Department of Agricultural Economics and Rural Development
Georg-August-Universität Göttingen, Germany

Kolawole Ogundari

Technical efficiency of smallholder farms in Nigeria

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Kolawole Ogundari
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Dedication:

I dedicate this dissertation to God Almighty, the giver of life

Abstract:

It is recognized that improvement in the efficiency of food crop production has policy relevance for food security program in developing countries of which Nigeria is a part. This is because the literature often stressed the importance of efficiency as a measure of performance by which production units are evaluated while identification of the causes of inefficiency is essential to the institution of public and private policies design to improve performance. The overall objective of this study is to contribute to the existing literature on efficiency as well as causes of inefficiency among smallholder farms in Nigeria. Against this background, paper I examined the development and drivers of the average technical efficiency (ATE) in Nigerian agriculture. The study was based on 64 efficiency studies covering 1999-2008. The major findings from this paper show that ATE significantly increased over time across the studies. Furthermore, 53% of the studies identified education as a significant determinant of technical efficiency (TE) while 38% indicated that experience is important. Extension is shown to be an important determinant by 23% while 19% identified age as a significant determinant of TE in Nigerian agriculture over the periods. Paper II identified the trends in crop diversification while examining its impact on the technical efficiency of smallholder farms in Nigeria. The findings show that cropping pattern increased significantly with the intensification of diversification. Also, the results demonstrate evidence of decreasing returns-to-scale and technical progress in food crop production. Education, extension, and crop diversification are identified as efficiency increasing policy variables. An average TE level of about 81% implies that an inefficiency level of about 19% is observed in this paper. Paper III investigated technical efficiency, inputs substitution and complementary effects using an output distance function while focusing on cassava production in Nigeria. The results show that increasing returns-to-scale as well as technical progress characterized cassava production. Fertilizer and pesticides are found to have significant substitution effects on cassava production while in pairs, farm size and pesticides, labour and fertilizer as well as fertilizer and pesticides jointly exhibit significant complementary effects on cassava production. An average TE level of about 72% implies an inefficiency level of about 28% is observed in the study. Paper II and III employed the stochastic frontier analysis (SFA) for the respective analyses based on a total of 846 observations covering 3 farming seasons (2006/07 - 2008/09). The data is from smallholder farms in southwestern Nigeria.

***Keywords*:** Agriculture, cassava, diversification, smallholder farms, technical efficiency, Nigeria

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Acronyms and Abbreviations

Abbreviation	Description
AE	Allocative Efficiency
ATE	Average Technical Efficiency
CBN	Central Bank of Nigeria
CDF	Cumulative Distribution Function
COLS	Corrected Ordinary Least Square
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EE	Economic Efficiency
FAOSTAT	Food and Agriculture Organization Statistical Database
FDH	Free Disposal Hull
FMARD	Federal Ministry of Agriculture and Rural Development
GDP	Gross Domestic Product
IRTS	Increasing Returns-to-Scale
MLE	Maximum Likelihood Estimates
MRT	Marginal Rate of Transformation
MRTS	Marginal Rate of Technical Substitution
MP	Marginal Product
NACRDB	Nigeria Agricultural Cooperative and Rural Development
NBS	Nigeria Bureau of Statistics
NEEDS	National Economic Empowerment & Development Strategy
OLS	Ordinary Least Square

Abbreviation	Description
PPF	Production Possibility Frontier
RTS	Returns-to-Scale
SFA	Stochastic Frontier Analysis
TE	Technical Efficiency

CHAPTER ONE

1.0. Introduction

1.1. An Overview of Nigerian Agriculture

Nigeria is a tropical country, characterized by high temperature and humidity as well as intense heat. It is located between Longitude 3^{o} and 15^{o} East and Latitude 4^{o} and 14^{o} North. The landscape of the country consists of lowlands, plains, highlands and plateaus. There are two major seasons in the country - the wet and dry seasons. The country occupies a total area of 92.4 million hectares which includes 91.1 million hectares of land and 1.3 million hectares of water bodies. The agricultural area is 83.6 million hectares, which comprises arable land (33.8 percent), permanently cropped land (2.9 percent), forest or woods (13.0 percent), pasture (47.9 percent), and irrigated land (2.4 percent) (Adetunji, 2006).

Nigeria has a population of about 144 million people with an annual growth rate of about 2.2 percent (NBS, 2010), of which 65 percent live in the rural areas (Philip *et al.* 2009).
Agriculture, which is the largest component of the rural economy in the country, is the main trust of many Nigerians as is the case in most of the sub-Saharan Africa countries. It is also the principal source of food and livelihood, making it a critical component of programmes that seek to reduce poverty and attain food security in the country.

Over 80 percent of the food needs of Nigerians are provided by the dominated smallholder farms in the country (Fayinka, 2004). NBS (2006) identified agriculture as the single largest employer among sectors (70 percent of labor force) and agricultural labor as the main and often time the only asset for the farm households in the country (Agenor *et al.* 2003).

Peasant farming characterises agricultural practice in Nigeria. Subsistence agriculture mainly takes care of the food needs of the farm households and produces little surplus for sale. This type of peasant agriculture, engages 95 percent of Nigerian farmers while farmers employed on corporate and government supported large-scale farms account for only 5 percent (Manyoung *et al.* 2005).

The farm households in the country engage in subsistence farming in which family needs determine the scale of production and wherein small plots of land are cultivated by individual owners or sub-owners following age-old methods without much control of the yields.

Traditionally, the farm households use family labor complemented with hired labour for farming operations. However, recent development shows that there is a growing increase in the use of hired labour; labor exchanges are also increasing with other farmers at peak seasons. This is because recent development shows that most farming families prefer to send their children to schools leaving only a few children available to participate in the farm operations at home.

Before the discovery of crude oil, agriculture was regarded as the mainstay of the national economy and contributed over 60 percent to the Gross Domestic Products (GDP) as against its recent contribution of approximately 40 percent despite the potential agricultural resources in the country (Tribune, 2010). According to Xinshen *et al.* (2010) relatively impressive economic growth rates were recorded during the 2000-07 period when the annual growth rate of GDP rose to 7.3 percent, compared to the periods of 1990-94 and 1995-99, when the economy grew at 2.6 and 3.0 percent per year respectively. These authors concluded that the agricultural sector has been a key driver of recent growth in the Nigerian economy. Between 1990 and 2006, the agricultural and oil sectors accounted for 47 and 39 percent of national growth, respectively.

Presented in figure 1.1 is the contribution of agriculture, oil & gas and the services industries to the Gross Domestic Products (GDP) at current producer prices, 1981-2006. The figure shows that, the contribution of the oil & gas industry surpasses that of the agriculture and service industry, while agriculture surpasses the services industry.

Figure 1.2 presents the contribution of the key five sub-sectors of Nigerian agricultural economy to the Gross Domestic Products (GDP) at current producer prices, 1981-2006. The figure shows that the crop sub-sector dominates in terms of contribution followed by the livestock, fishery, and forestry sub-sector. In fact, the crop sub-sectors accounts for 80 percent; livestock, 13 percent; forestry, 3 percent and fishery, 4 percent of the agricultural share of the GDP (CBN, 2009). Given the large size of the crop sub-sector, relative to the other three, the growth performance in this sector seems to drive the overall growth performance in the Nigerian agricultural sector.

Agricultural exports contributed to about 86 percent of Nigeria's total export in 1960. However, in 1984 the contribution dropped to 3 percent while in 2004 and 2008, the contribution dropped to as low as 0.81 percent and 0.2 percent respectively (CBN, 2008). This progressive reduction among other factors is partly attributed to the withdrawal of priority hitherto given to agriculture due to the heavy dependence on the oil sector since its discovery in the late sixties (Alabi, 2003).

The bane of agricultural development in Nigeria has always been associated with the following: inadequate supply of agricultural inputs, inadequate provision of reliable supporting services such as credit facilities, market information and extension activities, lack of appropriate package of technology for many farm enterprises or a poor response to technology adoption strategies, poor infrastructure, lack of properly prepared feasibility studies to identify problem areas as a guide to agricultural project execution, and inefficient policy and program implementation (Obeta, 1990; Idachaba 2004; Manyoung *et al.* 2005; Tribune, 2008).

Besides, there is also the argument that low public spending for agriculture is another impediment to agricultural advancement in the country (Manyoung *et al.* 2005). The Nigerian agricultural expenditure is far below international standards even when accounting for its level of income. The share of agriculture in the federal government's annual budget ranges between 1.3 percent and 7 percent from 2000 to 2007 and this has consistently fallen below the Maputo declaration of a 10 percent share of the country's total budget for agriculture (Fan *et al.* 2009). This is an indication of the low priority Nigerian governments have placed on the agricultural sector.

Growth in the agricultural sector has also not kept pace with the needs and expectations of the nation. Over the past 20 years, value added per capita in agriculture has risen by less than 1 percent annually. The average annual growth rate ranged from about 3.3 percent in the 1990s to an average of 6 percent between 2003 and 2007 (CBN, 2008). Most of the current growth rate has been attributed more to an expansion in cultivated land area rather than an increase in productivity (Manyoung *et al.* 2005).

The dismal performance of the agricultural sector in the last four decades prompted the government to initiate several agricultural schemes and programmes or economic programmes with an agricultural reform content to enhance agricultural development in Nigeria. The programmess include: Commodity Marketing Boards (1947-1986), National Accelerated Food Production Project (1970 to date), National Agricultural Cooperative Bank (1973 to date), Agricultural Credit Guarantee Scheme Fund (1973 to date), Agricultural Development Project (1975 to date), Operation Feed the Nation (1976 to date), River Basin Development Authorities (1977 to date), the Green Revolution (1979-1983), Directorate of Food, Roads and Rural Infrastructure (1986-1993), National Directorate of Employment Project (1986 to date), National Agricultural Land Development Authority (1991-1999), Structural Adjustment Program (1986-1994), Root and Tuber Expansion Project (2005 to date), The National Economic Empowerment and Development Strategies (NEEDS I of 2000-2007 and NEEDS II of 2008 to date), National Special Programme for Food Security (2002 to date), and National Fadama I program (2003 to 2007), National Fadama II program (2008 to date), and Presidential initiatives on selected commodities: Cassava, Rice, Cocoa, Vegetable oil, Livestock and Fisheries (1999 - 2007).

Although, these programmes and interventions helped to ensure that the agricultural sector achieved relative progress in some quarters, the majority of the completed programmes left a lot to be accomplished in terms of national food security. Supporting this observation, Idahchaba (2004) posited that empirical records of many of these programmes and projects are not impressive enough to bring about the expected transformation of the agricultural sector in the country. One of the indentified sources of failure for these programmes has been strongly linked to a lack of continuity that characterized their operation and implementation by the successive governments (Tribune, 2010). However this is not surprising because policy discontinuity has become the culture of the Nigerian government.

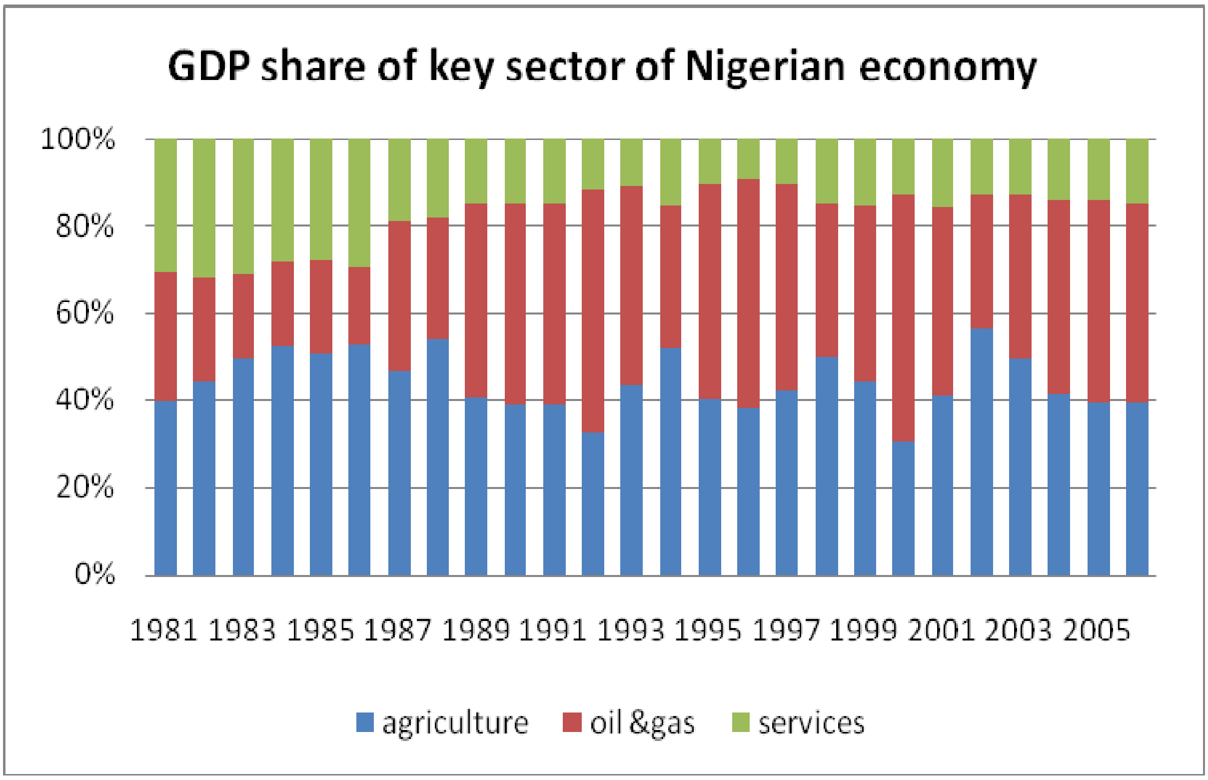

Figure1.1: Share of the key sectors of Nigeria economy to the Gross Domestic Product at current producer price, 1981-2006 (CBN, 2009)

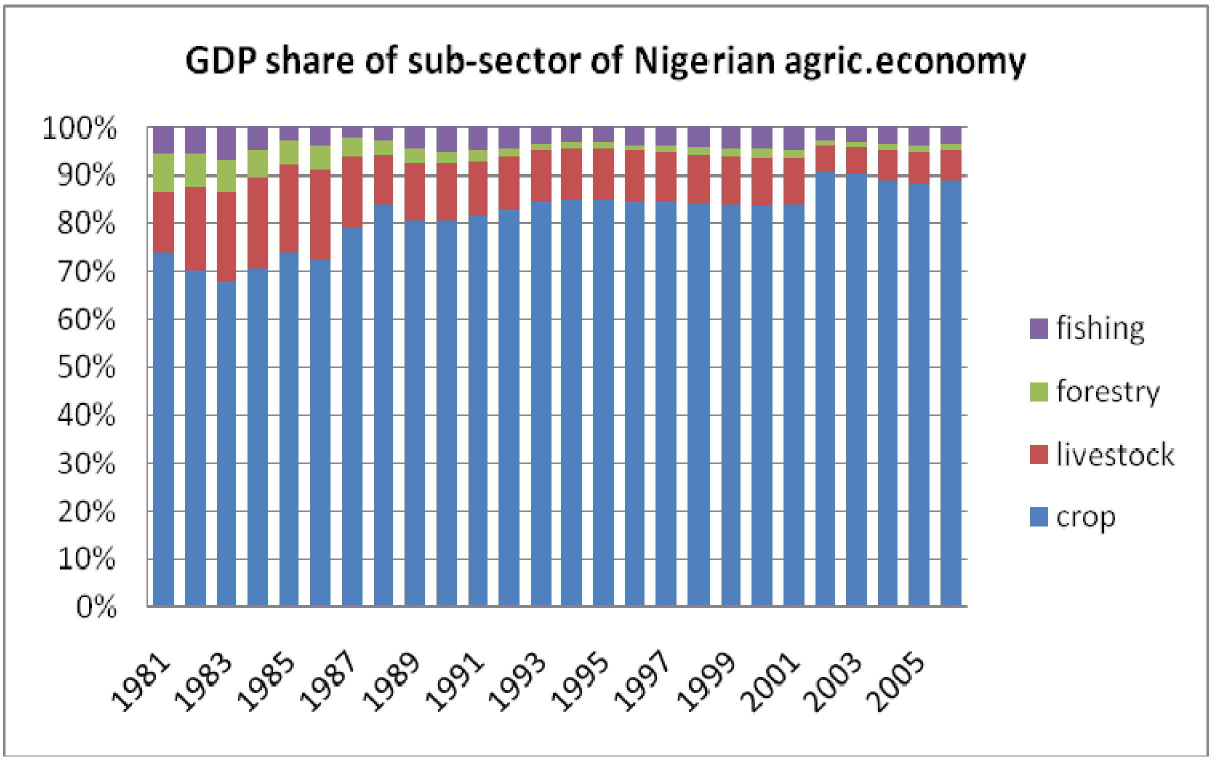

Figure 1.2: Share of sub-sector of Nigerian agricultural economy to the Gross Domestic Product at current producer prices, 1981-2006 (CBN, 2009)

1.2. Nigeria's food situation

Adequate intake of food and nutrition has been acknowledged not only as the basic sustenance of life but also as a key indicator of a healthy and productive life. According to Aromolaran (2004), food intake has been found to have a strong empirical linkage with both human health and productivity. At the national level, food has an economic, strategic and political significance.

In Nigeria for instance, persistent stagnation in food production is now a serious concern as per-capita growth of major food items has not been able to meet up with the demand of the increasing population (Sanusi *et al*. 2006). This observation has led to: *i*) a food demand supply gap thus leading to a widening of the gap between domestic food supplies and the total food requirement, and *ii*) an increase in food importation (FMARD, 2001).

Several factors have been attributed to the dismal performance of the food sub-sector of the Nigerian agricultural economy. For example, low mechanization, outdated land tenure systems, availability of inefficient extension advisory services, low adoption of research findings and technologies in some cases, high cost of farm inputs, access to credit, inadequate irrigation and storage as well as poor access to markets, have all contributed to keeping the productivity of food production low. Also identified are: urbanization, inflation and demand from neighboring countries which are among some of the factors that continue to affect food availability and accessibility as well as affordability to most Nigerians (Manyoung *et al.* 2005).

Crop production in Nigeria is dominated by cereal, root and tuber crops. Presently, the country is regarded as the largest producer of cassava, yam and cowpea in the world (Nkonya *et al.* 2010). Nigeria produces over 40 million tonnes of fresh cassava tubers per annum while IITA (2005) observed that Nigeria's cassava production has not only met domestic need but it has also met export demand from the European Union, China, and South Africa among others.

Although, Nigeria continues to import large quantities of cereals such as rice, wheat among others, even though the country could be self-sufficient in the production of rice most especially (Ogundari *et al.* 2010), there are indications that Nigeria is making appreciable progress in meeting her domestic needs for sorghum, millet and to some extent maize and cowpea (Manyoung *et al.* 2005).

Presented in figure 1.3 is the production trend of the key most produced staple commodities in Nigeria, 1980-2007. The figure reveals that cassava accounts for the largest share of crop production with an increasing trend in production until lately. Tribune (2008) observed that the growth indices of cassava production which fluctuate between stagnation and decline since 2006 till date, can be blamed in part on policy reversals and inconsistencies of the present administration. Furthermore, the figure shows that production increases in yam, maize, sorghum and millet have been more modest.

In a related development, Nkonya *et al.* (2010) observed that the productivity of commonly produced staples in the country is less than half of the potential yields. According to these authors, the approximately 12mt/ha, 14mt/ha, 1.1mt/ha, 1.1mt/ha and 12.3mt/ha of cassava, maize, sorghum, millet and yam yields currently observed in the country are below the potential yields of 28.4mt/ha, 4mt/ha, 3.2mt/ha, 2.4mt/ha and 18.0mt/ha respectively. This observation might possibly explain the production trends of the staples observed in figure 1.3.

Moreover, Abalu and D'Silva (1980) noted that improving Nigeria's food situation has always been challenged by a low level of farm resources, technology, productivity, and the role of the government vis-à-vis farmers in the achievement of technological change. This observation, however, seems to suggest that an improvement in the efficiency of food crop production is relevant for policies regarding food security programmes in the country.

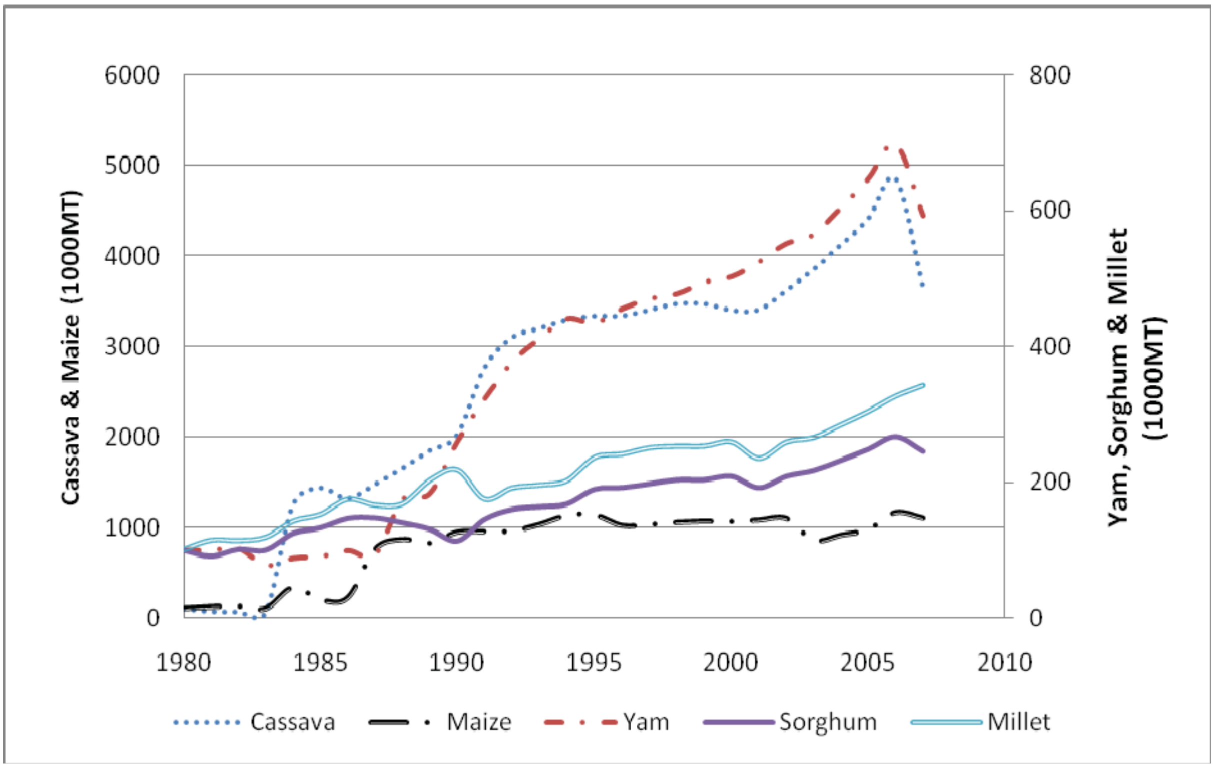

Figure 1.3: Production trends of the key most produced staple food commodities (1980=100), 1980-07 (FAOSTAT 2009)

1.3. Conceptual Framework

1.3.1. Roles of efficiency and productivity in agricultural development

The ultimate objective interest of economists in productivity and efficiency measures is to find ways of increasing output per unit of input. The economists also strive to attain desirable inter-firm, intra-firm, and inter-sector transfers of production resources, thereby providing a means of fostering economic development.

Productivity is an absolute term definable in terms of individual resources or a combination of them while efficiency is the combination of resources in relation to a frontier (standard). The crucial role of efficiency in increasing agricultural output has been widely recognized by researchers and policy makers alike. Thiam *et al.* (2001) highlighted the importance of efficiency as a means of fostering production which has led to the proliferation of efficiency and productivity studies in agriculture around the globe.

Ali and Chaudhry (1990) also stressed the importance of efficiency in developing agricultural economies where resources are meager and opportunities for developing and adopting better technologies lately started dwindling.

In agriculture, the analysis of efficiency is generally associated with the possibility of farms to produce the maximum level of output from a given bundle of resources or a certain level of output with the least cost. The implication of this is that an improvement in the productive efficiency of agricultural enterprises is likely to provide opportunities for farmers to produce more which could in turn lead to a rise in the welfare level of the farm families. This supports Wollni and Brümmer's (2009) observation that an increase in productive efficiency is capable of enhancing farmers' competitiveness and could also help them confront adverse economic conditions.

Nishimizu and Page (1982) also noted that agricultural output growth is not only determined by technological innovations but by the efficiency with which available technologies are used. This means that improvements in technical efficiency constitute a major component of total factor productivity growth, and are identified in literature as particularly important in the agriculture of developing economies (Brümmer *et al.* 2006), of which Nigeria is a part. Also, Brümmer (2006) observed that for these developing countries, the dynamics of technical efficiency change and technological change are probably the crucial factors for the development of total factor productivity in the aftermath of agricultural trade liberalization. These potential gains could help alleviate the rural poverty problem.

Because agriculture accounts for over 70 percent of the 140-million plus people (NBS, 2010) in Nigeria, it is important to understand the trends, sources, and drivers of the efficiency of the sector as a key indicator of performance for institutions designing private and public policy. This will go a long way to reduce poverty and enhance food security in the country.

Furthermore, a quantification of the production efficiency could also help shed light on conceivable reasons why farms differ in their level of efficiency in Nigeria.

1.3.2. Diversification of farm activities and agricultural efficiency: is there any link?

Agricultural diversification is considered as a resilience mechanism among peasant farmers (Ellis, 1993) as is the case in Nigeria. It is usually viewed as an important component of the overall strategy for small farm development. According to Ponti *et al*. (2007), crop diversification in particular has attracted considerable interests among traditional farmers around the globe. This view was also upheld by Gunasena (2000) who posited that many developing countries have incorporated a crop diversification strategy in several development programmess. A significant example of this is the well documented Asian experience in the successful use of a diversification strategy in the commercialization of agriculture in the 1990s (Hoque 2000; Mariyono 2007).

By diversification, the study refers to the number of economic activities an economic agent is involved in as well as the distribution of the share of these activities in the total economic activity of the agent. As market opportunities develop, the enterprise mix begins to respond to market forces; this perspective is more relevant in the context of altered economic development. However, the concept of diversification conveys different meanings to different people at different levels. For example in research related to marketing, diversification is said to be a measure of market concentration. Within agricultural production, diversification may be viewed as a process with three stages (Chaplin 2000). The first stage is considered as the cropping level which involves a shift away from monoculture. At the second stage, farms have more than one enterprise and many farmers produce and sell crops at different times of the year. The third stage is understood to be mixed farming where there is a shift in resources from one crop (or livestock) to a larger mix of crops (or livestock) or mixture of crop and livestock.

In a broader perspective, agricultural diversification can be categorized into: (i) geographical diversification (this represents the number of production location), (ii) crop diversification (this represents either the migration from low value to high value crops; single crop to multiple/ mixed crop; crop alone to crop with crop-livestock-fish-aquaculture or from agricultural production to production with processing and value addition), (iii) income diversification (this represents the number of income sources through off-farm activities).

Johnston *et al.* (1995) identified three dimensional benefits which could be derived as a result of engaging in crop diversification. These include: the economic, social, and agronomic benefits (see figure A2 of the appendix). The economic benefits include: seasonal stabilization of farm income to meet other basic needs of life such as the education of children, coverage of subsistence needs, most especially the meeting of family food security, and a reduction in the risk of the overall farm returns by selecting a mixture of activities whose net returns have a low or negative correlation while lessening price fluctuations. Social benefits include seasonal employment for farm workers and the presence of economies of scope which is a reflection of cost reduction associated with production of multiple outputs while the agronomic benefits include the conservation of precious soil and water resources, reduction in diseases, weed and insect build up, reduction in erosion, increase in soil fertility, and increase in yields[1]. These assertions were upheld by Caviglia-Harris and Sills (2005), Gunasena (2000), Chavas (2001) and Ali and Beyeler, (2002). Paul and Nehring (2005) also identified diversification as a significant factor explaining the differences in the level and variability of farm incomes between higher and lower-performing small farms. Several other micro-level studies support this proposition (von Braun 1995; Ramesh 1996; Vyas 1996; Delgado and Siamwalla 1999; Ryan and Spencer 2001).

Inasmuch as the potential benefits of crop diversification have been stressed, it is equally important to identify constraints associated with agricultural diversification in the literature which include: increasing labour requirement and supervision on the farm, soil suitability and availability and the cost of labour (Joshi *et al.* 2003). Considering the fact that agricultural diversification is a recognized phenomenon among smallholder farmers around the globe, the crucial concern for the distillation of policy is whether there is any relationship between crop diversification and farm level efficiency.

A search of the literature however suggests that the link between crop diversification and the efficiency of agricultural producers is quite mixed. While Guvele (2001) and van den Berg *et al.* (2007) revealed that crop diversification reduces income variability in Sudan and sustains a reasonable income level for Chinese farmers respectively, Kar *et al.,* (2004) and Rahman (2009) concluded that crop diversification increases agricultural production in India and Bangladesh respectively. Additionally, Llewelyn and Williams (1996) as well as Haji (2007)

[1] The benefits of crop diversification have both value-enhancing and value-reducing effects such that the net effect is ambiguous in some instances (Chaplin, 2000).

concluded that diversification significantly decreases the efficiency of farmers in Indonesia and Ethiopia respectively while Coelli and Fleming (2004) and Rahman (2009) reported that diversification improves the efficiency of farmers in Papua New Guinea and Bangladesh respectively.

The capability of crop diversification to enhance farm-level efficiency could be attributed to any of the following: *First*, under multiple cropping systems, crops not only compete for nutrients but can mutually benefit each other with regard to an improvement in soil fertility; a tendency to reduce diseases, weed and insect build up and the ability to reduce erosion among others. *Second*, output complementarities in terms of unobserved factors (e.g., farming experience gained from one crop could be replicated on another crop) and observed factors (method of production/ technical knowledge) under such a system of production have the tendency to positively impact the performance and production of another crop in the region. *Third*, using the same level of inputs that could have been used to produce one crop under a crop diversification system of farming implied that the efficiency is probably enhanced by input reduction rather than output expansion by the smallholder croppers under investigation in the region.

In a related development, if the degree of crop diversifies per plot is not curtailed within an efficient planting space based on the advice of agronomic experts; engagement in crop diversification could be disadvantageous. For example, overpopulation per plot of different plant species could limit the nutrient supply to crops, thereby affecting their production performances. Also, the fact that crop diversification requires adequate supervision on the farm implies that non adherence to a reasonable number of crops per plot as often suggested for easy monitoring could have adverse effects on production and possibly on the efficiency level of the production.

The study recognises the tension in the literature between the clear benefits of diversification to poor rural households in the short- and medium term as compared to the long term need for greater specialization. Nevertheless, it is important to stress how these phenomena developed as their impact on the livelihoods of economic agents might vary from region to region, from case to case or agents to agents.

1.4. Motivation of the study

The crucial role of efficiency as a means of fostering agricultural production has been widely recognised by researchers and policy-makers around the globe (Bravo-Ureta *et al.* 2007). The measurement of efficiency is important for the following reasons: *First*, it is a success indicator of performance by which production units are evaluated; *second*, the measurement of the causes of inefficiency makes it possible to explore the sources of efficiency differentials and the subsequent elimination of its causes; *third*, the identification of the determinants of efficiency levels is essential to the institution of public and private policies design to improve performance.

Brümmer (2006) stated that improvement in the major components of total factor productivity growth such as technical efficiency change is particularly important in the agriculture of developing countries. Also, Ajibefun (2006) observed that the measurement of efficiency is more important, given the fact that the efficiency of smallholder farmers is directly related to the productivity of agriculture in developing economies.

It can be inferred from the literature that farms not only benefit directly from an improvement in their efficiency level but efficient and productive farms tend to generate higher incomes and increase food production. For example, Wollni and Brümmer (2009) noted that an increase in the productive efficiency is capable of enhancing farmers' competitiveness and could also help them confront adverse economic conditions.

In the light of this, efficiency in crop production has become a topical issue in the food security programmes of many developing countries including Nigeria. For example in Nigeria, studies have shown that, a good knowledge of the current efficiency or inefficiency inherent in food production as well as the factors responsible for the level of inefficiency needs to be critically examined (Amaza and Olayemi 2002; Ogundari and Ojo 2005; Ajibefun 2006; Okoruwa *et al.* 2007). This is necessary because the per-capita growth of major food items has not been able to meet up with the demand of the increasing population in the country (Sanusi *et al*. 2006). In fact, recent statistics show that Nigeria's food production on the aggregate has been growing at a rate of about 2.5 percent per annum while the demand for food on the other hand has been growing at a rate of over 3.5 percent per annum (Akinyele, 2006).

This situation implies that food production is not keeping pace with the rise in demand and population growth which indicates that there is a relative food deficit in the country.

The constraints to the rapid growth of food production seem to be associated with a number of factors, key of which include low crop yield and resource productivity among the dominated smallholder farms in the country (Udoh, 2005). Manyong *et al.* (2005) observed that food production in Nigeria has been driven by an expansion in the area planted rather than an increase in productivity while Nkonya *et al.* (2010) concluded that the productivity of the traditional crops such as cassava, yam, and cocoyam, among others is below the potential yield levels in the country.

We acknowledge the fact that the allocative efficiency measure of productive efficiency is as important as its associated technical efficiency for the distillation of policy inference. Nevertheless, the present study focuses exclusively on the later because of the non-availability of reliable input prices needed for the quantification of allocative efficiency. Also, the imperfect input market that characterized the production unit under investigation might make it impossible to have a behavioral assumption such as the cost minimization imposed before allocative efficiency can be measured. Hence, the subsequent discussion focuses on the assessment/measure of technical efficiency among the smallholder farms in Nigeria.

First, the study seeks to understand the distribution of technical efficiency in Nigeria's agriculture and its drivers based on frontier studies in the country covering 1999-2008. This is important to provide institution of public and private policy-making with an important control mechanism for agricultural planning in the country. In addition, the study will quantify the effects of modeling choices and regional specific dummies on the reported technical efficiency estimates from the frontier literature in the country.

Second, an important phenomenon of great concern which is the stage at which many developing countries agriculture currently operates is the diversification of the portfolio of farm activities as discussed in the previous section. Unfortunately, empirical findings appear mixed with regard to the link between crop diversification and farm-level efficiency. However, because of increasing interest in this phenomenon among the smallholder farmers in the country (Fawole and Oladele 2005), it is vital to examine crop diversification trends and their effects on the efficiency of food crop production in the country. In other words the study seeks to ascertain whether there has been a major shift in cropping pattern and its subsequent impact on the technical efficiency level of the smallholder farmers in the country with the implication of whether crop diversification is a desirable strategy for food security programmes in the country.

Third, the strategic importance of cassava as a famine reserve crop in many rural households as well as a major item in the crop combination of most farming households with significant contribution to the total farm income in the country has been stressed (Bamire *et al.* 2004). Based on this, it is important to update the literature on the efficiency of the cassava industry with an implication to complement various efforts of research in improving cassava production in Nigeria.

1.5. Objectives of the study

The broad objective of this study is to examine the technical efficiency level of smallholder farms in Nigeria. However, in light of the discussions above, this study has the following specific objectives:

i. Examining the development and drivers of technical efficiency in Nigerian agriculture based on efficiency studies, 1999-2008;
ii. Identifying the trends in crop diversification while examining its impact on the technical efficiency of smallholder farms in Nigeria;
iii. Estimating technical efficiency, inputs substitution and complementary effects, while focusing on cassava production in Nigeria.

1.6. Organization of the study

The remaining parts of the study are divided into five chapters and organized as follows:

Chapter Two

Chapter two is devoted to the theoretical foundation relevant to the study. The chapter reviews the historical perspective of the efficiency methodology. This section further discusses production theory and production function and other definitions of efficiency. The theoretical framework, technique of efficiency measurement and, the econometric approach to efficiency measurement as well as the new development in SFA vis-à-vis *the output distance function* are discussed.

Chapter Three

This chapter is based on the meta-analysis of technical efficiency studies covering the period 1999-2008 with a focus on Nigerian agriculture. A total of 64 frontier studies which yield 86 observations are used for the meta-regression analysis. The paper qualitatively examines the distribution of the efficiency ratio in the sector based on the primary literature over the years. Likewise, we use descriptive statistics to identify which of the policy variables most influence the average technical efficiency (ATE) in the frontier studies. Further, a truncated meta-regression is employed in the paper to quantify the effects of modeling choices and regional specific dummies on the reported average technical efficiency (ATE) from the frontier studies.

Chapter Four

Chapter four investigates the trends in crop diversification and its impacts on the technical efficiency of smallholder farms in Nigeria. The paper employs unbalanced panel data covering 3 farming seasons (2006/07-2008/09) with a total of 846 observations on the smallholder croppers in the Southwestern part of the country. Herfindahl and Ogive indices are used for the computation of the diversification index while the stochastic frontier production model was also used for the estimation of the technical efficiency of the farms. The production output in this paper is the aggregated value of all food crops produced by the farmers.

Chapter Five

This chapter analyse technical efficiency, inputs substitution and complementary effects using an output distance function with a focus on cassava production in Nigeria. The paper employs the stochastic frontier output distance function because of the multiple-outputs and inputs characterization of the production technology of the farms. That is, the production output of the farms is disaggregated into the value of "cassava" and value of "other crops" produced in this paper. A total of 846 observations on the smallholder croppers from 2006/07-2008/09 farming seasons in the Southwestern Nigeria are used for the analysis.

Chapter Six

Chapter six winds up this dissertation by summarizing the major findings, conclusions and policy implications and directions for future research from the study are outlined.

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CHAPTER TWO

2.0. Theoretical foundation

2.1. Introduction

This chapter provides a review of efficiency methodology vis-à-vis a theoretical and analytical framework. Besides, issues related to the techniques of efficiency measurement such as parametric and non-parametric are discussed. Specifically, this chapter addresses an econometric approach to efficiency measurement such as the stochastic frontier analysis (SFA)-production model while the extension of SFA to the output distance function is highlighted. However, it is important to stress here that most of the materials used in this chapter can be found in the following literature possibly for further reading: Färe *et al.* (1994), Färe and Primont (1995), Kumbhakar and Lovell (2000), and Coelli *et al.* (2005).

2.2. Historical perspective of efficiency methodology

2.2.1. Production theory and production function

Production is the process of transforming inputs into outputs. Production, cost, profit and revenue functions are always the tools for examining the resource productivity and resource use efficiency of firms by production economists. In microeconomic theory, the production function is defined in terms of the *maximum* output that can be produced from a specified set of inputs, given the existing technology available to the firms involved (Battese, 1992). According to Beattie and Taylor (1985), a typical production function of a firm has the following assumptions: 1) production activity must be arranged such that production in one time period is, totally independent of the production in preceding and subsequent time periods; 2) all inputs and outputs must be homogeneous; and 3) the production function must be continuously twice differentiable.

The basic theory of production represents the production technology of a decision making unit (DMU) using the concept of the production possibility set described as follows:

Production possibility set

Following the work of Färe and Primont (1995), the production possibility set of a DMU is describe as a collection of all feasible input and output vectors which represent a subset of the space $\Re_{+}^{m+n}$, defined as:

$$T = \{(y, x) : x \text{ can produce } y\} \in \Re_{+}^{m+n} \qquad 2.1$$

Using mathematical notation, T can also be re-written as:

$$T = \left\{(y, x) : x \geq X\lambda,\ y \leq Y\lambda,\ \lambda^{i} \in \Re_{+}\ (i = 1,...,Q),\ \sum_{i=1}^{Q} \lambda^{i} = 1\right\} \qquad 2.2$$

where, **T** is the technology that describes all possible combination of *x* and *y* within a boundary $(\lambda^{i} = 1)$; Q is the number of DMU; *i* is the individual DMU; the production technology is assumed to have utilized a vector of inputs denoted by $x = (x_1,.....x_n) \in \Re_{+}^{n}$ to produce a non-negative vector of outputs denoted by $y = (y_1,.....y_m) \in \Re_{+}^{m}$. Super scripts ***n*** and ***m*** represent the number of inputs and outputs respectively. Basically, a DMU may select any input-output configuration $(y, x) \in T$ as its plan.

In order to ensure that production occurs according to the technology, the following properties need to be imposed on such technology. The properties are *nonemptiness, closeness*, *convexity, essentiality* and *free disposability* of inputs and outputs. Färe *et al.*'s (1994) production possibility set can be represented *by an input requirement set* $L(y)$ or an *output producible set* $P(x)$ or both. The input requirement set $L(y)$ represents the collection of all input vectors $x = (x_1,.....x_n) \in \Re_{+}^{n}$ that yields a predefined output vector $y = (y_1,.....y_m) \in \Re_{+}^{m}$ as $L(y) = \{x: (x, y) \text{ is feasible}\}$. Also, the output producible set $P(x)$ is the collection of all output vectors $y = (y_1,.....y_m) \in \Re_{+}^{m}$ producible from $x = (x_1,.....x_n) \in \Re_{+}^{n}$ as $P(x) = \{y: (x, y) \text{ is feasible}\}$.These production possibility sets are illustrated in figure 2.1 below

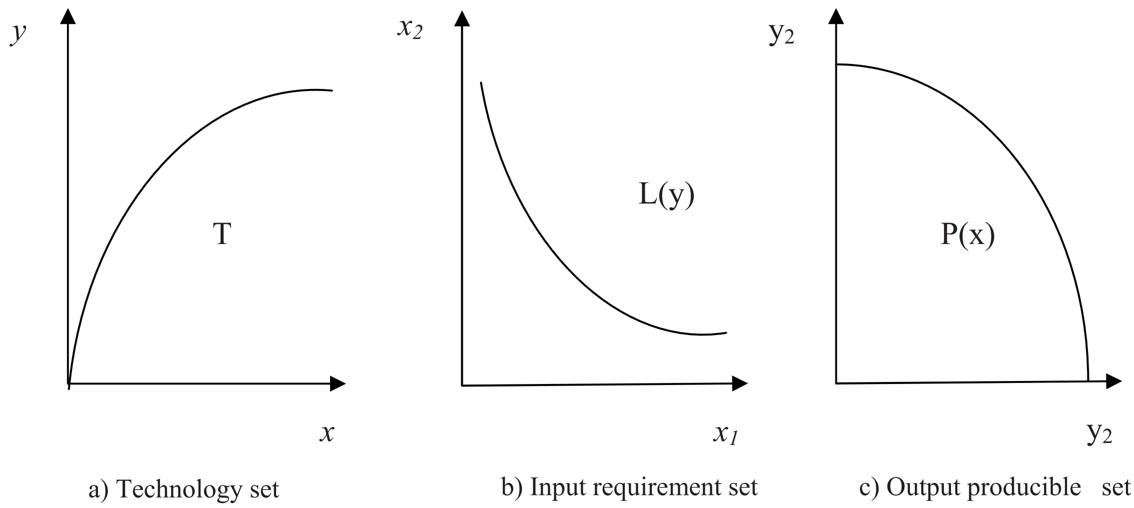

Figure 2.1: Production possibility sets

2.2.2. Production frontiers: Definitions and theoretical framework

The production frontier serves as a standard against which the efficiency of a production unit is measured/assess. A frontier is a bounding function while many bounding functions exist in microeconomics which includes: production, cost, revenue or profit function.

The standard production economic theory has a major weakness which is the assumption that all producers are efficient while an implicit assumption in the modern (frontier) efficiency analysis suggests otherwise (Coelli *et al.* 2005). However, Battese (1992) observed that most empirical studies up till the late 1960s used traditional least-square methods (OLS) to estimate production functions as the model for examining the resource-use efficiency of firms[1]. Unfortunately, the OLS measure of firm level efficiency is regarded inappropriate in modern efficiency analysis because the methodology estimates average frontiers rather than the true production frontier as often done with the modern (frontier) analysis (Coelli *et al.* 2005).

The frontier efficiency analysis represents a best practice technology against which the efficiency of units can be measured thereby accounting for the fact that some producers are inefficient contrary to standard production economic theory. Therefore, efficiency is a term widely used in economics and refers to how well a system or a unit of production is performing in

[1] The estimated functions are described as response (or average) functions (See Figure A2 in the appendix).

using resources to produce output given available technologies and relative to a standard (frontier firm) which is definable in terms of individual resources or combination of them (Fried, 2008).

The modern literature on efficiency and productivity was stimulated by the seminal paper of Farrell (1957) which benefited greatly from the earlier works of Koopmans (1951) and Debreu (1951). Koopmans (1951) provided a formal definition of technical efficiency while Debreu (1951) introduced measures of technical efficiency. Farrell characterized the efficiency of firms into technical, allocative, and economic (cost) efficiencies. Technical efficiency measures how much inputs can be reduced given the level of outputs (input efficiency) or how much outputs can be increased given the level of inputs (output efficiency). Allocative efficiency measures (for the case of technically efficient production) by how much costs can be reduced if the combination of inputs was optimal according to prices (input efficiency) or how much revenues can increase if the combination of outputs was optimal according to prices (output efficiency). Economic efficiency measures overall efficiency, in that it is the product of technical and allocative efficiencies.

Farrell's measure of the technical (TE), allocative (AE), and economic (EE) efficiencies using an input oriented efficiency measurement is depicted in figure 2.2. The figure shows a production possibility set fully described by a unit isoquant II' with two inputs x_1 and x_2 and one output y under the assumption of constant returns to scale (CRS). Every combination of inputs x_1 and x_2 along the unit isoquant II' is considered as a technically efficient point whereas any point above and to the right of it such as point **M** defines a technically inefficient point. If a given firm uses quantities of inputs defined by the point **M** to produce a unit output of isoquant II', the technical efficiency of the firm equal to **OK/OM** while the corresponding technical inefficiency equal to 1- **OK/OM**.

If information on input prices is known, and particularly the behavioral objective of cost minimization needed to make the interpretation meaningful is assumed in such a way that the input price ratio reflects the slope of the isocost line CC', the allocative efficiency of the firm equal to OL/OK while the corresponding allocative inefficiency level equal to 1- OL/OK. Economic efficiency is the product of the technical and allocative efficiencies and is equal to OL/OM while the corresponding economic inefficiency level equal to 1- OL/OM. The economic efficiency is the reduction in production costs that would occur if production were to occur at the allocatively (and technically) efficient point K' instead of the technically efficient (but allocatively inefficient) point **K.**

Färe *et al.* (1994) illustrated an output-oriented efficiency measure as depicted in the right side of figure 2.2. Under the output-oriented technique, efficiency is evaluated keeping inputs constant with a production possibility set described by a production possibility frontier PPF of two outputs y_2 and y_1 and one input x. Every combination of y_2 *and* y_1 on the PPF represented by ZZ' indicates a technically efficient point. Consider a firm with all possible combinations of y_2 *and* y_1 at point A', its technical efficiency is represented by OA'/OB while the corresponding technical inefficiency equal to 1-OA'/OB. However, if prices of outputs are known and used to construct an iso-revenue curve RR', the allocative efficiency will be equal to OB/OA while the corresponding allocative inefficiency will be equal to 1- OB/OA. The economic efficiency is the product of technical and allocative efficiencies and equal to OA'/OA while the corresponding economic inefficiency will be equal to 1-OA'/OA.

However, under constant returns to scale (CRS), input-oriented and output-oriented measures of technical efficiency are equivalent (Färe and Lovell, 1978).

Although, the initial concept of the unit efficient isoquant developed by Farrell (1957) has evolved into other alternative ways of specifying the production technology of a producer apart from his/her production function. Others include cost, revenue or profit frontier functions. The use of the distance function has also spread widely since Farrell's seminal measures of technical and allocative efficiency (Murillo-Zamorano, 2004).

In a related development, Farrell's concept has been extended to the non-radial efficiency measure proposed by Färe and Lovell, (1978). This includes directional distance function and hyperbola efficiency among others.

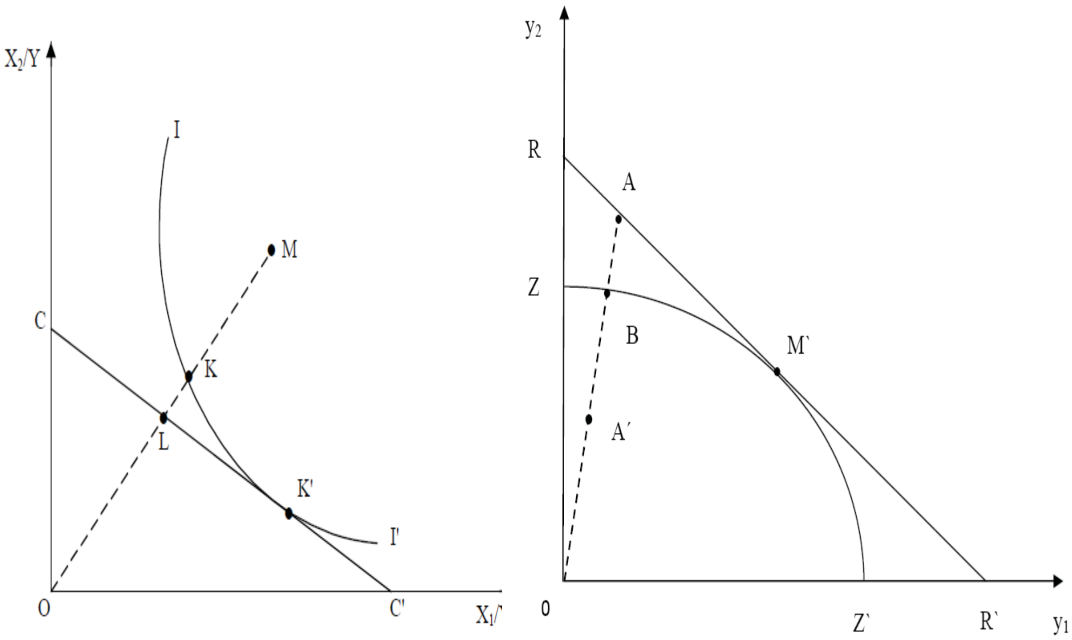

Figure 2.2: Input-oriented measure of technical, allocative & economic efficiencies — Output-oriented measure of technical, allocative, & economic efficiencies. *Source* (Coelli *et al,* 2005)

2.2.3. Techniques of efficiency measurement

The measurement of technical efficiency involves the construction of an efficient frontier. Different techniques have been utilized to estimate these efficient frontiers in the literature. Figure A2 in the appendix describes the taxonomy of frontier efficiency techniques. The two most popular frontier techniques used widely in the literature are the non-parametric and parametric methods.

The non-parametric is assimilated into the data envelopment analysis (DEA) first pioneered by Farrel (1957) and further developed by Charnes *et al.* (1978) and uses mathematical linear programming methods. Other non-parametric approach include free disposal hull (FDH).
There are two main parametric method which includes: the deterministic approach first pioneered by Aigner and Chu (1968) estimated by either mathematical programming or econometric techniques, and the stochastic frontier analysis (SFA), developed independently by Aigner *et al.* (1977) and Meeusen and von den Broeck (1977), that uses econometric techniques such as corrected ordinary least square (COLS), feasible generalized least square and maximum likelihood.

By construction, both the DEA and SFA base their efficiency assessments on the best practice in the sample at hand so that the best firms define the efficient frontier. This means that the efficient frontier is defined empirically.

The main strength of the SFA is in its ability to deal with stochastic noise and permits statistical testing of the hypotheses pertaining to the production structure and the degree of inefficiency. This perhaps explains why SFA is increasingly popular among researchers around the globe. Unfortunately, SFA is likely to be sensitive to the choice of the functional form. Detailed properties, advantages, disadvantages and differences between DEA and SFA are well documented in Coelli *et al.* (2005).

Therefore, subsequent discussions focus on the parametric method (SFA).This is because the methodology is advantageous in the analysis of farm efficiency in developing countries agriculture (Coelli *et al.* 2005) where data generation processes are often influenced by measurement errors. The measurement of efficiency using SFA has been intimately linked to the use of frontier functions such as *production, cost, revenue or profit frontier functions*. The production frontier function is also called the primal technology representation (also known as stochastic frontier production function) while cost, revenue and profit frontier functions are regarded as dual technology representation (known in the literature as stochastic frontier cost or revenue or profit function). The dual approach depends on the behavioral assumption of maximum profit/ revenue or minimum cost.
Although the primal approach has been the more common route used for SFA estimates, recent studies have turned to the dual approach most especially the cost and profit functions around the globe. Coelli (1995) identified three reasons for the application of the dual approach in empirical works as follows: (1) it reflects the alternative behavioural objective which can be cost minimization or profit/revenue maximization; (2) it is capable of handling multiple outputs technologies and (3) it has the ability to simultaneously estimate both technical and economic efficiencies.

2.2.4. The econometric approach to efficiency measurement

The parametric method is classified as the *deterministic or stochastic frontier analyses* according to the way inefficiency is defined and the inclusion of noise errors in the respective models. The deterministic frontier model was pioneered by Aigner and Chu (1968) followed by Afriat (1972) while further modification was carried out by Richmond (1974). The methodology employs the technological framework similar to DEA but differs with respect to its estimation. With an econometric approach, the deterministic model estimates rather than 'calculates' the parameters of the frontier functions. The SFA is the main focus of this study and is thus discussed in the following section.

2.2.4.1. The stochastic frontier analysis (SFA): *Production function model*

The stochastic frontier production model is motivated by the idea that deviations from the production frontier may not be entirely under the control of the DMU. This model acknowledges the effects of technical inefficiency as well as random shocks outside the control of the DMU on the production process.

The stochastic frontier production model was independently developed by Aigner *et al.* (1977), and Meeusen and van den Broeck (1977) and it is implicitly specified as:

$$y_i = f\left(x_{ki};\beta_k\right) \exp\left(v_i - u_i\right) \qquad 2.3$$

where, y_i denotes the value of the production of the i-*th* farm (i=1,….N); X_i is a *(1xk)* vector of the associated inputs; β is a *(kx1)* vector of unknown parameters to be estimated, and f represents functional form[2]. The term $v_i - u_i$ is a composed error component, where v_i represents random error (statistical noise/ measurement error) distributed symmetrically and u_i[3] is the asymmetric error term, which is assumed to be independently and identically distributed (u_i>1), captures technical inefficiency, and is independent of v_i. According to Murillo-Zamorano (2004), if the two error terms are assumed to be independent of each other and of the input variables, and additionally, one of the distributions mentioned in foot note 3 are used, then the likelihood functions can be defined and the maximum likelihood estimates (MLE) of Eqn.2.3 can be determined.

The basic structure of the stochastic frontier production model is depicted in figure 2.3. In this structure, the productive activities of the two firms, represented by ***m*** and ***n*** are the observed output q_m corresponding to the input x_m and output q_n to the input x_n respectively. Under the

[2] Studies have shown that the choice of functional form have consequence on the parameters of technology as well as the estimated technical efficiency (Kumbhakar and Lovell 2000; Coelli *et al.,* 2005; Henningsen and Henning 2009). Sauer *et al.,* (2006) suggested that the selection of a functional form must be guided by flexibility, regularity and linearity in the parameters, and must be parsimonious. The commonly used functional form in the estimation of the frontier models includes: Cobb-Douglas, the translog, and quadratic forms. Sauer *et al.,* (2006) concluded, that translog, functional form has the capability of fulfilling the flexibility and regularity conditions such as convexity, concavity, and curvature among others.

[3] Various distributional assumptions have been proposed in the literature to model the one-sided u_i. These include; half normal, exponential, truncated, and gamma distributions (see more details in Kumbhakar and Lovell 2000). The choice of the distributional assumption is sometimes guided by the computational convenience rather than the performance (Coelli *et al.,* 2005).

assumption that there were no inefficiency in the production of q_m (i.e., $u_m = 0$) and q_n (i.e., $u_n = 0$), the so-called production frontier for firm ***m*** and ***n*** are q_m^* and q_n^* respectively.

It is obvious from the figure that the production frontier q_n^* lies above the deterministic frontier because the production activity of firm ***n*** is associated with favorable conditions in which noise effects are positive (i.e., $v_n > 0$). Also the production frontier q_m^* lies below the deterministic frontier because the production activity of firm ***m*** is associated with unfavorable conditions in which noise effects are negative (i.e., $v_n < 0$).

According to Coelli *et al.* (2005), whenever the sum of the noise and inefficiency effects is less than zero (i.e., $v - u < 0$), the observed output lies below the deterministic frontier while $v - u > 0$ implies that the observed output lies above the deterministic frontier.

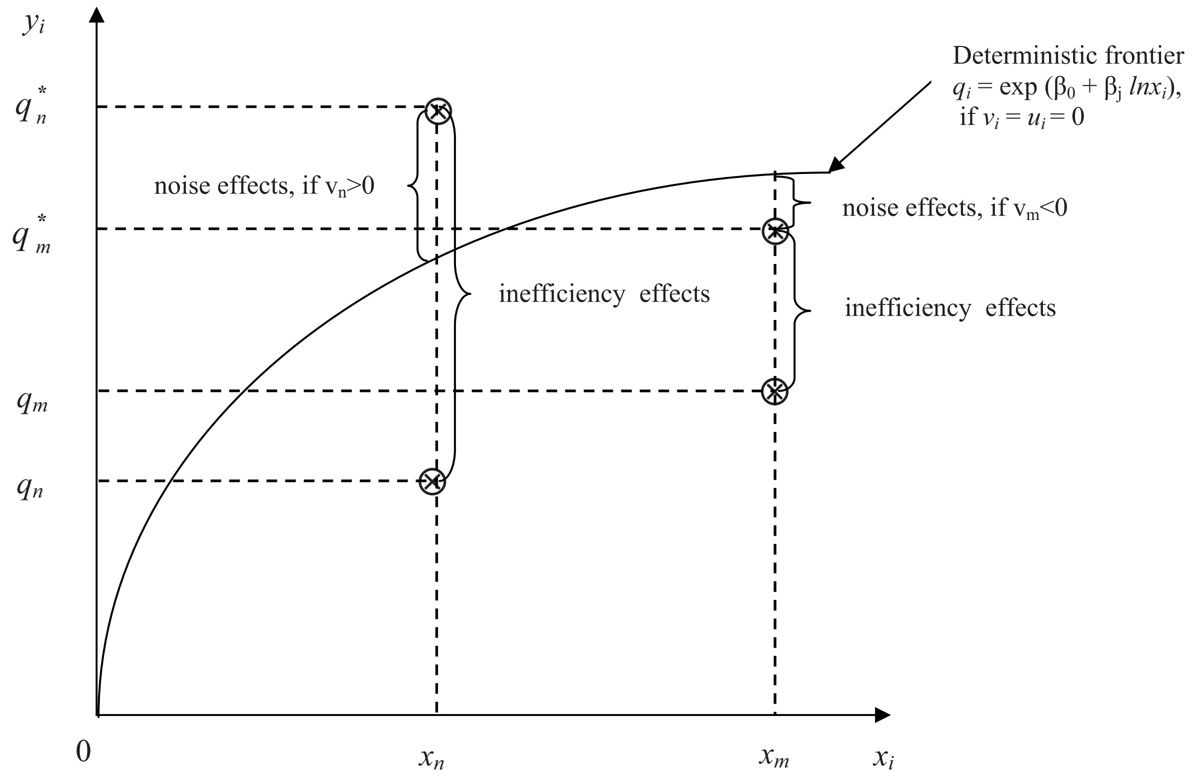

Figure 2.3.: Stochastic frontier production function, *source: Coelli et al. (2005)*

2.2.4.2. Technical efficiency measurement in SFA production models

Given the appropriate distributional assumptions of inefficiency error term u highlighted in the footnote 3, the technical efficiency of firms can be estimated using the Jondrow *et al.'s* (1982) conditional approach. For example if a half-normal distribution of inefficiency effects

(u) is assumed, the expected value of (u) conditional on the composed error ($v - u$) in Eqn.2.3 is equal to:

$$E\left[u_i \middle| e_i\right] = \frac{\sigma\lambda}{\left(1+\lambda^2\right)}\left[\frac{\phi\left(e_i\lambda/\sigma\right)}{\Phi\left(-e_i\lambda/\sigma\right)} - \frac{e\lambda}{\sigma}\right] \qquad 2.4.$$

where $\phi\left(e_i\lambda/\sigma\right)$ is the density of the standard normal distribution, $\Phi\left(-e_i\lambda/\sigma\right)$ is the cumulative distribution function of the standard normal, $\lambda = \sigma_u/\sigma_v$, $e = v_i - u_i$, and $\sigma = \left(\sigma_u^2 + \sigma_v^2\right)^{\frac{1}{2}}$.

Once conditional estimates of u_i have been obtained, Jondrow *et al.* (1982) calculate the technical efficiency of each producer as:

$$TE_i = 1 - E\left[u_i \middle| e_i\right] \qquad 2.5.$$

According to Kumbhakar and Lovell (2000), $exp\left\{-\left(u_i \middle| e_i\right)\right\}$ could as well be preferably used instead of $1 - E\left[u_i \middle| e_i\right]$ for calculating the technical efficiency. According to the authors, this approach is quite popular among researchers because Jondrow *et al.,* (1982)'s conditional estimate is no more than a first-order approximation to the general infinite series, $exp\left\{-\left(u_i \middle| e_i\right)\right\} = 1 - u_i + u_i^2/2 - u_i^3/3!$ ..... Battese and Coelli (1988) emphasized that the correct estimator should be based on the conditional expectation of the exponential of u_i and the technical efficiency calculated as $TE_i = E\left(exp\left\{-\left(u_i \middle| e_i\right)\right\}\right)$. In addition to the conditional expectation of u_i proposed by Jondrow *et al.* (1982), the conditional mode and median approach of u_i could as well be explored to derive the technical efficiency (*see details in* Kumbhakar and Lovell, 2000).

2.2.4.3. Incorporating exogenous variables in the SFA production frontier model

Generally, the objective of a stochastic production frontier model is not only to serve as a benchmark against which the technical efficiency of producers are estimated, but it is also used to identify the determinants of efficiency levels for policy inferences (Kumbhakar and Lovell, 2000). The authors suggested that the determinants of efficiency levels include: managerial characteristics such as age and the level of education of the producers, family size, and access to credit among others.

Earlier approaches incorporated the determinants of the efficiency levels along with input variables in a stochastic production frontier. Critiques of this approach pointed out that this formulation fails to explain variations in efficiency. Pitt and Lee (1981) and Kalirajan (1981) adopted a two-stage approach to associate variation in the estimated efficiency with variation in the determinants of the efficiency levels. With regard to this approach, the predicted technical efficiency (Eqn.2.5) is estimated using Eqn. 2.3 in the first stage. It is then regressed on the determinants of the efficiency levels as the second step using an OLS or Tobit regression model. This approach has been criticized because the identically distributed assumption of inefficiency terms is violated in the two-stage approach in which the predicted efficiencies are assumed to have a functional relationship with the exogenous variables (Kumbhakar and Lovell 2000; and Coelli *et al.* 2005).
Kumbhakar *et al.* (1991) proposed the single stage approach model where the determinants of the efficiency levels, the variables in a stochastic production frontier and the technical efficiency scores are estimated simultaneously. The single-stage approach was parameterized such that the mean of the pre-truncated distribution of inefficiency error term (μ_i) is to be a function of exogenous variables[4]. This model can be specified as:

$$\mu_i = \delta_0 + \delta_j Z_{ij} \qquad 2.6$$

where μ_i is the firm-specific mean technical inefficiency, z_{ij} is the matrix of exogenous variables that determines technical inefficiency and δ_j is a vector of the parameters to be estimated. In this formula, a negative sign of an element of the δ_j -vector indicates a variable with a positive influence on technical efficiency.

In an attempt to address the problem of heteroskedasticity in the inefficiency term u_i, Caudill and Ford (1993), Caudill *et al.* (1995), Wang and Schmidt (2002) and Alvarez *et al.* (2006) parameterize the variance of the pre-truncated distribution of υ_i. This development according

[4] It is equally important to note that with this specification, constant variance assumption is imposed on u_i while relaxing constant mean/mode property of truncated normal distribution.

to Kumbhakar and Lovell (2000) can be used to relax the constant-variance property of u_i by allowing the variance of the inefficiency u_i to be a function of exogenous variables. The authors concluded that by allowing the variance of the inefficiency term (u_i) to be a function of exogenous variables, there is the possibility of solving two problems at once. This thus corrects for heteroskedasticity while incorporating exogenous variables to investigate technical inefficiency effects which are similar in outcome to Eqn. 2.6.

The heteroskedasticity investigation of technical inefficiency effects according to the authors can be specified as:

$$\sigma_{ui}^2 = \mathrm{g}\left(Z_{ki};\delta_k\right) \qquad 2.7$$

where σ_{ui}^2 denotes the variance of u_i, z_k is the matrix of exogenous variables that determines technical inefficiency and δ_k is a vector of parameters to be estimated. Brümmer and Loy (2000) and Brümmer (2001) employed this approach in their papers.

In a related development, recent findings have confirmed that heteroskedasticity is potentially severed in the stochastic frontier production model (Hadri 1999; Kumbhakar and Lovell 2000). According to the authors, this can appear in either the one-sided error (u_i) or the random error (v_i). Kumbhakar and Lovell (2000) stressed that un-modeled heteroskedasticity in u_i will lead to biased estimates of the technology parameters as well as biased estimates of the efficiency of the individual producers. The authors also posited that although heteroskedasticity in v_i will generate unbiased technology parameters, it will definitely affect inferences concerning technical efficiency estimates. This development led to the specification of the heteroskedasticity corrected random error model as

$$\sigma_{vi}^2 = \mathrm{q}\left(X'_{ji};\varphi_j\right) \qquad 2.8.$$

where σ_{vi}^2 is the variance of the random error (v_i), X'_j are the variables thought to capture heterogeneity in production; these can be farm size, location, specialization among others.

There are a number of studies that have applied a double heteroskedasticity stochastic production frontier function. These include: Wang (2002), Hadri *et al.* (2003), Daidone and D`Amico (2009), and Loureiro (2009), among others.
The log-likelihood function of a double heteroskedasticity stochastic production frontier function as specified in Kumbhakar and Lovell (2000) is reproduced below

$$InL = \text{constant-}\frac{1}{2}\sum In\left(\sigma_{vi}^2 + \sigma_{ui}^2\right) + \sum In\phi\left(\frac{\varepsilon\lambda_i}{\sigma_i}\right) - \frac{1}{2}\sum\frac{\varepsilon_i^2}{\sigma_i^2} \qquad 2.9.$$

where

$$\sigma_{vi}^2 + \sigma_{ui}^2 = g\left(x;\tau_i\right) + \mathrm{q}\left(Z_i, D_i;\alpha_i\right) \qquad 2.10.$$

$$\lambda_i^2 = \frac{\sigma_{ui}^2}{\sigma_{vi}^2} = \frac{g\left(x;\tau_i\right)}{\mathrm{q}\left(Z_i, D_i;\alpha_i\right)} \text{ and } \varepsilon = \mathrm{v}_i - \mathrm{u}_i = \mathrm{y}_i - \mathrm{X}_i\beta \qquad 2.11.$$

ϕ is the cumulative density function and L is the log likelihood.

Accordingly, Eqn.2.3-2.8 could be estimated simultaneously by assuming a normal-half normal distributional for u_i while using the maximum likelihood estimation (MLE) technique (Kumbhakar and Lovell 2000).

2.2.5. The extension of the SFA model: *Stochastic output distance function*[5]

One of the significant extensions of the traditional SFA in modern research is the multiple inputs and outputs models otherwise known as the distance (primal) technology representation. The multiple outputs modeling of the production technology provides distinct effects for capturing different outputs in production processes. According to Shephard (1970), when many inputs are used to produce many outputs, distance functions provide a functional characterization of the structure of the production technology. Concept and properties of the distance function are well documented in the literature (Färe and Primont 1995; Kumbhakar and Lovell 2000; Coelli *et al.* 2005).

However, a significant advantage of this extension in frontier analysis is that a distance function approach (either output-oriented called output distance function or input-oriented called input distance function) allows the production frontier to be estimated without assuming seperability of inputs and outputs (Kumbhakar *et al.* 2007).

The choice of specification or approach to use in an empirical analysis is motivated by the production system described by the dataset under investigation. For example, Kumbhakar *et al.* (2007) posited that, an output distance function approach to measure technical efficiency is appropriate when output is endogenous (i.e., revenue maximization is the driving factor in the system) and inputs are exogenous while an input distance function approach to measure tech-

[5] We acknowledge other extension such as directional distance function, however, subsequent disucssion focus on the output distance function bcause of its application in the present research.

nical efficiency is appropriate when inputs are endogenous (i.e., cost minimization is the case) and output is exogenous.

In a related development, Paul and Nehring (2005) suggested that the choice depends on whether one believes production jointness or systems are more fundamental on the output or input side.
Based on this, the present study believes that the output distance function is advantageous for the analysis of the performance of cassava production relative to other crops grown by the smallholder farms in Nigeria. Cassava is a cash crop whose production is not only driven by food security but also by the possibility of higher revenue returns from the crop by most farm households in the country. Thus, subsequent discussion focuses on the output distance function which is being considered in the third paper of this dissertation.

The figure 2.4 below illustrates a typical multi-output production technology, which in the literature is called the production possibility frontier (PPF) with two outputs and one input. Following the work of Färe and Primont (1995), we assume in the present framework that a deviation of any firm from the frontier (boundary of output set) may be due to either - inefficiency or noise errors. The PPF describes the technically efficient points of production for various combinations of output that could be produced using a given factor endowment ***x*** while $\equiv P(x)$ represents the output set/vector which is bounded by the PPF. The $\equiv P^{A}(x)$ is the observed output set while $\equiv P^{B}(x)$ is the deterministic frontier when $v=u=0$, and $\equiv P^{C}(x)$ is the so-called frontier output when $v \neq 0$ *and* $u=0$. Production at any point on the PPF other than ***B*** (i.e., the *frontier*) represents sub-optimal performances which include points ***A*** and ***C*** in the figure.
The $\overline{AB}$ represents a departure from the technically optimum point of production (i.e., the *frontier point*) associated with inefficiency. This implies that the location of the firm in the neighborhood of ***A*** with reference to the best practice ***B*** signifies inefficiency in the firm's production process. Also, a firm located at point ***C*** implied departure from the technologically feasible point ***B*** which could be attributed to both inefficiency and noise (measurement error). Therefore, the proportional expansion of a firm operating at point ***A*** towards the boundary of the output set ***B*** requires upward scaling of y_2^A and y_1^A by a factor θ which needs to be minimized. The implication of this is that, while scalar outputs y_2^A and y_1^A of point A could be produced with input ***x***, so is the radially expanded larger output vectors y_2^B and y_1^B of point ***B***.

This process of the upwards adjustment of the output set $\equiv P^{\mathbf{A}}(x)$ towards the output set $\equiv P^{B}(x)$ while maintaining the same level of inputs is called the output distance function $D_0(x, y, t)$.

By construction $D_0(x, y, t)$ equals

$$D_0(x,y,t) = \frac{OA^*}{OB^*} \leq 1 \qquad \text{i.e., } D_0(\mathbf{x},\mathbf{y},\mathbf{t}) \leq 1 \;. \qquad 2.13.$$

The output distance $D_0(x,y,t)$ gives the reciprocal of the maximum proportional expansion of the output vector **y**, given inputs **x** and the characteristics of the technology completely. According to Brümmer *et al.* (2006) the most useful property of the distance function is that the reciprocal of the distance function $D_0\{x_j, y_m, t\}$ has been proposed as a coefficient of resource utilization of Debreu's (1959) and as a measure of Farrell's (1957) output-oriented technical efficiency TE_0. In this regard, we defined TE_0 as:

$$D_0\{x_j, y_m, t\} = 1/TE_0 \qquad \text{i.e., } D_0\{x_j, y_m, t\} \leq 1 \text{ while } TE_0 \geq 1 \,[6] \qquad 2.14.$$

[6] It is important to mention here that for our result to be consistent with most output-oriented parametric efficiency studies with technical efficiency bounded between zero and one, the study assumed the value of the output distance function as a direct measure of the technical efficiency that is bounded between zero and one, since $TE_0 \geq 1$ by construction. In this regard, Kumbhakar *et al.,* (2007) referred to the index TE_0 as the "natural technical efficiency" since it has the same orientation as the estimated output distance function $D_0\{x_j, y_m, t\}$ of Equ.9.

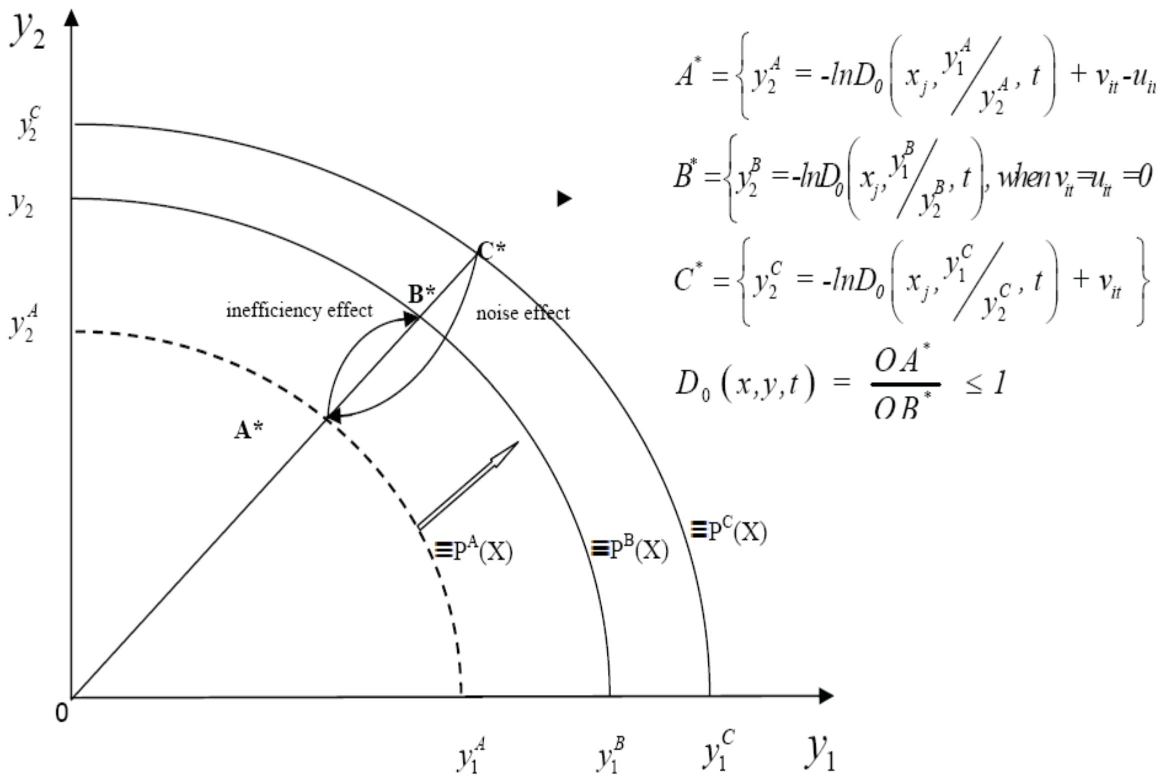

Figure 2.4: Stochastic frontier Output distance function (source: modification of the earlier version from Kumbhakar et al. 2007)

2.5. Conclusions

The literature review highlights the basic theory of the production technology of a decision making unit (DMU) upon which the underlining theoretical framework of the efficiency methodology is based. Although, various efficiency methodologies were discussed in this chapter, much emphasis is laid on the stochastic frontier analysis (SFA) technique because of its advantage in the analysis of farm level efficiency in developing countries where data generating processes (DGP) are often influenced by measurement errors as well as weather. Furthermore, this chapter stresses the consequences of un-modeled heteroskedasticity in stochastic frontier models which often leads to a biased production technology as well as efficiency estimates. The extension of the SFA model to incorporate production technology that embraces multiple outputs and inputs technologies, vis-à-vis an output distance function, is also highlighted.

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CHAPTER THREE

3.0. A meta-analysis of technical efficiency studies in Nigerian agriculture

3.1. Introduction

Agriculture is the main trust of many Nigerians as is the case in most of the sub-Saharan African countries. It is the principal source of food and livelihood security, making it a critical focus of programmes which seek to reduce poverty and attain food security in the country. The agricultural sector in Nigeria plays an important role in the overall economy through its significant contributions to rural employment, non-oil foreign exchange earnings, and the provision of industrial raw materials for other sectors in the country (Ogundari and Ojo, 2005).

The role of efficiency in increasing agricultural output has been widely recognized by researchers and policy makers around the globe as crucial policy making (Bravo-Ureta *et al.* 2007). Thiam *et al.* (2001) observed that the importance of efficiency as a means of fostering production has led to the proliferation of methodological and empirical frontier studies focusing on the efficiency of agricultural production around the globe.

Analysis of efficiency has received attention because of the importance of improving technical efficiency, which constitutes a major component of total factor productivity (TFP) growth most especially in the developing agriculture (Brümmer *et al.* 2006). For example in Nigeria, considerable effort has been devoted to the analysis of farm level efficiency by both academics and policy analysts in the country for more than a decade.

Meta-analysis is a tool which allows researchers to combine the results of several studies into a unified analysis that provides an overall estimate of interest (Sterne, 2009). Because the analyses of meta-analysis results from a group of studies, the problem of low statistical power in studies with small sample size is partly resolved, allowing more accurate data analysis conclusions (Nguyen and Coelli, 2009).

Therefore, given the number of efficiency studies which have been used to raise policy debates on the performance of Nigerian agriculture over the years, meta-analysis seems to have the needed impetus to further provide a clear picture of the distribution of technical efficiency which is important for the distillation of policy inferences.

An issue of concern in the literature is the sensitivity (particularly the direction) of the estimated efficiency indices to the characteristics of the data, the methodology, the choice of functional form and the location of the study, among others because studies generally differ across many of these dimensions (Thiam *et al.* 2001; Bravo-Ureta *et al.* 2007 and Moreira López and Bravo-Ureta 2009). Supporting this observation earlier, Koop and Smith (1980) concluded that the functional form has a discernable impact on the estimated efficiency whilst Griffin *et al.* (1987) revealed that the number of variables in a parametric model is an issue in the literature for functional form selection because of the possible effect of multicollinearity on the estimated parameters.

In view of this, Thiam *et al.* (2001) and Bravo-Ureta *et al.* (2007) suggested that, it is important to understand how study-specific characteristics account for the systematic effect on the efficiency indices. With regard to the reported average technical efficiency (ATE) estimates in the frontier studies, Thiam *et al.* (2001) shows that meta-analysis could be employed to investigate how study-specific characteristics influenced ATE indices such that differences across several studies are used as explanatory variables while ATE serve as an dependent variable in a regression model.

The present paper is designed to shed light on the distribution of the reported ATE as well as identification of factors that drives efficiency level of Nigerian agriculture over the years. Beside, the paper is expected to make a valuable contribution to the ongoing debate on Nigerian agricultural efficiency literature by investigating how study specific-characteristics account for systematic variations in the reported ATE estimates across the frontier studies in the country.

To investigate this empirically, a meta-dataset, generated from the existing studies on the ATE in Nigerian agriculture and covering the period 1999-2008 is employed to provide answers to the following research questions proposed in this paper:

i. How did the average technical efficiency estimates of Nigerian agriculture develop?

ii. What is the effect of the study specific-characteristics (data year, choice of functional form, sample size, number of inputs used, the degree of aggregation of output variables, location of the study, among others) on the reported average technical efficiency estimates across the frontier studies?

iii. Which of the socio-economic variables among farmers influence the reported mean technical efficiency estimates most across the studies?

The outline of the paper is as follows. Section 3.2 provides a review of stochastic frontier and meta-analysis methodology. In section 3.3, the methodology and detailed description of the data is provided. Section 3.4 presents the results while section 3.5 provides a summary and conclusion from the paper.

3.2. A review of stochastic frontier methodology and meta-analysis

3.2.1. Stochastic frontier methodology

Modern literature covering efficiency and productivity were stimulated by the seminal paper of Farrell (1957). Farrell characterized the efficiency of firms into technical, allocative, and economic (overall) efficiencies. Technical efficiency measures how much the inputs can be reduced given the level of outputs (input efficiency) or how much the outputs can be increased given the level of inputs (output efficiency). Allocative efficiency measures how much costs can be reduced if the combination of inputs was optimal according to prices (input efficiency) or how much revenues can increase if the combination of outputs was optimal according to prices (output efficiency). Economic efficiency is argued to measure overall efficiency, in that it is the product of technical and allocative efficiencies.

The two most popular techniques used widely in the literature are the non-parametric and parametric methods. The non-parametric method is assimilated into the data envelopment analysis (DEA) developed by Charnes *et al.* (1978) and uses mathematical linear programming methods. The two major parametric methods includes the deterministic frontier approach pioneered by Aigner and Chu (1968) and estimated by either mathematical programming or econometric techniques and the stochastic frontier analysis (SFA), developed independently by Aigner *et al.* (1977) and Meeusen and von den Broeck (1977), which uses econometric techniques.

The main strength of the SFA is its ability to deal with stochastic noise and permits statistical testing of hypotheses pertaining to production structure and the degree of inefficiency. This perhaps explains why the SFA is increasingly popular among researchers around the globe. Unfortunately, the SFA is likely to be sensitive to the choice of functional form. The detailed properties, advantages, disadvantages and differences between DEA and SFA are well documented in Kumbhakar and Lovell (2000) and Coelli *et al.* (2005) while subsequent discussion is based on the SFA because the methodology is the central focus of the frontier studies employed for the meta-analysis.

The measurement of efficiency using SFA has been intimately linked to the use of frontier functions such as the *production, cost, revenue or profit frontier functions*. The production frontier function is an example of primal technology representation also known as stochastic frontier production function. The cost, revenue and profit frontier functions are on the other hand regarded as a dual technology representation (known in the frontier literature as stochastic frontier cost or revenue or profit function). The dual approach depends on the behavioral assumption of maximum profit/ revenue or minimum cost and has the ability to simultaneously estimate both the technical and economic (cost) efficiencies. Besides this, it is capable of handling multiple outputs technologies (Coelli, 1995).

3.2.2. Meta-analysis

Meta-analysis provides the same methodological rigor to a literature review that we require from experimental research. Following the pioneer work of Glass (1976), meta-analysis has become the standard method of searching for general patterns in a body of existing specific research results. Policy analysts often use meta-analysis to generalize findings from a substantial body of existing literature that address the same research question and especially when there is a large amount of literature reporting such valuation worldwide (Hedges and Olkin 1985).

Meta-analysis is quite popular within medical and marketing research, while few literature in agricultural and resource economics have employed this technique to investigate how study-specific characteristics influence the empirical estimates from several outcomes over time. The few identified so far among natural science studies includes: Boyle *et al.* (1994), Smith and Huang (1995) and Smith and Kaoru (1990). Others include Marra and Schurle (1994) which syntheses studies on the effect of farm size on the measure of crop yield risk. Recent application includes Alston *et al.* (2000), Thiam *et al.* (2001), Bravo-Ureta *et al.* (2007), Moreira López and Bravo-Ureta (2009), and Hess and von Cramon-Taubel (2008). The first study synthesizes literatures on returns to agricultural research and development (R&D), while the second, the third and fourth examine technical efficiency in developing agriculture, developed agriculture, and dairy farms around the world, respectively. The last study employs a meta-analysis on a body of literature by simulating general and partial equilibrium of trade liberation under the Doha Development agenda.

One of the specific problems of meta-analysis is the lack of independence across observations (Espey *et al*. 1997) which is often responsible for biased standard errors. In the present paper, this problem is unlikely to be particularly severe. None of the studies used for the construction of the meta-dataset contributed more than the five data points which is the recommended limit by Espey *et al*. in order to avoid this problem. A general method for carrying out meta-analyses is the use of descriptive statistics in some cases or regression techniques. Sampling of most empirical analysis shows that meta-regression seems to be the popular tool among researchers. Alston *et al.* (2000) defined meta-regression as a quantitative method used to evaluate the effect of methodological and other study-specific characteristics on published empirical estimates of some indicators. Conversely, in the present paper, descriptive statistics and the application of the meta-regression technique offers the possibility to relate the summary information of several frontier studies focusing on Nigerian agriculture which is represented by the ATE, to a set of characteristics of these studies.

3.3. Methodology

3.3.1. Data source and description

A variety of sources were used to compile the list of studies used for the meta-analysis in this paper[1]. Although the initial search yields a total of 87 studies covering 1999-2008, 23 studies were excluded due to the following reasons: (1) limited number of dual and non-parametric (e.g., DEA) studies, and (2) studies that did not include full information on all the potential explanatory variables considered for the meta-regression. Hence, a total of 64 studies were considered for the analysis. None of the frontier studies employed panel data.
In a meta-analysis, each study constitutes a single observation with a sufficiently large number of independent observations. However, because some of the studies reported more than one ATE, a total of 86 observations were eventually used for the meta-analysis.

[1] The principal ones were: Google Scholar, ISI Web of Science, ASC index, previous bibliography, ajol.info, personal request from the authors and other online database. Some of the data bases include: American-Eurasian J. Agric. & Environ. Sci.; J. of Agri. & Soc. Sci; Research J. of Agric. Biol. Sci.; Agrekon; J. of Central Eur. Agric; Agric. Journal; : J. of Food, Agric. & Env.; Int. J. of Poultry Sci.; Int. J. Agric. Rural. Dev.; Int. J. of Science. Sci; Quarterly J. of Int. Agric.; J. of Agric.& Soc. Sci.; J. of Soc. Science; Research. J. of Applied Sci.; World J. of Agric. Sci.; J. of Animal and Vert. Adv; African Development Review; J. of Agric. & Rural Devt. in the Tropics and Subtropics; . App. Econ. Letter; J. Hum. Ecol. and Eur. J. of Soc. Sci. among others.

The study specific variables hypothesized to explain ATE are identified based on the theoretical framework and the earlier cited studies by Thiam *et al.* (2001) and Bravo-Ureta *et al.* (2007). Table 3.1 contains the summary statistics of variables used for the meta-regression analysis. ATE, DATAYEAR, NO.OBSER, NO.INPUT, and RANGE represented the reported average technical efficiency estimate from each study, year of the survey, number of observations, number of inputs used, and the range of differences between the minimum and the maximum ATE indices reported in the study, respectively. D_{Output} is a dummy variable which is equal to one if the output of the study is not aggregated (i.e., a single output) and zero if aggregated. D_{Cobb} is equal to one if the functional form is Cobb-Douglas. Further binary variables were defined for studies based on food crops (D_{Food}) and cash crop (D_{Cash}) production relative to studies with a focus on the $D_{non\text{-}crop}$ (the non-crop studies serves as the reference dummy). The list of binary control variables is completed by four regional indicators which include: Northcentral, Southwest, Southeast, and Southsouth relative to studies located in the $D_{northeast}$ (Northeast studies serve as the reference dummy) [2].

The list of the 64 case studies employed for the meta-analysis with full citation is presented immediately after the section 3.5 of this paper. Likewise, across the frontier studies, detailed information regarding the authors, year of publication, the location of the study in the country, type of agricultural production under investigation, number of observations and ATE from each study is presented in table A of the appendix.

[2] Nigeria is divided into 6 geopolitical zones (regions) which also reflect the agro-ecological zones in the country. Unfortunately, throughout our literature search, we are unable to locate a single study from the Northwest zone of the country.

Table 3.1: Summary statistics of variables used in the meta-regression

Variables	*Obs.*	*Mean*	*Std. Dev.*	*Min.*	*Max.*
MTE	86	0.7377	0.1447	0.22	0.99
DATAYEAR	86	2005.023	2.6103	1995	2007
NO.OBSER	86	126.977	124.96	30	1086
NO.INPUT	86	4.8851	1.0278	3	5
RANGE	86	0.6341	0.2174	0.03	0.96
D_{Food}	86	0.5930	0.4699	0	1
D_{Cash}	86	0.1279	0.3586	0	1
D_{Output}	86	0.7209	0.4591	0	1
D_{Cobb}	86	0.8140	0.4074	0	1
$D_{Northcentral}$	86	0.1163	0.2549	0	1
$D_{SouthWest}$	86	0.5233	0.4653	0	1
$D_{SouthEast}$	86	0.0814	0.2106	0	1
$D_{SouthSouth}$	86	0.2209	0.3586	0	1

3.3.2. Empirical model

Previous meta-regression for technical efficiency (Thiam *et al.* 2001 and Bravo-Ureta *et al.* 2007) employed a *two-limit* Tobit, i.e., the two studies employed a censored regression approach on ATE. McDonald (2008) argued that efficiency scores such as ATE are not generated by a censoring process but are fractional data by construction. According to the author, a Tobit estimation in this situation is inappropriate and it is therefore an inconsistent estimator. Although McDonald (2008) advocates the use of OLS for fractional data instead of a Tobit regression, the paper proposes a truncated regression against Tobit as well as OLS, because ATE is by definition constrained between zero and one so that the probability mass outside the unit interval is zero. That is $E\left(ATE_i / X_i\right)$ when OLS is used rarely provides the best description of the coefficients as a truncated regression by construction takes the limits of ATE into account unlike OLS while Tobit due to its data generating process, (DGP), is not an asymptotically efficient estimator (McDonald, 2008).

To provide an answer to the research questions raised in section 3.1 of this paper, we examine the systematic effect of the identified study-specific characteristics on the reported ATE estimates across the studies using the linear meta-regression model below:

$$ATE_{it} = \psi_0 + \sum_{k=1}^{4} \alpha_k X_{kt} + \sum_{j=1}^{8} \beta_j D_{jt} + \varepsilon_{it} \quad \text{t= 1995, ….. 2007} \qquad 3.1$$

where ATE is as earlier defined. X_k represented the continuous variables which includes; DATAYEAR, NO.OBSER, NO.INPUT and RANGE. D_j represented the dichotomous dummy variables such as; D_{Food}, D_{Cash}, D_{Output}, D_{Cobb}, $D_{Northcentral}$, $D_{Southwest}$, $D_{Southeast}$, and $D_{Southsouth}$. α_k and β_j are parameters to be estimated while ε_{it} represented the error term. Both $D_{non-crop}$, and $D_{northeast}$ were dropped from the analysis to prevent multicollinarity as reference dummies. Guided by the work of McDonald (2008) that $E(\varepsilon / X_{it})$ in Eqn. 3.1 is rarely normal because of the DGP of ATE, we test the residuals of the truncated regression for normality as suggested by the author. The result, however, shows that the normality assumption is rejected at p-value 0.0006.

If non-normality is detected, McDonald (2008) suggested a number of ways to solve this problem. This includes taking the logarithm of the ATE and relating it either to the explanatory variable or the logarithm of the observations or by simply transforming the ATE by a Box-Cox transformation (Box-Cox, 1964). We opted for the Box-Cox transformation because of its wide use in empirical analysis (for detail see Poirier 1978) and more importantly, most of the explanatory variables are dummy variables. From the Box –Cox, we obtain an estimated θ of 2.473 with a p-value of less than 0.001 against the null of θ equal to one.

The transformed ATE equals:

$$\left(transATE_{it} = \frac{ATE^{2.473} - 1}{2.473} \right) \qquad 3.2$$

The Table 3.3 shows the result of the re-estimated Eqn.3.1 with Eqn. 3.2 as the new dependent variable. These results are found to be robust against various possible violations of the model's assumptions: Neither normality homoscedasticity or lack of functional misspecification is rejected.

3.4. Results and discussion

3.4.1. Development of ATE in the Nigerian agriculture

To provide an answer to the first research question, figure 3.1 shows the distribution of the number of efficiency studies and the development of the reported mean ATE/year from the frontier studies[3]. The figure shows that the total number of the frontier studies reaches a peak in 2006.

With regard to the development of the reported ATE estimates by the year of publication, it is observed that a mean ATE of 0.67 was reported in 1999 as against 0.78 in 2001 which suggests approximately a 16% increased in the mean ATE between these periods. The mean ATE dropped from 0.78 in 2001 to 0.63 in 2004 which implies an approximately 19% decreased in the mean ATE. This later rose to an average of 0.79 in 2008 which also indicates a 25% approximate increase in the mean ATE between 2004 and 2008. Overall, given the number of studies per year, we observed that the mean ATE estimates increased approximately by 18% from 1999-2008.

The implication of this observation is that, despite the rising and falling trends that characterized the distribution of the reported mean ATE estimates as shown in the figure, there is evidence that average technical efficiency in the Nigerian agriculture increased by the year of publication relatively over time between the periods under scrutiny. This possibly might be an indication that farms in Nigeria are moving at least towards the frontier level.

The overall level of mean ATE estimates computed from all the frontier studies is 0.739 (see the lower panel of table 3.2). This value however, is not significantly different from the 0.737 value obtained by Bravo-Ureta *et al*. (2007) for African countries and 0.68 obtained by Thiam *et al.* (2001) for developing countries. Nonetheless, the overall mean ATE of 0.739 implies that there is still room for improvement in the efficiency of Nigerian agriculture as about 26% of the agricultural production could be expanded without any additional use of inputs in comparison to what could be achieved in the case of full technical efficiency farms in the country.

[3] We found that the studies cut across various sub-sector of Nigerian agricultural production systems. This include: food crops, cash crops (such as ; cocoa, oil palm, rubber latex), and non-crops (such as ; poultry, bee-keeping, and fish, rabbit, pig and crustacean)

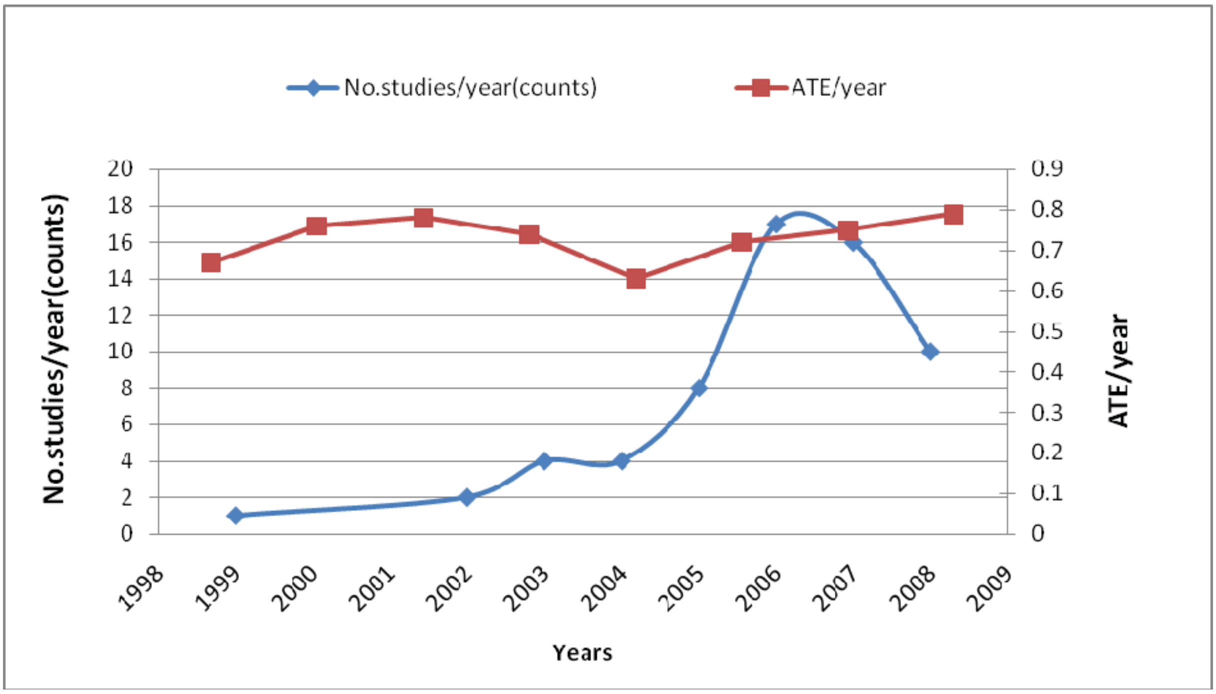

Figure 3.1: Distribution of the number of studies and ATE per year, 1999-2008

3.4.2. Distribution of ATE by the selected attributes of the studies

The summary statistics of the mean ATE by the various attributes of the frontier studies considered for the meta-regression analysis are presented in table 3.2. Studies on cash crops have the highest ATE with 0.81 followed by non-crops (0.75) and food crops (0.66). The mean ATE for studies with a non-aggregated dependent variable (i.e., single value output) is 0.82 compared to 0.66 for studies with an aggregated dependent variable. This result however is not surprising because in the process of aggregating, much information is lost which might have improved the predicted efficiency of the farms under investigation.

With regard to the choice of the functional form employed, we observed a mean ATE of 0.79 for studies with Cobb-Douglas, and 0.69 for translog. On the contrary, Thiam *et al.* (2001) and Bravo-Ureta *et al*. (2007) reported a higher average ATE for studies with translog compared to Cobb-Douglas. We find that there is no statistical difference between the ATE of Cobb-Douglas and translog in these studies.

Also presented in table 3.2 is the summary statistics of the mean ATE according to the geographic regions where the studies were conducted. The estimates for studies in the Southwest region was at an ATE of 0.842 with the largest number of observation (45) in 31 studies, followed by the Northeast 0.779 (5 in 4 studies), Southsouth 0.723 (19 in 15 studies), Northcentral 0.720 (10 in 7 studies), and Southeast 0.631 (7 in 7 studies). However, these results should be interpreted with caution because there were only few observations recorded in some of the regions.

Table 3.2: Distribution of mean ATE across the variables

Variables	No. of Obs.	No. of Studies	ATE Mean (Min-Max)
Characteristics of the data			
Food crops	51	40	0.656 (0.41-0.93)
Cash crops	11	9	0.806 (0.69-097)
Non-crops	24	15	0.754 (0.22-0.99)
Single output	62	44	0.823 (0.22-0.99)
Aggregated output	24	20	0.656 (0.53-0.93)
Choice of functional form			
Cobb-Douglas	70	56	0.791 (0.22-0.99)
Translog	16	8	0.688 (0.53-0.82)
Location of the study			
Northcentral	10	7	0.720 (0.62-0.81)
Northeast	5	4	0.779 (0.69-0.97)
Southwest	45	31	0.842 (0.53-0.99)
Southeast	7	7	0.631 (0.41-0.78)
South south	19	15	0.723 (0.22-0.91)
Overall estimates	**86**	**64**	**0.738 (0.22-0.99)**

3.4.3. The meta-regression result: effect of study-specific characteristics on ATE estimates

Presented in Table 3.3 is the estimate of the truncated meta-regression[4]. With regard to the year of the dataset (DATAYEAR), the estimated parameter shows that, the reported ATE significantly increased over time. Other study-specific characteristic such as sample size (NO.OBSER) and number of inputs used (NO.INPUT) significantly increased ATE. The negative and significant coefficient of RANGE implies that a higher range of efficiency indices produce lower ATE estimates across the frontier studies.

Studies with a focus on food crop (cash-crop) production significantly increased (decreased) reported ATE relative to the studies based on non-crop production (the dropped dummy) in the sampled studies. However, the coefficient of the cash-crop is corroborated by the annual statistical report released by the Central Bank of Nigeria, which shows a significant drop in the national production of key cash crops in the country (CBN 2006) most especially cocoa and oil palm.

[4] All estimates were obtained from STATA 10.

Also, studies using a non-aggregated dependent variable (i.e., single product) significantly increased ATE estimates whilst studies based on the Cobb-Douglas functional form have a positive but not statistically significant effect on the reported ATE indices across the frontier studies. The implication of the later is that, the functional form has unclear effects on the ATE indices which are consistent with the work of Thiam *et al.* (2001) and Bravo-Ureta *et al.* (2007).

The joint hypothesis of excluding the regional dummies, which represent the location of the studies, is rejected. Based on this, the positive and significant coefficients of the binary control variables; $D_{Northcentral}$, $D_{SouthWest}$ and $D_{SouthSouth}$ show that studies in the Northcentral, Southwest and Southsouth regions of the country significantly increased the reported ATE relative to the reference region $D_{NorthEast}$ (the dropped dummy). In contrast, studies from the Southeastern ($D_{SouthEast}$) part of the country significantly decreased the ATE relative to the reference region $D_{NorthEast}$.

Table 3.3: Estimates of the meta-regression of ATE

Variables		Parameters	Estimates
DATAYEAR	(X_1)	α_1	2.177*** (0.712)
NO.OBSER	(X_2)	α_2	0.420*** (0.124)
NO.INPUT	(X_3)	α_3	2.516* (1.489)
RANGE	(X_4)	α_4	-1.713*** (0.355)
D_{Food}	(D_1)	β_1	0.649** (0.328)
D_{Cash}	(D_2)	β_2	-0.534*** (0.188)
D_{Output}	(D_3)	β_3	0.249** (0.115)
D_{Cobb}	(D_4)	β_4	3.694 (2.399)
$D_{Northcentral}$	(D_5)	β_5	1.064** (0.549)
$D_{SouthWest}$	(D_6)	β_6	1.429*** (0.395)
$D_{SouthEast}$	(D_7)	β_7	-1.115* (0.667)
$D_{SouthSouth}$	(D_8)	β_8	3.210*** (0.634)
CONSTANT		ψ_0	1.469** (0.690)
Log likelihood		LL	119.108
Chi-square value		χ^2	49.14***

****, **,* denotes statistically significance level at the 1%, 5%, and 10%, respectively.*
Figure in parentheses represented the standard error

3.4.4. Identification of key drivers of ATE from the studies

Bravo-Ureta *et al.* (2007) stressed the importance of technical efficiency as a relative measure of managerial ability for a given technology. The implication of this assertion is that an increase in technical efficiency can be viewed as improvements in decisions-making which, in turn, are related to a set of controllable variables associated with the decision making unit (DMU). Household characteristics are commonly used to explain variation in smallholder efficiency level. However, the underlying assumption behind this is that differences in the level of efficiency are well described by set of controllable variables associated to the DMU which in the case are the smallholder farmers in Nigeria.

The existing literature proposes several variables in this context: education and age which relate the capacity of the DMU in terms of skills and experience; household size and credit as variables that may affect efficiency level through a smoother and timely use of inputs; extension contacts as potential efficiency shifter; off-farm employment and engagement in agricultural wage labour with a possibility to affect efficiency level via competing claims on labour resources, distance to market, among others. This observation, might possibly suggests why many frontier studies often contain quantitative results on sources of technical efficiency differences in addition to the estimated production frontier either in a single step or in a two step method.

Against this background, we take a closer look at those studies that estimated the sources of efficiency differential in addition to the estimated technical efficiency for further analysis. This is done in order to identify which farmers' socio-economic variables influence the ATE in Nigerian agriculture most over the years. 71 of the observations (83%) contain quantitative results on the sources of efficiency differential, usually incorporating farming household's demographic and socio-economic variables such as age, experience, credit, extension, household size, education, gender and membership in cooperative societies. Figure 3.2, revealed that education ranked highest with a significant impact on the ATE as extracted from the studies. This is followed in this order by years of experience, extension contacts, age, gender, credit, household size, and membership in cooperative as shown in the figure.

The implication of this is that, human capital development (e.g., education, experience mostly related to training on new agricultural technologies), intensification and perhaps re-structure or expansion of extension activities and farmer's access to capital market among others provide a measure of managerial ability through with which Nigerian agricultural productivity could experience a push into a new direction of growth and development in the country.

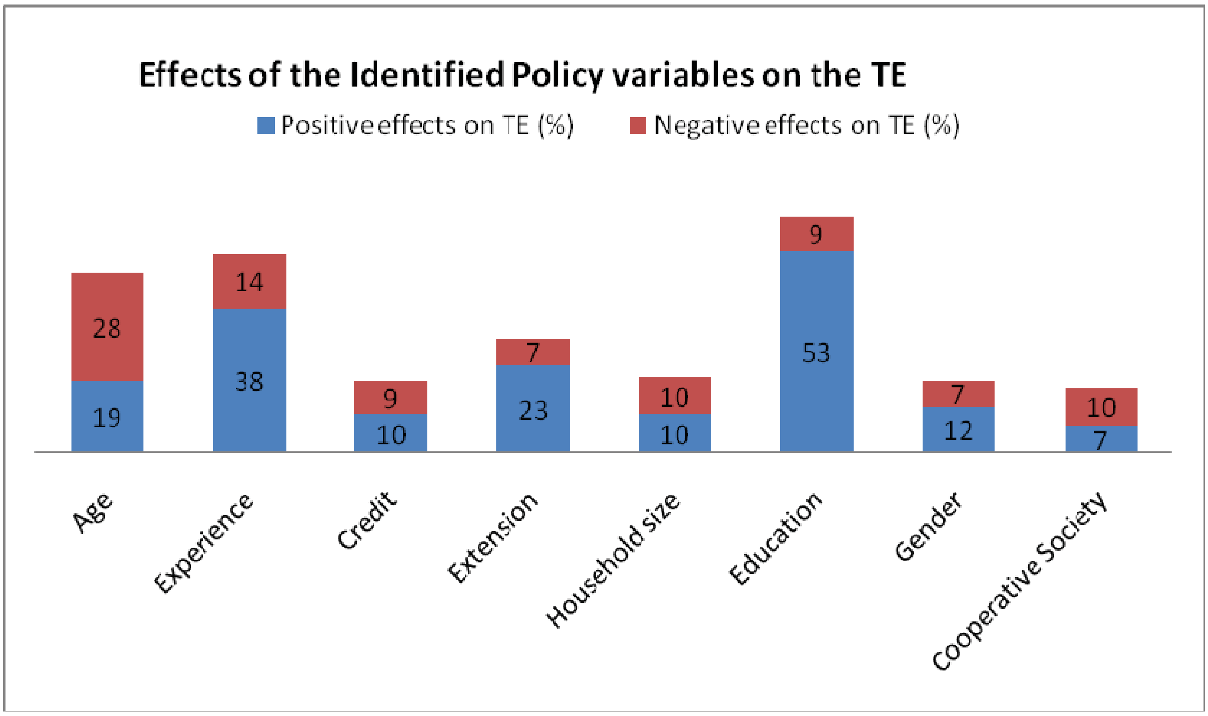

Figure 3.2: Identified policy variables and percentage of occurrence

3.5. Summary and conclusions

This paper in an attempt to infer relevant policy conclusions from the body of existing research with a focus on technical efficiency in Nigerian agriculture employed a meta-analysis on a total of 64 frontier studies which yield 86 observations. Specifically, the study provides an overview of the development of technical efficiency and identifies key drivers of efficiency in Nigerian agriculture over the years. In addition to this the paper examines how study-specific characteristics account for systematic variation in the reported average technical efficiency (ATE) from the frontier studies. To implement this, we regressed the ATE on the identified study-specific characteristics which includes: functional form used, sample size, number of input used, location of the study, among others.

The empirical findings show that the reported ATE in Nigerian agriculture increased significantly over the years. Sample size, number of inputs used, studies based on non-aggregated output variable (i.e., dependent variable is a single value variable) as well as studies with a focus on food crop production significantly increased reported ATE across the studies. The results of the regional effects on the ATE estimates using regional dummies shows that studies in the Northcentral, Southwest, and Southsouth regions of the country significantly increased ATE with reference to the studies in the Northeast part of the country.

A further finding of this paper which has implications for policies to improve efficiency and perhaps productivity in Nigerian agriculture is the evidence that, education, experience, extension contacts and credit significantly influence the ATE of Nigerian agriculture from 1995 to 2007. Although, this observation confirms what has been found in many studies relating to developing agriculture (Philip 1994; Weir 1999 and 2000; Asadullah 2005), we nonetheless suggested that government policies, strategies, and programs should accommodate these policy variables in order to shift the frontier of Nigerian agriculture upward.

Finally, we acknowledge that the selection of variables for the meta-analysis was constrained by a lack of published information on the study-specific characteristics used as explanatory variables in the regression. Nevertheless, the future challenge is to be able to increase the data points and the depth of information on each farm so that more data-demanding approaches (both parametric and non-parametric techniques) could be applied in order to gain further insights on the overall impact of study specific variables on efficiency differentials as well as the distribution of technical efficiency in Nigerian agriculture over time.

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CHAPTER FOUR

4.0. Crop diversification and technical efficiency of smallholder farms in Nigeria

4.1. Introduction

There is widespread agreement that agriculture is central to economic growth in countries of sub-Saharan African (Deigado, 1995) including Nigeria. For instance, Nigeria's agricultural sector is particularly important in terms of employment generation, contribution to gross domestic product (GDP), and export revenue earnings (Manyong *et al.* 2005).
However, Nigerian agriculture is overwhelmingly dominated by smallholder-subsistence farm economy responsible for over 90% of the country's agricultural output with rudimentary farm implements, low capitalization, and low yield per hectare (Olayemi, 1998).

In terms of growth, the agricultural sector of Nigeria's economy has achieved significant success in recent times. It attained the 7% growth targeted in the National Economic Empowerment and Development Strategy (NEEDS) - a macro-economic policy framework currently implemented in the country. Unfortunately, the 2.7% growth rate in the food sub-sector currently observed is far too low for a country whose population is growing at the rate of 3.5% (CBN 2006). This low growth rate in the food sub-sector is largely responsible for the worsening food insecurity in some parts of the country as domestic food production cannot keep pace with the rapid growing population of over 140 million people.

The most fundamental constraint to agricultural growth in Nigeria, despite her enormous agricultural potential, is the peasant nature of the production system, poor response to technology adoption, fragmentation of land, and loss/failure in the cropping activities that in turns cause variability in the production (Manyong *et al.* 2005). The later observation suggests why majority of the smallholder farmers in the country embrace a cropping pattern that is characterized by growing a wide variety of crop mix under multiple cropping systems in space adapted to various agro-ecological zones[1] known as crop diversification (Ajibefun, 2006).

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[1] Multiple cropping is the system whereby farmers cultivate many crops/intercrop simultaneously on the same piece of land. It is a resilience mechanism adopted by farmers in many regions of the world (Ellis, 1993). Petit and Bargouti (1992) identified crop diversification as a stage at which many developing agriculture are currently practicing.

Crop diversification has attracted considerable interest among peasant farmers around the globe because of the following inherent characteristics: 1) as a potential risk management tool against uncertainty, 2) income and employment generation opportunity, 3) ability to reduce diseases, weed and insect build up, and 4) possibility to increase soil fertility and among others (Singh, 2000). Also, Bamji (2000) posited that diversification within food crops and between food crops and livestock helps nutrition security, particularly for small and marginal farmers. Supporting this observation earlier, Ellis (1993) observed that peasant farmers often engage in risk aversion that result in farming practices with spatial diversification of crops portfolios and mixed cropping strategy primarily design to increase family food security rather than to maximize profit.

Recently, the issue of diversification triggered by the success in Asia in the 90s has gained much popularity around the globe (Hoque 2000; Mariyono 2007). For instance in Nigeria, diversification has been recognized as a phenomenon of interest among the smallholder farmers for ages (Fawole and Oladele, 2005). A search of the literature suggests that the impact of crop diversification on the livelihood of agricultural producers and their efficiency is quite mixed. While Guvele (2001) and van den Bergretta *et al.* (2007) revealed that crop diversification reduces income variability in Sudan and sustains a reasonable income level for Chinese farmers respectively, Kar *et al.* (2004) and Rahman (2009) conclude that crop diversification increases agricultural production in India and Bangladesh, respectively. Also, Llewelyn and Williams (1996) and Haji (2007) reveal that diversification significantly decreases efficiency of farmers in Indonesia and Ethiopia, respectively while Coelli and Fleming (2004) and Rahman (2009) report that diversification improves efficiency of farmers in Papua New Guinea and Bangladesh, respectively. The mixed findings from these studies indicate that the effect of crop diversification on agricultural productivity might vary from region to region or case to case.

Efficiency in food crop production is a topical issue in food security programs of many developing countries. The crucial policy role of efficiency in increasing agricultural output has been widely recognized by researchers and policy makers around the globe (Bravo-Ureta *et al.* 2007). The measurement of efficiency is more important, given the fact that efficiency of farmers is directly related to overall productivity of the agricultural sector (Ajibefun, 2006).

Since crop diversification has become a stage at which many developing agriculture are currently operates, while findings from the empirical studies highlighted above appear mixed with regard to its impact on agricultural productivity, it is important to raise the following questions: How has crop diversification developed in Nigeria? What is the relationship between crop diversification and technical efficiency of farmers in the country? Is crop diversification capable of increasing food production/food security to meet the rising demand in the country? Answers to these questions makes analysis of this nature worthwhile, as the results will shed light on whether crop diversification is a desired strategy for promoting agricultural development and perhaps food security in the country.

The rest of this paper is divided into the following sections. Section 4.2 outlines the review of efficiency and diversification literatures. Section 4.3 discusses the methodology. Section 4.4 presents the empirical results while section 4.5 provides conclusions and policy implications from the paper.

4.2. A Review of efficiency and diversification literature

The standard production economic theory assumes that all producers are efficient whilst implicit assumption in frontier efficiency analysis suggests that some producers are inefficient (Hailu *et al.* 2005). The crucial role of efficiency in increasing agricultural output has been widely recognized by researchers and policy makers around the globe. Broadly, two quantitative approaches are developed for measurement of production efficiency: parametric (deterministic and stochastic frontier models) and non-parametric (Data Envelopment Analysis, DEA) approaches. The advantages and limitations including model specification issues regarding these approaches are extensively discussed in Kumbhakar and Lovell (2000) and Coelli *et al.* (2005). Nonetheless, since DEA assume deviation from the frontier to be entirely attributed to inefficiency effects, the present study employs the stochastic frontier models because of its inherent stochasticity which assumes deviation from the frontier to the existence of random effects such as climatic conditions and inefficiency effects[2].

[2] This observation suggests why stochastic frontier models is preferred model for analyzing farm level efficiency in the developing agriculture where most variability in agricultural production is attributed to uncertainty related to climatic conditions such as drought, floods among others.

The stochastic frontier analysis (SFA) was developed independently by Aigner *et al.* (1977) and Meensen and van den Broeck (1977). It consists of two-part error terms: an inefficiency component (u_i) and a purely random component (v_i). According to Greene (2008), SFA is simply an extension of the familiar regression model on the theoretical premise that a production function represents an ideal, maximum output attainable, given a set of input bundles. SFA framework could be extended to the traditional primal representation of production technology (such as production or distance functions), or dual representation of production technology (such as profit, revenue or cost functions).

The concept of diversification conveys different meaning to different people at different levels. In research related to marketing for example, diversification implies a measure of market concentration. Within the agricultural enterprise, diversification may be viewed as a process with three stages (Chaplin, 2000). The first stage is considered as the cropping level which involves a shift away from monoculture. At the second stage, the farms have more than one enterprise and produce many crops that they could potentially sell at different times of the year. The final stage is understood as mixed farming where there is a shift of resources from one crop (or livestock) to a larger mix of crops (or livestock) or mix of crop and livestock.

Mengxiao (2000) described crop diversification as the complex diversification patterns of agricultural cropping systems found under the conditions of farming environments.
According to Johnston *et al.* (1995), crop diversification has three dimensional benefits which the author described as economic, social, and agronomic. The economic benefits include: seasonal stabilization of farm income to meet other basic needs of life like education of the children; coverage of their subsistence need, most especially meeting family food security; and a reduction of risk of the overall farm returns by selecting a mixture of activities whose net returns have a low or negative correlation while lessening price fluctuations. Social benefit include seasonal employment for farm workers while the agronomic benefits include: conserving precious soil and water resources, reduced diseases, weed and insect build up, reduced erosion, increased soil fertility, and increased yields (Caviglia-Harris and Sills 2005; Gunasena 2000; Ali and Beyeler 2002)[3].

[3] The benefits of crop diversification have both value-enhancing and value-reducing effects such that the net effect is ambiguous in some instances (Chaplin, 2000).

In a related development, Paul and Nehring (2005) observed that diversification is a significant factor explaining differences in the level and variability of farm income between higher and lower performing small farms. However, several other micro-level studies support the above proposition (von Braun 1995; Ramesh 1996; Ryan and Spencer 2001).

Many developing countries have incorporated a crop diversification strategy in several development programs (Gunasena, 2000). A significant example of this is the well documented Asia experience in the successful use of diversification strategy in the commercialization of agriculture in the 90s (Hoque 2000; Mariyono 2007).

Measuring Crop Diversification

Although, Herfindahl and Ogive indices are widely used in measure of market concentration, these indices are however employed to construct the diversification index used in the paper because the indices have been used to represent crop diversification and or specialization in the literature [4].

Herfindahl Index

The Herfindahl Index $\left(\mathrm{H}_D\right)$ is the sum of the squares of the acreage/revenue proportion of each crop in total cropped area/revenue. The index has widely been used in marketing and corporate firm studies as a measure of market concentration (Rhoades 1995; Ali and Byerlee 2002; Oluwadare *et al.* 2009). Recent application of this index to capture crop diversification or degree of specialization in agricultural production includes (Rahman 2009; Brümmer 2001; Brümmer *et al.* 2006).

A detailed description of the Herfindahl index as used in the present study is described below

$$\mathrm{H}_D = \sum_{j=1}^{J}\left(\frac{Y_j}{\sum_{j=1}^{J} Y_j}\right)^2 \qquad 0 \le \mathrm{H}_D \le 1 \qquad 4.1$$

[4] Other measure of diversification as observed in the literature includes: Simpson index, Entropy Index, Modified Entropy Index, Index of Maximum Proportion, and Composite Entropy Index.

where Y_j represents the area/revenue share occupied by the *j-th* crop in total area/total revenue Y. J is the total number of crops, that is, when maximum diversification occurs. The index ranges from zero, reflecting complete diversification (i.e., an infinite number of crops in equal proportion), to one, reflecting complete specialization (i.e., just one crop). It can be shown that this index attains a minimum value equal to 1/J.

Ogive Index

Application of the Ogive index to measure firm/farm level diversification includes: St. Louis (1980), Coelli and Flaming (2004) and Mekhora and Fleming (2004).
A detailed description of this index as used in the present study is described below

$$\text{Ogive}_i = \sum_{j}^{N_J} \left[\frac{\left(\text{Y}_j - 1/N_J\right)^2}{1/N_J} \right] \qquad 4.2$$

where N_J represents the number of the *j-th* crop activities cultivated by the *i-th* farmer, $1/N_J$ denotes a measure of precision which captures perfect diversification of the activities on the farm. Y represents the area/revenue share occupied by the *j-th* activities. The economic interpretation is that as $\text{Ogive}_i \to \infty$, it implies perfect specialization.

4.3. Methodology

4.3.1. The data and study area

The data used in this study came from a farm households' survey that was carried out in Southwestern Nigeria covering 2006/07, 2007/07 and 2008/09 farming seasons. The region is made up of six states (Ekiti, Ogun, Ondo, Osun, Oyo and Lagos). Of all these states, Lagos state is regarded as the financial capital of the country known for commerce rather than agriculture. Based on this, Lagos is not included in the survey while the remaining five states were adequately represented in the survey.
The farmers were randomly sample based on the list of food crops farmers provided by the extension personnel of the state's agricultural development program (ADP) with aid of a well-structured questionnaire. 282, 260, and 304 farms were sampled in 2006/07, 2007/08, and 2008/09 farming seasons, respectively. At the state level, a total number of 181, 206, 173, 141, and 145 farms were sampled in Ekiti, Ondo, Oyo, Osun, and Ogun states, respec-

tively. In all, we have 846 observations consisting of unbalanced panel data covering three farming seasons in the region[5].

The data for the analysis consist of information on crops such as cassava, yam, maize, cocoyam and sweet potatoes as extracted from the survey. Table B of the appendix contains the summary statistics of the information collected from the survey and subsequently used in the analysis.

4.3.2. Analytical framework

The basic stochastic frontier production function is specified as

$$y_i = f(x_i;\beta)\ \exp(V_i - U_i) \qquad 4.3$$

where y_i denotes the value of the production of the i-*th* farm (i=1,….N); X_i is a *(1xk)* vector of the associated inputs; and β is a *(kx1)* vector of unknown parameters to be estimated. v_i is a random error term (statistical noise) distributed symmetrically and u_i[6] is the asymmetric error term assumed to be independently and identically distributed (u_i>1) that captures technical inefficiency and is independent of v_i.

In line with Eqn.4.3, we defined technical efficiency of individual producers as the ratio of the mean output for i-*th* producer, given the values of the inputs x_i and its technical inefficiency effect (u_i), to the corresponding mean output if there was no technical inefficiency in the production (u_i=0) . This can be expressed as

$$TE_i = \frac{E\left(Y_i \mid u_i, X_k\right)}{E\left(Y_i \mid u_i = 0, X_k\right)} = \exp(-\upsilon_i) \qquad 4.4$$

where E denotes the expectation operator while TE_i takes a value on the interval (0, 1). $\mathbf{TE_i}$ =1 indicates a fully efficient farm and 0 implies a fully inefficient farm.

[5] Less than 10% of the farmers were repeatedly sample within the seasons.

[6] Various distributional assumptions have been proposed in the literature to model the one-sided u_i . These includes half normal, exponential, truncated, and gamma distributions (see more details in Kumbhakar and Lovell, 2000)

Generally, the objective of the stochastic production frontier model is not only to serve as a benchmark against which technical efficiency of producers are estimated, but to also explore how exogenous variables exert influence on producer performance (Kumbhakar and Lovell, 2000). To explore this in a single stage approach, Kumbhakar *et al.* (1991) parameterized the mean of the pre-truncated distribution of inefficiency error term u_i while Caudill and Ford (1993) parameterized the variance of the pre-truncated distribution of inefficiency error term u_i. The later approach is employed in the present study. A detailed description of these approaches is well documented in Kumbhakar and Lovell (2000).

4.3.3. Empirical model

The translog production frontier function which is flexible and most frequently used in empirical work is assumed for this study and expressed as

$$lny_{it} = \begin{pmatrix} \zeta_0 + \phi_{HL}\mathrm{D}_{Hlit} + \phi_f \mathrm{D}_{fit} + \phi_p \mathrm{D}_{pit} + \sum_{j=1}^{6}\beta_j lnX_{jit} + \tau_T \mathrm{A}(t) + \frac{1}{2}\sum_{j=1}^{6}\sum_{k=1}^{6}\beta_j lnX_{jit}.lnX_{kit} + \frac{1}{2}\tau_{TT}\mathrm{A}^2(t) \\ + \sum_{j=1}^{6}\kappa_{jT} lnX_{jit}.\mathrm{A}(t) + \omega_1 D_{ekiti} + \omega_2 D_{ondo} + \omega_3 D_{osun} + \omega_4 D_{oyo} + \varsigma_1 D_{2008} + \varsigma_2 D_{2009} + \pi \mathrm{HI}_{it} \end{pmatrix} + \mathrm{v}_{it} - \mathrm{u}_{it} \qquad 4.5$$

where In: natural logarithm; y_{it} : total value of farm produce for the i*th* farm in the t*th* time period; X_1: land; X_2: Hired labour which is equal to $ln\left[Max\left(Hlabour, 1 - D_{Hl}\right)\right]$; X_3 : Family labour; X_4: fertilizer which is equal to $ln\left[Max\left(fertilizer, 1 - D_f\right)\right]$; X_5: pesticides which is equal to $ln\left[Max\left(pesticide, 1 - D_p\right)\right]$; X_6: cost of planting materials; A(t): time dummies for each farming season of the sample. This dummy reflects a linear trend with 06/07 = 0, 07/08 = 1, and 08/09 = 2 is included in the model to account for technological change. D_{Hl} is a dummy which has a value of one if number of hired labour is positive and a value of zero if otherwise, D_f is a dummy which has a value of 1 if fertilizer usage is positive and 0 if otherwise, and D_p is dummy with a value of 1 if pesticide usage is positive and 0 if otherwise.

In an attempt to minimize bias in the coefficient of some of the variables in the Eqn.412, $ln\left[Max\left(Hlabour, 1 - D_{Hl}\right)\right]$, $ln\left[Max\left(fertilizer, 1 - D_f\right)\right]$ and $ln\left[Max\left(pesticide, 1 - D_p\right)\right]$ are included to account for zero usage of these variable inputs in the regression while D_{Hl}, D_f, *and* D_p account for intercept change (Battese,1997).

States dummies are also included in the production frontier to account for state specific effect in the production frontier. This include: D_{ekiti}, D_{ondo}, D_{osun}, and D_{oyo}, which are Ekiti, Ondo, Osun, and Oyo states, respectively (D_{ogun} is left out for estimation). Seasonal dummies were also included in the production frontier which include; D_{2008} and D_{2009} for 2007/08 and 2008/09 seasons, respectively (D_{2007} for 2006/07 is left out for estimation). Finally, the Herfindahl Index of crop diversification (HI) is included in the frontier regression to assess the impact of diversification on the technology frontier of the farmers.

In this study, we follow standard assumption on the stochastic error term v_{it} in the literature that $\boldsymbol{E}\left(\boldsymbol{v}_i\right) = 0$ for all $\boldsymbol{i}$, $\boldsymbol{E}\left(\boldsymbol{v}_i\boldsymbol{v}_j\right) = 0$ for all $i \, and j \left(i \neq j\right)$`, $E\left(v_i^2\right) = \sigma_v^2$, $E\left(u_i\right) > 0, E\left(u_i u_j\right) = 0$ for all $i \, and j \left(i \neq j\right)$`, and $E\left(u_i^2\right) = \sigma_u^2$. The stochastic terms v_i and u_i are assumed to be uncorrelated. Also we assumed, v_{it} is normally distributed as $N\left(0, \sigma_{vit}^2\right)$ with $\sigma_{vi}^2 = g\left(x_{ji}, D_{ki}; \tau_i\right)$ while u_i is assumed to be half-normally distributed as $N^+\left(0, \sigma_{uit}^2\right)$ with $\sigma_{ui}^2 = \mathrm{q}\left(Z_{is}, D_{pi}; \alpha_i\right)$.

A preliminary examination of the OLS residuals of the estimated relationship between the variables included in Eqn.4.5 suggested the possibility of heteroskedascity[7]. Based on this, the analysis allows a double heteroskedascity error structure in the SFA. Heteroskedascity in both v_i and u_i are tested for and estimated in the paper.

For the likely variables to control for the presence of heteroskedascity in the two-sided error term we follow the suggestion of Hadri *et al.* (2003) and Loureiro (2009) that heteroskedascity in u_i is likely to be affected by size-related variables. In this regard, we include the farm size to capture differences in the farm harvest while site specific location variables such as states dummies were included to capture size and location differences across the region as

$$\sigma_v^2 = \exp\left(\tau_0 + \tau_1 lnX_{landit} + \tau_2 D_{ekitit} + \tau_3 D_{ondot} + \tau_4 D_{osunt} + \tau_5 D_{oyot}\right) \qquad 4.6$$

where σ_v^2 represents the variance of the two sided error (v_i), $In\mathrm{X}_{ji}$ is the logarithm for land while the state dummies are as indicated by the subscripts. However, a model with ho-

[7]Earlier we check for heteroskedasticity in the residual using Breusch-Pagan test, the result failed to reject the null hypothesis of no heteroskedasticity at p-value of 0.000.

moskedastic statistical variance from the restriction results that all the τ parameters except the intercept are equal to zero is tested for.

Following traditional technical inefficiency effect model in the literature, the variance of the inefficiency error is modeled as a function of the farmers' socio-economic variables, state and seasonal dummies as

$$\sigma_u^2 = \exp\begin{pmatrix} \omega_0 + \alpha_1 Z_{age} + \alpha_2 Z_{gender} + \alpha_3 Z_{family} + \alpha_4 Z_{educ} + \alpha_5 Z_{credit} + \alpha_6 Z_{exten} + \alpha_7 Z_{nonfarm} + \alpha_8 Z_{index} \\ + \delta_1 D_{ekiti} + \delta_2 D_{ondo} + \delta_3 D_{osun} + \delta_4 D_{oyo} + \delta_5 D_{2008} + \delta_6 D_{2009} + \Gamma_1 Index.D_{2008} + \Gamma_2 Index.D_{2009} \end{pmatrix} \quad 4.7$$

where σ_u^2 represents variance of one-sided error term (u_i), Z_{age}: age of the primary decision makers in the study area, Z_{gender}: gender dummy of the primary decision makers in the study area (male =1, 0 otherwise), Z_{family} : family size (this represents only the core family members), Z_{educ}: years of schooling the farmer, Z_{credi} : credit dummy (access =1, 0 otherwise), $Z_{exten.}$: number of contacts with extension agents, $Z_{nonfarm,}$: non farm income dummy (participation=1, 0 otherwise), Z_{index}: Crop diversification index. The states and seasonal dummies are included as earlier defined and described. The interaction between seasonal dummies and the crop diversification index includes; $IndexD_{2008}$ and $IndexD_{2009}$. However, a model with homoskedastic inefficiency variance from the restriction results that all the parameters of Eqn. 4.7 except the intercept ω_0 are equal to zero is tested for.

Estimated parameters of Eqn. (4.5-4.7) are jointly carried out using maximum likelihood procedures in STATA10 used for the analysis.

4.4. Results and discussion

4.4.1. The development and trends in crop diversification

Table 4.1 presents the average score for the computed Hefindahl and Ogive Indices of crop diversification based on crop hectrage and total revenue for the 2006/07-08/09 farming seasons and on state basis. The surveyed households were observed to have portfolios consisting of a maximum of 5 activities (or enterprises)[8]. However, these activities include; cassava, yam, maize, potatoes, and cocoyam. These crops are either solely cropped or mixed by the farmers.

[8] The observed maximum number of 5 activities is based on data availability as obtained from the respondents rather than pre-determine from inception of the survey.

The result of the correlation between these indices shows that the index in pair is significant and positively correlated as indicated by p-value of 0.000. Subsequently, we thus focus our discussion on the Harfindahl index of cropped acreage.

It is clear from the table that the proportional measures of crop diversification reveal a shift towards more diversification cropping patterns among smallholder farms in the study. This is interpreted as evidence of intensification of crop diversification in the region[9]. For example, the computed average 0.498, 0.457, and 0.425 for 2006/07, 2007/08, and 2008/09 farming seasons, respectively justify this observation. Also, further calculation shows about 15% [10]downward trends in the computed Herfindahl Index from 2006/07 to 2008/09 farming seasons which was found to be significant at *p-value* of 0.0012. The implication of this is that, there is evidence that cropping pattern increased (by about 15%) significantly with intensification of crop diversification in the Southwestern Nigeria.

A further confirmation of this observation is the result of Cuzick's non-parametric trend test of the index condition on the seasons. The z-score of -5.87 with p-value 0.000 shows that there is indeed strong evidence of downward trends in diversification (meaning increased crop diversity) in the region.

However, a second look at the dataset, we observed that out of the 62 farms that were repeatedly sampled throughout the three seasons, 43 farms (representing 69%) increased the number of portfolios of activities/ enterprises on their farms, 8 farms (13%) maintain the number of activities/enterprises on their farms while 11 farms (18%) decreased the number of activities/ enterprises on their farms. This observation could be interpreted as a further indication of increase intensification of crop diversification among the smallholder farmers in the region.

Summarizing the index by state shows that crop diversification is higher in Osun state with an average index of 0.440. This is followed by 0.449, 0.451, 0.456 and 0.494, respectively, for Oyo, Ogun, Ondo and Ekiti states in that order.

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[9] The index is constructed such that a value tends towards one $(H_{iD} \rightarrow 1)$ implies specialization or a value tends towards zero $(H_{iD} \rightarrow 0)$ implies diversification.

[10] This is computed by $\left[\frac{H_{D08/09} - H_{D06/07}}{H_{D06/07}}\right] x100 = \left[\frac{0.425 - 0.498}{0.498}\right] x100 = -14.65\%$

The overall average Herfindahl index of 0.459 with standard deviation of 0.205 was obtained. The distribution of this index is presented in figure 4.1. As shown in the figure, majority of the farms are located in the region with the index of less than 0.5 suggesting that most of the farm households embraces crop diversification in the study area.

The literature shows that rural households' decision to embrace crop diversification could occur either as a result of decision to minimize production risk, to meet family food security/nutrient intake, to stabilize farm income, or to ensure a free flow of income. However, the present study indicates that significant trends towards crop diversification could probably be attributed to the following (see Figure 4.2)[11]. Firstly, the variability in non-farm income per capita could suggest why farms in the study embrace crop diversification to meet perhaps family food security and other obligations, although the income per capita from the core farm activities seems to be stable (see figure 4.2). Nonetheless, farmers that relied on non-farm income to complement their stable farm income in order to meet other family obligations could resolve to crop diversification once the non-farm income becomes un-stable or an unreliable source of extra income for the family. Secondly, drawing from the view of Davidova *et al.* (2000) that participation of higher cropping diversity has negative effects on non-farm income might explain why the propensity to diversify significantly increases in the study. For example, increased labour requirement and supervision of farm have been identified in the literature as major constraints associated with crop diversification. The fact that 38% of the farms participate in the non-farm income suggests that more than half of the farms have the propensity to diversify because of available labour and timely supervision of the farm.

[11] The non-farm income of the households comprises trading, bricklaying, tailoring, taxi drivers, civil servants, teachers and mechanics.

Table 4.1: Trends in Crop Diversifcation by farming season and states

	Herfindahl_Area Index			***Herfindahl_Total Rev. Index***			***Ogive Index***		
	Mean	**Max**	**Min.**	**Mean**	**Max**	**Min.**	**Mean**	**Max.**	**Min.**
2006/07	0.498	1	0.224	0.568	1	0.230	1.362(2.6)	4(5)	0.121(1)
2007/08	0.457	1	0.210	0.515	1	0.216	1.192(3.2)	4(5)	0.052(1)
2008/09	0.425	1	0.213	0.434	1	0.208	1.032(3.3)	4(5)	0.063(1)
Ekiti	0.494	1	0.225	0.561	1	0.294	1.361(2.8)	4(5)	0.325(1)
Ogun	0.451	1	0.224	0.417	1	0.216	1.156(3.2)	4(5)	0.062(1)
Ondo	0.456	1	0.184	0.541	1	0.235	1.172(2.9)	4(5)	0.102(1)
Osun	0.440	1	0.191	0.479	1	0.208	1.104(3.2)	4(5)	0.052(1)
Oyo	0.449	1	0.201	0.490	1	0.214	1.137(3.1)	4(5)	0.098(1)
Pooled	**0.459**	**1**	**0.210**	**0.504**	**1**	**0.208**	**1.191(3.0)**	**4(5)**	**0.052(1)**

Figure in parentheses represents average number of activities

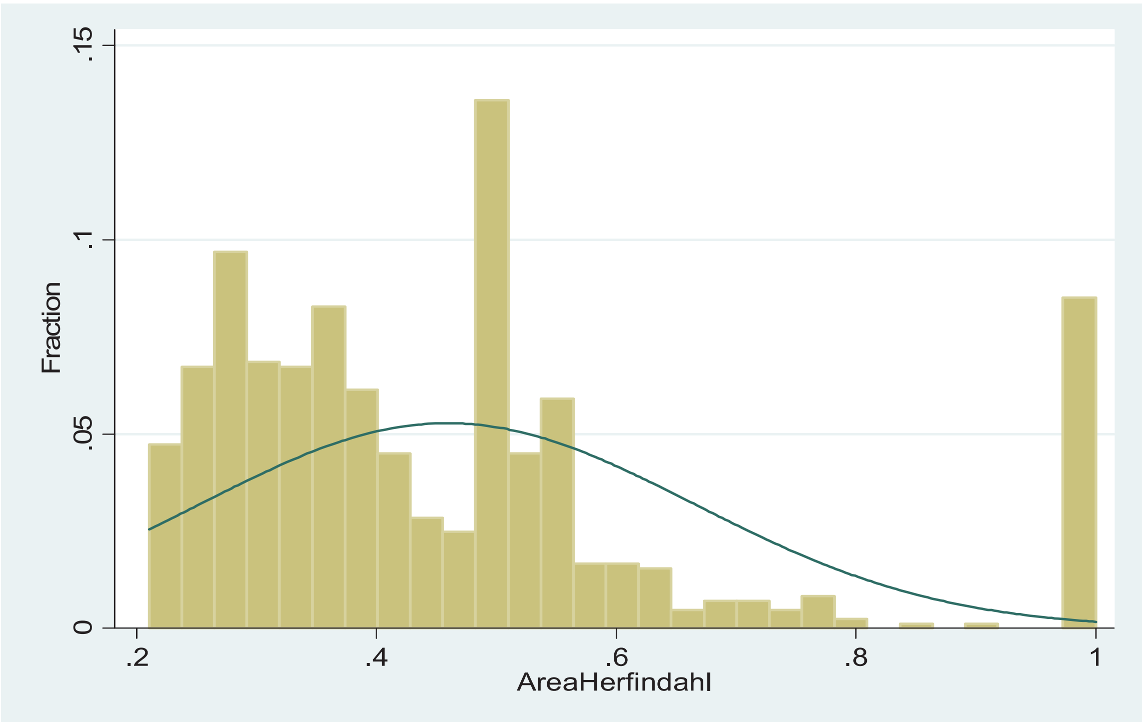

Figure 4.1: Distribution of Herfindahl index for cropped hectrage

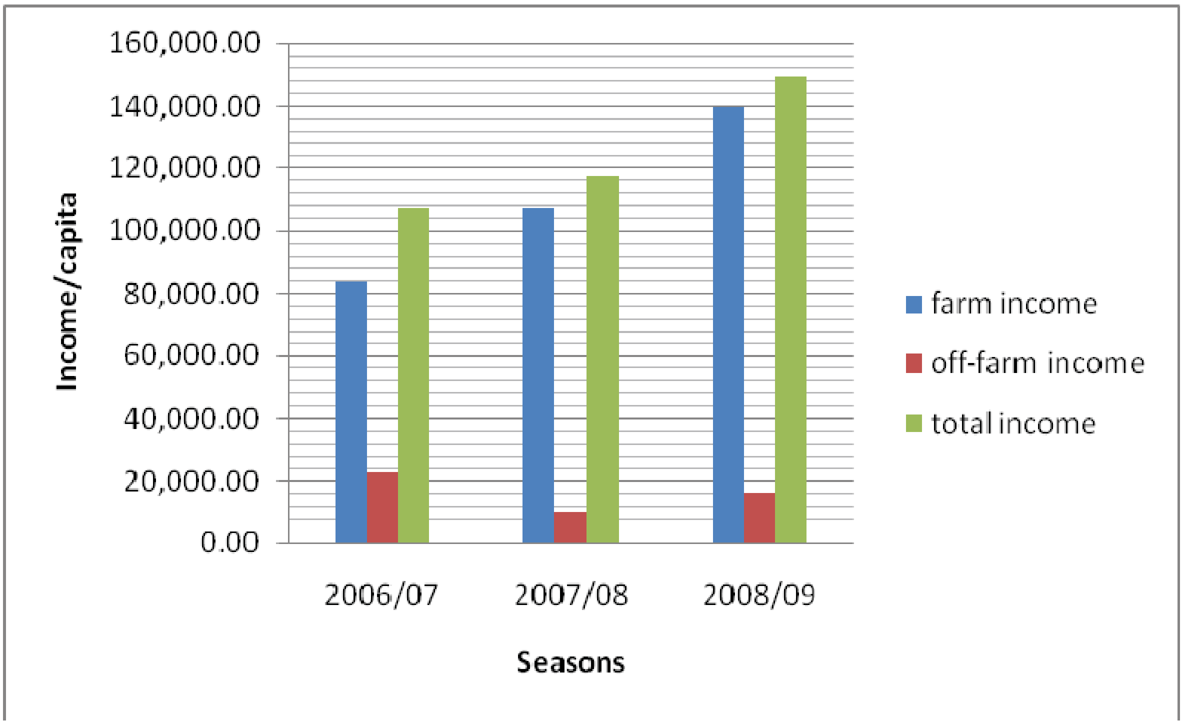

Figure 4.2: Distribution of average households' annual gross income, off-farm income and gross farm income per capita

4.4.2. Hypotheses tests

The results of the likelihood ratio tests[12] carried out during the analysis are presented in Table 4.2. The first null hypothesis indicates the rejection of Cobb-Douglas specification at 5% level of significance (second row). Thus, the specification for the translog stochastic frontier production function is more suitable to derive a conclusion from the data. The null hypothesis of homoskedastcity v_i and u_i is rejected as revealed by the third row. The null hypothesis of homoskedasticity v_i with heteroskedasticity u_i is also rejected as shown in the fourth row. The fourth hypothesis of homoskedasticity u_i with heteroskedasticity v_i which also doubles as the test of the effects of technical inefficiency is rejected (fifth row). The implication of the fourth hypothesis is that, there is presence of technical inefficiency effects in the study.

[12] We constructed the likelihood ratio test using the statistics $LR = -2\left[\ell n\left(LH_R - LH_U\right)\right]$, where LH_R is the value of the maximized log-likelihood for the restricted and LH_U represents that of unrestricted. This statistics follows a χ^2 distribution with $T_R - T_U$ denoted degree of freedom, where T_R and T_U represents the number of variables in the restricted and unrestricted samples, respectively.

Table 4.2: Likelihood-ratio tests

Null Hypotheses	***Log likelihood***	***LR***	***Critical-value (5%)***	***Decision***
Translog i.e., Full Heteroskedasticity preferred model	473.68			
H_{01}: $\beta_{jki}=0$ i.e., Cobb-Douglas Vs Translog	412.17	123.02	41.34	Reject H_0
H_{02}: $\ell n \sigma_v^2 = \ell n \sigma_u^2 = const.$ i.e., Homoskedasticity in both v_i & u_i errors	402.41	142.54	32.67	Reject H_0
H_{03}: $\ell n \sigma_v^2 = const$ i.e., Homoskedasticity in v_i error	408.35	130.66	11.07	Reject H_0
H_{04}: $\ell n \sigma_u^2 = const$ i.e., Homoskedasticity in u_i error and No. technical effect	432.16	83.04	23.69	Reject H_0

4.4.3. The elasticities and returns-to-scale

The maximum likelihood estimates (MLE) of preferred heteroskedasticity corrected stochastic frontier production function model are presented in Table 4.3. Before the estimation, all the input and output data are normalized by their respective sample means, which makes it possible to interpret the *first-order* parameters directly as partial production elasticities at the sample mean (Coelli *et al.* 2005). At the point estimate, the estimated output elasticity of land, hired labour, family labour, fertilizer, pesticide and materials were positive and therefore consistent with economic theory. The variables were significantly different from zero, with at most a 10% level of significance with the exception of family labour and materials. Non significant of family labour in food crop production in Nigeria was also observed in the work of Oyekale (2006), and Oyewo and Fabiyi (2008). Hired labour with the highest elasticity implies that this variable is important in food production among smallholder farmers in the country.

This study checked for the monotonicity condition with respect to all inputs at their individual point estimates in accordance with Sauer *et al.* (2006). This result is based on the number of individual point estimates with production elasticities that are non-positive. In this regard, the results show that 13% of the elasticities are negative for land; hired labour: 9%; family labour: 26%; fertilizer: 21%; pesticides: 23% and materials: 34%.

The sum of the first-order elasticities suggests that an average farm from the sample experience decreasing returns-to-scale (DRTS) of 0.959. The implication of this is that if all the inputs are jointly increased by 1%, the food production would increase by about 0.96% which is an indication that quantities of some inputs in the production function exceed the scale efficient point. A search of the literatures shows that a similar finding was obtained in the developing agriculture by Binam *et al.* (2004), Tijani (2006), Chirwa (2007), and Solis *et al.* (2009).
The variable "time trend" accounts for technical change. At the point estimate, the positivity and significance of this variable implied technical progress in food crop production from the analysis.

The positive significant dummies of Oyo and Osun states implied a higher frontier for farms in these states, with reference to Ogun state. Also the positive significance of seasonal dummies is an indication of the positive seasonal effects on the production frontier in the study.

Although the impact of the Herfindahl Index is positive on the frontier, this variable is not significantly different from zero. Table 4.3 also presents the result of heteroskedasticty v_i. It shows that land and the states dummies for Ekiti, Osun, and Oyo decreased the stochastic variance with the exception of the dummy for Ondo state while only the dummy for Osun state is not significantly different from zero.

4.4.4. Technical inefficiency effects

The relationship between the variance of the inefficiency term and socio-economic variables of the farmers, production characteristics, and seasonal and state dummies is presented in the lower panel of Table 4.3. This result also doubles as a measure of technical inefficiency effects.

The results show that gender[13], family size, and credit increased the variance of technical inefficiency (i.e., decreased technical efficiency) of the farmers. Only gender is significantly different from zero. The implication of this is that, technical efficiency of household heads that are male decrease significantly compared to that of their female counterparts. This observation conform to the findings of Adesina and Djato (1997), Bozogln and Ceyhan (2007) and Erhabor and Emekaro (2007). Nonetheless, a possible explanation for this could be attributed to the time of supervision devoted to the activities on the farms by the female household heads compared to their male counterparts as most male household heads spend most of their time in pursing non-farm activities as observed by Oladeebo and Fajuyigbe (2007).

In a related development, age, education, extension, and non-farm income decreased the variance of the inefficiency term (i.e., increased technical efficiency). Education and extension are significantly differently from zero. This observation follows *a priori* expectation, given that education is an important factor in technology adoption. Educated farmers are expected to be receptive to improved farming techniques and therefore should have a higher level of technical efficiency than less educated farmers.

An important objective of this study is to examine the relationship between crop diversification and technical efficiency of the farms. To this end, the sign of the Herfindahl index of crop diversification (α_8) suggests that specialization increases the technical inefficiency variance (i.e., diversification improve technical efficiency TE)[14,15].

A plausible reason for this observation can be attributed to the fact that under multiple cropping systems, crops not only compete for nutrients but can mutually benefit each other (Ajibefun 2006). Such agronomic benefits of crop diversification as highlighted in the literature include improvement in soil fertility; tendency to reduce diseases, weed and insect build up and possibility to reduce erosion among others.

[13] Gender (male-headed households =1; female-headed households=0 while the female headed households are mostly widows and the rest divorce.

[14] The index is constructed such that a positive sign on coefficient of this variable implies a negative impact of specialization and vice versa.

[15] It is important to mention that the square of the Herfindahl index in the inefficiency variance function was found to be insignificant and thereby dropped from the final model.

In addition to this, output complementarities in terms of unobserved factors (e.g., farming experience gained from one crop could be replicated on another crop) and observed factors (method of production/ technical knowledge) under such a system of production have the tendency to positively impact the performance and production of another crop in the region.

It is equally important to stress that improvement in the efficiency level associated with crop diversification as observed in the present study, could also be a link to Shultz's (1964) *"poor-but-efficient hypothesis"*. For example, using the same level of inputs that could have been used to produce one crop under crop diversification system of farming implied that the efficiency is probably enhanced by input reduction rather than output expansion by the smallholder croppers under investigation in the region. Also, it's possible that labour force is used in a more balanced way among the activities thereby enhanced the level of efficiency of the farmers.

Results in this study are consistent with the work of Coelli and Fleming (2004) and Rahman (2009) but contrary to the finding of Liewelyn and Williams (1996), Oyekale (2007) and Haji (2007). This means that the impact of crop diversification on technical efficiency is quite mixed and perhaps varies from region to region.

The results of the states dummies were quite mixed. The coefficients of the dummies for Ondo, Osun, and Oyo implied increased technical inefficiency, with reference to the Ogun state. The Osun states dummy is significantly different from zero at the 10% level of significance. The dummy for Ekiti was found to increase TE with reference to the Ogun state dummy which is not significantly different from zero.

For the seasonal effects, the coefficients of 2007/08 and 2008/09 seasonal dummies show that technical inefficiency of the farms decreased in 2007/08 and 2008/09 farming seasons relative to the farms in the 2006/2007 farming season.

Likewise, the cross-effects of the crop diversification index and seasonal dummies suggest that technical inefficiency of the farms increased as farm embraces specialization in 2007/08 and 2008/09 farming season compared to the farms in the 2006/07 farming season.

Table 4.3: Estimates of the stochastic frontier production model

Variables	*Parameters*	*Coefficients*	*Std. Error*	*P-value*
Production variables				
D_Hiredlabor	φ_1	0.1052*	0.0557	0.059
D_Fertilizer	φ_2	0.0747***	0.0127	0.000
D_Pesticide	φ_3	-0.0361*	0.0203	0.075
In(land)	β_1	0.1089*	0.0642	0.089
In(Hired labour)	β_2	0.3713***	0.1075	0.000
In(Family labour)	β_3	0.0862	0.0812	0.288
In (Fertilizer)	β_4	0.2958***	0.0746	0.000
In(Pesticide)	β_5	0.0617**	0.0321	0.054
In(Materials)	β_6	0.0354	0.0297	0.233
Time trend	τ_T	0.0498***	0.0196	0.011
0.5[In(land) x In(land)]	β_{11}	0.0045	0.0519	0.938
0.5[In(Hired labour) x In(Hired labour)]	β_{22}	-0.1421***	0.0525	0.007
0.5[In(Family labour) x In(Family labour)]	β_{33}	0.0953	0.1022	0.351
0.5[In (Fertilizer) x In (Fertilizer)]	β_{44}	-0.2014**	0.0951	0.034
0.5[In(Pesticide) x In(Pesticide)]	β_{55}	0.2504	0.8135	0.758
0.5[In(Materials) x In(Materials)]	β_{66}	0.0146	0.0254	0.565
0.5[Time trend x Time trend]	τ_{TT}	0.0173***	0.0047	0.000
In(land) x In(Hired labour)	β_{12}	0.7951**	0.4589	0.083
In(land) x In(Family labour)	β_{13}	-1.4501	1.3459	0.281
In(land) x In (Fertilizer)	β_{14}	0.0029**	0.0013	0.026
In(land) x In(Pesticide)	β_{15}	0.2152	0.3715	0.562
In(land) x In(Materials)	β_{16}	0.2374***	0.0825	0.004
In(land) x Time trend	κ_{1T}	0.0105	0.0128	0.412
In(Hired labour) x In(Family labour)	β_{23}	-0.5469*	0.3062	0.074
In(Hired labour) x In (Fertilizer)	β_{24}	0.2063	0.1614	0.201
In(Hired labour) x In(Pesticide)	β_{25}	-0.5529	0.3791	0.145
In(Hired labour) x In(Materials)	β_{26}	0.2216	0.2272	0.329
In(Hired labour) x Time trend	κ_{2T}	0.0978***	0.0305	0.001
In(Family labour) x In (Fertilizer)	β_{34}	-0.0008	0.0019	0.998
In(Family labour) x In(Pesticide)	β_{35}	2.0604	1.3809	0.673
In(Family labour) x In(Materials)	β_{36}	-1.8611	1.2241	0.128
In(Family labour) x Time trend	κ_{3T}	0.3035	0.2437	0.213
In (Fertilizer) x In(Pesticide)	β_{45}	-0.3386*	0.1968	0.085
In (Fertilizer) x In(Materials)	β_{46}	-0.0062	0.0127	0.592
In (Fertilizer) x Time trend	κ_{4T}	0.2452**	0.1101	0.026
In(Pesticide) x In(Materials)	β_{56}	0.0369	0.2821	0.895
In(Pesticide) x Time trend	κ_{5T}	0.1073	0.1484	0.469
In(Materials) x Time trend	κ_{6T}	0.0194	0.0204	0.341
D_Ekiti	ω_1	-0.0278	0.0377	0.460
D_Ondo	ω_2	0.0952	0.1498	0.523
D_Osun	ω_3	0.1723*	0.0937	0.066
D_Oyo	ω_4	0.1098*	0.0629	0.081
D_2008	ς_1	0.0345***	0.0126	0.006
D_2009	ς_2	0.0134**	0.0061	0.028
Herfindahl index of crop diversification (HI)	π	0.0533	0.0439	0.227
Constant	ζ_0	2.1025***	0.1341	0.000
Stochastic variance ($\ell n \sigma_v^2$)				
In(land)	τ_1	-0.0621**	0.0271	0.022
D_Ekiti	τ_2	-0.0923***	0.0286	0.001
D_Ondo	τ_3	1.3293***	0.5456	0.015
D_Osun	τ_4	-1.0366	0.6704	0.122
D_Oyo	τ_5	-1.4164***	0.7812	0.069
Constant	τ_0	-4.7422***	1.3254	0.000
Inefficiency variance ($\ell n \sigma_u^2$)				
Age	α_1	-0.0322	0.0241	0.182
Gender	α_2	0.3051**	0.1523	0.045
Family Size	α_3	0.0618	0.0547	0.259
Education	α_4	-0.1726***	0.0539	0.001
Extension contacts	α_5	-0.0260**	0.0118	0.027
Credit	α_6	0.1712	0.1551	0.269
Non-farm income	α_7	-0.1026	0.1374	0.455
Herfindahl index of crop diversification(HI)	α_8	1.0712***	0.3598	0.003
D_Ekiti	δ_1	-0.2524	0.5623	0.654
D_Ondo	δ_2	2.4731	1.866	0.185
D_Osun	δ_3	1.6874*	0.9104	0.064
D_Oyo	δ_4	1.9081	1.2981	0.194
D_2008	δ_5	-0.3369***	0.0938	0.000
D_2009	δ_6	-0.2577***	0.1269	0.042
Herfindahl index of crop diversification **x** D_2008	Γ_1	0.6355***	0.2073	0.002
Herfindahl index of crop diversification **x** D_2009	Γ_2	0.2684**	0.1157	0.020
Constant	Ψ_0	-3.6913***	0.8175	0.000

****, **,* denotes statistically significant at 1%, 5%, and 10%, respectively.*

4.4.5 Estimated Technical efficiency

Table 4.4 provides mean technical efficiency scores for the pooled sample at the seasonal level and states level while the distribution of technical efficiency scores is presented in figure B of the appendix. The results show that technical efficiency scores ranges from 0.457 to 0.996. The 2008/09 farming season recorded the highest efficiency score of 0.846 (0.103). This is followed by 0.805(0.126) and 0.766 (0.109) for 2007/08 and 2006/07 farming seasons, respectively. The estimated technical efficiency scores shows that there is an increasing trend in the efficiency in the region based on the three farming seasons considered in the study.
There is a significance increase in the estimated technical efficiency score from 2006/07 to 07/08 and 2006/07 to 08/09 indicated by subscript *"a"* with p-value of 0.000 (Table 4.4). We also found evidence of a significant increase from 2007/08 to 2008/09 indicated by subscript *"b"* with p-value of 0.000.

The implication of this is that over the seasons, there is evidence of significant improvement in the technical efficiency level of the farms in the region. This could be attributed to the level of education of the farmers and the number of contacts with extension services as demonstrated in the lower panel of Table 4.3.
A scrutiny of the states' technical efficiency scores indicates that Osun state recorded the highest technical efficiency estimate with an average of 0.837(0.115). This is followed by Ondo, Ogun, Oyo and Ekiti states with average efficiency of 0.818(0.115), 0.816(0.097), 0.801(0.102) and 0.766(0.167), respectively.

An overall average technical efficiency of 0.807 with standard deviation of 0.128 implies an average technical inefficiency of about 19%. The economic interpretation of this is that an average farm in the sample requires 19% more resources to produce the same output (or meet the same objectives) as an efficient farm on the frontier.

A comparison of the average technical efficiency score obtained in this study with other studies focusing on food crop production in the region is discussed as follows. The 0.81 obtained in the present study is consistent with 0.82 reported by Ajibefun *et al.,* (2002) compared to 0.70 and 0.52 reported by Fasasi (2007) and Awoyinka *et al.,* (2009), respectively.

Table 4.4: Mean efficiency scores by the whole sample, season, and states estimates

	Number of farms	*Mean Efficiency*
Pooled Results		
Mean	846	0.8065
Std.Dev.		0.1281
Minimum		0.4572
Maximum		0.9958
By Seasons		
2006/2007 farming season		
Mean	282	0.7657
Std.Dev.		0.1097
Minimum		0.4572
Maximum		0.9789
2007/2008 farming season		
Mean	260	0.8045[a]
Std.Dev.		0.1269
Minimum		0.4787
Maximum		0.9828
2008/2009 farming season		
Mean	304	0.8461[a,b]
Std.Dev.		0.1034
Minimum		0.4973
Maximum		0.9956
By States		
Ekiti State		
Mean	181	0.7659
Std.Dev.		0.1669
Minimum		0.5665
Maximum		0.9668
Ogun State		
Mean	145	0.8162
Std.Dev.		0.0965
Minimum		0.5278
Maximum		0.9752
Ondo State		
Mean	206	0.8184
Std.Dev.		0.1153
Minimum		0.5207
Maximum		0.9957
Osun State		
Mean	141	0.8373
Std.Dev.		0.1155
Minimum		0.4787
Maximum		0.9869
Oyo State		
Mean	173	0.8014
Std.Dev.		0.1017
Minimum		0.4572
Maximum		0.9863

[a]Significant increase in this mean score compared to that of 2006/07; [b]Significant increase in this mean score compared to that of 2007/08.

4.5. Conclusions and policy implications

This paper examines trends in crop diversification and its impact on technical efficiency of smallholder croppers in Southwestern Nigeria using heteroskedastic stochastic production frontier model on unbalanced panel data covering three farming seasons (2006/07-2008/09) with 846 observations. The results revealed evidence of increasing diversification as indicated by various indices employed in the study. The implication of this is that crop diversification as opposed to specialization is regarded as an important cropping system in the region.

The elasticity of output with respect to land, hired labour, family labour, fertilizer, pesticide and materials are positive and significant with the exception of family labour and planting materials. There is evidence of technical progress in food crop production in the region. The computed returns to scale suggest decreasing returns to scale in the study.

The result of technical inefficiency effects shows that education, extension and crop diversification significantly increase technical efficiency of the farmers. The implication of this is that the propensity to diversify crop enterprises enhances the technical efficiency level of farmers in the region. This implies that intensification of diversification is advantageous for farmers' economic performance in the Nigerian agricultural food production process.
The overall technical efficiency of about 81% obtained from the analysis implies that an inefficiency level of about 19% is observed from the analysis.

Finally from the perspective of increasing rural households' farm income and food security, crop diversification is demonstrated in this study as a policy goal in Nigeria taking Asia experience in 90s as a challenge. In this regard, the study makes the following policy recommendations: 1) policies that increase extension-farmer contact ratio and motivation of educated farmers into farming, and 2) policies that publicizes and encourages farmers on the enormous advantage of diversification into nutrient-rich and high-value crops such as horticultural crops (fruits and vegetables) in combination with traditional crops in the region[16]. For example, Sani *et al.* (1996) in their study on the impact of diversification on small farms economy in Kangra district of Himachal Pradesh Pakistan observed that diversification of arable farming systems with commercial enterprises such as high yielding milk animals, poultry birds, bee-keeping, floriculture etc resulted in marked increase in the farm income from 6 to 138 percent. However, such novel encouragement is capable of improving rural farm income generation and better nutrition/diet intake in Nigeria.

[16] Although, we acknowledge the fact these recommendation is not directly related to the findings from the study, nonetheless, the potential benefits of farmers integrating high value crops such as vegetables with their traditional staples motivates this recommendation judging from the Asia experience in the 1990s.

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CHAPTER FIVE

5.0. Estimating technical efficiency, input substitution and complementary effects using output distance function: a study of cassava production in Nigeria

5.1. Introduction

Cassava (*manihot esculenta crantz*) is a perennial, vegetatively propagated shrub, grown throughout the lowland tropics. The crop is not only regarded as a benchmark for food security in the sub-Saharan Africa, but is also known as the second most important staple crop after maize, in terms of calorie intake. Presently, cassava is the only crop whose production level has tripled over the past 50 years while its development has further been advanced on the continent by the activities of the International Institute of Tropical Agriculture (IITA) located in Nigeria. IITA has distributed more productive new varieties that are resistant to a number of diseases as well as drought. African countries produce over 103 million metric tonnes cassava per annum with Nigeria accounting for approximately 35 million metric tons per annum (FAOSTAT, 2009).

Nigeria has the largest harvest in the world; three times more than the production level in Brazil and almost double the production level in Thailand and Indonesia. IITA (2005) attributed the large harvest in Nigeria to rapid population growth, internal market demand, availability of high yielding improved varieties of cassava tuber, and increase acreage of farm land allocated to cassava in the country.

Broadly speaking, cassava growing belts falls within three agro-ecological zones in Nigeria which includes: southwest, southeast, and the north-central regions. As a staple as well as cash crop, cassava has certain inherent characteristics which make it attractive especially to smallholder farmers in the country. First, the crop is capable of thriving on soils where other crops, most especially grains, failed (Nweke *et al.* 1994). Secondly, cassava is regarded as a famine reserve crop which requires relatively low amounts of inputs (Enete *et al.* 2005). Thirdly, the crop can withstand stress such as drought as it can stay in the ground for several months (Nweke *et al.* 1994). Fourthly, cassava is available all year round, thus providing household food security (Taiwo, 2006). Lastly, although cassava is cheap to cultivate, it can generate good income for peasant farmers.

Cassava production is well suited to intercrop with short-duration crops such as: maize, cowpea, melon, okra, and several leafy vegetables (Ugwu and Nweke, 1996). Other crops that can be intercropped with cassava include: sweet potatoes, yam, and cocoyam (Chukwuji, 2008). Traditionally, an average of three to five crops is often intercropped with cassava. The crops are selected on the basis of differences in growth habits and can be combined in either simple or complex mixtures. This implies that cassava production in the country is characterized by a mixed cropping pattern of production systems. In fact, Aderinola *et al.* (2006) in a study of comparative analysis of three cassava-based farming systems in Nigeria which includes: cassava-sole, cassava + maize, and cassava + other crops, concluded that the cassava expansion program of the Nigerian government would enjoy a boost through the promotion of the cultivation of cassava with other crops. A similar observation was observed by Chukwuji (2008).

Cassava's multiple uses facilitated greater utilization in Nigeria. The crop is majorly produced by the farmers in the country primarily for consumption and for sale in the village markets. Beside this, it can be processed into several secondary products of industrial value such as : chips, pellets, flour, adhesive, alcohol, and starch which are essential raw materials in the livestock, feed, ethanol, textile, confectionery, wood, food and soft drinks industries (Kormawa and Akonroda, 2003).

The trends in cassava production, area, and yield in Nigeria for the timeframe 1980-2007 are presented in Figure 5.1. The figure shows that both the production and yield follow a similar pattern characterized by fluctuation in trend while the total harvested area exhibits an increasing trend.

Cassava constitutes a major item in the crop combination of the most farmers and contributes significantly to total farm income in Nigeria (Bamire *et al.* 2004). This observation could offer reasons as to why the federal government of Nigeria launched the "Presidential Committee on Cassava Export Promotion" in 2001 with the aim of making cassava a major non-oil foreign exchange earner because of its comparative advantage in the country. Following this initiative, cassava production increased between 2000/2001 to 2005/2006 farming seasons while production has since then stagnated (see Figure 5.1). A lot factors have been linked to the sudden decline in cassava production in the country, part of which include lack of continuity of previous administration policies on the cassava expansion program by the current government in the country (Nigerian Tribune 2008). This however, is not surprising because policy discontinuity has become successive in the Nigerian government's culture.

Another factor which was resilient/echoed among the industry's experts/researchers is the level of productivity (i.e., input, output growth or input and output mix productivities) and the efficiency of the cassava industry in the country (Onu and Edon 2009, Edeh and Awoke 2009, Udoh and Etim, 2007). Thiam *et al.* (2001) highlighted the importance of efficiency as a means of fostering the production process. However, in the context of cassava production, this observation implies that understanding of efficiency of cassava farms will provide agricultural policy makers needed information to boost the production of the crop in the country.

This paper seeks to update literature on the efficiency of the Nigerian cassava industry while it will at the same time complement various efforts of research in improving cassava production in the country. Because cassava traditionally is grown with other crops, the present study examines the technical efficiency of cassava production amidst other crops in Nigeria using a primal output distance function. Therefore, the objective of the study includes: 1) to investigate input complementary and substitution effects on cassava production in the country and 2) to examine seasonal trends in technical efficiency of cassava production in the country.

The outline of the paper is as follows. Section 5.2 introduces the theoretical framework of the output distance function. In section 5.3, we present the methodology and detailed information on the study area. Section 5.4 describes the results and discussion. Section 5.5 summarizes and concludes the findings.

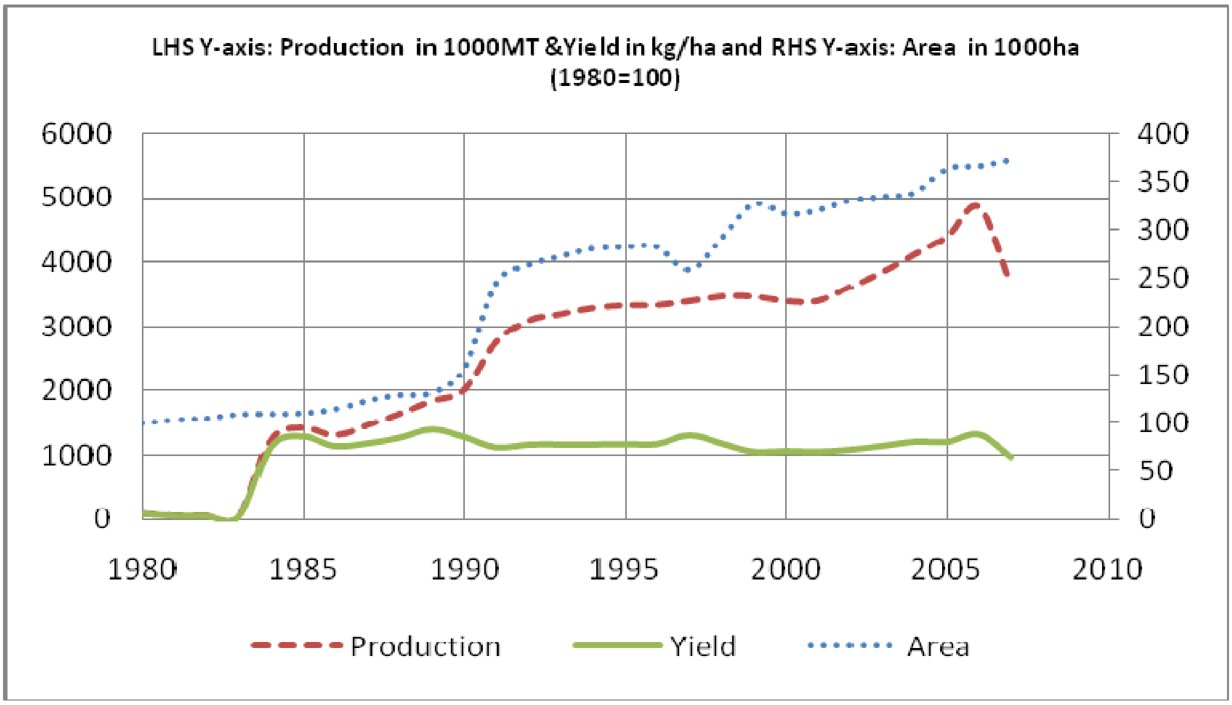

Figure 5.1: Trends in Production, Area, and Yield of Cassava in Nigeria, 1980-2007 (FAOSTAT, 2009)

5.2. Theoretical framework

5.2.1. The multiple outputs and distance function

Multi-outputs and inputs modeling of the production technology provide distinct effects of capturing different outputs and inputs in the production processes. According to Shephard (1970), when many inputs are used to produce many outputs, the distance function provides a functional characterization of the structure of the production technology. The concept and properties of the distance function are well documented in the literature (Färe 1988; Färe and Primont 1995; Kumbhakar and Lovell 2000; Coelli *et al.* 2005).

However, in the distance function approach, the researcher chooses between the input and the output distance-oriented approaches and estimates the distance function of his/her choice depending on the direction/focus of the study (Daidone and D'Amico 2009). These primal functions represent a technical (substitution) relationship among and across the inputs and outputs - not economic optimization (Paul and Nehring 2005). A significant advantage of the distance function is that neither the input distance function nor the output distance function depends on any explicit behavioral assumptions such as cost minimization, revenue maximization, and profit maximization (Kumbhakar and Lovell 2000; Coelli *et al.* 2005).

The output distance function is constructed following the assumption that each observed point of production by the producer is scaled radially towards the boundary of production in order to operate on the production frontier. The input distance function on the other hand is constructed with the assumption that producer focuses mainly on reducing inputs to produce a fixed output by radically scaling down the input vectors in order to operate on the production frontier.

According to Kumbhakar *et al.* (2007), an output distance function approach to measure of technical efficiency is appropriate when output is endogenous (i.e., revenue maximization is the driving factor in the system) and inputs are exogenous, while an input distance function approach to measure of technical efficiency is appropriate when inputs are endogenous (i.e., cost minimization is the case) and output is exogenous.

Cassava (*manihot esculenta crantz*) which is the focus of this paper is regarded as a cash crop which production is not only driven by food security but expectation of higher revenue returns to the overall farm production systems by most farm households in the country. Based on this, we believe output distance function is advantageous for the analysis of performance of cassava production relative to other crops grown by the smallholder farms in Nigeria. Thus subsequent discussion focuses on the output distance function which is being considered in this paper.

The output distance function takes an output–expanding approach to the measurement of the distance of a producer to the boundary of production possibility frontier (Kumbhakar and Lovell, 2000). It gives the minimum amount by which an output vector can be deflated by factor θ and still remain producible with a given input vector as

$$D_0(x,y,t) = \min\left\{\theta : y/\theta \in P(x)\right\} \qquad 5.1$$

The interpretation of Eqn.5.1 is that the output distance function seeks the largest proportional increase in the observed output vector given that the expanded vector $\left(y_m / y_{1i}\right)$ must still be an element of the original output set $P(x)$.

Using set notation, Eqn.5.1 could be described further as

$$D_0(x,y,t) \leq 1 \Leftrightarrow y \in P(x) \qquad 5.2$$

$$D_0(x,y,t) = 1 \Leftrightarrow y \in \text{IsoqP}(x) \quad 5.3$$

$$P(x) = \{y : D_0(\mathbf{x,y,t}) \le 1\} \quad 5.4$$

where $D_0(x,y)$ is non-decreasing, linearly homogenous, and convex in outputs ***y***, and non-increasing and quasi-convex in the inputs ***x***; $P(x)$ is the set of the output vectors ***y*** which can be produced using the input vector ***x***. $\text{IsoqP}(x)$ is the boundary of the output set as $\text{IsoqP}(x) = \{y: y \in P(x) \Rightarrow \lambda y \in P(x), \lambda > 1\}$. $D_0(x,y,t)$ takes a value of 1 whenever the output vector lies on the outer boundary of the output set.

Accordingly, $D_0(x,y,t)$ measures the inverse of the vector θ by which the production of all the output quantities could be increased while still remaining within the feasible production set $P(x)$ for the given input level (O'Donnell and Coelli, 2005). However, Figure 5.2 described a typical multi-output production technology otherwise called the production possibility frontier (PPF) with two outputs and one input. The PPF describes the technically efficient points of production for various combinations of the output that could be produced using a given factor endowment ***x***. $\equiv P(x)$ represents the output set/vector which is bounded by the PPF.

In the present framework, we assume that the distance of any firm from the frontier (boundary of output set) could be attributed to either - inefficiency or noise or both. The production at any point on the **PPF** other than ***B*** (i.e., the *frontier*) represents sub-optimal performances which include points ***A*** and ***C*** in the figure. For example, $\overline{AB}$ represents the departure from the technically optimum point of production (i.e., the *frontier point*) associated with inefficiency. Meaning that location of firm in the neighborhood of ***A,*** with reference to the best practice ***B,*** signified the level of inefficiency in the firm's production process. Also, a firm located at point ***C*** implies departure from the technologically feasible point ***B***; this could be attributed to both inefficiency and noise (measurement error).

However, the proportional expansion of a firm operating at the point ***A*** towards the boundary of the output set ***B*** requires upward scaling of y_2^A and y_1^A by a vector θ which needs to be minimized. This process of upwards adjustment of the output set $\equiv P^{\mathbf{A}}(x)$ towards the frontier output set $\equiv P^{B}(x)$ while maintaining the same level of the inputs is called the output distance function $D_0(x,y,t)$.

By construction $D_0(x, y, t)$ is equal to

$$D_0(x,y,t) = \frac{OA^*}{OB^*} \leq 1 \qquad \text{i.e., } D_0(\mathbf{x},\mathbf{y},\mathbf{t}) \leq 1 \ . \qquad 5.5$$

The output distance $D_0(x,y,t)$ gives the reciprocal of the maximum proportional expansion of the output vector **y**, given the inputs **x** and characteristics of the technology completely.

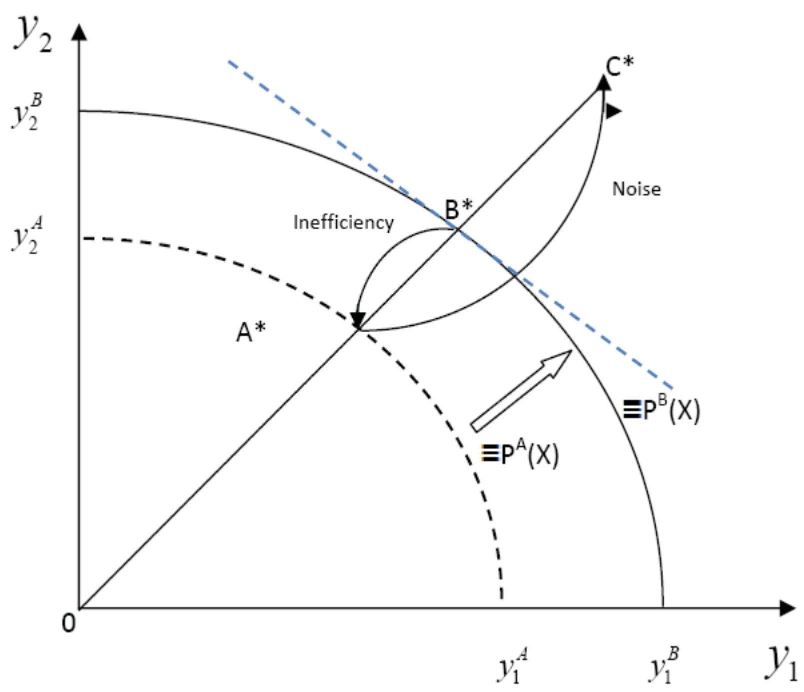

Figure 5.2: Illustration of Output Distance function (Adapted from Kumbhakar et al., 2007)

5.2.2. Stochastic frontier output distance function

The pioneering work of Farrell (1957) and Debreu (1959) paved way for the understanding and measurement of firm level efficiency in the literature. Farrell's illustration of this concept theoretically provides the highly needed impetus to analyze technical efficiency in terms of a realized deviation from an idealized frontier isoquant (Greene, 2008). Broadly, two quantitative approaches are developed to implement Farrell's definition of efficiency which includes: parametric (stochastic frontier analysis, SFA) and non-parametric (Data Envelopment Analysis, DEA) approaches. These approaches are well discussed in Kumbhakar and Lovell (2000) and Coelli *et al.* (2005).

Nonetheless, the main strengths of SFA over DEA are in its ability to deal with the stochastic noise and permit statistical testing of hypotheses pertaining to the production structure and the degree of the inefficiency. This observation suggests why the SFA is widely popular among researchers around the globe.

The empirical studies applying the SFA techniques are designed to represent the technology by a boundary function which reflects *best-practice* production defined in terms of the maximum real output technologically possible to produce given available inputs (Paul *et al.* 2000). A typical example of such technology representation includes: the primal production and distance functions framework and dual representation of the production technology such as cost, profit and revenue functions.

The stochastic frontier analysis (SFA) model was independently developed by Aigner *et al.* (1977) and Meensen and van den Broeck (1977) to describe the production function technology, but the SFA's extension to dual and primal distance function technology representations have become popular in the last two decades. The SFA has two error terms; the technical inefficiency error u_i and the white noise error component v_i. The v_i represents factors that might generate irrelevant noise in the data such as measurement error while u_i denotes unobserved factors for e.g., attributed to technical inefficiency in deterministic models as shown in the Figure 5.1.

Based on the reasons highlighted in the section 5.2.1, the following discussion focuses on the stochastic Output Distance function model as discussed in Färe and Primont (1995) and Kumbhakar and Lovell (2000).
We defined the stochastic frontier "output distance" relative to the output set P(x) as

$$D_0\left(x_j, y_m, t\right) = \min\left\{\theta : {y_m}/{\theta} \in P\left(x\right)\right\} \quad 5.6$$

$$D_0\left(x_j, \theta y_m, t\right) = \theta \,.\, D_0\left\{x_j, y_m, t\right\} \;\forall\, \theta > 0 \text{ for all } x \in \Re^{j}_{+}, y \in \Re^{\mathbf{m}}_{+} \quad 5.7$$

Following Lovell *et al.* (1994), one of the outputs is arbitrarily chosen while the reciprocal of the selected output is equal to the deflating vector θ. In this case, we choose output y_1 such that $\theta = {1}/{y_{1i}}$ which when substituted into Eqn.5.7 gives

$$D_0\left(x_j, {y_m}/{y_{1i}}, t\right) = {1}/{y_{1i}} \,.\, D_0\left\{x_j, y_m, t\right\} \quad 5.8$$

Taking the log of both sides of Eqn.5.8 equal to

$$lnD_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) = -lny_{1i} + lnD_0\left\{x_j, y_m, t\right\} \qquad 5.9$$

Re-arranging Eqn.5.9 yields

$$-lny_{1i} = lnD_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) - lnD_0\left\{x_j, y_m, t\right\} \qquad 5.10$$

According to Brümmer *et al.* (2006), the most useful property of the distance function is that the reciprocal of the distance function $D_0\left\{x_j, y_m, t\right\}$ has been proposed as a coefficient of resource utilization of Debreu (1959) and a measure of Farrell (1957) output-oriented technical efficiency TE_0.

In this case, we defined TE_0 as

$$D_0\left\{x_j, y_m, t\right\} = \frac{1}{TE_0} \quad \text{i.e., } D_0\left\{x_j, y_m, t\right\} \le 1 \text{ while } TE_0 \ge 1 \text{ [1]} \qquad 5.11$$

Recall that at the frontier $D_0\left\{x_j, y_m, t\right\} = 1$ in the section 5.2.1. Therefore taking the log of Eqn.5.11 yields

$$lnD_0\left\{x_j, y_m, t\right\} = -lnTE_0 \qquad 5.12$$

And substituting Eqn.5.12 to Eqn.5.10 gives

$$-lny_{1i} = lnD_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) - lnTE_0 \qquad 5.13$$

TE_0 is estimated from $TE_0 = \exp\left(-\hat{u}_t^+\right)$, where $\hat{u}_t^+ = E\left[-u_t^+ \middle| \varepsilon\right]$ (Jondrowl *et al.* 1982).

Since $TE_0 = \exp\left(-\hat{u}_t^+\right)$ and taking the log of this expression in line with Eqn.5.13 gives $lnTE_0 = -\hat{u}_t^+$ which when substitute into Eqn.5.13 gives[2]:

$$-lny_{1i} = lnD_0\left(x_j, \frac{y_m}{y_{1i}}, t\right) + \hat{u}_t^+ \qquad 5.14$$

To have a specification identical with the standard stochastic frontier production model proposed by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977), we multiply both

[1] It is important to mention here that for our result to be consistent with most output-oriented parametric efficiency studies, with technical efficiency bounded between zero and one, the study assumed the value of the output distance function as a direct measure of the technical efficiency which is bounded naturally between zero and one, since $TE_0 \ge 1$ by construction. In this regard, Kumbhakar *et al.* (2007) referred to the index TE_0 as "natural technical efficiency" since it has the same orientation as the estimated output distance function $D_0\left\{x_j, y_m, t\right\}$ of Eqn.5.11.

[2] Eqn.5. 14 is simply $lnD_0\left(x_j, y_m, t\right) = -\hat{u}_t^+$ in Equ.10 and $0 < D_0\left(x_j, y_m, t\right) \le 1$, which implies that $-\infty < lnD_0\left(x_j, y_m, t\right) \le 0$

sides of Eqn.5.14 by (-1) while adding another error term v_t to eliminate effects of "white noise" in the empirical model as earlier illustrated in the Figure 5.2 as[3]

$$lny_{1i} = -lnD_0\left(x_j, {y_m}/{y_{1i}}, t\right) - u_t + v_t \qquad 5.15$$

Rearranging Eqn.5.15 gives

$$lny_{1i} = -lnD_0\left(x_j, {y_m}/{y_{1i}}, t\right) + v_t - u_t \qquad 5.16$$

Since in a distance function context, the Cobb-Douglas functional form has the wrong curvature in the ${y_m}/{y_{1i}}$ space, $D_0\left(x_j, {y_m}/{y_{1i}}, t\right)$ of the Eqn.5.16 is, specified with the translog output distance function, where the presence of squared terms and interaction terms gives a high degree of flexibility , easy calculation and imposition of homogeneity in the outputs is possible (Brümmer *et al.*2002; Brümmer *et al*. 2006).

Therefore, we defined the translog output distance function as

$$-lnD_0\left(x_j, {y_m}/{y_{1i}}, t\right) = \begin{cases} -\alpha_0 - \sum_{m=1}^{M-1}\psi_m lny^*_{mit} - \sum_{j=1}^{J}\beta_j lnx_{jit} - \varphi_T A(t) - \frac{1}{2}\sum_{m=1}^{M-1}\sum_{s=1}^{M-1}\psi_{ms} lny^*_{mit} lny^*_{sit} \\ -\frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{J}\beta_{jk} lnx_{jit} lnx_{kit} - \frac{1}{2}\varphi_{TT}A^2(t) - \sum_{m=1}^{M-1}\sum_{j=1}^{J}\tau_{mj} lny^*_{mit} lnx_{jit} \\ -\sum_{m=1}^{M-1}\kappa_{mT} lny^*_{mit}A(t) - \sum_{j=1}^{J}\phi_{jT} lnx_{jit}A(t)_t \end{cases} \qquad 5.17$$

Substituting Eqn.5.17 into Eqn.5.16 gives Eqn.5.18 which is the stochastic frontier "Output distance" function specification used in the present study[4] as

$$lny_{1it} = \begin{cases} -\alpha_0 - \sum_{m=1}^{M-1}\psi_m lny^*_{mit} - \sum_{j=1}^{J}\beta_j lnx_{jit} - \varphi_T A(t) - \frac{1}{2}\sum_{m=1}^{M-1}\sum_{s=1}^{M-1}\psi_{ms} lny^*_{mit} lny^*_{sit} \\ -\frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{J}\beta_{jk} lnx_{jit} lnx_{kit} - \frac{1}{2}\varphi_{TT}A^2(t) - \sum_{m=1}^{M-1}\sum_{j=1}^{J}\tau_{mj} lny^*_{mit} lnx_{jit} \\ -\sum_{m=1}^{M-1}\kappa_{mT} lny^*_{mit}A(t) - \sum_{j=1}^{J}\phi_{jT} lnx_{jit}A(t) + v_t - u_t \end{cases} \qquad 5.18$$

where $y^*_m = {y_m}/{y_1}$ is the normalized output distance function by one of the outputs, which in this regard is y_1, to impose linear homogeneity property. By using linear homogeneity of out-

[3] It is important to mention here that, a transformation of the left LHS of Eqn.5.12 from negative sign to positive sign in Eqn.5.13 reverse the signs of the estimated coefficients corresponding to the usual output distance function.

[4] We recognize an issue that arises from implanting output distance function models which include; problem of endogeneity bias and problem of which output might be used as normalizing factors. For the former, Coelli and Perelman (2000) argue that this should not present econometric problems because only rations of the outputs appear as regressions and these ratios may be assumed to be exogenous, since the distance function is defined for radial (proportional) expansion of all outputs, given the input levels and hence by definition output ratio are held constant for each firm. The second issue with regard to which output might used as normalizing factor, Coelli and Perelman stressed further that the final results are invariant to this choice.

put distance function, Eqn.5.17 can be transformed into an estimable regression model (Coelli and Pereman, 2000; Brümmer *et al*. 2002; Coelli *et al.* 2005; Brümmer *et al.* 2006). Furthermore, O'Donnel and Coelli (2005) suggested that certain regularity conditions such as monotonicity (non-increasing inputs and non-decreasing outputs) and curvature (convexity in outputs and quasi-convexity in inputs) properties must theoretically hold for this function (Eqn.5.18). These conditions however, require the following Euler's restrictions.

Homogenous of order +1 in output restriction ensured that;

$$\sum_{m} \psi_{m} = 1, \; m = 1, 2, \ldots\ldots M \qquad 5.19a$$

$$\sum_{s} \psi_{ms} = 0, \; m = 1, 2, \ldots\ldots M$$

$$\sum_{j} \tau_{mj} = 0, \; j = 1, 2, \ldots\ldots J$$

$$\sum_{m} \kappa_{mT} = 0, \; m = 1, 2, \ldots\ldots M$$

The imposition of the Eqn.5.19a ensures that output distances with respect to the boundary of the production set are measured by radial expansion.

Symmetry restriction ensured that;

$$\beta_{jk} = \beta_{kj}, \; k=j = 1, 2, \ldots\ldots J \qquad 5.19b$$

$$\psi_{ms} = \psi_{sm}, \; m = s = 1, 2, \text{--} M$$

As revealed by O'Donnel and Coelli (2005), the elasticities of the output distance with respect to the inputs and the outputs can be derived using the expression

$$\frac{\partial lnD_0(x,y,t)}{\partial lnx_j} = \left(\beta_j + \sum_{j=1}^{J} \beta_{jk} lnx_{kit} + \sum_{m=1}^{M-1} \tau_{mj} lny^{*}_{mit} + \sum_{j=1}^{J} \phi_{jT} A(t) \right) \leq 0 \qquad 5.20a$$

$$\frac{\partial lnD_0(x,y,t)}{\partial lny_m} = \left(\psi_m + \sum_{m=1}^{M-1} \psi_{ms} lny^{*}_{sit} + \sum_{j=1}^{J} \tau_{mj} lnx_j + \sum_{m=1}^{M-1} \kappa_{mT} A(t) \right) \geq 0 \qquad 5.20b$$

According to Chamber (1988), production theory suggests that $D_0(x,y,t)$ is non-increasing in $x\left(\frac{\partial lnD_0(x,y,t)}{\partial Inx_j} \leq 0 \right)$, which is a condition for ensuring monotonicity in the inputs, and non-decreasing in $y\left(\frac{\partial lnD_0(x,y,t)}{\partial lny_m} \geq 0 \right)$,which is also a condition for ensuring monotonicity in the outputs.

In a related development, Chamber (1988) and O'Donnell and Coelli (2005) suggested that fulfilling curvature (i.e., quasi-convex in ***x*** and convex in ***y***) property in accordance with production theory implied that principal minors of bordered Hessian matrix (i.e., the coefficients of square terms of $\boldsymbol{x_j}$ in $D_0(x,y,t)$) must strictly be negative in sign for ***x***. Also for fulfillment of the curvature (i.e., convex) property in ***y***, it is expected that the principal minors of the Hessian matrix (i.e., the square terms of y* in $D_0(x,y,t)$) must strictly be positive in sign. Because the objective of the study is, not only to estimate the output-oriented technical efficiency TE_0, but rather to, examine in addition how exogenous variables exert influence on the producer performance. In this case, we employed heteroskedasticity corrected inefficiency models proposed by Caudill *et al.* (1993) to implement this as

$$\sigma^2_{ui} = q(Z_i, D_i; \alpha_i) \qquad 5.21$$

Also we corrected for the heteroskedasticity in the noise components using the relationship

$$\sigma^2_{vi} = g(x; \tau_i) \qquad 5.22$$

The double heteroskedasticity in the stochastic frontier production model is advantageous, because un-modeled heteroskedasticity in stochastic frontier models might leads to a biased production technology as well as efficiency estimates (Kumbhakar and Lovell, 2000). Equations (5.18, 5.21-22) were jointly estimated using the maximum likelihood estimation procedure in STATA10.

5.2.3. Scale economy, inputs substitution and complementary biases

The distance function is not only used to estimate the efficiency levels and the change in productivity, the *first* and *second order* elasticities could as well be used to explore the extent to which productivity increases with the inputs, outputs and their respective cross effects. According to Paul *et al.* (2000), a common interpretation in terms of (actual or proportional) slopes of curves in y_1-y^*_m, y_1-x_j and x_j-x_k spaces in an output distance function framework represents familiar ground from production possibility frontiers (PPF), production function and isoquant respectively.

Therefore, the *first order* elasticties with respect to the outputs in y_1-y^*_m space ($-\varepsilon_{D_0,y_m} = -\partial \ell n D_0 / \partial \ell n y^*_m = \partial \ell n y_1 / \partial \ell n y^*_m = (\partial \ell n y_1 / \partial \ell n y_m)(y_m / y_1) = \varepsilon_{y_m}$) measures the

proportional/absolute/relative shadow values of y_m^* to y_1 in the overall production. According to Paul *et al.* (2000), the elasticity ε_{y_m} essentially reflects the tradeoff of y_1 and y_m (given all inputs levels) as embodied in a PPF. Grosskopf *et al.* (1995) described this tradeoff as the slope of PPF or simply the marginal rate of transformation (MRT) between $\mathrm{y_m}$ and $\mathrm{y_1}$ in terms of output production or shares in the overall production. A positive $\varepsilon_{\mathbf{y}_m,\mathbf{y}_1}$ elasticity implies a negative shadow share contribution of $\mathrm{y_m}$ relative to $\mathrm{y_1}$ in the overall production (i.e., MRTS = the slope of PPF)[5].
Also, the *first order* elasticties with respect to the inputs in y_1-x_j space ($-\varepsilon_{D_0,x_j}$ = $-\partial \ell n D_0 / \partial \ell n x_j = \partial \ell n y_1 / \partial \ell n x_j = \left(\partial \ell n y_1 / \partial \ell n x_j\right)\left(x_j / y_1\right) = \varepsilon_{x_j}$) measures the proportional/absolute /relative contribution of x_j to y_1 while all output ratios and thus output composition constant y_m^*. ε_{x_j} is analogous to the estimates from the parameters of the standard production function models.

However, the summation of individual *first order* output elasticities for the inputs x_j (i.e., ε_{x_j}) results in the output-oriented distance function based scale economy measure in the y_1-x_j space analogous to a returns to scale (RTS) estimate from a production function as $-\sum_j \varepsilon_{D_0,x_j} = \sum_j \partial \ell n y_1 / \partial \ell n x_j = \sum_j \varepsilon_{x_j}$ [6] (Färe and Primont 1995). The RTS measure the overall increase in the output if all inputs increase proportionally let say by 1%. Because the manner with which Eqn.5.18 is specified, a negative ε_{x_j} elasticity is interpreted as an indicator of positive returns or the contribution of $\mathrm{x_j}$ to the production of $\mathrm{y_1}$.

The *second-order* $\varepsilon_{x_j x_k}$ cross-effect coefficients implied technological bias measures which provide insights about the inputs jointness (i.e., complementary/ substitution effects of the

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[5] The shadow share/contribution of $\mathrm{y_1}$ in the overall production/productivity could be obtained by using the homogeneity restriction of Equ.19a as $\varepsilon_{\mathbf{y}\mathbf{D}_0\mathbf{y}_1} = 1 - \sum_m \varepsilon_{\mathbf{y}_m,\mathbf{y}_1}$

[6] If not computed in absolute value, scope economies otherwise called returns to scale in the traditional stochastic frontier production function equal $-\sum_j \varepsilon_{\mathbf{x}_j,\mathbf{y}_1}$. Note that the negative sign in the front of the summation is a reflection of the foot note 4.

inputs) in a production systems since y_m^* argument of the function is fixed (Paul *et al.* 2000 and Paul and Nehring 2005).
We illustrate the substitution effects of the inputs as shown in the work of Paul *et al.* (2000), using a Hicksian-style's definition of technical change bias to provide insights about the cross-effect between inputs x_j and x_k which reflects x_j-x_k substitutability bias measure as

$$\sigma_{jk} = \partial S_j / \partial \ell n x_k = S_j . \left(\varepsilon_{jk} - \varepsilon_{x_j} \right) = \left(\varepsilon_{x_j} \right) . \left(\varepsilon_{jk} - \varepsilon_{x_j} \right) = \partial \varepsilon_{x_j} / \partial \ell n x_k = \beta_{jk} \qquad 5.23$$

where S_j is defined as the cost share in the usual cost function framework. Invoking duality property since we are not dealing with the cost function, S_j technically equals the proportional marginal product (MP) in production function framework as $\partial \ell n y_1 / \partial \ell n x_j = \varepsilon_{x_j} . \varepsilon_{jk}$ represents the coefficients of cross-effect between x_j and x_k which indicates the shift or impact of x_k on the MP_j as $\varepsilon_{jk} = \partial \ell n MP_j / \partial \ell n x_k$. According to Paul and Nehring (2005), Eqn.5.23 implies that $\sigma_{jk} = \varepsilon_{jk} = \beta_{jk}$ thus reflect substitutability between inputs x_j and x_k when $\beta_{jk} < 0$ (i.e., negative).

With regard to the complementarities of the inputs, Paul and Nehring (2005) concluded that if x_j and x_k in the *second order* elasticity $\varepsilon_{jk} = \partial \varepsilon_j / \partial \ell n x_k$ in some sense " move together", an increase in x_k shifts up the contribution and thus marginal product of x_j, suggesting that, x_j and x_k are complementary or act as a system with $\beta_{jk} > 0$ (i.e., positive).
Similar illustration could be extended to investigate the cross-effect bias between the outputs. Of course, such bias could be interpreted as the contribution of a change in y_s to the productivity or shadow valuation of y_m relative to its impact on the overall production, weighted by the implicit share or contribution of the production of y_m. This is not the focus of the present paper as we are limited by the numbers of exogenous output variables $\left(y_m^* \right)$ in the output distance function.

However, various measures described above with exception of the last paragraph serve as the basis with which the present paper examines the returns-to-scale, the inputs substitution and complementary effects as indicators of resource-productivity in cassava production in in an output distance function framework in Nigeria.

5.3.0. Methodology

5.3.1. The data and study area

The data used in this study came from a farm households' survey that was carried out in southwestern Nigeria. Southwestern Nigeria is the second leading cassava producing region in the country with the highest average national yield of about 14 metric tonnes/ha per annum (IITA 2005). The survey covered three farming years: 2006/07 to 08/09. Five states in the region were adequately represented in the survey which includes: Ekiti, Ogun, Ondo, Osun and Oyo states.

The respondents were randomly sample based on the list of farmers provided by the extension personnel of the states' agricultural development program, ADP. In all 282, 260, and 304 farms were sampled in 2006/07, 2007/08, and 2008/09 farming seasons, respectively. At the state level, 181, 206, 173, 141, and 145 farms were sampled in Ekiti, Ondo, Oyo, Osun, and Ogun states, respectively. An overall 846 observations were used for the analysis in the region.
Food crops grown in the region includes: maize, yam, cassava, cocoyam, potato, melon, cowpea, among others under mixed cropping systems. But in the in the present study, five portfolios of crops were observed grown either solely or mixed by the farmers which include: cassava, yam, maize, cocoyam and potatoes. Detailed descriptions of the data used in the analysis are presented in the Table C1 of the appendix.

5.3.2. Empirical model

The stochastic output distance function with two outputs and five inputs and time trend used in the empirical application of Eqn.5.18 is specified as

$$lny_{1it} = \begin{cases} -\alpha_0 - \pi_f D_{fit} - \pi_p D_{pit} - \psi_m ln\left(y_{2it} / y_{1it} \right) - \sum_{j=1}^{J} \beta_j lnx_{jit} - \varphi_T A(t) \\ -\frac{1}{2}\psi_{mm} ln\left(y_{2it} / y_{1it} \right)^2 - \frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{K} \beta_{jk} lnx_{jit}.lnx_{kit} - \frac{1}{2}\varphi_{TT} A^2(t) \\ - \sum_{j=1}^{J} \tau_{mj} lnx_{jit}.ln\left(y_{2it} / y_{1it} \right) - \kappa_{mT}\, ln\left(y_{2it} / y_{1it} \right).A(t) \\ - \sum_{j=1}^{J} \phi_{jT} lnx_{jit} A(t) - \sum_{s=2}^{6} \eta_s D_{states} - \sum_{n=2}^{3} \xi_n D_{FS} \end{cases} + v_{it} - u_{it} \qquad 5.24$$

where y_{1it} represents value of cassava produced in naira by *i-th* farm at season *t*; y_{2it} is the normalized output which is equal to the "output ratio" of the value of other crops (i.e., maize, yam, cocoyam and sweet potatoes) relative to the value of cassava produced by *i-th* farm at season *t*. x_{jit} represents the *j-th* inputs used by *i-th* farm at season *t*. The inputs included in the model are land (x_1), labour(x_2), fertilizer(x_3) which is equal to $\boldsymbol{ln}\left[\boldsymbol{Max}\left(\boldsymbol{fertilizer}, 1 - \boldsymbol{D}_f \right) \right]$, pesticide($x_4$) which is equal to $\boldsymbol{ln}\left[\boldsymbol{Max}\left(\boldsymbol{pesticide}, 1 - \boldsymbol{D}_p \right) \right]$, and cost of planting materials(x_5). D_f is a dummy which has a value of 1 if fertilizer usage is positive and 0 if otherwise, and D_p is a dummy with a value of 1 if pesticide usage is positive and 0 if otherwise.

In an attempt to minimize bias in the coefficient of some of the variables in the equation 5.24, $\boldsymbol{ln}\left[\boldsymbol{Max}\left(\boldsymbol{fertilizer}, 1 - \boldsymbol{D}_f \right) \right]$ and $\boldsymbol{ln}\left[\boldsymbol{Max}\left(\boldsymbol{pesticide}, 1 - \boldsymbol{D}_p \right) \right]$ are included to account for zero usage of these variable inputs in the regression while D_f, *and* D_p account for intercept change (Battese, 1997).

$A(t)$ represents the time trend which captures technological change. D_{states} represents state dummies. This include; D_{ekiti}, D_{ondo}, D_{osun}, and D_{oyo}, which are dummies for Ekiti, Ondo, Osun, and Oyo states, respectively (D_{Ogun} is left out for estimation). Seasonal dummies were also included in the production frontier which includes: D_{2008} and D_{2009} for 2007/08 and 2008/09 seasons, respectively (D_{2007} for 2006/07 is left out for estimation).

In this study, we follow standard assumption on the stochastic error term v_{it} in the literature that $E(v_i) = 0$ for all $\boldsymbol{i}$, $\boldsymbol{E}\left(\boldsymbol{v}_i \boldsymbol{v}_j \right) = 0$ for all $i \; and j \; (i \neq j)$`, $E\left( v_i^2 \right) = \sigma_v^2$, $E(u_i) > 0, E\left( u_i u_j \right) = 0$ for all $i \; and j \; (i \neq j)$`, and $E\left(u_i^2 \right) = \sigma_u^2$. The stochastic terms v_i and u_i are assumed to be uncorrelated. Also we assumed, v_{it} is normally distributed as

$N\left(0,\sigma_{vit}^2\right)$ with $\sigma_{vi}^2 = g\left(x;\tau_i\right)$ while u_i is assumed to be half-normally distributed as $N^+\left(0,\sigma_{uit}^2\right)$ with $\sigma_{ui}^2 = \mathrm{q}\left(Z_i, D_i;\alpha_i\right)$.

For the heteroskedasticity in v_{it}, we include farm size to capture differences in the farm harvest while site specific location variables such as states dummies were included to capture size and location differences across the region. This choice however, is in line with work of Hadri *et al*., (2003) and Loureiro (2009) as

$$\sigma_v{}^2 = \exp\left(\tau_0 + \tau_1 InX_{landit} + \tau_2 D_{ekitit} + \tau_3 D_{ondot} + \tau_4 D_{osunt} + \tau_5 D_{oyot}\right) \qquad 5.25$$

where $\sigma_v{}^2$ represents the variance of the two-sided error (v_i), $In\mathrm{X}_{\mathrm{ji}}$ is the logarithm for land while the state dummies are as indicated by the subscripts.

Following, the traditional technical inefficiency effect model in the literature, variance of the inefficiency error is, modeled as a function of the farmers' socio-economic variables, state and seasonal dummies as

$$\sigma_u{}^2 = exp\begin{pmatrix} \omega_0 + \alpha_1 Z_{age} + \alpha_2 Z_{gender} + \alpha_3 Z_{occupation} + \alpha_4 Z_{family} + \alpha_5 Z_{educ} + \alpha_6 Z_{credit} + \alpha_7 Z_{exten} \\ +\alpha_8 Z_{nonfarm} + \delta_1 D_{ekiti} + \delta_2 D_{ondot} + \delta_3 D_{osunt} + \delta_4 D_{oyot} + \delta_5 D_{2008} + \delta_6 D_{2009} \end{pmatrix} \qquad 5.26$$

where $\sigma_u{}^2$ represents the variance of one-sided error term (u_i), Z_{age}: age of the primary decision makers in the study area, $Z_{\mathrm{occupation}}$: major occupation dummy of the primary decision makers in the study area (farming =1, 0 otherwise), Z_{gender}: gender dummy of the primary decision makers in the study area (male =1, 0 otherwise), Z_{family} : family size (this represents main family members), Z_{educ}: years of schooling the farmers, Z_{credi} : credit dummy (access =1, 0 otherwise), Z_{exten}: number of contacts with extension agents, Z_{nonfarm},: non farm income dummy (participation=1, 0 otherwise), Z_{index}: crop diversification index. With respect to the states we includes: D_{ekiti}, D_{ondo}, D_{osun}, and D_{oyo}, which are dummies for Ekiti, Ondo, Osun and Oyo states, respectively (D_{Ogun} is left out for estimation). Similarly, the states dummies are also included: D_{2008} and D_{2009} for 2007/08 and 2008/09 seasons, respectively and D_{2007} for 2006/07 is left out for estimation.

5.4.0. Results and Discussions

5.4.1. Results of hypotheses

The results of the likelihood ratio tests[7] carried out during the analysis are presented in Table 5.1. The null hypothesis of homoskedastcity v_i and u_i is rejected as revealed by the second row. The null hypothesis of homoskedasticity v_i with heteroskedasticity u_i is also rejected as shown in the third row. The last hypothesis of homoskedasticity u_i with heteroskedasticity v_i which also doubles as the test of the effect of technical inefficiency is rejected. The implication of this hypothesis is that, there is presence of technical inefficiency effects in the study.

Table 5.1: Results of Hypotheses

Null Hypotheses	Log likelihood	LR	Critical-value (5%)	Decision
Translog i.e., Full Heteroskedasticity preferred model	-460.14			
H_{01}: $\ell n\,\sigma_v^2 = \ell n\,\sigma_u^2 = const.$ i.e., Homoskedasticity in both v_i & u_i errors	-489.49	58.70	30.14	Reject H_0
H_{23}: $\ell n\,\sigma_v^2 = const$ i.e., Homoskedasticity in v_i error	-468.37	16.46	11.07	Reject H_0
H_{03}: $\ell n\,\sigma_u^2 = const$ i.e., Homoskedasticity in u_i error and No. technical effect	-482.47	44.66	23.69	Reject H_0

5.4.2. Resource-Productivity in cassava production

The result of the maximum likelihood estimates of the elasticities of the output distance function is presented in the Table C2 of the appendix while Table 5.2 summarizes the first order (in absolute value) and the cross terms biases (elasticties) to ease subsequent interpretation and discussion. Before the estimation, the data was normalized at the sample mean, meaning that the *first-order* distance elasticities serve as the partial elasticity (the measure of resource-productivity) of production with respect to the inputs.

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[7] We constructed the likelihood ratio test using the statistics $LR = -2\left[\ell n\left(LH_R - LH_U\right)\right]$, where $\mathbf{LH_R}$ is the value of the maximized log-likelihood for the restricted and $\mathbf{LH_U}$ represents that of unrestricted. This statistics follows a χ^2 distribution with $\mathbf{T_R - T_U}$ denoting the degree of freedom, where $\mathbf{T_R}$ and $\mathbf{T_U}$ represents the number of variables in the restricted and unrestricted samples, respectively.

However, Tables 5.2 shows that all input elasticities (land, labour, fertilizer, pesticide, and materials) are significantly different from zero and therefore, posses the expected signs at the sample mean. As noted by Brümmer *et al.* (2002) distance elasticities for a "well-behaved" input must be negative as also revealed by Table C2[8] of the appendix. The implication of this is that estimated elasticities of the output distance function satisfy the property of monotonicity at the sample mean.

Using the homogeneity restriction in the output of Eqn.5.19a, the share of cassava in the total farm production is computed as 0.3816 which is equivalents to about 38% while the share of other crops stood at about 62% (see the lower panel of Table 5.2). This result however, is consistent with the primary data (see Table C1 of the appendix) where "other crops" appear to have a larger share of the total revenue relative to the value of cassava output.
In a related development, the -0.6184 coefficient of "other crops" at the sample mean could as well be interpreted as the slope of the production possibilities frontier, i.e., the marginal rate of transformation (MRT) between "other crops" grown by the farmers and cassava produced relative to output mix/ composition. The coefficient is significantly different from zero. Furthermore, higher distance elasticity with respect to labour (0.686) in absolute value reflects increasing share of this variable with respect to other variable inputs included in the distance function. This indicates that labour is an important variable input in cassava production in the region. However, this observation is consistent with the finding of Dvorak (1996) that a large share of labour is an indication that labour as a factor of production is generally of overwhelming importance and may take up to 90% of the costs of production in many Africa farming systems. This position is also upheld by Enete *et al.,* (2001) and Nweke (1994) that cassava root yield responds positively to the use of labour in sub-Saharan Africa.

Färe and Primont (1995) show that the scale elasticity analogous to returns to scale (RTS) can be calculated as the negative sum of the input elasticities or simply sum of the absolute input elasticities. In this regard, the sum of the absolute distance elasticities with respect to the inputs (Table 5.2) gives a measure of the scale of 1.193, indicating increasing returns-to-scale (IRTS) in cassava production in the region. The economic interpretation of this is that, a 1% joint increase of the inputs generates a more than proportional expansion in the cassava produced by about 1.2%.

[8] This assertion however, conformed to the present study because of the manner in which Eq.20 is specified (see foot note 4).

The coefficient of time trend which indicates technology change shows that there is a significant evidence of "technical progress" in cassava production relative to other output composition in the region. This observation might possibly be due to the availability of improved cassava technologies to the farmers by the International Institute of Tropical Agriculture (IITA), Nigeria and Federal Ministry of Agriculture in Nigeria. These agencies have successfully distributed over 12 varieties of cassava tuber in the country for the past 15 years.

With regard to the violation of the monotonicity in output and inputs at the individual point estimate, we found evidence that 5% of the observation violates monotonicity i.e., $\left(\frac{\partial \ln D_0(x,y,t)}{\partial \ln y_m} \geq 0 \right)$ in "other crops". For the inputs $\left(\frac{\partial \ln D_0(x,y,t)}{\partial \ln x_j} \leq 0 \right)$, we found evidence that 3% of the observation violate monotonicity for land while it violates monotonicity for the other factors as follows: labour - 2%, fertilizer - 12%, pesticides - 23% and materials - 27%.

With regard to the curvature, quasi-convexity in inputs ($\boldsymbol{x_j}$) is rejected at the sample means. This is because the principal minors (the square terms of the $\boldsymbol{x_j}$) of the Table C2 of the appendix are non-negative with the exception of land and pesticides.
In related development, we found evidence of convexity in the output at the sample mean for the "other crops" in the distance function as the square term of this variable is positive in the Table C2 of the appendix.
The positivity and significance of seasonal dummies is an indication of positive seasonal effects on cassava production in the study.

5.4.3. Cross-terms effects (biases) of the inputs: *Input substitution and complementary*

The right panel of Table 5.2 presents the summary result of the cross-term biases of the inputs. We found significant evidence of input complementary effects between land and pesticide, labour and fertilizer, and fertilizer and pesticide. Economic interpretation of this is that, joint effects of the pairs of these variables contribute significantly to cassava production in the region.

Also, we found significant evidence of input substitution effects between labour and pesticide. A plausible reason for this observation could be attributed to the high cost of pesticides (as most of the farmers indentified high cost of inputs such as fertilizer and inputs as a major production problem). Such development might force the farmers to substitute labour for pesticides to carryout basic post-planting operations such as weeding on the farms. Supporting this argument from the earlier findings in the study is the fact that labour appears to have the highest share of output distance elasticities while less than 60% of the farms used pesticides.

Table 5.2: Returns-to-scale in absolute value and cross-terms effects (biases) of the inputs

Inputs	*first-order* elastcities	Cross-terms effects of the inputs (*second -order* elastcities)			
		$\varepsilon_{x2,y1}$	$\varepsilon_{x3,y1}$	$\varepsilon_{x4,y1}$	$\varepsilon_{x5,y1}$
[a]Cassava $_{y1}$	**-0.3816**				
Other crops$_{y2}$	**-0.6184*****				
Land$_{x1}$	0.1776**	0.0641	-0.0113	**0.1786*****	-0.0275
Labour$_{x2}$	0.6858***		**0.1005***	**-0.2056*****	0.0324
Fertilizer$_{x3}$	0.1608***			**0.0368***	-0.0682
Pesticide$_{x4}$	0.1520***				-0.0083
Materials$_{x5}$	0.0169*				
[b]RTS	**1.1931**				

[b]$\varepsilon_{D0,y1}=1-\varepsilon_{y2D0y1}$; [b]RTS $=\sum \varepsilon_{xjy1}$; ***, **,* *denotes statistical significance at the 1%, 5%, and 10%, levels respectively.*

The result of the heteroskedasticity in the white noise v_i (see middle panel of Table C2 of the appendix) shows that land size as well as dummies for Ekiti, and Osun states decreased the variance of the white noise while dummies for the Ondo and the Oyo states increased the variance of the noise. However, only land, dummies for Ekiti and Ondo states significantly different from zero.

5.4.4. Technical inefficiency effect

The result of the heteroskedasticity inefficiency error terms which double also as the technical inefficiency effects shows that gender, family size, occupation, education, extension, and credit decreased the variance of inefficiency (i.e., enhanced technical efficiency) of the cassava production in the sample. Only occupation (i.e., farming), credit, and extension were significantly different from zero. Also, age and non-farm income were found to increase the variance of the technical efficiency of the farmers. None of these variables were significantly different from zero.

The result of the state dummies shows that the Ekiti and Oyo states dummies significantly decreased technical efficiency of cassava production in the region in reference to the Ogun state dummies. The coefficients of seasonal dummies shows that the technical inefficiency of the farmers in 2007/08 and 2008/09 farming seasons decreased significantly with reference to the 2006/2007 farming season.

5.4.5. Technical efficiency estimates

Presented in Table 5.3 is the deciles distribution of the estimated output-oriented technical efficiency scores by seasons as well as the pooled estimates. Figure C in the appendix on the other hand shows the density distribution of the pooled technical efficiency scores. The result shows that, the technical efficiency of the pooled sample ranged between 0.0921 to 0.9323 with an average technical efficiency of 0.721 which implies a technical inefficiency level of about 28%. The economic interpretation of this is that, an average farm in the region requires about 28% more resources to produce the same quantity of cassava as an efficient farm on the frontier. The bottom line is that, there is still room for improvement in the cassava production in the country.

This observation however, might be a reflection of the poor performance of the cassava industry in the country despite being the largest harvest in the world. For example, the average National yield of 12 tonnes/ha is far below the expected average of 28 tonnes/ha (Nkonya *et al.* 2010).

The density plot helps shed more light on the distribution of the efficiency scores in the sample. The distribution shows that a large mass of the efficiency scores are distributed between 0.65 - 0.85 as also indicated in the fourth column of Table 5.3.
Also, presented in Table 5.3 is the result of the technical efficiency by seasons. An average efficiency score of 0.665, 0.741 and 0.757 was obtained for 2006/07, 2007/08, 2008/09 farming seasons, respectively. A Cuzick's nonparametric test for trend across ordered displays a z score of 6.74 and p-value of 0.000. The implication of this is that, there is significance evidence of increased trend in technical efficiency from 2006/07-2008/09[9,10] farming seasons.

[9] Supporting this observation also is the subscript a and b below table 5.3 which shows that at the sample mean, there is evidence of significant increase in the average efficiency score from the 2006/07-2008/08 farming seasons.
[10] A possible driver of the significance improvement in the technical efficiency could be linked to the earlier result of the positive impact of extension services on the technical efficiency. This is because accessibility to extension facilitates adjustment towards the technology prospect.

Furthermore, the cumulative distribution function, CDF (Figure 5.3) offers an understanding on whether distribution of the seasonal efficiency scores is, robust across the sample. From the figure, it seems the 2008/09 CDF and 2007/08 CDF lie almost side by side while 2008/09 CDF is slightly located on the right side of 2007/08. The close proximity of 2008/09 CDF to 2007/08 could be attributed to marginal differences between the average efficiency scores (see Table 5.3).
From the figure, the 2008/09 CDF is located on the right hand side of the 2006/07 farming season while the 2007/08 CDF is located on the right side of that of the 2006/07 farming season. Since none of the distribution crosses each other, it suggest that the CDFs can be classified as first-stochastic dominance with the distribution of the technical efficiency for the 2008/09 farming season dominating the other two seasons while the distribution of the technical efficiency of 2007/08 farming season dominates the 2006/07 farming season.

A comparative analysis of the average technical efficiency obtained from the present study with previous efficiency studies with a focus on the Nigerian cassava industry is discussed as follows. The average score in the present study is higher than 66%, 61%, and 56% obtained by Adeleke *et al.,* (2008), Bamire *et al.,* (2004) and Ohajanya (2005), respectively while this is below 74% and 77% obtained by Udo and Etim (2007) and Iheke (2008), respectively[11].
The result of the efficiency score by states shows that Ogun state recorded the highest efficiency of 0.744. This however, is followed by Osun state: 0.742, Ondo state: 0.718, Oyo state: 0.717 and Ekiti: 0.695. With an exception of Ogun and Osun states, the results of the other states are barely different from each other at the sample mean.

[11] It is important to stress here that these studies used the standard stochastic frontier production function

Table 5.3: Deciles Distribution of the technical efficiency

Range	2006/07		2007/08		2008/09		Pooled	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
0.00-0.10	1	0.35	0	0	0	0	1	0.12
0.11-0.20	6	2.13	0	0	1	0.33	7	0.83
0.21-0.30	9	3.19	3	1.15	4	1.32	16	1.89
0.31-0.40	12	4.26	4	1.54	6	1.97	22	2.60
0.41-0.50	23	8.16	2	0.77	13	4.28	38	4.49
0.51-0.60	29	10.28	14	5.38	18	5.92	61	7.21
0.61-0.70	55	19.50	41	15.77	37	12.17	133	15.72
0.71-0.80	76	26.95	96	36.92	86	28.29	258	30.50
0.81-0.90	65	23.05	95	36.54	129	42.43	289	34.16
0.91-1.00	6	2.13	5	1.92	10	3.29	21	2.16
Total	**282**	**100**	**260**	**100**	**304**		**846**	**100**
Mean	0.6645		0.7414[a]		0.7572[a,b]		0.7214	
Std.Dev.	0.1829		0.1404		0.1202		0.1549	
Min.	0.0921		0.1490		0.1917		0.0921	
Max.	0.9287		0.9252		0.9323		0.9323	

[a]Significant increase in this mean score compared to that of 2006/07; [b]Significant increase in this mean score compared to that of 2007/08.

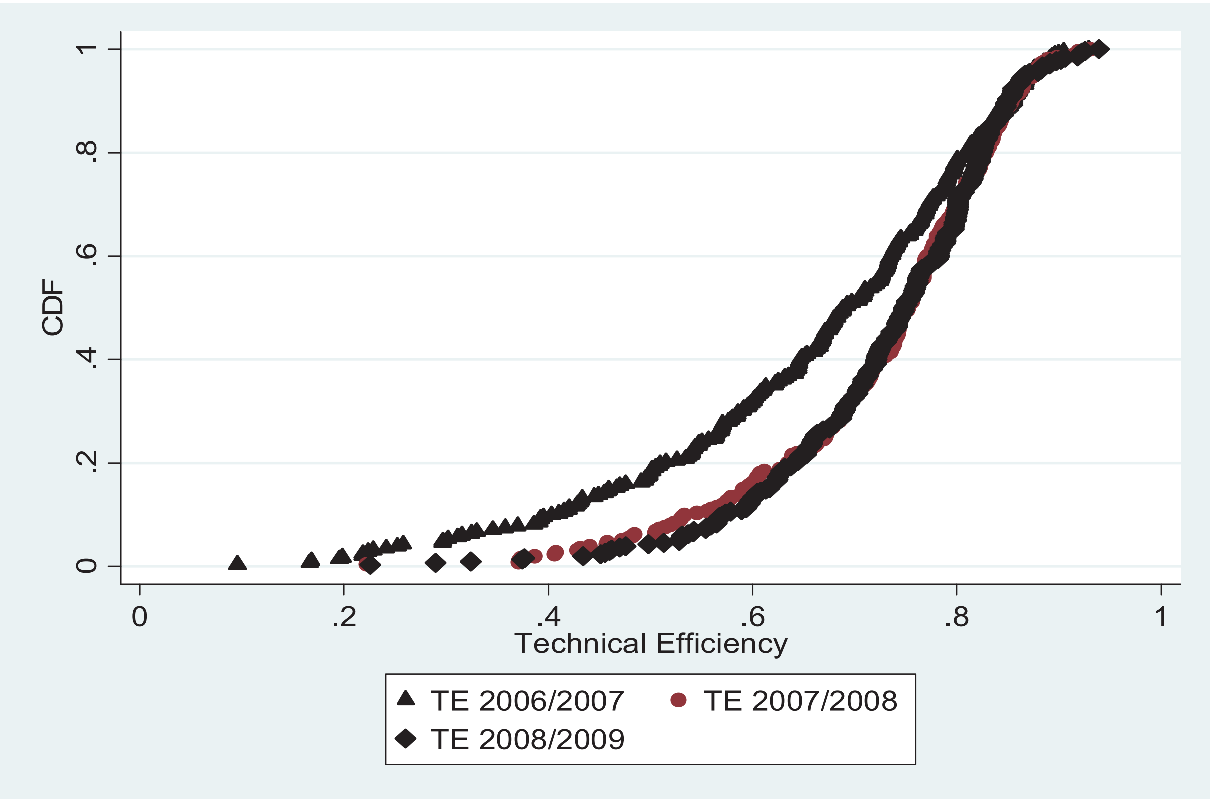

Figure 5.3: *Cumulative Distribution Function of the estimated Technical Efficiency scores by seasons; Kolmogorov-Smirnov test of equality-of-distributions indicates that the estimated seasonal technical efficiency scores do not have the same distributions with p-value of 0.073, 0.000, and 0.000 between 2007/08& 2008/09, 2006/07& 2007/08, and 2006/07& 2008/09, respectively.*

5.0. Conclusions

This paper estimates technical efficiency, inputs substitution and complementary effects using an output distance function with a focus on cassava production relative to “other crops” in the southwestern Nigeria. The study employed unbalanced panel data covering the 2006/07 to 2008/09 farming seasons with a total of 846 observations.

The results show that the marginal rate of transformation (MRT) between “other crops” grown by the farmers and cassava produced relative to the output mix is negative and significantly different from zero which is consistent with theory. Furthermore, the result of the partial elasticity of production with respect to the inputs shows that, farm size, labour, fertilizer, pesticides, and materials monotonically increased cassava production in the region. Similarly, we found evidence of increasing returns-to-scale as well as technical progress in cassava production in the sample.

The cross-term effects of the inputs indicate evidence of significant complementary effects between inputs which includes: farm size and pesticides, labour and fertilizer, fertilizer and pesticides on cassava production in the region. Also, there is evidence of significant substitution effects between labour and pesticides.
The result of the efficiency scores shows an average score of about 72% which implies that an inefficiency level of about 28% is observed from the study. This however, indicates ample room for improvement in cassava production in the country. Also, we found evidence of increasing trend in the technical efficiency from 2006/07 to 2008/09 farming seasons.
Extension, credit and occupation (i.e., farming) were policy variables increasing efficiency of the farmers in the sample.

Finally, the study suggests intensification of policies that will enhance technology transfer via effective and reliable extension services and farmer’s access to credit as well as incentives that will encourage and increase the number of full time farmers entering cassava production. Such policies and incentives will provide the needed impetus to upwardly shift the frontier of cassava production in Nigeria from the present position.

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CHAPTER SIX

6.0. Summary, conclusions and policy implications and directions for future research

6.1. Introduction

This chapter provides a summary of the major findings from the various papers that make up the dissertation as well as the conclusions and policy implications drawn from these papers while directions for future research are highlighted.

6.2. Summary of major findings

The overall objective of this study is to update the literature on the efficiency of smallholder farms while providing the institution of public and private policy design with important control mechanisms for agricultural planning in the country. A study of this nature is vital because the role of efficiency, as a means of fostering agricultural production, has been widely recognized and stressed by researchers and policy-makers around the globe.

Beside, a good knowledge of the sources of efficiency differential is likely to provide opportunities for farmers to produce more, which could in turn lead to a rise in the welfare level of the farm households and perhaps competitiveness among the producing units.

In light of this, the subsequent discussion summarizes the key findings from the papers that make up the dissertation with paper one addressing the objective one of the study earlier mentioned in chapter one of this dissertation. Likewise, paper two and three address issues raised in objectives two and three respectively.

Objective **one** examined the development and drivers of average technical efficiency (ATE) in Nigerian agriculture based on 64 frontier studies which yield 86 observations covering 1999-2008. Using truncated regression, the major findings from the paper show that the reported ATE estimates increased significantly over time. This observation might possibly imply that apparently increased average technical efficiency (ATE) in the Nigerian agriculture is primarily due to technological change over the years. Study-specific characteristics included in the regression such as sample size, the number of inputs used as well as studies based on crop production, significantly increased the ATE estimates. Further analyses show that studies in the Northcentral, Southwest, and Southsouth regions of the country produced higher ATE levels relative to the Northeastern region. Within the sample, 53 percent identified education as a significant determinant of technical efficiency while 38 percent showed that experience is an important factor. Extension was revealed to be an important determinant by 23 percent while 19 percent identified age as a significant determinant of technical efficiency in Nigerian agriculture within the period under investigation.

Objective **two** identified the trends in crop diversification while examining its impact on the technical efficiency of smallholder farms in Nigeria. The paper employed the Herfindahl and Ogive indices to compute the diversification indices while the stochastic frontier production model was used to estimate the technical efficiency level of the farms. Unbalanced panel data covering 3 farming seasons (2006/07 to 2008/09) with a total of 846 observations are used for the analysis. The results of both the Herfindahl and Ogive indices showed that cropping pattern increased significantly with the intensification of crop diversification in the paper. For example, the result of the Herfindahl index based on the size of the farm allocated to each of the farm enterprises by the farmers indicates that an average index of 0.498, 0.457 and 0.425 for 2006/07, 2007/08, and 2008/09 farming seasons, respectively was obtained from the analysis which justify this observation. Furthermore, the result of the stochastic frontier production model demonstrates the evidence of decreasing returns-to-scale and technical progress in the food crop production in the region. Education, extension, and crop diversification are identified as efficiency increasing policy variables while an average technical efficiency level of about 81 percent was obtained from the analysis. The latter implies that food crop production with the current output fall far below the frontier level by 19 percent in the study area.

Objective **three** investigated technical efficiency, inputs substitution and complementary effects using the output distance function while focusing on the cassava production relative to other output composition in the Nigerian crop production. The paper employed the stochastic frontier distance function on a total of 846 observations which covered 3 farming seasons from 2006/07 to 2008/09. The result of the stochastic frontier distance function shows that the (negative) shadow value of "other crops" grown by the farmers in course of crop production relative to cassava produced in the output mix is about 62% and significantly different from zero. This observation however implies a significant evidence of the marginal rate of transformation (MRT) between "other crops" grown by the farmers and cassava produced relative to output mix/ composition in the study area. We also observed that increasing returns-to-scale as well as technical progress characterised cassava production in the region as revealed in the results of the stochastic frontier distance function. Furthermore, fertilizer and pesticides are found to have significant substitution effects on cassava production in the sample. Likewise, we found evidence that in pairs, farm size and pesticides, labour and fertilizer as well as fertilizer and pesticides jointly exhibit significant complementary effects on cassava production in the region. An average technical efficiency level of 72.1 percent, which implies an inefficiency level of approximately 28 percent, is observed from the study while extension, credit and, occupation (i.e., full time farming) are indentified as efficiency increasing policy variables from the study.

6.3. **Conclusions and policy implications**

The consensus messages drawn from the papers that make up this dissertation shed light on the important indicators for the performance of the Nigerian agricultural sector and, most especially, the food sub-sector which is the technical efficiency. Findings of this nature are impetus for agricultural planning with the possibility of highlighting the drivers of the efficiency of crop production in the country. For example, the mean efficiency scores from each of the papers showed that there is still room for improvement in the Nigerian crop production as each of the scores fall far below the frontier score.
Also, the technological progress observed in the paper II and III indicates that agricultural production has an inherent potential with the capability of increasing crop production to meet the growing food demand in the country.

In view of this, the study suggests the implementation of policies that promote improved efficiency through known-tested agricultural technologies which are capable of shifting the frontier of agricultural production upward in the country. This implies that productivity improvement from a technology perspective may serve as a panacea for sustainable crop production in the country.

However, a reliable way of achieving this is via improvement in the funding of agricultural research activities as well as intensification in the dissemination of agricultural technologies among farmers. There is no doubt that, a reliable extension advisory service programmes should be seen as a panacea to increase the spread of improved technologies to the farmers in the country.

The objective of this study is not only to examine technical efficiency but to also identify the drivers of efficiency as a matter of policy concern in Nigerian agriculture. The fact that the papers identify education, credit, and extension contacts among others as the key drivers of efficiency of crop production in the country underscores the importance of these policy variables to reposition the industry in the country. While all the papers indentify extension as a key driver of efficiency of crop production in the country, paper I and II also reveal education as the main drivers of efficiency of the sector in the country. In addition, the fact that only paper I and III indentify access to credit underscores the significant contribution of this policy variable in improving efficiency level of the Nigerian crop production. Based on this, the research concludes that government policies, strategies, and programmes should be design to enhance extension activities and capita market (credit availability) in the Nigerian agricultural production. To this end, provision of infrastructure supports services and credit programmes that are free of bureaucratic processes so as to improve agricultural production are need in the country. For example, provision of infrastructure support services such as good road network in the rural communities will help ease technology transfer to the farmers and perhaps farm produce to the market by the farmers' families. Likewise, availability of capital market to the farmers either via private or public credit schemes designed purposely to lessen the bureaucratic loan process associated with the Nigeria Agricultural Cooperative and Rural Development Bank (NACRDB) is essential. NACRDB is the federal government of Nigeria's institution responsible for disbursement of soft loan to farmers' cooperative society for onward lending to their members. Unfortunately, activities of NACRDB remain unpopular because of the bureaucratic and poor credit delivery systems associated with its operations among the peasant farmers in the country.

There is also the need to embrace policies that provide incentives to the young, able and educated farmers to come into farming in Nigeria. This is important to change the outlook of the participants in Nigeria's agricultural production system which, incidentally, is ageing. The implication of this is that higher education is expected to enhance the rate of adoption of improved technologies which reduces the level of technical inefficiency.

Besides, intensification of farmers training on modern technologies through the activities of extension operations across the country such as the farmers' field school or training & visit systems of agricultural extension is another way to improve the performance of the farmers in the country. However, we acknowledge the challenges associated with extension programmes which impede this suggestion in the country. For example extension personnel need to be motivated with better working conditions most especially in the area of transportation. They need to be provided with transportation facilities such as a motorcycle and bicycle to enable them regularly visit farming communities are recommended. Also, incentives such as special allowances for the extension personnel that will enable them reside in the communities. Closer proximity to the target communities by the extension personnel is a key factor needed to increase the rate of adoption of technologies among the farmers.

Finally, the increasing trends in crop diversification observed in one of the papers, as well as evidence of a positive significant nexus between diversification and the efficiency of farmers is considered. In view of these, the study suggests that the relevance of this phenomenon for policy formulation should be taken into account to promote crop production among the dominated smallholder farms in the country. That is, the use of diversification as a strategy to boost agricultural production (as practiced in Asia in 1990s) by the Federal Government of Nigeria should be looked into by policy makers in the country.

The literatures have shown that high value crops not only have the potential to raise farm income but possibility to promote export earning and increase rural employment. This observation has led to the popularization of increase cultivation of high value crops among policy makers in the developing countries.

In light of this, the research suggests the implementation of programmes by the Nigerian Government that educate the farmers on the potential benefits of incorporating high value crops which have greater returns such as vegetables with their traditional crops while engaging in crop diversification. Traditional crops such as cassava, yam, maize, potatoes, and cocoyam can be grown alongside high value crops such as vegetables in the region as revealed in the literature. This strategy no doubt could go a long way in raising farm income in addition to the possibility of enhancing agricultural development and perhaps food security in the country.

6.4. **Directions for future research**

This study has made a significant update of the literature on the efficiency of smallholder farms in Nigeria. Nevertheless, various areas of future research work remain.

First, an important finding of this study is the significant contribution of years of schooling to efficiency level of the farmers in the study. In light of this, the future challenge could be a model that takes into account the educational level of household heads as well as that of other household members as a possible shifter of efficiency level of the family farms in the country.

In addition, an alternative model could be explored such that the educational level of the farm household vis-à-vis male educational level and female educational level is incorporated as a shifter of technical efficiency in order to unravel gender specific educational impact on the efficiency of the smallholder farms in the country. This however could possibly highlight the further influence of gender on efficiency differentials in the future research.

Second, an area of opportunities for further research is the possibility of focusing on research that tend to shed more light on the relationship between crop diversifications and other sources of income by the farm families with implication on the technical efficiency of the farmers. This is important because a farmer’s decision to engage in crop diversification is associated with their income level and perhaps other sources of income to the farm families. Therefore an attempt to simultaneously consider this in a model will unravel the connection between these important phenomena of interest among peasant farmers and implication on the productivity and efficiency of the farmers. Furthermore, it will be of interest to analyze factors determining crop diversification while incorporating a measure of farmers’ risk attitude to capture the associated effect of risk on crop diversification and efficiency level of farmers.

Third, with regard to paper one (i.e., objective one), it will be of future research interest to increase the data points for further research so that more data-demanding approaches (both parametric and non-parametric techniques such as the dual frontier) could be included in such quantitative review. Also, a possible future extension to this paper could be the grouping of the primary studies based on the agro-ecological classification rather than the regional classification as used in the paper. Because of differences in the yield potential of different ecological zones across the country, such classification might shed more light on the environmental impact on the efficiency of the Nigerian agricultural production systems.

In addition to this, incorporation of the per capita Gross Domestic Products (GDP) contribution of agriculture to the overall GDP as possible explanatory variables in the regression could further shed light on the exact relationship between the efficiency level in the Nigerian agricultural sector and the agricultural growth over time in the country.

Four, an issue of concern for future research could be the possibility of using a relatively long balanced panel data (e.g., 5 years upward) to analyze changes in the technical efficiency and other components of total factor productivity growth (e.g., scale related change, inputs and outputs allocative efficiency related change with respect to the inputs and outputs) of smallholder farms in the country.
Moreover, the balanced panel could further be explored to carry out enhanced analysis with more data and methodologically demanding approach such as the dynamic efficiency frontier in the Nigerian agricultural production systems. An exercise of this nature in the long run could be more advantageous in understanding the key components of agricultural productivity and the dynamic nature of agricultural production over time for the distillation of agricultural policy in the country.

Also, the availability of a balanced panel data could help shed more light on the cropping pattern that is most engaged in by the farmers over time since the same farms are interviewed over a given period of time. The results of such a study might show whether crop diversification could be explored as a policy goal to enhance food security and, perhaps scope economies in the Nigerian agricultural production systems.

Appendix A. Description of the study area and the data used for the paper II and III

The data used in the second and the third papers came from a farm household's survey that was carried out in the Southwestern Nigeria. The survey covered three farming year of 2006/07-08/09[1]. The region is made up of six states (Ekiti, Ogun, Ondo, Osun, Oyo a nd Lagos). Lagos state is regarded as the financial capital of the country known for commerce rather than agriculture. The remaining 5 states were adequately represented in the survey. Figure D of this appendix represents the Map of the region.

The southwestern Nigeria falls on the Latitude 6^0 to the North and the Latitude 4^0 to the South. It is marked by the Longitude 4^0 to the West and 6^0 to the East. The vegetation is typically rainforest; however, climatic changes over the years have turned some parts of the rainforest to derived Savannah. The geographical location of the region covers about 114,271 km^2 which is approximately 12% of Nigeria's total land mass. The total population of the region is put at 15,456,789 (NBS, 2010). The region is bounded in the North by Kogi and Kwara states, East by Edo and Delta states, South by Atlantic Ocean and West by Republic of Benin. The two main seasons in the region are heavy rainfall during the rainy season (April to October) and dry wind during the dry season (November - March).

Agricultural sector forms the base of the overall development thrusts of the southwestern Nigeria, with farming as the main occupation of the people in the area.
The Agricultural production in the region comprises of cultivation of staple crops, vegetables, fruits and tree crops; livestock activities and fish farming. The food crops grown in the region includes; maize, yam, cassava, cocoyam, potato, melon, cowpea, and vegetables under mixed cropping practices. However, yam, maize, cassava, sweet potatoes and cocoyam are the five portfolios of activities or enterprises observed among the sample farms either as sole crop or mixed crops in the survey.
The farmers interview for the study were randomly sample with a well structured questionnaire (the questionnaire used is appended in the section B of this appendix) based on the list of food

[1] Less than 10% of the farmers were repeatedly sample within the seasons.

crop farmers provided by the extension personnel of the state's agricultural development project (ADP). The extension personnel were involved in administering of the questionnaire. The detail characteristics of the data by state basis and the seasons are presented in the Table D of this appendix.

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Appendix B: Questionnaire for the paper II and III

Dear Respondents,

I am please to inform you that this questionnaire is basically prepared to obtain relevant information that will assist me in my research work. Please, kindly give accurate information and be assured that all information obtained will be strictly treated as confidential and sincerely restricted for research purpose of which it is meant for.

Thanks for your anticipated cooperation.

Interviewer ID:………………… Respondent's Identification No…………

Date of Interview………………

Section A: Demographic Data

1. a. State:…………………………………………………………………………….

   b. Name of Town/Village.:…………………………………………………………

2. Sex of the household head: Male { }; Female { }

3. Marital Status: Single { }; Married { }; Widowed { }; Divorced { }

4. Age of household head:……………………………………………………..................

5. Household size:

Ranges	Number
No. of male adult (> 18years)	
No. of female adult (>18 years)	
No. of children (< 18 years)	

6a. Highest Educational Level for household head *(Please indicate appropriately)*:

Level of education	Head of household
Non-formal education –equivalent to zero yrs of education	
Primary education- equivalent to 6yrs of education	
Secondary Education- equivalent to 12yrs of education	
OND/NCE graduate - equivalent to 15yrs of education	
HND/BSc- equivalent to 16yrs of education	
Msc/PhD- equivalent to over 16 years of education	

6b. Highest Education Level for household members (*Please indicate appropriately*):

Level of education	Male adult (> 18years)	Female male adult (> 18years)	Children (< 18 years)
Non-formal education -0 yrs			
Primary education-6yrs			
Secondary Education-12yrs			
OND/NCE graduate -15yrs			
HND/BSc-16yrs of education			
Msc/PhD-above 16 years			

7. For how long have you been in farm business?...yrs.

8a. Major occupation of the household head: farming [ ] Non- farming [ ]

8b. If non-farming, kindly indicate appropriately with average income per month

Nature of non-farming activities	Tick appropriately	Income per month (₦)
Self –employment e.g. trading e.t.c		
Wage labour		
Others:		

Section B: Input data and production expenses

1. What category of labour did you use in your farm?

Category of Labour used	*Please tick appropriately*
Family labour	
Hired labour	
Both	

2. For hired labour please complete this table:

On average:	Land clearing	Heaping	Planting	Weeding	Spraying	Harvesting	Other operations
No. of labour used							
No. of days worked							
Person-days/year							
Average Wage rate per man-day (₦) =							

3. For family labour used please complete this table:

		Land clearing	Heaping	Planting	Weeding	Spraying	Harvesting
male(>18 yrs)	No. used						
	No. of days worked						
Female (>18yr)	No. used						
	No. of days worked						
Children (<18 yrs)	No. used						
	No. of days worked						

4. For the operating expenses, kindly complete this table

No	Items	Qty	Price/unit (₦)
1.	Planting materials(cassava cuttings);*kg [ ]/No. of bundles[ ]		
2	Fertilizers ; *kg [ ] / Bag [ ]		
3.	Herbicides (litres)		
4	Pesticides (litres)		

** Please indicate the measure of the inputs perhaps kg or no. of bundles or bags*

5. Other expenses incurred

Average cost of transportation	Cost (₦)
: to market to buy inputs	
: to market to sell farm produce	
: personal or family transportation to and from the farm	

6. For the durable items used in your farm, complete this table:

Items	Quantity	Unit price (₦)	Life Span(Years)
Cutlass			
Hoes			
Spraying Pump			
Spade			
basket			
Head pan			
files			
wheelbarrow			

7. Size of the farm cultivated **(****Note: 10,000 heaps = 1hectare***)**

Farm size allocated to cassava (ha) or N o. of heaps*	
Other crops cultivated by the farmers apart from cassava	
Farm size allocated in ha or No. of heaps* for :	
Farm size allocated in ha or No. of heaps* for :	
Farm size allocated in ha or No. of heaps* for :	
Farm size allocated in ha or No. of heaps* for :	
Farm size allocated in ha or No. of heaps* for :	

Section C: Farm output data

1. For your cassava production complete this table:

	Average	Number of heaps
Average output per 200 heaps in (Kg)/bags*		
Farm gate price per kg/bag (₦)		

**Note: Indicate which quantity is used i.e. kg/bag (underline appropriately)*

2. Please kindly indicate the quantity of the output obtain from the other crops indicated in the question 7 of section B:

The Crops								
	average	No. of heaps	average	No. of heaps	average	No. of heaps	average	No. of heaps
Average output per 200 heaps in (Kg)/bags*								
Farm gate price per kg/bag (₦)								

**Note: Indicate which quantity is used (simply under line appropriately)*

Section D: Credit and market information / extension visit

1a. Did you obtain credit from any source?

Yes	
No	

Indicate appropriately

1b. If yes (1a) what is your source of credit:

Source of credit	Amount (₦)	Interest paid in a year
Money lender		
Friends		
Relatives		
Cooperatives		
Commercial Banks		
Grants		
Government agency		

2. Sources of information on the prevailing price of produce

Sources	Tick appropriately
Extension agents	
Print media	
Friends and family	
Radio broadcast	

3. Please kindly indicate the number of extension visit to your farm

No. of Visit/month	
No. of months	

Section E: General information

1. What do you think have been the trend in income level and other standard of living as a cassava farmers based on the scale provided? (*Please indicate appropriately*)

	Increased	Same before	decreased
Cash income			
Food availability especially famine season			
Purchase of household items			

2. Are you aware and patronage Nigeria agricultural insurance cooperation:

   Yes [ ] No [ ]

3. Please kindly give information on the asset possessed:

Assets	Value (₦)
Crop unsold in previous season	
Value of the whole farm enterprises	
Residential assets	
Others	

4. What difficulties did you face in the course of your cassava production?......................

5. What is likely assistance you want, government to provide?...

Appendix C:

Curriculum Vitae

Kolawole OGUNDARI

Current contact information

Department für Agrarökonomie und Rurale Entwicklung,
Georg –August Universität,
Platz der Göttinger Sieben 5,
D-37073, Göttingen, Germany
Telephone Number: +49551394845
Fax: (+49)5513912177
Email (s): ogundarikolawole@daad-alumni.de
ogundarikolawole@yahoo.co.uk

Personal data

Date of Birth:	15th May 1975.	Sex:	Male
Place of Birth:	Akure (Southwest), Nigeria	Citizenship:	Nigerian

Education/ Academic Qualifications

2007- 2010	Doctoral Student, Dept. of Agricultural Economics & Rural Development, Georg-August-University of Goettingen, Germany
2003- 2006	Masters of Agricultural Technology-M. Tech (Agricultural Economics), Federal University of Technology Akure, Nigeria
1996- 2001	Bachelor of Agricultural Technology-B. Tech (Agric. Econs. & Extension), Federal University of Technology Akure, Nigeria

Scholarship, Awards and Grants

Aug.2009	CTA/IAAE travel grant to attend International Association of Agricultural Economist (IAAE) conference, August. 16-20, 2009, Beijing China
July.2008	Second Best Aquaculture Student paper (ACRSP) presented at the International Institute of Fisheries Economics and Trade (IIFET) conference, July 22 -25, 2008 in Nha Trang, Vietnam.
July.2008	International Institute of Fisheries Economics and Trade (IIFET) aquaculture travel grant to attend IIFET 2008 Vietnam Conference, July 22-25, 2008 in Nha Trang Vietnam.

Oct.2007- German Academic Exchange Service (DAAD) Scholarship award for PhD

Program at Georg-August-Universität Göttingen, Germany

June. 2007- German Academic Exchange Service (DAAD) Scholarship award for German Language undertaken at Goethe-Institute in Göttingen

Dec. 2004 Ondo State Government of Nigeria's Annual Postgraduate Scholarship-Merit Award for the Masters of Agricultural Technology.

Working Experience

Period: **16.01. 2007 – 31.05. 2007**

Organization*:* International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

Position: Research Associate under project PROSAB in IITA-Maiduguri station, Nigeria.

Responsibilities: Facilitate input, output and credit market for farmers under the project.

Period: **02. 01. 2003 – 15. 01. 2007**

Organization: St. Mattiahs' Anglican High School, Akure, Ondo state Nigeria.

Position: Class Teacher

Responsibilities: Teaches Agricultural Science at all senior classes

Period: **01.06. 2001- 27.05. 2002**

Organization: Planning, Budgeting and Monitoring Unit, Obafemi Awolowo University,

Ile-Ife, Osun State, Nigeria (One year National Youth Service mandatory primary assignment).

Position: Data Analyst

Responsibilities: Computation of staff establishment data.

Research interests

1. Productivity and efficiency analyses
2. Household's food and nutrient analyses
3. Food security and poverty issues

Publications

1. Ogundari, K. (2010). Farm-level and resource-use efficiency: application of stochastic frontier models to aquaculture farms in Southwest Nigeria. *World Aquaculture Magazine*, Vol.41 (2): 17-21.
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17. Folayan, J.A, A. E. Oguntade and K. Ogundari (2006). Effect of deregulation policy on cocoa marketing in Nigeria. *Agricultural Journal* Vol. 1 (4):320-323.
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1. Ogundari, K and O. Akinbogun (2009). Modeling production efficiency with risk: a case study of aquaculture farms in Nigeria. Paper presented at 5th Bi-annual North American Association of Fisheries Economists, 17th-20th May 2009, Newport University of Rhode Island, USA.
2. Ogundari, K (2009). A meta-analysis of technical efficiency studies in Nigerian agriculture. Paper presented at the International Association of Agricultural Economists 2009 Conference, August, 16-22, Beijing China
3. Ogundari, K., T. T. Amos and S.O. Ojo (2008). Estimating Confidence Intervals for Technical Efficiency of Rainfed Rice Farms in Nigeria. In Osakwe, *et al*. (eds.). Paper presented and appeared in the proceeding of 42nd Annual Conference of Agricultural Society of Nigeria-“Agricultural Development in Nigeria: Issues and Challenges”.19th-23rd Oct.2008, Abakaleke, Nigeria, pp. 346-350.
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Appendix D: Tables and figures

Table A: Survey of frontier studies in Nigerian agriculture, 1999-2008 (for Paper I)

Authors	*Year*	*Region*	*Type of production*	*Sample size*	*ATE*
Amaza & Olayemi	2002	Northeast	Food crops	123	0.69
Amos *et al.*	2004	Northcentral	Food crops	72	0.62
Adeoti and Adeoti	2008	Northcentral	Food crops (With HIV)	55	0.52
Adeoti and Adeoti.	2008	Northcentral	Food crops (Non-HIV)	100	0.70
Ukoha and Chukwuma	2007	Northeast	Egg Production	60	0.58
Ajibefun	2006	Southwest	Cassava	50	0.76
Ajibefun	2006	Southwest	Maize	50	0.70
Ajibefun	2006	Southwest	Rice	50	0.72
Agbabiaje	2003	Southwest	Poultry (small scale)	56	0.99
Agbabiaje	2003	Southwest	Poultry (medium scale)	40	0.99
Agbabiaje	2003	Southwest	poultry (large scale)	44	0.97
Okoruwa *et al.*	2007	Northcentral	Rice	240	0.83
Ajani and Ugwu	2008	Northcentral	Food crops	120	0.85
Bamiro	2008	Southwest	Pig Production	100	0.43
Nwaru *et al.*	2006	Southeast	Food crops (loan-benef.)	57	0.50
Nwaru *et al.*	2006	Southeast	Food crops (non-benef.)	75	0.44
Olarinde *et al.*	2008	Southwest	Bee-keeping	60	0.85
Ike & Odjuvwuederhie	2006	Southeast	Yam	120	0.41
Kareem *et al.*	2008	Southwest	Fish (concrete pond)	34	0.88
Kareem *et al.*	2008	Southwest	Fish (earth pond)	51	0.89
Okike *et al.*	2004	Northeast	Food crops	314	0.68
Okike *et al.*	2004	Northeast	Food crops	246	0.86
Onyenweaku & Effiong	2005	Southsouth	Pig	60	0.84
Ohajianya	2005a	Southeast	Poultry	180	0.43
Ojo *et al.*	2006	Southwest	Fish	200	0.68
Umoh	2006	Southsouth	Food crops	90	0.72
Amaza *et al.*	2006	Northeast	Food crops	1086	0.68
Ajibefun & Abdulkadri	1999	Southwest	Food crops	98	0.67
Amos	2007a	Southwest	Cocoa	250	0.72
Udoh & Nsikat	2007	Southeast	Cocoyam	90	0.85
Onyenweaku & Nwaru	2005	Southeast	Food crops	187	0.57
Amaza & Ogundari	2008	Northeast	Soybean	182	0.79
Udoh & Falake	2006	Southsouth	Food crops	120	0.73
Udoh	2006	Southsouth	Food crops	180	0.77
Ekunwe & Orewa	2007	Northcentral	Yam	200	0.62
Tijani	2006	Southwest	Rice	45	0.87
Amos	2007b	Southwest	Crustacean	200	0.70
Awoniyi & Omonona	2006	Southwest	Yam (wetland farmers)	30	0.80
Awoniyi & Omonona	2006	Southwest	Yam(upland farmers)	75	0.79
Shehu & Mshelia	2007	Northeast	Rice	180	0.96
Iwala *et al.*	2006	Southsouth	Oil palm	241	0.78
Ojo	2005	Southwest	Oil palm	100	0.75
Ogundari & Ojo	2005	Southwest	Food crops	240	0.87

Appendix D: Tables and figures (cont'd)

Table A: Survey of frontier studies in Nigerian agriculture, 1999-2008 (Cont'd)

Authors	*Year*	*Region*	*Type of production*	*Sample size*	*ATE*
Okezie & Okoye	2006	Southeast	Eggplant	120	0.78
Idiong	2007	Southsouth	Rice	112	0.77
Ajibefun *et al.*	2002	Southwest	Food crops	67	0.82
Ogundari & Aladejimokun	2006	Southwest	Cocoa	240	0.73
Erhabor & Emokaro	2007	Southsouth	Cassava (Edo south)	63	0.72
Erhabor & Emokaro	2007	Southsouth	Cassava (Edo central)	40	0.91
Erhabor & Emokaro	2007	Southsouth	Cassava (Edo north)	53	0.83
Iheke	2008	Southeast	Cassava	160	0.77
Ojo	2003	Southwest	Poultry	200	0.76
Idiong *et al.*	2007	Southsouth	Rice (swamp)	56	0.77
Idiong *et al.*	2007	Southsouth	Rice (upland)	40	0.87
Bamiro *et al*	2006	Southwest	Poultry	114	0.88
Ajibefun *et al.*	2006	Southwest	Food crops (rural)	100	0.66
Ajibefun *et al.*	2006	Southwest	Food crops (urban)	100	0.57
Awoyemi & Adeoti	2006	Southwest	Cassava (male)	183	0.88
Awoyemi & Adeoti	2006	Southwest	Cassava (female)	104	0.95
Tijani & Baruwa	2008	Southwest	Cacao	126	0.52
Ogundari	2008	Southwest	Rice	96	0.75
Alabi & Aruna	2005	Southsouth	Poultry	116	0.22
Giroh *et al.*	2008	Southsouth	Rubber latex	100	0.80
Aburime *et al.*	2006	Southwest	Bee-keeping	33	0.55
Adepoju	2008	Southwest	Egg Production	86	0.76
Adeoti	2006	Northcentral	Rice (irrigated)	130	0.84
Adeoti	2006	Northcentral	Rice (rain-fed)	104	0.67
Ohajianya	2005b	Southeast	Cassava	180	0.56
Ajao *et al.*	2005	Southwest	Fish	100	0.72
Udoh	2005	Southsouth	Vegetable	320	0.66
Binuomote *et al.*	2008	Southwest	Egg Production	51	0.82
Akanni	2008	Southwest	Fish (MPF)	120	0.65
Akanni	2008	Southwest	Fish (MF)	102	0.80
Ogundari & Odefadehan	2007	Southwest	Cocoa (T & V)	80	0.69
Ogundari & Odefadehan	2007	Southwest	Cocoa (FFS)	80	0.77
Ajibefun	2003	Southwest	Food crops (Ekiti state)	100	0.65
Ajibefun	2003	Southwest	Food crops (Ogun state)	82	0.56
Ajibefun	2003	Southwest	Food crops (Ondo state)	100	0.66
Ajibefun	2003	Southwest	Food crops (Osun state)	93	0.71
Ajibefun	2003	Southwest	Food crops (Oyo state)	86	0.62
Okoruwa & Bashasha	2006	Northcentral	Rice (upland)	120	0.81
Okoruwa & Bashasha	2006	Northcentral	Rice (lowland)	120	0.76
Giroh & Adebayo	2007	Southsouth	Rubber latex	129	0.50
Fapohunda *et al.*	2005	Southwest	Fish	120	0.83
Udoh & Etim	2008	Southsouth	Waterleaf	70	0.82
Effiong & Onuekwusi	2007	Southsouth	Rabbit	60	0.62
Overall average					**0.74**

§All studies cited here employed parametric frontier.

Appendix D: Tables and figures (cont'd)

Table B: Summary statistics of variables for the regression (for Paper II)

Variables	*Unit*	*Symbol*	Statistics			
			Mean	**Std. Dev.**	**Min.**	**Max.**
Total farm output[a]	Naira	Y	2,553.65	2,345.391	60.067	14,532.8
Land	Hectares	X_1	2.318	1.651	1	8.6
Hired labour	Mandays	X_2	141.17	103.103	0	378
Family labour	Mandays	X_3	109.10	76.247	8	437
Fertilizer	Kilogram	X_4	219.81	135.595	0	1650
Pesticide[b]	Litre	X_5	0.975	1.3781	0	10
Materials [c](monetary value, naira ₦)	Naira	X_6	34,755.16	19,359.74	6,200	262,855
Time trend	06/07=0,..08/09=2	X_7	1.026	0.832	0	2
$D_{fertilizer}$ (used=1)	Dummy	D_f	0.728	0.4452	0	1
$D_{pesticide}$ (used=1)	Dummy	D_p	0.521	0.4998	0	1
D_{Hlab} (used=1)	Dummy	D_{hl}	0.668	0.3751	0	1
Age	Years	Z_1	51.304	10.745	25	76
Gender (male=1)	Dummy	Z_2	0.715	0.4516	0	1
Family size	Counts	Z_3	5.382	2.369	0	15
Education	Years	Z_4	9.514	5.371	0	16
Extension	Count	Z_5	6.746	3.660	0	19
Credit (access =1)	Dummy	Z_6	0.667	0.471	0	1
Non-farm income (participation =1)	Dummy	Z_7	0.387	0.487	0	1
Diversification index	Count	Z_8	0.459	0.206	0.210	1
State & Seasons Dummies						
Ekiti	Dummy	D_1	0.214	0.410	0	1
Ondo	Dummy	D_2	0.243	0.429	0	1
Osun	Dummy	D_3	0.167	0.373	0	1
Oyo	Dummy	D_4	0.204	0.404	0	1
Year_2007	Dummy	D_5	0.333	0.471	0	1
Year_2009	Dummy	D_6	0.359	0.480	0	1
No of Observation			**846**			

[a]the total farm output includes aggregated total revenue from cassava, yam, maize, sweet potato and cocoyam deflated by the 2008 consumer price index of 179.80 naira for food; [b]pesticides is expressed as weighted cost of herbicides and insecticides divided by the sum of their respective (Tornquist) price indices; [c]materials is the total costs of planting materials which include the cost of seeds, cuttings, and tubers planted by the farmers.

Appendix D: Tables and figures (cont'd)

Table C1: Summary statistics of variables in the regression (for Paper III)

Variables	Description	Mean	Std. Dev.	Min.	Max
Total value cassava[a]	Total Revenue from cassava in Naira	780.425	708.319	0	6,282.276
Total value of Other crops[b]	Total Revenue from other crops[e] in Naira	1,731.318	1,939.93	0	11,777.9
Land	Total size of the farm in hectare	2.318	1.651	1	8.6
Labour	Total family and hired labour in manday	250.265	128.449	38	647
Fertilizer	Total quantity of fertilizer used in kilogram	219.81	135.595	0	1650
Pesticide[c]	Total quantity of pesticide used in litre	0.975	1.378	0	10
Materials[d]	Total costs of planting materials incurred in Naira	34,755.16	19,359.74	6,200	262,855
Time trend	2006/07=0,2007/08=1 and 2008/09=2	1.026	0.832	0	2
$D_{fertilizer}$	Equal to 1 if fertilizer usage is positive; 0 otherwise	0.728	0.445	0	1
$D_{pesticide}$	Equal to 1 if pesticide usage is positive; 0 otherwise	0.521	0.500	0	1
Age	Age of the primary decision maker in years	51.304	10.745	25	76
Gender	Equal to 1 if the primary decision maker is male	0.715	0.452	0	1
Household size	Total number of households members	5.382	2.369	0	15
Occupation	Equal to 1 if farming is major occupation	0.779	0.415	0	1
Education	Total years of schooling of the decision makers	9.515	5.371	0	16
Extension	Total number of contacts with extension agents	6.746	3.660	0	19
Credit	Equal to 1 if access to credit; 0 otherwise	0.667	0.471	0	1
Off-farm income	Equal to 1 if participated in non-farm income	0.387	0.487	0	1
State & Seasons Dummies					
D_{ekiti}	Equal to 1 if the farms are from Ekiti state	0.214	0.410	0	1
D_{ondo}	Equal to 1 if the farms are from Ondostate	0.243	0.429	0	1
D_{osun}	Equal to 1 if the farms are from Osun state	0.167	0.373	0	1
D_{oyo}	Equal to 1 if the farms are from Oyo state	0.204	0.404	0	1
$D_{2007/08}$	Equal to 1 if its 2007/08 farming season	0.333	0.471	0	1
$D_{2008/09}$	Equal to 1 if its 2008/09 farming season	0.359	0.480	0	1

[a,b] the total value of these items have been deflated by the 2008 consumer price index of 179.80 naira for food; [c]pesticide is expressed as weighted cost of herbicides and insecticides divided by the sum of their respective (Tornquist) price indices; [d]materials is the total costs of planting materials which include the cost of seeds, cuttings, and tubers planted by the farmers. [e]The other crops include aggregated total revenue from yam, maize, potato and cocoyam.

Appendix D: Tables and figures (cont'd)

Table C2: Estimates of the Stochastic Distance Function (Paper III)

Variables	Parameters	Estimates	Std. Dev.	P-value
D_Fertilizer	π_1	0.2249***	0.0404	0.000
D_Pesticide	π_2	-0.0558**	0.0289	0.054
In Othercrops (y_2/y_1)	ψ_m	0.6184***	0.0370	0.000
In Land(x_1)	β_1	-0.1776**	0.0797	0.045
In Labour (x_2)	β_2	-0.6858***	0.0567	0.000
In Fertilizer (x_3)	β_3	-0.1608***	0.0457	0.000
In Pesticide(x_4)	β_4	-0.1520***	0.0472	0.001
In Materials (x_5)	β_5	-0.0169*	0.0091	0.083
Time trend	φ_T	-0.0471**	0.0023	0.036
0.5(In Other crops)^2	ψ_{mm}	0.0926***	0.0331	0.005
0.5(In Land x_1)^2	β_{11}	-0.2881***	0.0915	0.002
0.5(InLabour x_2)^2	β_{22}	0.1651*	0.0900	0.067
0.5(In Fertilizer x_3)^2	β_{33}	0.2517***	0.0931	0.007
0.5(In Pesticide x_4)^2	β_{44}	-0.1108	0.0555	0.842
0.5(In Materials x_5)^2	β_{55}	0.0542	0.0377	0.150
0.5(Time trend)^2	φ_{TT}	0.1272***	0.0322	0.000
In(Other crops) x In(Land x_1)	τ_{m1}	-0.0982**	0.0479	0.041
In(Other crops) x In(Labour x_2)	τ_{m2}	0.0629	0.0475	0.185
In(Other crops) x In(Fertilizer x_3)	τ_{m3}	0.1023***	0.0395	0.010
In(Other crops) x In(Pesticide x_4)	τ_{m4}	0.1145***	0.0388	0.003
In(Other crops) x In(Materials x_5)	τ_{m5}	-0.0651***	0.0249	0.009
In(Other crops) x Time trend	τ_{mT}	0.0641***	0.0233	0.006
In(Land x_1)x In(Labour x_2)	β_{12}	0.0642	0.0766	0.403
In(Land x_1)x In(Fertilizer x_3)	β_{13}	-0.0113	0.0743	0.879
In(Land x_1)x In(Pesticide x_4)	β_{14}	0.1786***	0.0642	0.005
In(Land x_1)x In(Materials x_5)	β_{15}	-0.0275	0.0418	0.510
In(Labour x_2)x In(Fertilizer x_3)	β_{23}	0.1005*	0.0561	0.086
In(Labour x_2)x In(Pesticide x_4)	β_{24}	-0.2056***	0.0747	0.006
In(Labour x_2)x In(Materials x_5)	β_{25}	0.0324	0.0426	0.446
In(Fertilizer x_3)x In(Pesticide x_4)	β_{34}	0.0368*	0.0186	0.052
In(Fertilizer x_3)x In(Materials x_5)	β_{35}	-0.0682	0.0490	0.281
In(Pesticide x_4)x In(Materials x_5)	β_{45}	-0.0083	0.0304	0.786
In(Land x_1)x Time trend	Φ_{1T}	0.0633	0.0403	0.116
In(Labour x_2)x Time trend	Φ_{2T}	-0.1565***	0.0409	0.000
In(Fertilizer x_3)x Time trend	Φ_{3T}	-0.0048	0.0376	0.899
In(Pesticide x_4)x Time trend	Φ_{4T}	0.0481	0.0361	0.183
In (Materials x_5) x In(Time trend)	Φ_{5T}	0.0006	0.0220	0.979
D_2008	Ξ_1	0.1275***	0.0539	0.018
D_2009	Ξ_2	0.1076**	0.0540	0.046
Constant	α_0	-0.1859***	0.0541	0.001
Variance of v_i				
InLand x_1	τ_1	-1.1474***	0.3785	0.002
D_Ekiti	τ_2	-0.4142**	0.2069	0.045
D_Ondo	τ_3	0.0841**	0.0430	0.051
D_Osun	τ_4	-0.2453	0.2995	0.412
D_Oyo	τ_5	0.1991	0.1324	0.133
Constant	τ_0	-2.2355***	0.1946	0.000
Variance of u_i				
Age	α_1	0.0062	0.0076	0.419
Gender	α_2	-0.1312	0.1475	0.374
Family Size	α_3	-0.0253	0.0338	0.455
Major Occupation	α_4	-0.3147*	0.1650	0.057
Education	α_5	-0.0116	0.0129	0.369
Extension	α_6	-0.0484*	0.0261	0.064
Off-farm income	α_7	0.0701	0.1367	0.608
Credit	α_8	-0.3805***	0.1479	0.010
D_Ekiti	δ_1	0.3878*	0.2235	0.083
D_Ondo	δ_2	0.2688	0.2317	0.246
D_Osun	δ_3	0.1486	0.2634	0.573
D_Oyo	δ_4	0.5753**	0.2654	0.030
D_2008	δ_5	-0.6199***	0.2009	0.002
D_2009	δ_6	-0.8474***	0.2150	0.000
Constant	ω_0	-0.4429**	0.1944	0.023
Average TE= 0.7214				

****, **,* denotes statistical significance at the 1%, 5%, and 10% levels, respectively.*
Note: Although the state dummies are included in the production frontier, they are not reported in order to maximize the space in the table because the coefficients are not significance.

Appendix D: Tables and figures (cont'd)

Table D: Summary of the data by state and the seasons

States	Farming Seasons			Total
	2006/2007	2007/2008	2008/2009	
EKITI	78	68	35	181
ONDO	73	64	69	206
OYO	59	44	70	173
OSUN	27	44	70	141
OGUN	45	40	60	145
Total	282	260	304	846

Appendix D: Tables and figures (cont'd)

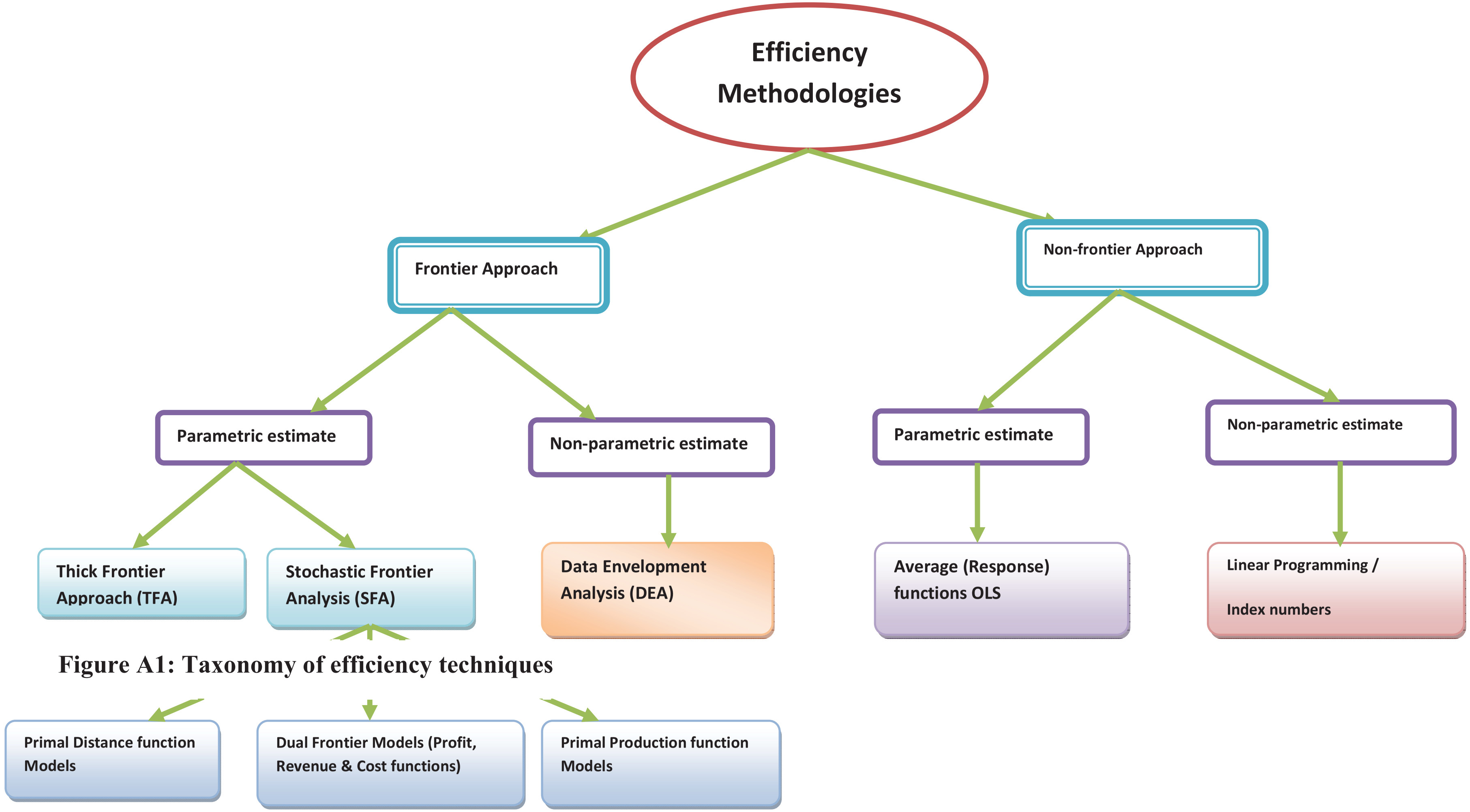

Figure A1: Taxonomy of efficiency techniques

Appendix

Appendix D: Tables and figures (cont'd)

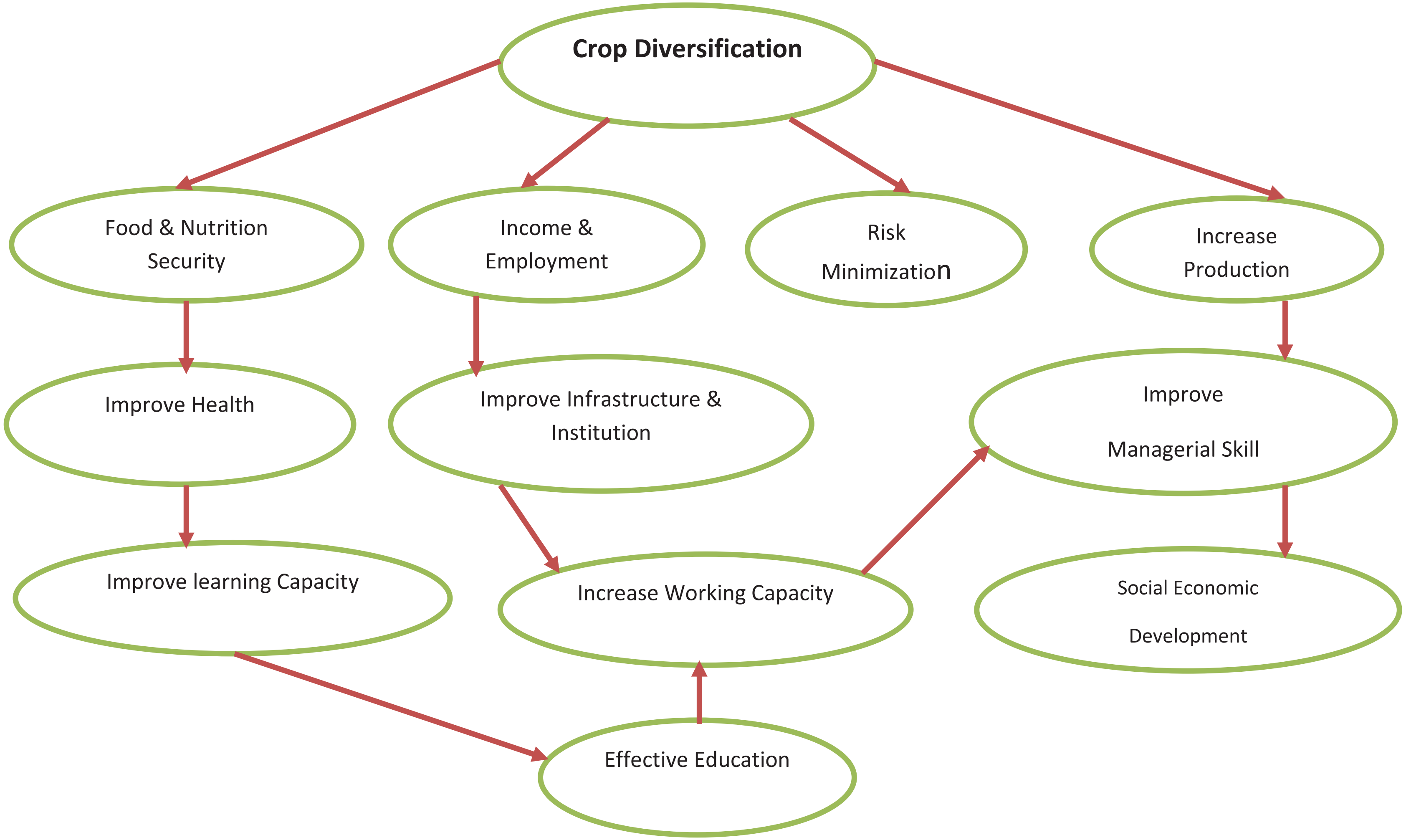

Figure A2: Potential options for engaging in crop diversification

Appendices

Appendix D: Tables and figures (cont'd)

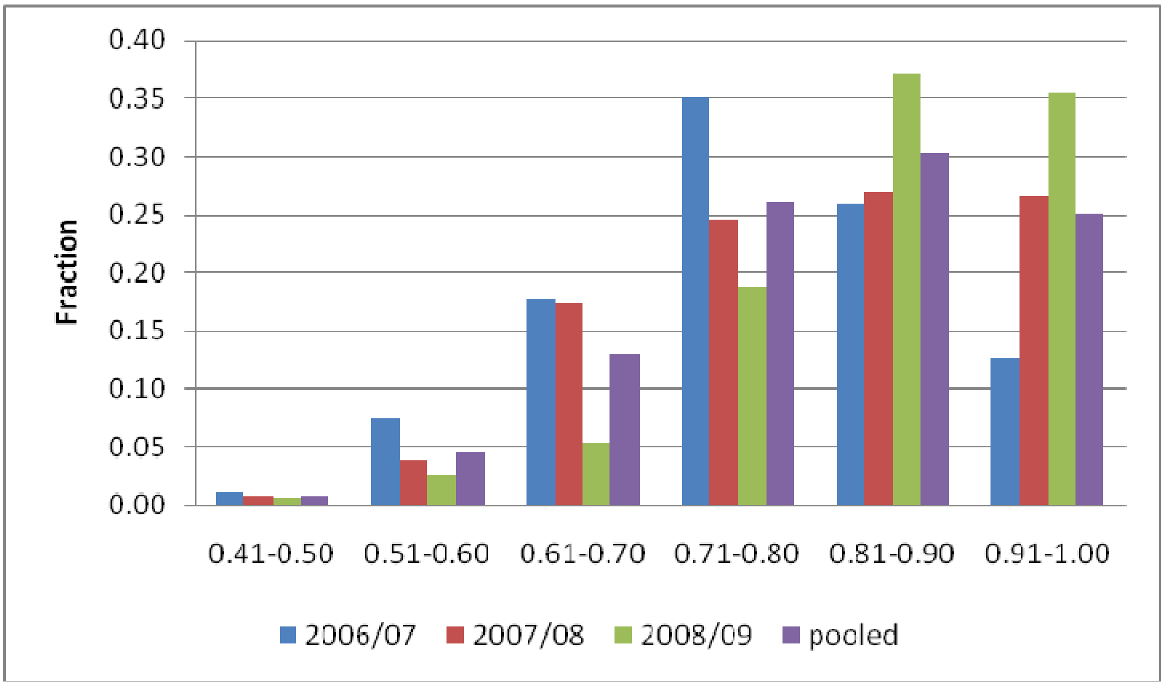

Figure B: Distribution of the technical efficiency scores by whole sample and seasons

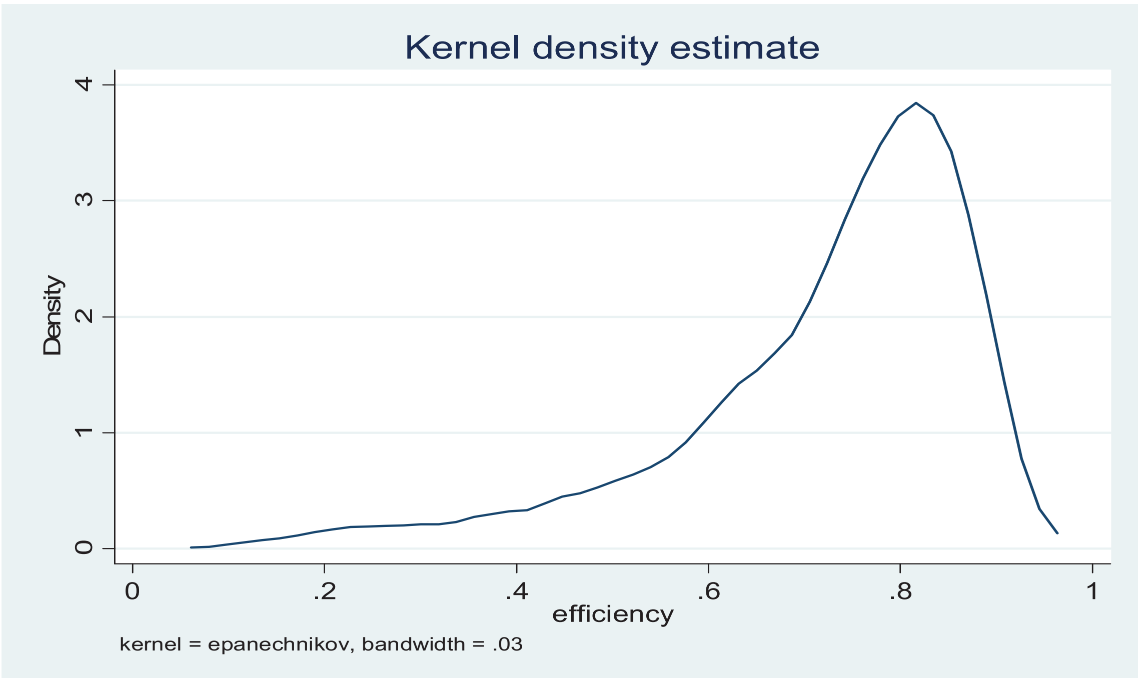

Figure C: Density distribution of the estimated technical efficiency

Appendix D: Tables and figures (cont'd)

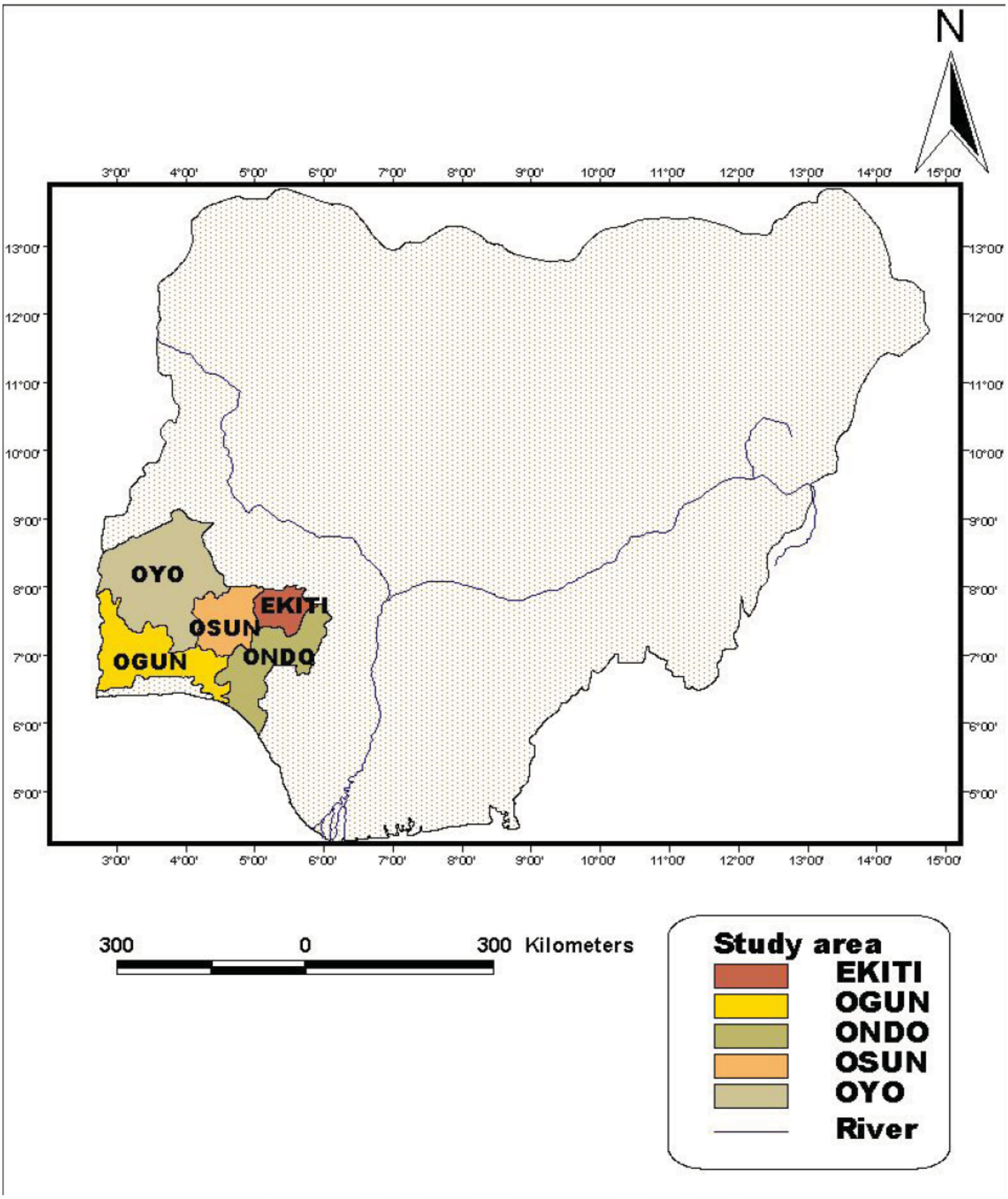

Figure D: Map of Nigeria showing the study area