23.05bags per acre). This quantity is colossal enough to motivate farmers to continue the 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.

7.4 Summary

The econometric estimation of the impact of technology adoption packages on productivity performance (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 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 show that *FISs* and *IATs* have varied 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). Conversly, if non-adopters of *IATs* decide to adopt *IATs*, their rice yield will increase by 1.1929Mt/Ha (5.57bags/acre). Also, joint adopters of *FISs* and *IATs* are better off in terms of rice yield than their counterparts who adopted either of the two.

CHAPTER EIGHT

SUMMARY, CONCLUSIONS AND POLICY RECOMMENDATIONS

8.1 Introduction

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

8.2 Summary

In Ghana, rice is produced in almost all the agro-ecological zones even though the leading producing agro-ecological zones are GSZ, FSTZ and CSZ. The activity supports both the rural and the national economies. 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. It is against this backdrop that stakeholders (e.g. researchers, NGOs and policy makers) are making efforts to not only bridge the gap between potential and actual rice yield but also the gap across the agro-ecological zones. One of the efforts is the development and extension of improved rice production technologies while farmers also improve upon existing indigenous practices.

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. Principal component analysis was used to classify farmers into non-adopters and adopters of *FISs*, *IATs* as well as both *FISs* and *IATs*. Differences in rice yields among the various technology package adopters were tested using Welch t-test. The new-two step stochastic metafrontier model was used to estimate and identify the determining factors of productivity performances of farmers in the three agro-ecological zones, namely GSZ, FSTZ and CSZ. The GLM was used to analyse the drivers of technology gap ratio. To estimate the impacts of technology adoption typology on rice yield, MESRM was used. The study used both primary and secondary data.

A multi-stage sampling technique was used to sample 907 rice farmers across the three agro-ecological zones. The primary data were collected through face-to-face interviews with the use of semi-structure questionnaire. The secondary data were obtained from Ghana Meteorological Agency and MoFA.

8.3 Key Findings of the Study

Farmers were typologically 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. Rice producers are enjoying 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.

In general, the factors which positively and significantly influenced technical efficiency of farmers in the study area are sex, non-lodging of rice, perceived high rainfall amount, contract farming, FBO membership, extension contacs, years of education, improved seed, access to irrigation facilities, well-coordinated and synergised adoption of *IATs*. Conversely, technical efficiency is negatively influenced by uniform and synergised adoption of *FISs*. Farmers in CSZ are more technically efficient in rice production than their counterparts in the other two agro-ecological zones.

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 the probability of adopting *IATs* increases with number of extension visits, credit access, contract farming and closeness of the farmers to input markets as well as to Accra, the capital town. 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.

Lastly, 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 not adopting than adopting *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.

8.4 Conclusions

This study analysed rice productivity heterogeneity and policy implications for *FISs* and *IATs* in Ghana. The study has shown that rice farmers are 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. Also, while adoption of *IATs* has the highest impact on rice yield, a joint adoption of *FISs* and *IATs* results in a higher rice yield than the sole adoption of *FISs*.

Similarly, rice production in the agro-ecological zones as well as Ghana at large, is at increasing returns to scale which implies that the inputs are 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 good infrastructure, favorable environmental conditions, favourable government and NGO policy support and *IATs* and farmer innovations improve rice productivity performances of farmers in Ghana. The adoption of modern technology package (i.e. *IATs*) is the best technology option in terms of increasing yield.

8.5 Policy Implications and Recommendations

This study provides empirical evidence that rice farmers especially those in GSZ still 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 package 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 farmers targeted in the whole country especially GSZ considering the high percentage of non-adopters of the modern 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 and technical services 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 and not just a wholesale approach.

The long-term policy for government and NGOs are that good road infrastructure and construction of irrigation facilities should be pursued so as to enhance farmers' efficiency to increase rice productivity close to the 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 (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 improve upon and make them available to farmers.

8.6 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 develop a typology of 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. This has elimanted the biases which are associated with the pooling method of estimating metafrontier model.

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 many studies.

8.7 Suggestions for Future Research

While this study analyses rice productivity heterogeneity and policy implications for *FISs* and *IATs* in Ghana, it falls short of the analysis of the marketing efficiency of local rice. 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 higher 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.

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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	Slash 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 or cutlass to harvest rice (1 if yes and 0 otherwise)
P_{14}	Use of sickle 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}	Storage of rice in bags (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}	Use of wood ash to speed-up germination (1 if yes and 0 otherwise)
I_{21}	Transplanting of seedlings with approximate spacing (1 if yes and 0 otherwise)
I_{22}	Broadcasting in rows with approximate spacing (1 if yes and 0 otherwise)
I_{23}	Dibbling/drilling with approximate spacing (1 if yes and 0 otherwise)
I_{24}	Use of mulch to suffocate weeds and keep moisture (1 if yes and 0 otherwise)
I_{25}	Incorporation of rice straw into soil (1 if yes and 0 otherwise)
I_{26}	Colouring of rice seed to prevent identification by rodents or bird after seeding (1 if yes and 0 otherwise)
I_{27}	Use of cassette magnetic ribbon to scare birds (1 if yes and 0 otherwise)
I_{28}	Construction of water bunds to allow water to stay on the field (1 if yes and 0 otherwise)
I_{29}	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_{30}	Rouging (1 if yes and 0 otherwise)
T_{31}	Use of certified seed (1 if yes and 0 otherwise)
T_{32}	Clear the land before plough and harrow with tractor (1 if yes and 0 otherwise)
T_{33}	Plough and harrow the land directly without clearing (1 if yes and 0 otherwise)
T_{34}	Rotovation of the land (*Tilling and crossing*) (1 if yes and 0 otherwise)
T_{35}	Puddling the field 3 to 4 days before seeding (1 if yes and 0 otherwise)
T_{36}	Soaking of seed in water to speed-up germination (1 if yes and 0 otherwise)
T_{37}	Adoption of formal irrigation (1 if yes and 0 otherwise)
T_{38}	Spraying the weeds and pests with herbicides or pesticides (1 if yes and 0 otherwise)
T_{39}	Application of fertilizer (1 if yes and 0 otherwise)
T_{40}	Control of storage and field pests using chemical pesticides (1 if yes and 0 otherwise)
T_{41}	Use of combine haverster (1 if yes and 0 otherwise)
T_{42}	Use of stationary thresher to thresh rice (1 if yes and 0 otherwise)
T_{43}	Storage of rice in warehouses (1 if yes and 0 otherwise)

Appendix 2: Definition and Measurements of Explanatory Variables used 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	GSZ (1 if a farmer is located in GSZ, 0 otherwise)
FSTZ	FSTZ (1 if a farmer is located in FSTZ, 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)

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
GSZ	**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
FSTZ	**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
CSZ			
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: 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.

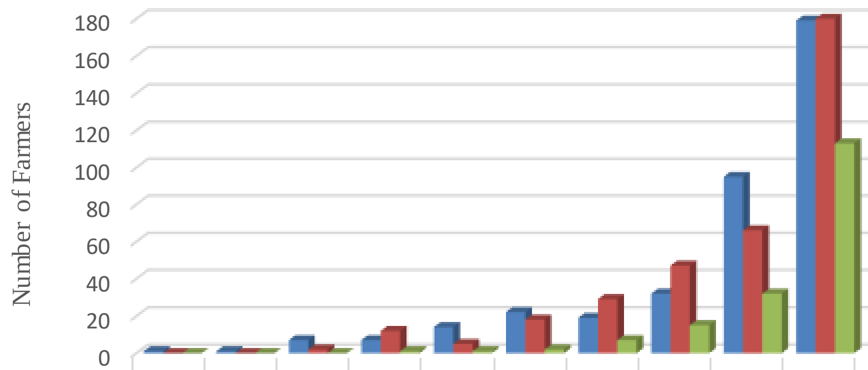
a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

Source: Analysis from field data (2017)

Appendix 5: Communalities

IFPs, Farmer Innovations and Scientifically IATs	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
Slash 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
Selection of 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 and keep moisture	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
Construction of water bunds to allow water to stay on the field	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
Plough and harrow the land directly without clearing	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)

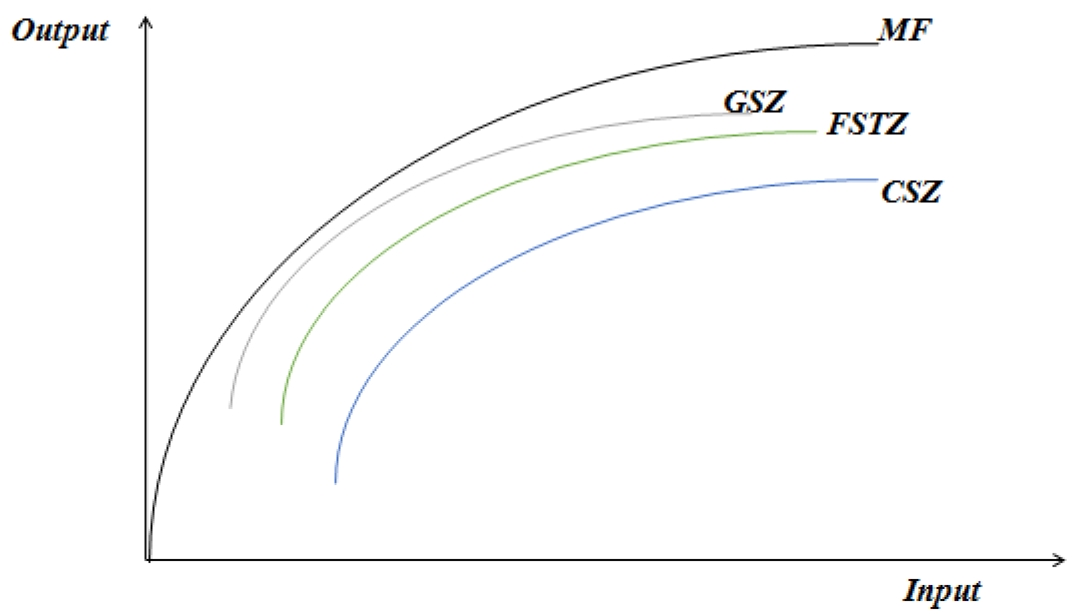


	0.00 – 0.10	0.11 – 0.20	0.21 – 0.30	0.31 – 0.40	0.41 – 0.50	0.51 – 0.60	0.61 – 0.70	0.71 – 0.80	0.81 – 0.90	0.91 – 100
Guinea Savannah	1	1	7	7	14	22	19	32	95	179
Forest Savannah Transition	0	0	2	12	5	18	29	47	66	180
Coastal Savannah	0	0	0	1	1	2	7	15	32	113

Technical Efficiency Scores

Appendix 6: Frequency Distribution of Technical Efficiencies

Source: Analysis from field data (2017)



Appendix 7: Frequency Distribution of Technical Efficiencies
Source: Analysis from field data (2017)

Appendix 7: Research Questionnaire

University for Development Studies
Faculty of Agribusiness and Communication Sciences
Department of Agricultural and Resource Economics

Resear[illegible]c: Productivity Heterogeneity of Rice Production in Ghana: Policy Implications for Farmer Innovations and IATs

Serial n[illegible]of questionnaire …………………..

Please [illegible]***ce yourself to respondent:*** My name is ________________ . I am an enumerator collecting data on behalf of Mr. Franklin N. Mab[illegible]lent of University for Development Studies, Tamale. The research aims at examining farmer innovation systems (*FISs*) and imp[illegible]agricultural technologies (*IATs*) used for rice production, their effects and policy implications for improvement in rice product[illegible]efore I begin, I would like to assure you that your responses will be strictly used for academic research and will be treated confider[illegible]our name would not be mentioned anywhere in the research work. Therefore, try as much as possible to be accurate and objectiv[illegible]ur responses.

A. [illegible]**ENCE INFORMATION**

Enume[illegible]ode		Name of community		Name of region	
Date o[illegible]ew:	……./………/……………	Name of district		Name of agro-ecological zone	

B. [illegible]EHOLD DEMOGRAPHIC CHACRATERISTICS AND FARMING ACTIVITIES

1. [illegible]lent's basic characteristics

1.1 Ag[illegible]pondent (number)	………….
1.2 Se[illegible]ondent	(1) Male [ ] (2) Female [ ]
1.3 Ma[illegible]us of respondent	(1) Single/unmarried [ ] (2) Married [ ] (3) Widow or widower [ ] (4) Divorced/Separated [ ]
1.4 Ho[illegible]size (number)	………………..
1.5 Ho[illegible]composition by sex	(1) Number of males:………. (2) Number of females:…………..
1.6 Tic[illegible]est level of educati[illegible]eted 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 Nu[illegible]ears of schooling by resp[illegible]	…………………..

Note: Ho[illegible]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 montl[illegible]

2 Hou[illegible]s income generated from on-farm and off-farm activities in 2014/15 cropping season

2.1 Tick [illegible] source of household's cash income (1) Agricultural activities [ ] (2) Non-agricultural activities [ ]
2.2 State [illegible]entage proportion of household's cash income from agricultural activities: …………. %
2.3 State [illegible]entage proportion of household's cash income from non-agricultural activities: …………. %
2.4 If yo[illegible]n-agricultural activities in 2.1 above, tick the actual main (major) source of household cash income (*Tick only one*)
(1) Trad[illegible] (2) Full-time/part time salary employment [ ] (3) Craftsmanship [ ] (4) Remittances [ ]
(5) Other sources [ ] (please specify)……………………….

3 Acc sic social amenities

Basic s nity/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 l ary school					
3.2 Hea rs					
3.3 Port er					
3.4 Nat tricity grid					
3.5 Pub privately own toilet (at least pit latrine)					
3.6 Ban commercial)					

4 Acce icultural extension services and information in 2014/15 cropping season

4.1 I le below

Ha ver sou ass dvice fro c. ext orker? Yes o [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 V you often get/hear information about **new rice production technology** (e.g. new variety, new chemicals, new farming practices etc)? Tick as many as appli

(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 Cre ss, amount and use in 2014/15 cropping season

5.1] e table below

Did you obtain a credit d the last farming season (2014/2((1) Yes (2) No	f yes, please state credit source 1) Commercial banks [ ] 2) Rural banks [ ] 3) Credit unions (*susu* groups)] 4) Governmental credit rogramme [ ] 5) NGO credit programme [ ] 6) Shopkeeper/traders in the illage/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? (Gh¢)	What was the total amount received ? (Gh¢)	How much of the credit was used for rice farming ? (Gh¢)	How much of the credit was used for other agricultural purposes? (Gh¢)	How much of the credit was used for non-agricultural purposes? (Gh¢)	How much do you have to pay back? i.e. (loan + interest) (Gh¢)	How many month s did you use in payin g the loan?
				………	……	……....	………..	………….	……….	……

5.2 nember of any credit or savings' and loans' group? (1) Yes [ ] (2) No [ ]

5.3 I .2, please mention the nature of the organization/institution ………….

6 Soci l of the farmer

Types c ation	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 Far l organization			
6.2 Cre avings' 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. *experience and rice cultivation decisions*

many years have you been farming? ………..

tion the crops you normally cultivate:

………..

:h of the crops mentioned above is the main? ……………………………….

many years have been engaged in rice production? ………..

the reasons why you cultivate rice: 1. ……………………………………………………. 2.

…………………………………………………………

3. ……………………………………………. 4. ……………………………………………………. 5.

…………………………………………………

9. *agricultural policy interventions and other things*

ou apply subsidized fertilizer on your rice farm in 2014/2015 cropping season? (1) Yes [ ] (2) No [ ]

ou apply subsidized pesticides on your rice farm in 2014/2015 cropping season? (1) Yes [ ] (2) No [ ]

ou use subsidized certified planting materials (rice seeds) in 2014/2015 cropping season? (1) Yes [ ] (2) No [ ]

far is your rice farm from the house? …………………..Km

long will it take to walk to your farm? …………..hours …………..minutes …………..seconds

the table below

Commu	**District capital**	**Product market (rice selling market)**	**Input market**	**Agricultural extension office**
Distanc				
Means transpo	(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 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 [ ]
Motoral	(1) Motorable [ ] (2) Unmotorallable [ ]	(1) Motorable [ ] (2) Unmotorallable [ ]	(1) Motorable [ ] (2) Unmotorallable [ ]	(1) Motorable [ ] (2) Unmotorallable [ ]

10. Labo Requirements

10.1 abour for rice production in 2014/15 cropping season *(Note this: one manday is 8hrs)*

Farming	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
Prepar nursery bed										
Plantin sery bed										
Manua g of the land										
Mecha animal power clearing of land										
Plough										
Harrov										
Transp of seedlings										
Direct planting										
1st Fert plication										
1st App of manure										
Sprayi e-emergence weedicides										
Irrigati ring/construction of bounds										
Roggin val 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										

Harves										
Thresh ng and bagging										
Transp										
Postha st control										
TOTA							……	….....	…….	……….

10.2 On a how much mandays of communal labour was provided by males for rice production in 2014/15 cropping season? ……….. *(Note this: one manday*

10.3 On a how much mandays of communal labour was provided by females for rice production in 2014/15 cropping season? ……….. *(Note this: one manday*

10.4 bour for rice production in 2014/15 cropping season ***(Note this:*** *one manday is 8hrs)*

Farming	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
Prepar nursery bed										
Plantin sery bed										
Manua g of the land										
Mecha animal power clearing of land										
Plough										
Harrov										
Transp of seedlings										
Direct planting										
1st Fert plication										
1st App 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)										

Mecha animal power weed control										
Sprayi ective weedicides										
2nd fert plication										
2nd App of manure										
On-fiel ontrol										
Harves										
Thresh ng and bagging										
Transp										
Postha st control										
TOTA							…….	………	………	……

11. achinery operations and animal traction for rice production in 2014/15 cropping season

Number of rice cultivated in 2014/2015: ………….								
Rice fa ivity	Tractor ploughing	Tractor harrowing	Animal ploughing	Animal harrowing	Mechanical weed control	Combined harvesting and threshing	Transportation	Irrigation
Number								
Cost pe								
Total c	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Overall s (Gh¢) (a)+(b)+ e)+(f)+(g)+(h)								

12. ge and cost of rice production in 2014/15 cropping season

12.1 ariable inputs

Name c variable	Name of variety of rice seed			Chemical fertilizer			Pest control agrochemicals		Water for irrigation	Organic fertilizer (compost and FYM)	Total cost of variable inputs (Gh¢)
				Ammonia	NPK	Liquid fertilizer	Weedicides	Insecticides			
Units											
Quantity											
Unit price (Gh¢)											
Total cost											

(Gh¢)											

12.2 ixed inputs

Name c 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 l of years be used												
Quantit												
Unit pri (Gh¢)												
Total cc fixed in (a) X (b												

11. ractices, innovations and technologies: Indigenous Farming Practices (*IFPs*), Farmer Innovation Systems (*FISs*) and ed Agricultural Technologies (*IATs*)

cate agro-ecological system that you use in cultivating rice.

(1) Valley bottom/lowland rainfed [ ] (2) Irrigation [ ] (3) Controlled flooding [ ] (4) Upland [ ]

(5) Other [ ] (specify)………………………….

all the methods of farming you use in cultivating rice. (you can tick more than one)

[ ] *IFPs*: They are relatively unimproved older farming practices handed over to you by your parents, grandparents or any other older family members or friends).

[ ] *FISs*: 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 IATs. It is also defined as the combination of existing techniques or technologies in new ways in order to enhance their impact (Wills, 2012).

[ ] *IATs*: 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 ... le below concerning 2014/2015 rice production activities.

Rice far... vity	**Indigenous Farming Practices (*IFPs*)**	**Farmer Innovation Systems (*FISs*)**	**Improved Agricultural Technologies (*IATs*)**
	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	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	Tick the method(s) of improved agricultural technology (ies) you use for each of the rice production activities stated in the first column of this table
Seed se...	[ ] 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 *IATs*
Land pr...	[ ] 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 *IATs*
Seeding (nursery management and seedling transplanting and direct seeding)	[ ] 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
	[ ] 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 *IATs*
Soil mo manage	[ ] 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 *IATs*
Weed c manage	[ ] 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
	[ ] 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 *IATs*
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 *IATs*
Field pe… manage…	[ ] 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 *IATs*
Method… harvest… threshi…	[ ] 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 *IATs*
	[ ] 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

Metho… …ge and storage manage…	[ ] 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
	[ ] Storage of paddy rice in bags	[ ] Storing paddy rice with neem (*Azdirachta indica)*extract or dried chopped 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 *IATs*

12. ***…l in the table by writing the names of varieties of rice cultivated, quantity sold, consumed, offered as gift, lost as well as the unit pric e per … of paddy rice sold from 2014/15 cropping season.***

Varietie… cultivat… 2013/14 season	…g	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¢)	

15. lisasters and constraints

15.1 e table below

In th of th prod -cropping season, did any rse events affect your rice?	Low temperature	High temperature	Strong winds	Low rainfall	Heavy rainfall or flooding or waterlogging	Drought	Fire	Soil erosion	Pest or diseases infestation
[1] Y No									

15.2 the main constraints facing rice production in your community.

…………………………………………………………………………………………

…………………………………………………………………… 3.

…………………………………………………………………………………………

…………………………………………………………………… 5.

…………………………………………………………………………………………

16. Resp household ID/House No:……………… Telephone no of respondent (if any) ……………………………..

THANK YOU

Append… Iatrix for Objectives, Methods, Key Findings, Conclusions, Implications and Policy Recommendations

Objecti…	Method of analysis	Key findings	Conclusions and policy implications	Policy recommendations
To … fy farmers … to technol… adoptio… gy and de… ly estimat… ne impact … ch typolog… ce 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 *FISs* and *IATs*. ii. *IATs* are more adopted in CSZ. 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 is *IATs*.	*IATs* should be highly promoted among farmers in the whole country but more emphasis ahould be given to their promotion among farmers in CSZ
To m… ne determi… of rice o… nd estimat… o- ecologi… ne specific… al efficien… nd metafro… technic… efficien… ce farmers … n.	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 GSZ, forest savannah and CSZ are 82.21%, 83.57% and 89.10% respectively, whereas the metafrontier technical efficiency of farmers in GSZ, FSTZ and CSZ 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 CSZ are more technically efficient in rice production than their counterparts. Farmers in GSZ have the highest metafrontier technical efficiency	i. Farmers should jointly increase capital, labour, farm size, pesticides and fertilizer except quantity of seed ii. Farmers are urged to reduce seeding rate to the recommended level

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Appendix 8: Matrix for Objectives, Methods, Key Findings, Conclusions, Implications and Policy Recommendations

To in the determi agro-ec zone technic efficien metafro technic efficien rice fai Ghana.	New-Two Step Stochastic Metafrontier Translog Model	Technical inefficiencies 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 long term 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*
To technol ratio (*T* identify influenc factors	New-Two Step Stochastic Metafrontier Translog Model and Generalised Linear Model (GLM)	i. Farmers in GSZ have the highest TGR (92.62%) followed by farmers in FSTZ (91.07%) with CSZ 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 CSZ have the highest potential of increasing rice yield. ii. Good infrastructure, favorable environmental conditions, favourable government and NGO policy supports, *IATs* and *FISs* 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 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 work during peak periods.

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Appendix 8: Matrix for Objectives, Methods, Key Findings, Conclusions, Implications and Policy Recommendations

To ide drivers farmers decisio adopt p technol package	Multinomial Endogenous Switching Model	i. Factors motivating the adoption of *FISs* are FBO advice, years of rice farming experience and farness of input market whereas probability of adoption of *IATs* increases with extension visits, credit access, contract farming, location of farmers in CSZ, closeness of the farmers to input markets as well as Accra. ii. Older farmers and farmers who have access to input subsidy have higher probability of jointly adopting both *FISs* and *IATs*	Farmers will be motivated to adopt *IATs* when they have access to extension advice, credit, engaged in contract farming, have easy access to improved inputs.	Contract farming concept, provision of improved rice seeds, intensification of agricultural extension services should be vigorously pursued to the latter
To as impacts technol adoptio package yield study a	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 as well as MFTE. Wholesome recommendation of *FISs* to all farmers is not justifiable. ii. The superior technology that can increase rice 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 should be given to its promotion among farmers in CSZ 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 *FISs* and improved upon and made available to farmers for adoption