EFFECTS OF LATE DELIVERY OF FERTILIZER UNDER THE FARMER INPUT SUPPORT PROGRAM ON TECHNICAL EFFICIENCY AND MAIZE PRODUCTION IN ZAMBIA

By

Thelma Sichone Namonje

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Agricultural, Food and Resource Economics — Master of Science

2015

ABSTRACT

EFFECTS OF LATE DELIVERY OF FERTILIZER UNDER THE FARMER INPUT SUPPORT PROGRAM ON TECHNICAL EFFICIENCY AND MAIZE PRODUCTION IN ZAMBIA

By

Thelma Sichone Namonje

This thesis examined the effects of late delivery of subsidized fertilizer on smallholder farmer's technical efficiency and maize production in Zambia using nationally representative cross-sectional household survey data for the 2010/11 agricultural season. A maize yield response model at field level was estimated using a Stochastic Frontier Approach for cross-sectional data. Results indicate that late delivery of fertilizer reduces technical efficiency and maize yield by 4.2%. The estimated results are then extrapolated to quantify the loss in national maize output. The foregone maize output due to late delivery of fertilizer in the 2010/11 farming season was 84,924 metric tons. When valued at the government's maize purchase price, the forgone income is equivalent to USD 21.2 million. Furthermore, by limiting the sample to only households that obtained fertilizer from the Farmer Input Support Program (FISP), a probit model was used to determine whether household and individual attributes affect timely receipt to fertilizer. It was found that households with large landholding size and high value of productive assets were more likely to receive fertilizer on time, *ceteris paribus*. It was also found that households with social connections with village headmen/chiefs were more likely to receive fertilizer on time compared to other households. These results indicate that late delivery of FISP fertilizer is not random and that the relatively poor and marginalized rural households are disproportionately incurring the lower production and income effects of late fertilizer delivery.

I dedicate this work to my parents, my husband and to the memory of my grandmother.

ACKNOWLEDGEMENTS

I would like to extend my gratitude to a number of people who were very instrumental over the entire thesis writing process.

First and foremost, I would like to acknowledge the tremendous support that I have received from my major Professor, Thom Jayne. Thank you, Dr. Jayne for your guidance and encouragement for the past two years. You inspired me to think positively all the time and your encouraging words helped me to work extra hard. I would also like to acknowledge the contributions and feedback from the rest of my committee; Dr. Andrew Dillon and Dr. Robert Richardson.

Special thanks to Dr. Roy Black though he was not formally in my committee, he spent many hours helping me with my analysis. Your constant feedback was invaluable throughout this process. Furthermore, I would like to thank Dr. Nicole Mason who constantly responded to a lot of my questions in a timely manner.

I would also like to express my many thanks to Chewe Nkonde who provided useful comments on my work. And to my friends Brian Mulenga and Mary Lubungu from Indaba Agricultural Policy Research Institute (IAPRI) thank you for responding to my numerous questions concerning the data.

In addition, I would like to thank the MasterCard Foundation Scholars Program for funding my studies and stay here at Michigan State University.

I extend my thanks to the staff and faculty members in the Department of Agricultural Food and Resource Economics. Thanks to all my friends who made me have a memorable time during my stay in Michigan.

Lastly but not the least, I would like to thank my husband Michael Kapembwa who was always the first one to read and comment on my work. Thank you my love for your support throughout this journey. To my parents, thank you for believing in me and for your prayers and constant encouragements.

I am forever indebted to Jehovah God my maker who never ceases to amaze me. Thank you for the many blessings you have bestowed on me throughout my entire life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Introduction and Problem Statement

After having been phased out in the 1990s and early 2000s, farm input subsidy programs have recently been reinstated in Sub-Saharan Africa (SSA) as a major policy tool to expand national food production and food security. Zambia is among the many countries in SSA that have revived farm input subsidy programs over the past decade. In 2002, Zambia introduced the Fertilizer Support Program (FSP) and under this program, the beneficiaries[1] were entitled to 8 50kg bags of fertilizer[2] and 20kg bag of hybrid maize seed. However, in 2009 the Zambian government reduced the size of the input pack per farmer by half to increase the number of targeted beneficiaries and the program name was also changed to the Farmer Input Support Program (FISP). For more details about FISP refer to MACO (2009) and Mason et al. (2013a).

One of the stated goals of FISP is to ensure timely, effective and adequate access to agricultural inputs in form of fertilizer and hybrid seed to smallholder farmers (MACO, 2011). However, timely delivery of inputs has continued to be a major challenge despite persistent calls to correct this problem by farmers and other stakeholders. Given that late application of fertilizer is widely understood to lead to sub-optimal plant growth and hence depress the efficiency with which farmers use fertilizer, it is possible that late delivery of subsidized fertilizer may have a substantial effect on national maize output and even on maize price levels. However, to my knowledge, these issues have never been quantified in Zambia or any other country in SSA.

---

[1] According to the FSP guidelines, individual beneficiaries include smallholder farmers who are members of a registered cooperative/farmer organization and are capable of cultivating 0.5ha of maize.
[2] Fertilizer consists of four 50kg bags of Compound D basal fertilizer and four 50kg bags of Urea for top dressing

Figure 1 depicts a maize field for a particular farmer in Zambia's Choma District. The farmer told an official from the Ministry of Agriculture and Livestock (MAL) that in anticipation of receiving seed and fertilizer from FISP, she had hired a tractor to plough the field in preparation for planting. But due to the delays in delivery of inputs from FISP, she sourced additional funds and purchased inputs from a nearby private fertilizer retailer and planted part of her field. The section on the left is the maize she planted early with the inputs purchased from the private retailer while the section on the right shows the maize she planted when she eventually received inputs from FISP. This example illustrates how smallholder farmers in Zambia can be affected by the late delivery of inputs from FISP. This farmer is one of the few smallholder farmers in Zambia who purchased farm inputs from both commercial traders and FISP.

Figure 1: Maize Field in Choma District

Source: Key informant from MAL (January, 22nd 2014)

According to data collected from 8,839 households participating in the Rural Agricultural Livelihood Survey data (RALS) in 2012, 48.9% of the households acquired fertilizer either from the government or commercial traders in the 2010/2011 agricultural season. And out of these households, 48.7% obtained fertilizer only from FISP and 12.9% acquired fertilizer from both FISP and commercial traders. Of all FISP recipients, 21.48% reported receiving their basal fertilizer after optimal planting time. The farming season may vary slightly in different areas of Zambia depending on the start of the first rains, but normally begins in late November or early December. Most farmers prepare land towards end of October in order to take advantage of the first rains. However, planting and fertilizer application can only be done when these inputs are readily available to the farmers. In a telephone conversation with Mr. Simukondo from the Conservation Farming Unit (CFU) in Zambia, he indicated that planting of maize is considered to be late when it is done in the third week of December and beyond. He further indicated that they encourage farmers to apply fertilizer at two different stages; i) the first "basal" application is done at planting to encourage root growth. And according to Sangoi et al. (2007), fertilizer application before or at planting increases nitrogen availability in the soil during early plant growth and mitigate the yield losses due to nitrogen stress. ii) The second "top dress" application is done when the plant reaches knee high which is approximately 3 to 4 weeks after planting (personal communication, June 26, 2014). Timing of nitrogen application has been reported extensively in the literature (Vetsch and Randall 2004; Hammad et al. 2011; Sawyer 2008) and one of the problems associated with late application of nitrogen is the suppression of maize yield due to nitrogen deficiency. The general conclusion among researchers has been that nitrogen should be applied closest to the time when the plant is absorbing the greatest amounts of nutrients around three weeks after the plant emerges (V6[3] growth stage). The study by Walsh (2006) shows that delayed nitrogen application until the V10 growth stage (five weeks after plant emerges) resulted in decreased yield. Although the impact in any particular year will vary

[3] V6 and V10 refer to vegetative stages in plant growth when plant has six and ten leaves respectively (McWilliams et al. 2010)

according to the timing of rainfall through the season (Sangoi et al. 2007) fertilizers applied after the recommended stages are likely to contribute sub-optimally to plant growth and to yields

In Zambia, late delivery of fertilizer from FISP has been a perennial problem and reports from officials from MAL, as of January 24th, 2014 indicate that farmers were still receiving fertilizer as late as January which is two months after the beginning of the farming season. This problem has persisted for a long time despite government's assurances that inputs will be delivered in a timely manner in the next agricultural seasons. While problems of late delivery of farm inputs has been reported almost every year since the inception of the subsidy program, to my knowledge no study has looked at its effects on foregone national maize production. Nor have previous studies examined whether late delivery is potentially non-random with respect to rural household characteristics, an issue that may have important political economy dimensions. Moreover, private fertilizer wholesalers and retailers have complained that late delivery of FISP fertilizer may create problems that affect the private sector's ability to supply fertilizer in a timely manner as well. Rural retailers and shop owners expressed fears that the quantity of fertilizer demanded at full market price from the private sector would decrease if more farmers acquire fertilizer from FISP. Consequently, the retailers wait to see whether government programs are operating in their area before purchasing substantial amounts of fertilizer for sale in their shops (ZNFU 2008; World Bank 2010). In this way, late delivery of FISP fertilizer may have knock-on effects on the quantity and efficiency of fertilizer acquired through commercial channels. Late delivery of fertilizer can therefore detrimentally affect governments' objectives of increasing fertilizer use and improving productivity among smallholder farmers, and can affect the benefits of the subsidy program relative to its cost. These issues have received little empirical investigation to date.

Therefore, the motivation of this study is to provide relevant information to policy makers about the potential effects of chronic late delivery of inputs under the government's Farmer Inputs Subsidy Programme on farmers' technical efficiency and crop yield, and to estimate the foregone national maize production from late delivery from the FISP program. The study will also identify policy options for improving the input distributions under FISP and addressing some of the concerns that surround the implementation of this program.

1.2 Existing Literature on Input Subsidy Programs

Several studies in the field of international development have investigated the effects of subsidized fertilizer on private sector input distribution (Xu et al., 2009a; Ricker-Gilbert et al., 2011; Mason and Jayne, 2013) and others have investigated the impacts of input subsidy programs on household welfare of smallholder farmers (Mason and Smale 2013; Jacob Ricker-Gilbert 2013).

Ricker-Gilbert et al. (2011) investigated the effects of the subsidy program in Malawi on farmers demand for commercial fertilizer. Their findings indicate that while targeting of fertilizer subsidies to the rural poor contributes to increased fertilizer use, input subsidy programs had a negative effect on farmers' demand for commercial fertilizer. Similarly, Xu et al. (2009a) investigated whether subsidy programs in Zambia "crowd in" or "crowd out" private sector operations. They found that the subsidy program for fertilizer resulted in crowding out of private traders in areas where the private sector had been active. Their findings indicate that when FISP fertilizer goes up by 1kg/ha, use of fertilizer from the private retailers goes down by 0.99kg/ha. They also found that crowding-in effects were more likely to occur in areas with low private sector activity. These findings indicate that the effects of input subsidy programs on total fertilizer use may vary greatly according to the extent to which private input distribution systems are well established in an area.

Other studies have examined the characteristics of input subsidy recipients (e.g., Chibwana et al., 2010; Ricker-Gilbert et al., 2011; Mason and Jayne, 2013). In both Malawi and Zambia, the selection of beneficiaries' under the input subsidy programs affects the degree to which the intended goals of the subsidy programs will be achieved. This is because the income levels of the selected households affect the degree of crowding out of private sector fertilizer sales and also the contribution of the subsidy program to total fertilizer use and maize output. Moreover, the efficiency with which farmers use fertilizer is not uniform, and different beneficiary selection criteria may affect fertilizer use efficiency at the national level (e.g., Ricker-Gilbert and Jayne 2015 forthcoming).

The studies described above confine their analyses to addressing crowding in and crowding out impacts on private sector fertilizer distribution over the past years as the input subsidy programs have been scaled up to address the goal of poverty reduction in SSA. While these studies present useful information in addressing the problems associated with subsidy programs, it is also important to understand how the timing of input delivery affects the levels of efficiency of smallholder farmers and, relatedly, farmer incomes and national crop production levels. The study by Duflo et al. (2011) based on experiments in Kenya show that the availability of fertilizer just after harvest when farm households tend to be in a relatively good cash flow position had a bigger impact on fertilizer use than a situation in which fertilizer was only available at planting time. The authors argue that such small time-limited discounts have a potential to induce substantial increases in fertilizer use than heavy subsidies.

Analyses to date show that there is an increase in the number of beneficiaries (recipients) of subsidized inputs in Zambia (Mason et al. 2013), however late delivery of fertilizer has also continued over the years. To my knowledge, only one study by Xu et al. (2009b) has investigated the effect of timely delivery of fertilizer to smallholder farmers in Zambia on crop yield. They found that timely receipt of fertilizer increased maize yield by 11% overall. Timely receipt of fertilizer is likely to be correlated with the timing of fertilizer application, which has a direct effect on crop yield. However, in Xu et al. (2009b) timely receipt of fertilizer is not specific to a particular fertilizer source, that is, whether fertilizer was obtained on time from the government or private traders. This thesis builds up on the work of Xu et al. (2009b) by using more precise information on how late delivery of FISP fertilizer affects maize yield and technical efficiency of smallholder farmers. The current study also explicitly accounts for the potential endogeneity of timely receipt of subsidized fertilizer in the estimation of the impact on technical efficiency and maize production. The focus of this study is on maize production because Zambia's input subsidy program is largely targeted towards maize producers.

1.3 Study Objectives

Firstly, based on anecdotal reports from Zambia, consignments of fertilizer for distribution through the government subsidy program may arrive in two or more deliveries. This results in the rationing of subsidized fertilizer in the first round; beneficiaries who do not receive their allocation in the first round need to wait until the next consignment arrive. Therefore, some farmers in a particular area receive early while others in the same area receive their allocation later, a pattern that is borne out in the data. For this reason, the distribution of subsidized fertilizer may not be random, and therefore the binary variable of whether a household received fertilizer on time is potentially endogenous. I therefore determine whether timely receipt of fertilizer is affected by particular characteristics of the household, a question not addressed in any prior work on fertilizer subsidy programs in SSA to my knowledge.

Secondly, I investigate to what extent late delivery of subsidized fertilizer affects the level of technical efficiency among smallholder farmers in Zambia. I define technical efficiency as the ability of a farm to produce maximum possible output with the available combination of inputs. In most cases firms and farmers alike rarely operate at their technically efficient levels due to a number of reasons such as weak management skills, lack of information, distance to major roads and many other factors. Among many other inefficiency variables that have been highlighted in literature (Chirwa 2007; Liu and Myers 2008; Seyoum et al. 1998), I include late delivery of subsidized fertilizer to evaluate its impact on technical efficiency. I also estimate the distribution of technical efficiency for farms where households reported to have received fertilizer late and those that received it on time. Thirdly, I determine how much national maize output is lost due to late delivery of FISP fertilizer to the farmers. In doing so, I address the following research questions.

1.4 Research Questions

Research Question 1: Does the timeliness of receipt of subsidized fertilizer vary across FISP beneficiaries in Zambia? Are there specific household and individual factors that affect timely receipt of fertilizer?

Why is this question important? Abundant evidence from the political economy literature suggests that goods and services allocated through government programs may favor relatively well connected individuals and households (Van de Walle 2001). It is possible that the preferential status of well-connected and influential individuals may also explain household-level variations in the timeliness of services and goods provided through state allocation processes. This would in turn shed light on the impacts of state expenditures on the achievement of rural poverty reduction goals. Notably, the FISP in Zambia is explicitly budgeted under the government's Poverty Reduction Strategy Programme. To the extent that the rural poor make less efficient use of subsidized fertilizer as a result of receiving it late, this may affect the government's poverty reduction goals. Moreover, if late delivery is correlated with certain household characteristics, these results would need to be taken into account in studies designed to identify whether certain kinds of farmers (e.g., those with greater farm sizes, wealth, or education) affect the efficiency with which farmers use inorganic fertilizers.

Research Question 2: To what extent does late delivery of subsidized fertilizer contribute to technical inefficiency among smallholder farmers?

Why is this question important? The Zambian government has devoted between 25 and 45 percent of its annual agricultural budget to input subsidy programs over the past decade. Though the subsidy program may have improved farmers' access to agricultural inputs, late delivery of such inputs often affects the efficiency with which inputs are utilized. Estimating the magnitude of the effect of late delivery on technical inefficiency may shed light on the urgency of policy interventions to address the problem. The subsidy program is intended to improve agricultural productivity among smallholder farmers it is therefore important to provide evidence based information to the government on the effect of late delivery of fertilizer on farmers' efficiency in maize production.

Research Question 3: How much national maize output is foregone due to late delivery of fertilizer to the farmers?

Why is this question important? Policy debates have recognized the challenges that arise in the context of input subsidy programs including the huge budgetary burden they impose on most developing countries. But because most of subsidy programs like the FISP have been applauded for raising national output for staple grains like maize, the programs have remained a popular tool that policy makers continue to view as effective for achieving national food security goals. However, the forgone national food production attributable to late delivery of inputs under government subsidy programs has not been extensively discussed in policy debates. This study therefore estimates the effect of late delivery of FISP fertilizer on aggregate national maize output for the case of Zambia.

1.5 Study Contributions

This thesis contributes to a number of innovative insights about the performance of fertilizer subsidy programs in Zambia, with potentially broader implications for Africa. Firstly, this is the first analysis to evaluate the effects of late delivery of subsidized fertilizer on technical efficiency of smallholder farmers in SSA. Second, this is the first study that treats late receipt of subsidized fertilizer as endogenous in the estimation of the impact of late delivery on outcomes. Lastly, this study considers how farm income and maize output are affected by late delivery of government fertilizer.

These contributions are aimed to provide policy makers in Zambia with accurate information on how important national policy goals are affected by late distribution of subsidized fertilizer, a problem that has persisted since the re-introduction of government input subsidies on a large scale.

CHAPTER 2: DISTRIBUTION OF FISP FERTILIZER IN ZAMBIA

2.1 FISP Distribution System

In 2002, the Zambian government initiated the Fertilizer Support Program (FSP), now called Farmer Input Support Programme (FISP), which aims to improve access to farm inputs (fertilizer and seed) by smallholder farmers. Since 2002, the input subsidy program has expanded in terms of funds allocated to the program and the number of beneficiaries (see details in Mason et al., 2013a). While this increase may be an indication of increased use of fertilizer and subsequent increased maize output, the subsidy program has been characterized by a number of challenges in its implementation. Since its inception, FISP has been implemented by the Ministry of Agriculture and Cooperatives (MACO), now called Ministry of Agriculture and Livestock (MAL). One of the main challenges with the implementation of the program is serious delays in delivering inputs to the farmers. According to the FISP implementation guidelines (MACO 2010), inputs are supplied by private suppliers (fertilizer private companies) who are selected by the government through a tender process. Compound D, a basal fertilizer to be applied at planting time, is usually supplied by Nitrogen Chemicals of Zambia, a state-owned company (Baltzer and Hansen 2011). Urea, a top dress fertilizer to be applied 3 to 4 weeks after planting is imported by the two private fertilizer companies (Omnia fertilizer Zambia Limited and Nyiombo Investments Limited). These two firms have been awarded the contracts for urea distribution under the FISP every year since the inception of the program in 2002 (Baltzer and Hansen 2011; Mason et al., 2013a). The suppliers deliver fertilizer to the main fertilizer depots in the districts and local transporters within the district deliver the inputs to designated collection point. The local transporters ensure that inputs are received by the farmer organizations within the districts

(MACO, 2010). Figure 2 shows a summary of the distribution channel for the subsidized fertilizer.

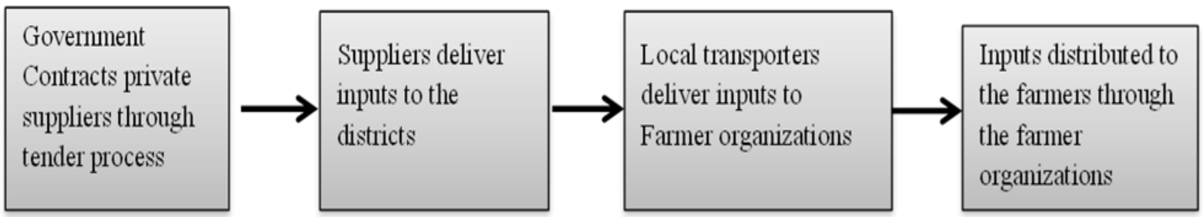

Figure 2: Distribution Channel for FISP Fertilizer

Source: FISP implementation Manual (MACO, 2010)

While the FISP guidelines have stipulated that inputs should be available for retrieval by farmers before the beginning of the agricultural season in November, about 21.48% of the FISP beneficiaries reported to have received their basal fertilizer late. The delays in delivery of inputs are often due to government budgeting procedures and programme administration. The budget allocation to FISP changes every year and stakeholders (farmers, private traders etc.) do know how many subsidized input packages will be distributed until the budget is approved by parliament (Baltzer and Hansen, 2011). Prior to 2011, the Zambian fiscal year was running from 1st April to 31st March and this therefore meant that once there is a delay in approving the budget by the parliament, contracting the private suppliers to procure fertilizer would also be delayed. However, though the Zambian fiscal year has since changed to run from 1st January to 31st December and government announces the budget by 31st of October, delays in fertilizer procurement have still continued. During an interview with Mr. Banda from the Ministry of Agriculture and Livestock (MAL), he indicated that government often delays in procuring fertilizer even when the budget has already been approved and this has led continuous delays in distributing fertilizer under FISP. He also indicated that the other source of delay is due to transportation challenges from the main fertilizer depots to the farmer organizations/cooperatives within the districts. This has since led to the delivery of FISP fertilizer in multiple consignments to a particular area. The early consignments of FISP fertilizer are therefore rationed, and consequently some farmers receive their fertilizer earlier than others (personal communication, August 7, 2014). Sometimes, delays in delivering fertilizer are due to lack of payment to the suppliers. For example, in the 2007/08 agricultural season, the contracted suppliers suspended fertilizer deliveries due to lack of payments from the government (ZNFU, 2008). This therefore meant that farmers who had paid for fertilizer could not receive their supplies in time for application. The other implication of late delivery of inputs is that FISP beneficiaries are required to make up-front payments for the inputs and this ties up their scarce resources to FISP and makes it difficult to purchase inputs from alternative input providers even when they are available.

2.2 Fertilizer Delivery from Government and Private Retailers

This section uses household survey data to examine fertilizer delivery patterns for both government and private retailers over the 2006 to 2012 period. Figure 3 below shows the percentage of households that reported to have received basal fertilizer late either from government or private retailers for the 2006/07 to 2011/12 agricultural seasons. The pattern displayed on the graph shows that there is a positive correlation between the timing of delivery of fertilizer from FISP and the private retailers. For periods between 2007/08 and 2008/09 when there was a higher percentage of households receiving fertilizer late from FISP, the graph shows a similar pattern for basal fertilizer from private traders. Though causality cannot be established here, the graph shows that when fertilizer from FISP is delivered late, there is a higher likelihood that farmers receive their inputs late from the private sector as well.

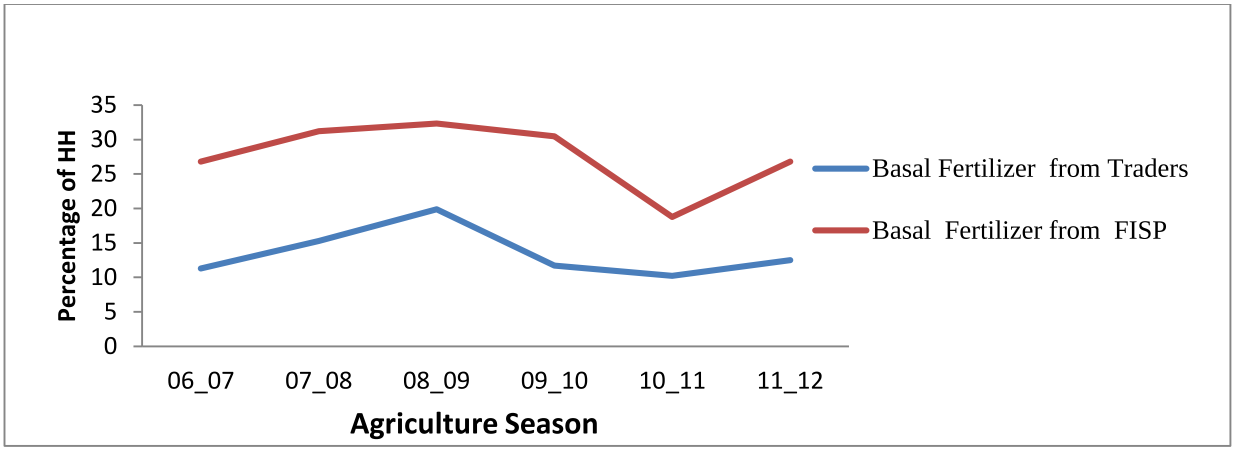

Figure 3: Percentage of Households that reported to have received basal fertilizer late

Source: Own calculations using MACO/CSO Crop Forecast Surveys, 2008/09-2011/12 and Supplemental Survey 2008

Based on anecdotal reports, private fertilizer distributors in Zambia have indicated that they often wait to see where FISP is operating and the quantities of FISP inputs to be distributed in a particular area to avoid over stocking (ZNFU, 2008). This therefore implies that if the Zambian government delays in distributing the FISP fertilizer, private fertilizer retailers might in some cases stock their fertilizer late as well. The delays in delivery of FISP fertilizer may have negative implications on the operations of the private traders and also on farmers relying on commercial channels for their farm inputs. Though this is not the focus of this study it is important to highlight some of the known challenges that are imposed on the operations of the private fertilizer retailers due to late delivery of FISP fertilizer.

2.3 Distribution of Fertilizer Sources by Province

Fertilizer in Zambia is predominantly used for maize production by the smallholder farmers. Out of the smallholder farmers that had maize fields in the 2010/11 agricultural season, 58.1% acquired fertilizer either from FISP or commercial traders. Based on statistically representative household survey data to be described in Section 3, Table 1 shows the distribution of fertilizer sources for the households that used fertilizer on their maize fields within the provinces and the share of households that had maize fields in the 2010/11 agricultural season. Column 2 shows the proportion of households that had at least one maize field while column 3 shows the percentage of households that used fertilizer on their maize fields. The table clearly shows that most households had maize fields in the 2010/11 farming season however, there is a wide variation in terms of fertilizer use within the provinces. Column 3 shows that the majority of the households in Western Province did not use fertilizer on their maize fields. Central and Lusaka provinces recorded the highest percentage of households applying fertilizer on their maize fields. Columns 4, 5 and 6 of Table 1 further breaks down the sources of fertilizer for the maize-growing households in the provinces. With exception of Central and Southern provinces, the main source of fertilizer for smallholder farmers in Zambia is from FISP with values ranging from 29.21% to 81.85%. Central Province has the highest percentage (50.15%) of households purchasing fertilizer only from commercial traders while Northwestern province shows that over 80% of the smallholder farmers purchased fertilizer from FISP only. Column 6 in Table 1 shows that with exception of Eastern and Southern provinces, most of the smallholder farmers rarely purchase fertilizer from both commercial traders and FISP. Northwestern Province recorded the least with only 3.30% of the households purchasing from both FISP and commercial traders. From Table 1, I can infer that FISP is the main source of fertilizer for smallholder farmers.

Table 1: Distribution of fertilizer sources in provinces & proportion of HHs with Maize fields

Province	Proportion of HHs with Maize field	% HH that used Fertilizer on maize fields	Fertilizer Source		
			FISP Only %	Commercial Traders Only%	Both sources%
Central	0.95	76.4	29.39	50.15	20.45
Copperbelt	0.96	68.2	40.68	31.14	28.18
Eastern	0.98	56.7	44.62	21.28	34.09
Luapula	0.62	61.1	60.47	23.01	16.52
Lusaka	0.99	76.6	39.78	37.28	22.94
Muchinga	0.85	70.6	51.05	29.37	19.58
Northern	0.65	70.9	57.65	18.51	23.84
N/Western	0.86	49.8	81.85	14.85	3.30
Southern	0.93	48.2	29.21	35.57	35.22
Western	0.83	14.9	72.57	10.62	16.81

Source: Own calculations using RALS Data 2012

One of the expected outcomes of a subsidy program like FISP is increased maize production among the beneficiaries. However, the program does not appear to have a substantial effect on maize yields among the program participants. According to the findings by Mason et al. (2013a), a 1 kg of subsidized fertilizer on average increased maize output by only 1.88 kg. The magnitude of the effect of the subsidized fertilizer on maize output is quite contrary to the expectation. Late delivery could be one of the underlying reasons for such a small magnitude.

Studies that have looked at maize yield response to fertilizer have underscored the importance of timeliness of fertilizer application (Jones and Jacobsen 2003; Xu et al. 2009b). Agricultural production in Zambia by the smallholder farmers is predominately rain-fed and this makes their maize production vulnerable to changes in the rainfall patterns. According to Jones and Jacobsen (2003), timing of fertilizer application is essential for optimizing both yield and quality. They further indicate that proper timing of fertilizer application reduces nutrient losses, increases the efficiency of nutrient usage and prevents damage to the environment.

Figure 4 shows the percentage of households receiving basal fertilizer late. From the graph below Copperbelt and Luapula provinces had a higher percentage of households that reported to have received fertilizer late. On the other hand Lusaka and Eastern provinces had a small percentage of households receiving basal fertilizer late. There is considerable variation within the provinces with regard to timely receipt of fertilizer.

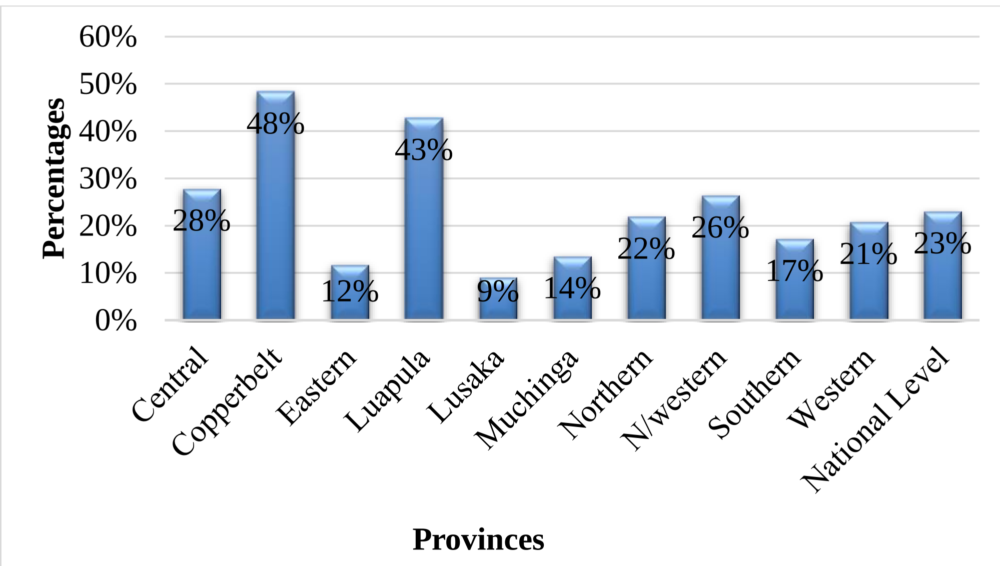

Figure 4: Percentage of households that received basal fertilizer late in 2010/11 by province

Source: Own calculation using RALS Data 2012

CHAPTER 3: DATA AND SAMPLE SELECTION

3.1 Data

The data used in this study are based on the Rural Agricultural Livelihoods Survey (RALS) which was conducted by the Central Statistics Office (CSO) and the Ministry of Agriculture and Livestock (MAL) in collaboration with Indaba Agricultural Policy Research Institute in Zambia. RALS was conducted in 2012 and it covers the 2010/11 agricultural season. The RALS data set provides comprehensive information on 8,839 households and it derives its sampling frame from the Zambia 2010 census. This data is statistically representative at the provincial level of rural farm households cultivating less than 20 hectares of land for farming and/or livestock production purposes. For details of the RALS sampling frame see IAPRI (2012).

3.2 Sample Selection

In this section, I describe the sample selection used for the analysis. This study addresses the three research questions outlined in Section 1. Two different models are estimated and each model has a specific sub-sample. From the 8,839 households that were interviewed for RALS, 48.9% (4,886 households) acquired fertilizer from either the government under FISP and/or from the private fertilizer retailers. Given that the overall goal of this study is to understand the effect of late delivery of FISP fertilizer on maize production, the sample of interest is households that acquired fertilizer in the 2010/11 agricultural season. I further break down the 4,886 households into two categories; (i) households acquiring fertilizer from the government (n=3,359), and (ii) households acquired fertilizer from the private fertilizer retailers (n=2,567). It should be noted that of these two groups, 1,040 households acquired fertilizer from both the government and private channels.

I. *Sample for the first Research Question: Are there specific household and individual factors that affect timely receipt of fertilizer?*

During the RALS interviews, households were asked whether fertilizer from a particular source (government or private channel) was available to them when they needed it. And from the households that acquired fertilizer from FISP, 21.48% and 20.74% reported to have received basal and urea fertilizer late respectively. The first objective is to determine whether household characteristics and other social-economic factors affect timely receipt of fertilizer from FISP. To address this objective, I narrow my focus to households that acquired fertilizer from FISP and use the household as the unit of observation to determine the factors influencing timely receipt of fertilizer. Since the dependent variable takes a value of 1 if the household received fertilizer on time and 0 if otherwise, I utilize a binary response model to answer this question. Details of the model specification and variables used are outlined in Chapter 5.

II. *Sample for the second and third objective: To what extent does late delivery of subsidized fertilizer contribute to technical inefficiency among smallholder farmers?*

The second and third objectives are the core elements for this study. I determine the effects of late delivery of FISP fertilizer on technical efficiency of smallholder farmers and maize output. While fertilizer acquired through FISP can be used on various crops, the intended purpose of FISP is to increase maize productivity of the smallholder farmers since maize is the staple crop for the majority of the Zambian population. For these two objectives, I keep maize fields as the unit of analysis. Field-level data are available for each sampled household and out of the 8,839 households in the data set, 7,425 households had at least one maize field (84%). However, out of these 7,425 households that had maize fields in the 2010/2011 agricultural season, about 58.2%

(4,322 households) used fertilizer on their maize fields. Though the unit of analysis for the second and third research question is maize fields, I limit it to households that had at least one maize field and acquired fertilizer from FISP for the 2010/11 agricultural season. Since I intend to estimate the effect of late delivery of FISP fertilizer on maize production among the FISP participants, non-fertilizer using households will not appear in the estimation because they would not have any impact on yield or national maize production resulting from late FISP delivery. However, to estimate the foregone national maize production due to late delivery of fertilizer, I include all households that used fertilizer. For the selected sample, some of the households had multiple maize fields but the majority only had one field. Maize is often intercropped with other crops in Zambia but for this sample, only 2.29% (87 fields) of the fields were intercropped. Since the percentage of intercropped fields is very small I do not expect this to affect the estimated yield. The data used include observations at field level, household, Standard Enumeration Area (SEA) and cluster level.

3.3 Other Data Sources

I supplement the RALS data with other data from different sources to answer my second and third objective. The data include; (i) dekad (10-day period) rainfall data for the 2010/11 growing season which is available at cluster level. This rainfall data was obtained from TAMSAT and more details can be obtained on http://www.met.reading.ac.uk/tamsat/about/; (ii) Soil types and pH data used in the study are available at Standard Enumeration Area level (SEA) and were published by the Ministry of Agriculture and Cooperatives (MACO); and (iii) data on percentage of households reporting to have received fertilizer late either from FISP or the private traders obtained from MACO/CSO crop forecast surveys 2008/09 - 2011/12 & supplemental survey 2008. Details of the variables used for estimating the second model are discussed in Chapter 6.

CHAPTER 4: CONCEPTUAL FRAMEWORK AND METHODS

4.1 Production Theory

A typical rural household in Zambia function as a multiproduct firm deriving income from of agricultural production of various crops and other activities. I therefore assume that smallholder households organize their labor and other farm resources with the objective of maximizing utility subject to the various constraints across all farm enterprises. Agricultural production plays a key role in the Zambian economy accounting for over 70% of the labor force in rural communities. While there are many crops that are produced by smallholder farmers in Zambia, this thesis focuses on maize because of its importance as a staple food crop and also in the input subsidy program in Zambia.

Maize yield (Y) on field i is modeled as a function of a vector of physical inputs and other factors that may affect yield. The general form for yield function is given by:

$$Y_i = f(X_i, Z_i, \varepsilon_i) \qquad (4.1)$$

Where Y represents maize yield, X is a vector of inputs used such as seed, fertilizer and labor; Z is a vector of other shifters which includes household characteristics that are likely to influence yield; and ε is the error term that captures unobservable characteristics in the production function that may affect yield. Equation 4.1 shows a production function which is simply a relationship between the level of inputs and the resulting level of output (yield). Given the equation above, I can derive the marginal physical product (MPP) and average physical product (APP) of each input X. The MPP of an input describes an additional level of output that can be produced by employing one more unit of that input while holding other inputs constant and it is derived by taking the first derivate of Y with respect to that input.

$$MPP_{Xi} = {}^{\partial Y_i}/_{\partial X_i} \tag{4.2}$$

Furthermore, the average physical product (APP) is calculated as output divided by input and it is a measure of efficiency of input use.

$$APP_{Xi} = {}^{Y_i}/_{X_i} \tag{4.3}$$

Estimating production functions requires all relevant inputs to be included in the model to avoid specification bias. However with the use of household survey data it reasonable to assume that some of the important covariates that affect yield are unobserved for example management skills of the farmer may appear in the error term (ε_i). Management skills are often reflected in the choice of inputs and input utilization which has an effect on potential yields. It is therefore reasonable to believe that management skills are likely to be correlated with the X and Z variables. A number of techniques have been developed which can be applied to ensure that the estimated parameters are unbiased and consistent. If the unobserved covariates are time invariant, the use of panel dataset helps to mitigate the problem of unobserved heterogeneity by applying techniques such as random effects (RE), fixed effects (FE) and correlated random effects (CRE) (see details in Wooldridge 2010). However if the unobserved covariates are not time invariant a different approach is required to achieve unbiased and consistent estimates of the parameters. In the same lines some of the components in the Z variables may include sample and selection bias issues hence the need to control for and mitigate such sources of bias.

4.2 Concept of Production Frontier Functions

One assumption of production theory is that it presupposes full technical efficiency among producers in the sense that firms (farms) are assumed to be producing maximum possible output for any combination of inputs. However, there exists a gap between the theoretical assumption of technical efficiency and reality hence the need to measure it. Farmers and firms alike may be operating beneath their production frontier owing to incomplete knowledge of best practices or due to poor management skills. In this study, I model the production function by incorporating technical inefficiency. This is motivated by the idea that deviations from the production frontier might not be entirely under the control of the farm being studied. I therefore measure the effect of late delivery of subsidized fertilizer on technical efficiency of smallholder farmers and maize output. While late delivery of fertilizer may not have a direct effect on maize output, it does affect the efficiency with which inputs are utilized in terms of timing of planting and fertilizer application.

To account for and estimate the extent of technical inefficiency, production frontier functions are often used. This study therefore uses a frontier production function as opposed to the traditional production function to estimate the effect of late delivery of subsidized fertilizer. One major advantage of frontier production functions is their ability to estimate the level of technical efficiency of individual firms and also account for the sources of inefficiency that prevent firms from operating at their full potential.

The principal behind efficiency measures involves comparison of observed output with the potential (or attainable) output. However, the potential output is not known in practice and thus must be estimated. Two quantitative approaches are commonly used for frontier estimation; parametric (Stochastic Frontier Approach) and non-parametric (Data Envelopment Analysis) which involve econometric methods and mathematical programming techniques, respectively (Greene 2008). The major difference between the two approaches which has been highlighted in most literature is that parametric frontier approaches imposes a functional form on the production function and makes assumptions on the distribution of the one-sided error term. While non-parametric approach does not impose any functional form on the production function nor does it make assumptions about the distribution of the error term. The main strengths of Stochastic Frontier Approach (SFA) are that not only does it allow for technical inefficiency, but also deals with the random errors arising from statistical noise or measurement errors (Coelli, 1995). The error term in the stochastic frontier model is composed of two parts; a symmetric component which captures the random effects outside the control of the firm as well as a one-sided component that captures the effects of inefficiency (Cullinane et al. 2006).[4] For the purpose of analysis, this thesis will pursue stochastic frontier approach as opposed to Data Envelopment Analysis.

4.3 Methods

This study follows a model specification of the stochastic production frontier as outlined by Battese and Coelli, (1995). The model is composed of the stochastic frontier which serves as a standard against which firm's efficiency is compared and a non-negative random error term which represents technical inefficiency. Measures of efficiency levels involve estimating the unknown production frontier which is defined as:

$$Y_i^* = X'_i\boldsymbol{\beta} + V_i \qquad (4.4)$$

Where Y^* is unobserved frontier output on field i, (i is equal to 1, 2… N); X_i is a vector of explanatory variables (inputs) that determine the yield; β is a vector of unknown parameters to

[4] Data Envelopment Analysis (DEA) is deterministic and does not allow for possible influence of measurement errors. It assumes that all observed deviations from the estimated frontier are a result of technical inefficiency.

be estimated and V_i is a symmetric random error which accounts for any random variations in production due to factors outside the control of the farmer (such as climate, measurement errors, etc.) and is assumed to be independently and identically distributed as $N(0, {\sigma_v}^2)$. The actual (observed) output Y equals the frontier (Y^*) minus a one-sided error term U_i which captures the technical inefficiency. The basic stochastic model is given by:

$$Y_i = \alpha + X_i\beta + V_i - U_i \quad (4.5\ )$$

Where Y_i is expressed as a log of output/yield and X_i is a vector of inputs expressed in log form. The one-sided error term measures the extent to which observed output deviates from potential output. The two error terms: V_i and U_i are independent of each other. The technical inefficiency term (U_i) is assumed as a function of a vector of explanatory variables (Z_i) and unknown parameters (δ) to be estimated. In a linear equation, the technical inefficiency effects can be specified as follows:

$$U_i = \delta Z_i + W_i \quad (4.6)$$

Where W_i is an unobservable random variable, which is defined by the truncation of the normal distribution with mean zero and variance (σ^2). The model specification for technical inefficiency (U_i) in Eqn. (4.6), follows the model proposed by Battese and Coelli (1995) and Kumbhakar et al., (1991). In this case, the inefficiency term is composed of the deterministic component explained by the exogenous variables (Z_i). The unobservable random variables (W_i) may include farmer's ability, management skills among others. The distribution of the U_i is commonly assumed to be half-normal which is denoted as $N(0, \sigma_u^2)$ but there are other distributional specifications which are outlined in detail by Greene (2008). A positive coefficient in δ indicates that an increase in the corresponding exogenous variable (Z_i) increases mean technical inefficiency and it also increases the variance of the technical inefficiency (Amsler et al. 2013).

The parameters in Eqns. (4.5) and (4.6) can be estimated using a one-step maximum likelihood method which is generally proposed for simultaneous estimation of the stochastic frontier and the inefficiency term. Previously, technical efficiency was estimated using a two-step procedure where the frontier function was estimated first using a normal production function and secondly the inefficiency term was regressed on the exogenous variables in the second step. But the two-step procedure often produces biased results and this has been extensively discussed by Wang and Schmidt (2002) .

Technical efficiency of each individual farm is defined as a ratio of the observed output to the corresponding frontier output conditioned on the levels of inputs used by the farm. And by construction the technical efficiency of a firm is between 0 and 1 and is inversely related to the level of technical inefficiency effects $(-U_i)$. The technical efficiency of production is therefore defined by:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{\exp(x_i\beta + V_i - U_i)}{\exp(x_i\beta + V_i)} = e^{-U_i}$$

$$= e^{-(Z_i\delta + W_i)} \quad (4.7)$$

The technical efficiency estimates in Eqn. (4.7) are predicated after estimating the stochastic frontier model using MLE method. The likelihood function is estimated in terms of the variance parameters $\sigma_s{}^2 \equiv \sigma_u{}^2 + \sigma_v{}^2$ and $\gamma \equiv \sigma_u{}^2/(\sigma_s{}^2)$. The parameter γ is the ratio of the error variances from Eqn. (4.5) and it has a value between zero and one (Battese and Coelli, 1995). If

γ equals zero, then the model reduces to a traditional mean response function in which Z_i can be directly included into the production function (Suyanto, Salim, and Bloch 2009).

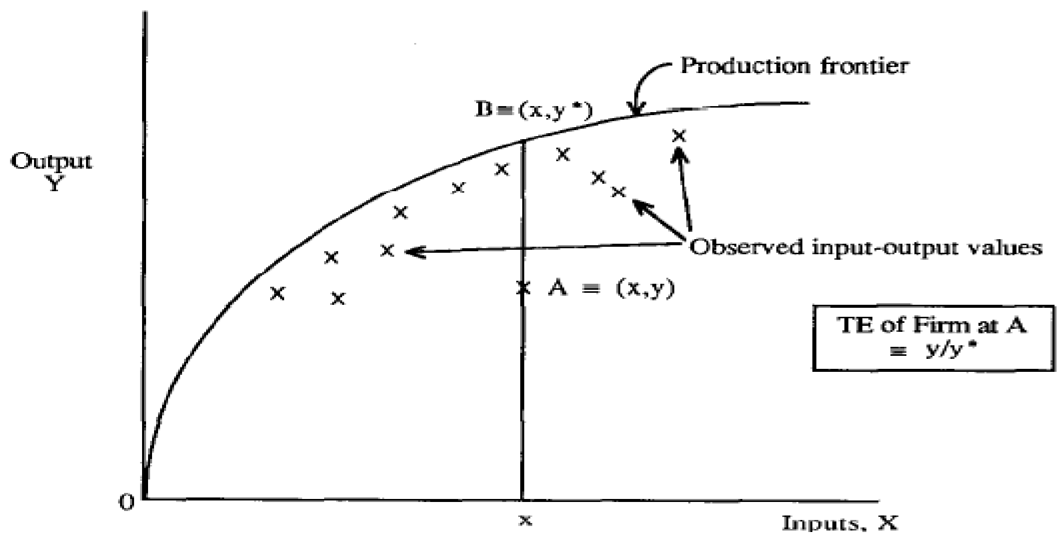

Figure 5: Technical Efficiency of Firms in Input-Output Space

Source: Battese, (1992)

From Figure 5, potential output (frontier output) for a given farm can be calculated once the technical efficiency indices have been estimated.

$$\text{Potential output} = \frac{\text{Observed output}}{TE} \qquad (4.8)$$

4.3.1 Functional Form for production frontier

Estimation of stochastic frontier model requires imposing a functional form on the production function. Identification of the functional form that best fits the given data for SFA is critical as the choice of the functional form may have some implications for the estimated results. In view of that, I conduct hypothesis test to choose the appropriate functional form that best fits the data used for this study. Two functional forms are commonly used in the estimation of stochastic frontier models; Cobb-Douglas and Translog functional forms. Both functional forms are linear in parameters and thus can also be estimated in a linear regression framework. However, the Translog presents a more flexible functional form as opposed to the Cobb-Douglas production function and can be used for the second order approximation (Coelli et al. 2005). The functional form of the stochastic frontier in this study is determined by testing the adequacy of the Cobb-Douglas relative to the less restrictive Translog. Since the two equations are nested a likelihood ratio (LR) is used to test the null hypothesis that the Cobb-Douglas production function is an adequate representation of the data.

i) Cobb-Douglas production function

$$\ln(Y_i) = \beta_0 + \sum_{i}^{n} \beta_i \ln X_1 + v_i - u_i \tag{4.9}$$

ii) Translog production function

$$\ln(Y_i) = \beta_0 + \sum_{i}^{n} \beta_i \ln X_1 + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln X_i \ln X_j + v_i - u_i \tag{5.0}$$

The appropriate functional form for this study is determined by the likelihood ratio (LR) test result which is presented in Chapter 6.

4.3.2 Distribution assumption for one-sided error term

As indicated in section 4.2, for the stochastic frontier model to be estimable one needs to make an assumption about the distribution of the inefficiency term(U_i). Three types of distributions are commonly used in literatures; half-normal, exponential and truncated normal distributions. However there is no prior justification for choosing one distributional form over the other, since all three have advantages and disadvantages and the choice of distributional specification is often a matter of computational convenience (Coelli et al. 2005). This study estimates the stochastic frontier model using sfcross command in Stata as outlined by Belotti et al. (2012) and in order to estimate the partial effects of the variables (Z_i) in the inefficiency term, the appropriate distribution for U_i is a truncated normal. I therefore assume that the distribution of technical inefficiency term (U_i) for this study is truncated normal specified as $N^+(\mu_i, \sigma_i^2)$. Past studies that have assume a truncated normal distribution include; Wang (2002) and Amsler et al. (2013).

4.3.3 Controlling for Heteroskedasticity

One of the challenges with using survey data is the problem of heteroskedasticity. Heteroskedasticity is a violation of one of the requirements of ordinary least squares (OLS) in which the error variance is not constant. Therefore, the best place to start when conducting the heteroskedasticity test is to run an OLS regression. The consequences of heteroskedasticity are that the estimated coefficients are unbiased but inefficient I therefore test for heteroskedasticity before running the stochastic frontier model. The details of the test are outlined in Chapter 6.

4.3.4 Controlling for Endogeneity

First and foremost, I recognize that distribution of fertilizer to the FISP beneficiaries within a community is not done randomly; some households receive it earlier than others. It is likely that the variable of interest in the inefficiency term, "fertilizer received late" is correlated with the unobservable factors (W_i). This is because the distribution of fertilizer maybe based on individual and household specific characteristics. I therefore suspect that timely receipt of fertilizer by the households is likely to be endogenous when used as a covariate in the inefficiency equation. Failure to correct for endogeneity may lead to biased estimates of the effect of late delivery on the technical efficiency of maize production. Because one of the main objectives of this thesis is to estimate the effect of late fertilizer delivery, it is important to account for the potential effects of endogeneity. To test for endogeneity I employ the control function approach (CF) which is described in details in Chapter 6.

CHAPTER 5: FACTORS AFFECTING TIMELY RECEIPT OF FERTILIZER FROM FISP

5.1 Introduction

In this chapter, I discuss the socio-economic factors that affect timely receipt of fertilizer from FISP. Agriculture cooperatives/farmer organisations are the main conduits that the Zambian government uses to distribute farm inputs to the FISP beneficiaries at the community level. According to the FISP implementation guidelines (MACO, 2010), membership to a registered cooperative/farmer organisation is the first criterion for an individual to be a FISP beneficiary. However, not all households that acquired fertilizer from FISP in 2010/11 farming season were members or had at least one household member belonging to a cooperative/farmer organisation.

Delays in receiving fertilizer from FISP are commonly associated with delays in government budegetary processes as well as administrative and logistical challenges. This would imply that delays in FISP delivery to a particular area would result in all households in that area receiving their consignments late. There should be little variation in responses among households within a given area. However, as described in Section 2, FISP fertilizer is often distributed to communities in multiple consignments. Some households therefore receive fertilizer from the first delivered consignment while other recipients obtain their fertilizer in later-delivered consignments. Local FISP and cooperative authorities may therefore influence which intended beneficiaries receive fertilizer on time through the farmer cooperatives. I therefore investigate the factors that influence whether a household will receive fertilizer on time using a binary response model.

5.2 Binary Response Model

In order to determine the factors influencing whether a household receive their fertilizer on time or not, the most appropriate model specification includes a binary dependent variable which takes a value of one if fertilizer was received on time and zero if otherwise. Two standard binary response models that are typically used are logit model and probit model. Linear probability model (LPM) which is fitted by ordinary least squares (OLS) is also used sometimes but it has two major drawbacks; (i) the fitted probabilities can be less than zero or greater than one and (ii) the partial effect of any explanatory variable is constant (Wooldridge, 2008). In a standard binary outcome models, the conditional probability takes the form:

$$\Pr(y_i = 1|X) = F(X_i{}'\beta) \qquad (5.1)$$

Where Pr is the probability of the binary outcome y, which is dependent on a set of exogenous explanatory variables X_i; βs are the unknown parameters to be estimated. The predicted probability falls between zero and one $(0 \leq Pr \leq 1)$ and $F(.)$ is a specified parametric function form for $X_i{}'\beta$. The two models (logit and probit) are similar except that they assume different functional forms. A logit model assumes a logistic distribution specified as $F(.) = \Lambda(.)$ while a probit model assumes a standard normal distribution specified as $F(.) = \Phi(.)$ (Park 2009). Since both models are non-linear the estimated coefficients cannot be interpreted like linear models therefore partial effects are estimated. The two models are estimated using maximum likelihood estimation (MLE) given their non-linearity. For this study a probit model is chosen to determine the factors that influence whether a household receives fertilizer on time or not. The probability model is therefore given by: $Y_i = \alpha_i + \boldsymbol{X_{ij}}\beta + \varepsilon_i$ (5.2)

In this chapter I confine the population to households that acquired fertilizer from FISP to estimate the factors that influence timely receipt of FISP fertilizer. I have therefore excluded all the households that did not acquire fertilizer from FISP in the 2010/11 agricultural season. Refer back to Chapter 3 for the sample selection used in this chapter.

5.3 Description of Variables

This section describes all the variables used in the probit model. The variables include household attributes and other social-economic indicators that might plausibly influence whether a particular household receives fertilizer on time or not. The household attributes include age, education and gender of the household head, the number of household members, value of productive assets[5] and landholding size. I use education and age as a proxy for human capital and experience. The expectation is that older and educated farmers are likely to have some social influence within the community and therefore likely to be considered first when distributing fertilizer. However, education level of the household head can also have countervailing effects on the probability of receiving fertilizer on time from FISP. Educated farmers may have multiple sources of income that enables them to purchase fertilizer from private fertilizer retailers hence reducing their dependence on FISP fertilizer.

In 2009, a number of changes were made to FISP and one of those changes was involving the traditional leaders and other community leaders in the selection of FISP beneficiaries (MACO 2010). Furthermore, in 2011 the government decided that traditional leaders at chief level should be included among the beneficiaries of FISP (MACO, 2011). I therefore include binary variables of whether the household head or spouse is related to the village head (headman/headwoman) or

[5] Productive assets include both animal and equipment assets. I use this as a proxy for household wealth as opposed to household income which can be potentially endogenous.

chief. The hypothesis is that farmers who have family relations with either village headmen/women or chiefs are more likely to receive their fertilizer earlier than others. I also include access to information through two possible channels (1) extension services, and (2) membership in a cooperative/farmer organization. The expectation is that since extension workers are actively involved in FISP, farmers who have access to extension services may receive fertilizer earlier than those who are not. Membership in a registered cooperative is the first official criterion for an individual farmer to be a FISP beneficiary, however not all FISP recipients for the 2010/11 agricultural season belonged to a cooperative or any farmer organization (90.3% were members of the cooperative/farmer organization). Two distance variables are included in this model; distance to the district town center and distance to the point of collection for the FISP fertilizer. I use the distance variables as a proxy for transport cost, time and access to markets. The distance variables are expected to be inversely related to the probability of receiving fertilizer on time. Table 2 shows the percentile distribution of the individual and household variables among FISP recipients; the sample is confined to households that purchased fertilizer under FISP for the 2010/11 farming season. All the explanatory variables in this model are assumed to be exogenous. This assumption is reasonable because the variables are pre-determined when fertilizer is distributed to the farmers.

Table 2: Distribution of variables among FISP recipients

		Percentiles of distribution				
Variables	Mean	10th	25th	50th	75th	90th
Education of the household head (years)	6.9	1	5	7	9	12
Age of the household head (years)	46.7	30	36	44	56	67
Number of household members (count)	6.49	3	5	6	8	10
Distance to the district town center (Km)	35.87	5	14	27	50	75
Distance to FISP point of collection (Km)	5.03	0	1	2	5	10
Value of productive assets (ZMW)[6]	28,200	760	1,660	5,270	17,300	43,900
Total landholding size (Ha)	4.74	0.81	1.75	3.038	5.765	9.91
Female head (=1)	0.15					
Household head related to Headman (=1)	0.42					
Spouse related to the Headman (=1)	0.259					
Household head is headman/headwoman (=1)	0.055					
Spouse related to the chief (=1)	0.071					
Head related to chief	0.103					
Household accessed extension services (=1)	0.368					
Member of farmer organization (=1)	0.903					

Source: RALS data 2012

5.3.1 Model Specification

In this section I describe the probit model used for estimation. And as a check on the robustness of the results, I include SEA fixed effects (community fixed effects) using a linear probability model (LPM). The SEA forms the lowest geographical unit in the dataset and contains approximately 150-200 households (two to four villages). The households in this data set were

[6] Approximately US$1= 5 Zambian Kwacha (ZMW)

sampled from the various SEAs (SEAs therefore gives a representation of the survey population in a particular area).

The probability Y of receiving fertilizer on time for household i is given by:

$$Y_i = \beta_0 + \beta_1 Femalehead + \beta_2 Educ + \beta_3 Age + \beta_4 HHSIZE + \beta_5 Dist.District + \beta_6 Dist.FISP + \beta_7 ProdAssets + \beta_8 RelatedHH + \beta_9 RelatedSpouse + \beta_{10} HHheadman + \beta_{11} RelatedSpousCh + \beta_{12} Landholding + \beta_{13} Acces\_ext + \beta_{14} MemberCoop + \beta_j Prov \qquad (5.3)$$

The model is estimated using Stata 12 and the coefficients presented in the results Table 4 are the average partial effects (APEs) computed using the margins command or dprobit procedure in Stata. The dprobit procedure also computes the marginal probabilities of the variables used in the model. I also included the provincial dummies in the probit model to control for regional variations.

5.4 Results

5.4.1 Descriptive Analysis

Before presenting the results from the probit model estimation, consider the descriptive results presented in Table 3 for difference in means for the explanatory variables between the households receiving fertilizer late and on time. The results in Table 3 show that there are some significant differences between households that received fertilizer on time and those that received it late. In this study I use total landholding size and value of productive assets as a proxy for household wealth. Without controlling for other factors, households with more landholding size and with relatively high value of productive assets received fertilizer on time compared to less wealthy households. Furthermore, there is a significant difference in kinship ties to the village headmen or chiefs between the household receiving their fertilizer on time and those receiving it late. Households receiving fertilizer on time on average were significantly more likely to be related to either the village headmen/women or had kinship ties with the village headmen/chiefs. It should also be noted that households that received fertilizer on time were living approximately 4.3km farther away from the district town centers but closer to the FISP collection point than those who received their fertilizer late. Other variables that show a significant difference include the education level of the household head and household size. Most of the mean differences shown in Table 3 are statistically significant with *P*-values under 5%. The descriptive statistics strongly suggests that there are statistically significant differences in household and individual characteristics between households that received fertilizer late and those that received it on time. However, we need to employ multivariate techniques to determine whether these relationships are maintained after holding constant the effects of other factors.

Table 3: Descriptive Statistics of Difference in Means

Variable Name	Means		Difference in Means	P-Value
	Fertilizer received late	Fertilizer received on time		
Female head (=1)	0.141	0.157	0.016	0.295
Education of the HH head	7.269	6.822	0.447	0.008
Age of the HH head	47.263	46.652	0.611	0.328
Number of HH members	6.775	6.432	0.343	0.006
Distance to the district town	32.34	36.65	4.31	0.002
Distance to FISP collection point	5.292	4.986	0.305	0.554
Value of productive assets (ZMW)	22,138	31,265	9,127	0.109
Total landholding size (Ha)	4.161	4.886	0.725	0.034

Table 3 (cont'd)

HH Head related to Headman (=1)	0.336	0.437	0.101	0.000
Spouse related to Headman (=1)	0.244	0.294	0.049	0.008
HH head is headman/woman (=1)	0.034	0.060	0.026	0.010
Spouse is related to the chief (=1)	0.050	0.077	0.026	0.021
HH accessed extension services (=1)	0.765	0.789	0.024	0.195
Member of farmer organization (=1)	0.913	0.900	0.012	0.352

Source: Own calculations using RALS Data 2012 *significant differences with two-tailed difference of means test

5.4.2 Econometric Results

In this section, I review the econometric findings related to factors influencing timely receipt of fertilizer from FISP. The results from the probit and LPM are presented in Table 4. I begin by focusing on the results from the probit model estimates. The coefficients from the non-linear model are slightly difficult to interpret and therefore I report the average partial effects (APEs) of the estimated model. From the results presented in Table 4, there are a number of variables that are useful to explore. In terms of individual characteristics, only gender of the household head is not a predictor of timely receipt of fertilizer. The results show that an additional year of formal education and age of the household head makes the household 0.46 and 0.11 percentage points less likely to receive their fertilizer on time. Comparing the household head's level of education at the 25th and 75th percentiles of the distribution (5 years vs. 9 years), the results indicate that the latter group is 1.6 percentage points more likely than the former group to receive their FISP fertilizer on time. Furthermore, households with more land and productive assets are more likely to receive their fertilizer on time. A 1 ha increase in landholding size increases the probability of receiving fertilizer on time by 0.37 percentage points. As the landholding size increases from the 25th to the 75th percentiles of the sampled households (from 1.75ha to 5.8ha), the probability of getting fertilizer on time increases by 1.5 percentage points. Differences in the households' productive farm assets also influence the probability of receiving FISP inputs on time. Each additional 1,000 ZMW in the value of productive assets is associated with a 0.027 percentage point increase in the household's probability of receiving fertilizer on time. Other factors held constant, households at the 75th percentile of farm assets were 4.22 percentage points more likely to obtain their FISP inputs on time compared to households at the 25th percentile of assets. These findings on household assets are consistent with previous studies on input subsidy programs in Zambia and Malawi. The findings by Mason et al. (2013a) and Xu et al. (2009a) suggest that on average, households with more landholding size and with high value of farm equipment received more subsidized fertilizer compared to less wealthy households. Furthermore, the findings by Ricker-Gilbert et al. (2011) indicate that household assets and landholding size are both positively correlated with the quantity of subsidized fertilizer received by the farmers in Malawi. The results presented in this study and the studies highlighted above further suggest that not only is FISP disproportionately allocated to wealthier households but also the distribution of fertilizer is first targeted to such households. The results in Table 4 further indicate that there is a positive correlation between kinship ties and the probability of receiving fertilizer on time and all the coefficients are statistically significant. Holding other factors constant, the probability of getting fertilizer on time for households with kinship relations with the village headmen/women or chiefs is 4.3 and 5.3 percentage points higher than other households. These findings are not surprising since traditional leaders are actively involved in the selection of beneficiaries. It is therefore likely that the distribution of fertilizer may be rationed first towards their close relations.

It should also be noted that households who received fertilizer on time were living closer to the FISP collection points but this variable is not statistically significant in both the econometric estimation and in the descriptive statistics. However, households living farther away from the District town centers were more likely to receive fertilizer on time. The results suggest that residing an additional 20 km away from the district town center increases the probability of receiving fertilizer on time by 0.14 percentage points, a relatively small but statistically significant effect. Furthermore, the results show some provincial variation in terms of timely receipt of fertilizer. On average households in Copperbelt and Luapula provinces are less likely to get fertilizer on time compared to households in Eastern, Muchinga and Lusaka provinces. As shown in Figure 4, Copperbelt and Luapula provinces had the highest percentage of households reporting to have received the basal fertilizer late.

One limitation with the data used for this analysis is that it is cross-sectional and therefore I cannot run household fixed effects to control for unobserved heterogeneity. However, I check the robustness of the probit results by using SEA fixed effects. The results presented in the LPM include the SEA fixed effects. With the exception of the dummy variable of whether the household head is the headman/woman, nearly all the variables in the probit model and LPM have the same magnitude of the average partial effects and the significant levels. Including the community fixed effects does give us confidence that the estimated results from the probit model are robust.

Table 4: Average Partial Effects (APE) for Binary response model (Dependent variable is =1 if household receives FISP fertilizer on time)

	Probit Model	LPM
Female HH Head (=1)	0.0182	0.0165
	(0.0188)	(0.0196)
Education of HH Head (years)	-0.0046**	-0.0047**
	(0.0019)	(0.0019)
Age of HH Head (years)	-0.0011**	-0.0011**
	(0.0005)	(0.0005)
Value of Productive Assets (‘000 ZMW)	0.00027***	0.00038***
	(0.0045)	(0.0045)
Total landholding size (ha)	0.0037**	0.0020**
	(0.0015)	(0.0009)
Distance to FISP collection point (Km)	-0.0003	-0.0003
	(0.0006)	(0.0006)
Distance to the District town center (Km)	0.00066**	0.00065**
	(0.00023)	(0.00022)
Household size (count)	-0.0087***	-0.0085***
	(0.0025)	(0.0025)
HH Head Related village head (=1)	0.0429***	0.0439***
	(0.0143)	(0.0146)
HH Head is the village head (=1)	0.0530*	0.0504
	(0.0280)	(0.0309)
Spouse related to the village head (=1)	0.0083	0.0084
	(0.0192)	(0.0191)
Spouse related to the Chief (=1)	0.0485**	0.0477*
	(0.0240)	(0.0264)
Extension service (=1)	0.0206	0.0212
	(0.0167)	(0.0164)
Member of cooperative (=1)	-0.0260	-0.0257
	(0.0214)	(0.0228)
Provincial dummy variables (Central Base)		
Copperbelt	-0.2015***	
	(0.0378)	
Eastern	0.1309***	
	(0.0261)	
Luapula	-0.1689**	
	(0.0391)	
Lusaka	0.1551***	
	(0.0308)	
Muchinga	0.1108***	
	(0.0295)	

Table 4 (cont'd)

Northern	0.0536*	
	(0.0302)	
North Western	0.0298	
	(0.0344)	
Southern	0.0731**	
	(0.0309)	
Western	0.0995**	
	(0.0432)	
Observations	**3,351**	**3,351**

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

CHAPTER 6: TECHNICAL EFFICIENCY AND MAIZE YIELD RESPONSE

In this chapter, I estimate the stochastic production frontier model using the methods described in Chapter 4 to understand the effect of late delivery of fertilizer on technical efficiency and maize production. I begin by describing the variables used in the model then present some results for model diagnostics. Lastly, I highlight the key findings from this analysis.

6.1 Description of Variables in the Stochastic Frontier Model

I devote this section to discussing the variables used in the estimation of the stochastic production frontier. The variables used in the model are split into two groups; those in the production frontier and those in the inefficiency term. Table 5 includes all the variables in the production frontier while Table 6 includes the variables that affect technical efficiency.

6.1.1 Variables in the Production Frontier

The variables included in the production frontier were collected at field level and some at community level. To estimate the stochastic production function in this study, inputs and output are expressed per hectare and therefore, land is not explicitly included as an input. However, expressing output and inputs in per hectare terms brings about some measurement errors resulting from very small fields. Yield and input use on such fields are frequently measured with significant errors and therefore to address this measurement problem, fields that met any of the following conditions were discarded from the dataset prior to running the regression in order to limit potential measurement errors: (1) Any missing values; (2) plot size of less than 0.2 hectares; (3) yield equal to 0 kg per ha or greater than 10,000 kg per ha; (4) seed rate of less than 5kg per ha or more than 60kg per ha and (5) Nitrogen per hectare of less than 10kg. The ranges were determined based on understanding the reasonable input use in Zambia and the recommended input rates set by the Ministry of Agriculture and Livestock.

Table 5: Descriptive statistics of variables used in the production frontier

Variables		Percentile of distribution				
	Mean	**5**	**25**	**50**	**75**	**95**
Maize yield (kg/ha)	2,865	799	1,704	2,588	3,680	5,856
Seeding rate (kg/ha)	25	12	20	23	29	47
Nitrogen in applied fertilizer (kg/ha)	88	28	56	82	112	168
# of weeks after planting for first weeding	4	2	3	4	4	6
Number of rainfall stress periods	1.7	0	1	2	2	3
Hybrid seed (=1)	0.88					
Acrisols soils (=1)	0.39					
Ferralsols soils (=1)	0.34					
Other soil types (=1)[7]	0.047					
Tillage using a plough (=1)	0.38					
Tillage before the rains (=1)	0.15					
Soil pH below 4.4 (=1)	0.41					
Soil pH between 4.4 and 5.5 (=1)[8]	0.57					
Soil erosion (=1)	0.15					
Manure or compost (=1)	0.10					

Source: Own calculations using RALS Data 2012

Table 5 shows that yields were positively skewed with a mean of 2.9 metric tons per ha. Only about 5% of the fields yielded more than 5.8 metric tons per ha; 35% of the fields yielded less than 2.6 ton/ha and about 5% of the fields yielded less than 1 ton/ha. Based on the MACO crop production guide, the recommended seeding rate is within 15-30kg/ha. The mean seeding rate

[7] Lixisols soil type is used as a base in this model
[8] Soil pH between 5.5 and 7.1 is used as a base (neutral soils)

was 25kg/ha which is within the recommended usage. On 5% of the fields, the seeding rate was 56% higher than the recommended rate.

6.1.2 Fertilizer Measure Used

In Zambia, two types of fertilizers that are commonly used by farmers (distributed under FISP) include, Compound D which is typically used as basal fertilizer and it contains 10% nitrogen and 20% phosphorous.[9] The recommendation from field extension officers is that basal fertilizer should be applied at planting to promote root growth or after the emergence of seedling. For top dressing application, urea is often used which contains 46% nitrogen and should be applied when the plant has reached knee high which is usually 3-4 weeks after planting. The national recommended application rate is 200kg of basal fertilizer (compound D) and 200kg of top dressing fertilizer (Urea) per hectare of maize (ZARI 2002). However these rates do not take into account the differences in soil types and conditions across various fields. The nutrient composition of the different types of fertilizer is important in analyzing crop yield response to fertilizer. For the two commonly used fertilizers in Zambia, nitrogen and phosphorus are typically used in fixed proportions. For this sample, nitrogen and phosphorus are highly correlated as shown in Figure 6 (correlation coefficient of 0.95) and therefore, the two nutrients cannot be included together in the production frontier. To estimate maize yield response function, I use the rate of nitrogen applied as an index since it's the most important nutrient in maize growth and it is computed from fertilizer application for each field according to the quantity used and composition in the two types of fertilizers used[10]. A 100kg of Compound D basal fertilizer contains 10kg of nitrogen whereas 100kg of urea fertilizer contain 46kg of

---

[9] Throughout this paper, we refer to phosphorous as a proxy for P_2O_5 found in Compound D fertilizer

[10] For the major fertilizers compound D and urea, they use nitrogen and phosphorus in fixed proportion and therefore the rate of application of nitrogen should give a reasonable measure of the impact of fertilizer on maize yield.

nitrogen. On less than 2% of the fields either compound D or urea was applied but on the majority of the fields both basal and top dress fertilizer was applied.

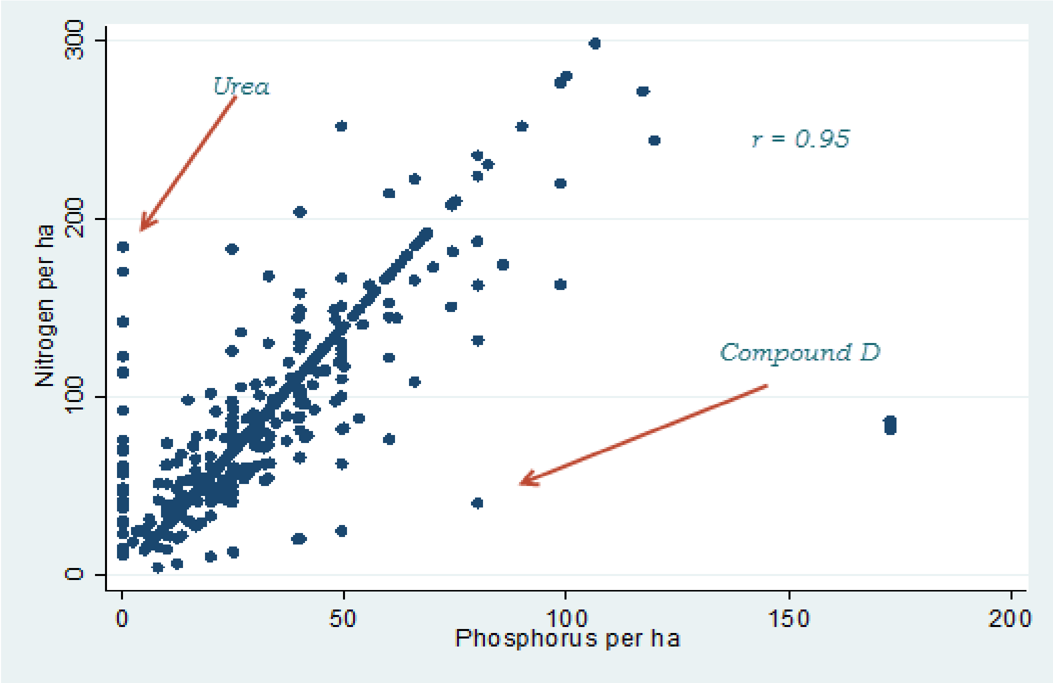

Figure 6: Scatter Plot of Nitrogen and Phosphorous rates

Source: Own calculations using RALS data 2012

Based on the national recommended rates for top dress and basal fertilizers, the recommended rate for nitrogen application is therefore 112kg per hectare of maize planted. From Table 5, the distribution of nitrogen application rates shows that most of the farmers did not apply fertilizer at the recommended rate. Only on 25% of the fields was fertilizer applied at the recommended rate. The mean and median nitrogen application rates are 27.3% and 34.1% below the recommended rate respectively. And on 5% of the fields the rate of application was at least 50% above the recommended rates.

Table 5 also shows the distribution of binary variables that are used in the production frontier. Seed input is captured by two variables; one measuring the amount used and an indicator variable measuring the type of seed variety used. Maize seed is classified as either hybrid or local variety and hybrid seed was used on 88% of the fields. In this study, weeding is used as a proxy for labor input since it has a direct effect on the growth of the plant. Nearly all the fields in the data set were weeded at least once; the number of weeks after planting when the household did their first weeding was used to capture the impact of timing of weeding on maize yield. The timing of when weeding is carried out has a bearing effect on the growth of maize and yield levels since weeds tend to compete with the crop for nutrients.

6.1.3 Soil types and Soil pH

Farm input use is under the control of the farmer and farmers determine how much of each input to use on their fields. While resource availability can be the major determining factor, soil quality partly plays a role in determining how much fertilizer is used on a given field. Besides knowing how much of each input the farmers used on a particular field, this study takes into account the different soil types available for the various fields. The type and characteristics of soil is important in determining plant growth, nutrient intake (e.g. fertilizer) and level of output. Most of the areas in Zambia are covered by Acrisols and Ferrasols soil types which account for 39% and 34% respectively of the fields in this study. These soils are mostly clayish and are considered to be moderately suitable for maize production (ZARI 2002). The second important group of soils includes Lixisols accounting for 21.72% of the sample fields in this study and these are considered to be more fertile soils. Other soil types account for 4.67% of the remaining fields in the sample. Based on the soil characteristics, three dummy variables are used in this study. The Lixisols soil type is the base subsumed into the intercept term. The three soil dummy variables include; Acrisols soils, Ferrasols soils and a dummy for other soil types. The soil types used in this study may not completely capture the variability in soil fertility conditions at field level, which often correlates with farm management practices. I therefore use two field level proxies to control for some variability that are not captured by the soil types. The first proxy is a dummy variable for use of manure or compost to control for organic fertilizer use. Use of manure or compost is a common practice among farmers to increase the organic matter and improve soil fertility however, only on 10% of the fields was manure applied. The second proxy is a dummy of whether or not a field is prone to soil erosion and 15% of the fields were prone to soil erosion. Soil erosion often results in the loss of topsoil and organic matter which has a direct effect on crop yield. These proxies therefore partially control for the impact arising from differences in soil quality.

According to the crop production guide for MAL, pH between 4.7- 6.5 is ideal for maize production (ZARI 2002). Meanwhile pH of 4.4 is considered as a critical threshold for maize production in Zambia and values below it (more acidic soils) will result in plants not having access to the necessary soil nutrients leading to limited root growth, wilting and diminished yields (ZARI 2002). The second pH threshold affecting growth occurs at 5.5 due to the effect of acidity on phosphoric fertilization (basal fertilizer). Therefore, to control for soil acidity, pH is included in the model using indicator variables. Two indicator variables are used in this model, the first is designated to fields where pH is below 4.4 and the second one is designated to fields with pH ranging between 4.4 and 5.5. 57% of the fields in this study are on acidic soils (pH in the range of 4.4 to 5.5); 41% are in very acidic soils (pH below 4.4) and the pH for neutral soils accounting for 2% of the fields is used as a base (pH range of 5.5-7.1).

I control for the type of tillage method the farmers used for land preparation and when the tillage was done. Tillage method used has been found to have an impact on yield and on the soil structure in previous studies. The type of tillage equipment used and the timing of plowing easily cause soil erosion (Allah 2011). On 38% of the fields, farmers used a plough for land preparation and only 15% of the fields were tilled before the beginning of the rains.

6.1.4 Rainfall

Nearly all the maize fields for smallholder farmers in Zambia are rain-fed and rainfall is an important determinant of maize yield. The rainfall data from TAMSAT is available at SEA level; for this analysis I choose to use a measure of moisture stress as opposed to total rainfall. Moisture stress is defined as the number of 20-day periods between November and March with less than 40mm of rain for the 2010/11 agricultural season. Moisture stress is estimated from the available rainfall data. Use of moisture stress is said to be a better measure for moisture condition than total rainfall since total rainfall does not reflect the distribution of rainfall overtime (Liu and Myers 2008).

The estimated stochastic frontier function as specified in Chapter 4 transformed in logarithm is:

$$\begin{aligned} lnyield_i = {} & \beta_0 + \beta_1 lnFert_i + \beta_2 lnseed_i + \beta_3[0.5(lnfert_i)^2] + \beta_4[0.5(lnseed)^2 \\ & + \beta_5(lnseed_i)(lnfert_i) + \beta_6(lnWeeding) + \beta_7[0.5(lnweeding)^2 \\ & + \beta_8 Stress_i + \beta_9(lnseed_i)(Stress_i) + \beta_{10}Hybrid_i + \beta_{11}Soilerosion_i \\ & + \beta_{12}Manure_i + \beta_{13}pHbelow4.4_i + \beta_{14}pH4_5 + \beta_{15}Acrisols + \beta_{16}Ferralsols \\ & + \beta_{17}Othersoils + \beta_{18}Plough_i + \beta_{19}TilRains + V_i - U_i \qquad (6.1) \end{aligned}$$

6.1.5 Factors affecting Efficiency

To explain the sources of inefficiencies among smallholder farmers, I use household and individual attributes such as; age, gender and education of household head; household size; distance variables; extension services; landholding size and value of productive assets. Previous studies have found that education level is positively correlated with technical efficiency in maize production (Seyoum et al. 1998; Chirwa 2007; Liu and Myers 2008). I also investigate the effects of gender on technical efficiency of maize farmers by including a dummy variable for the gender of the household head. Chirwa (2007) used a SFA to estimate the level of technical efficiency among smallholder maize growers in Malawi. He found that use of hybrid seed and education level of the household head had a positive effect on technical efficiency of the smallholder farmers. Other studies have extensively looked at the relationship between efficiency and farm size like the case of Alvarez (2004) and Kumbhakar et al. (1991) they found that large farms were relatively more efficient as compared to smaller farms. Furthermore, distance to markets and major roads, access to extension and credit services as well as other physical infrastructure have been highlighted in literatures of development economics to contribute to improving farm productivity and technical efficiency (Jacoby, 1998).

Therefore, determining factors that might contribute to technical inefficiency can help draw policy conclusions about the impacts that investments in programs like extension, education, rural roads, credit facilities and subsidy programs might have on technical inefficiency.

In their study to investigate technical efficiency and productivity of maize producers in Ethiopia, Seyoum et al., (1998) found that involvement with extension advisers tends to reduce technical inefficiency in maize production. In the case of Liu and Myers (2008), the authors used household demographics and socio-economic variables to explain farm inefficiencies among maize producers in Kenya. They found that there is a negative relationship between technical efficiency and distance to the nearest public transportation. Their findings suggest that a one-kilometer closer to public transportation would increase yield per acre by 3.7%. Furthermore, the findings by Darko and Ricker-Gilbert (2013) show that the quantity of subsidized fertilizer received by the household had a positive effect on profit efficiency among smallholder farmers in Malawi.

These highlighted studies present some empirical evidence on the impacts of investments in extension, transport infrastructure and subsidy programs on production efficiency. But most of these studies have only focused on the direction of the effect with exception of Liu and Myers (2008) while overlooking the magnitude of the effect. This study takes into account both the direction and magnitude of the effects of the variables in the inefficiency term. In addition to some of the variables that have been used in previous studies to measure the sources of technical inefficiency, I introduce a new variable of interest to better explain the effect of late delivery of subsidized fertilizer on technical efficiency. Table 6 shows the descriptive statistics of the variables used in the inefficiency model.

Table 6: Descriptive statistics of variables in the Inefficiency term

Variables	Percentile of distribution					
	Mean	**5**	**25**	**50**	**75**	**95**
Fertilizer received late (=1)	0.25					
Age of HH head (years)	46.7	27	36	44	56	73
Education of HH head (years)	7.1	0	5	7	9	17
Female head (=1)	0.14					
Distance to FISP collection point (Km)	5.25	0	1	2	5	20
Distance to District town center (Km)	36.23	2	15	29	50	90
Value of productive assets (‘000’ZMW)	29,700	500	1,910	6,410	21,000	92,800
Access to extension service (=1)	0.79					
Household size (member)	6.6	3	5	6	8	12

Source: Own calculations using RALS Data 2012

Given the variables used in the inefficiency term, the estimated model for technical inefficiency term (U_i) as specified in Chapter 4 is given by:

$$U_i = \delta_0 + \delta_1 Fertlate + \delta_2 Eduhead + \delta_3 Age + \delta_4 femhead + \delta_5 Prod\_Asset + \delta_6 HHsize + \delta_7 Acces\_ext + \delta_8 Dist\_Fisp + \delta_9 Dist\_townCen \qquad (6.2)$$

6.2 Model Diagnostics

Prior to estimating the stochastic frontier model I run a number of test described in Chapter 4.

6.2.1 Choice of functional form

As highlighted in Chapter 4, estimating a stochastic frontier model requires imposing a functional form on the production frontier. A likelihood ratio (LR) test was used to test the null hypothesis that a Cobb-Douglas production function is an adequate representation of the data.

The null hypothesis that a Cobb-Douglas specification is an adequate representation of the data was rejected in favor of the translog production function (refer to Eqns. 4.9 and 5.0). The second test explores the null hypothesis that each farm is fully technically efficient and hence the technical inefficiency effects are zero($H_0: \gamma = \delta_0 = \delta_j = 0$) refer to Eqn. (4.6). If the null hypothesis is true, the model collapses to a traditional production function (average response function (or OLS). The second hypothesis is also rejected indicating the presence of inefficiency effects in the model. Table 7 gives a summary of the hypothesis test results

Table 7: Hypothesis Test Results

Test	Null Hypothesis	Calculated value	p-value	Decision
1	$H_0: \beta_{ij} = 0$	28.75	0.000	Reject H_0
2	$H_0: \gamma = \delta_0 = \delta_j = 0.$	230	0.000	Reject H_0

6.2.2 Testing for Heteroskedasticity

Heteroskedasticity is prevalent in a lot of survey data; therefore I use the Breusch Pagan/Cook-Weisberg test for heteroskedasticity. The null hypothesis of homoscedasticity was rejected at 1% significance level (*chi-square (27) = 78.68, p-value= 0.000*). If the model been estimated in this study is an OLS, the robust option command in Stata gives more accurate standard errors. In the case of stochastic frontier's approach, neglecting heteroskedasticity in the symmetric random error (V_i) and/ or one-sided error term (U_i) leads to biased estimates of the inefficiency parameters (Belotti et al. 2012). I therefore estimate the stochastic frontier model using the sfcross command in Stata 12 designed for cross-sectional data with the options *usigma* and *vsigma* to take into account both sources of heteroskedasticity. Incorporating the *usigma* and *vsigma* options in the stochastic frontier estimation significantly improves the estimates (Belotti et al. 2012).

6.2.3 Dealing with possible endogeneity of timely receipt of subsidized fertilizer

As already highlighted in Chapter 4, distribution of fertilizer is not done randomly and therefore timely receipt of fertilizer is potentially endogenous. Therefore, I use a control function (CF) approach to deal with the potential correlation between the timely receipt of fertilizer and the unobservable random variables (W_i). The CF approach entails estimating a reduced form equation where the variable fertilizer received on time/late is regressed on the explanatory variables in Equation 6.2 plus at least one instrumental variable. The residuals from the reduced form equation are then included as an additional regressor in the original equation. The significance of the coefficient on the residual both tests and controls for correlation between $Fertlate$ and W_i (for more details see Imbens and Wooldridge 2007; Lewbel 2004). The reduced form model for timely receipt of fertilizer is modeled using probit and the residuals are included as additional regressor. The CF approach requires an instrumental variable (IV) to be used in the reduced form model that is not in the inefficiency model.

Following the results obtained in Chapter 5, households with bigger landholding size, high value of assets and those with kinship relations with the village headmen/women or chiefs received their fertilizer on time as opposed to poorer households with less social connections. The appropriate IVs for this study are dummy variables for whether or not the household head is related to the village headman or chief. These IVs are likely to influence whether a household receives fertilizer on time or not but they do not influence the level of technical efficiency for a given farm. This makes it reasonable to assume that the instruments themselves are exogenous.

The model as described in Eqns. (6.1) and (6.2) is estimated jointly using (one-step) maximum likelihood.

6.3 Stochastic Frontier Estimation Results

Appendix 2 presents the results for the production frontier and the inefficiency term estimated using the stochastic frontier approach and Appendix 1 gives the definition of the variables used in the stochastic frontier function. The results shown in appendix 2 are estimated from two different production functions however, for this study, the appropriate functional form which fits the data is a Translog production. And therefore, the discussion of the results is based on the Translog production function estimates.

6.3.1 Yield Determinants

The coefficients for the Translog production function are not very informative per se; to determine the effect on each individual input in the production frontier, partial derivatives of log yield in Equation 6.1 with respect to the inputs are estimated. Since the model was estimated linear in logs, the partial derivatives estimated at the sample mean gives output elasticity with respect to seed and nitrogen. The estimated elasticity is given by:

$$e_j = \frac{\partial lnY_i}{\partial lnX_{ij}} = \beta_j + \sum_{j=1}^{2} \beta_{jk}\, lnX_j \qquad (6.3)$$

Two input elasticities are estimated in this study. Using Equation 6.1, the output elasticity with respect to nitrogen and seed are defined as:

$$e_{Nfert} = \frac{\partial Y}{\partial LnNitrogen} = (\beta_1 + 2\beta_3 + \beta_5) \qquad (6.4)$$

$$e_{lnseed} = \frac{\partial Y}{\partial lnseed} = (\beta_2 + 2\beta_4 + \beta_5 + \beta_8) \qquad (6.5)$$

Table 8: Estimated elasticities with respect to inputs evaluated at the sample means

Variable Input	Translog
Nitrogen	0.639
	(0.0008)
Seed	0.320
	(0.0015)

Note: Standard errors in parentheses

Table 8 reports the input elasticity estimates for fertilizer and seed calculated at their respective sample means. The results show that a 1% increase in the quantity of nitrogen applied increases maize output by 0.64% ceteris paribus. Similarly a 1% increase in the seeding rate will increase output by 0.32%.

Partial effects of other continuous variables can be derived similarly by taking the partial derivative of equation (6.1) with respect to a particular variable. Partial effect of a dummy variable is derived as the difference between the expected yields when the dummy variable changes from 0 to 1. The estimated partial effect for hybrid seed dummy is 0.267 therefore, for fields that used hybrid seed yield was higher by 26.7% compared to fields where local seed varieties were used. A study by Liu and Myers (2008) also found that hybrid seed users in Kenya had a higher output elasticity with respect to fertilizer and seed compared to local seed users. This therefore implies that use of hybrid seed coupled with inorganic fertilizer has a large positive impact on yield. Furthermore, fields that are prone to soil erosion had 4.11% less yield compared to other fields, ceteris paribus. The variation in yield can also be explained by the effect of soil acidity. Holding other factors constant, yield on fields where pH is in the 4.4 to 5.5 range had 32.98% more yield than fields which are in more acidic soils. While fields in very acidic soils (pH less than 4.4) had 23.09% fewer yields compared to fields in neutral soils.

Based on the observed yield, Figure 7 shows that most of the higher yields are in fields where the pH is in the range of 4.4 to 5.5.

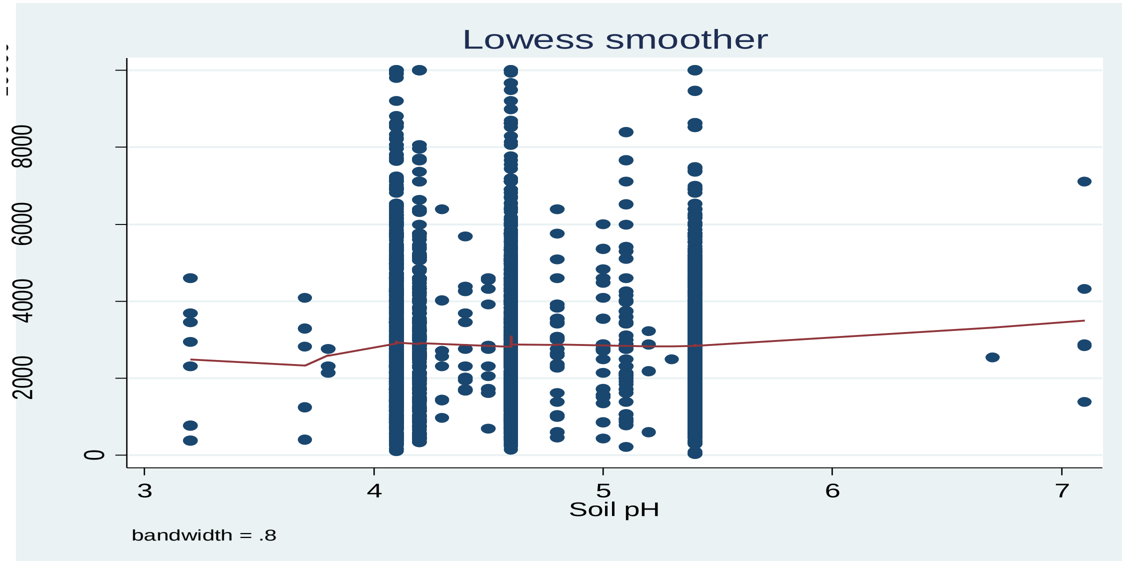

Figure 7: Observed Yield and Soil pH

Source: Own calculations using RALS 2012 Data

6.3.2 Marginal and Average Product of Nitrogen

In this section, I will look at yield response to applied fertilizer and therefore will discuss the marginal product (MP) and average product (AP) of nitrogen. The AP and MP are influenced by the rate of fertilizer application and other variables in the production frontier. In stochastic frontiers, the marginal products are downscaled by the level of technical efficiency (Henningsen 2014). Therefore the MP of nitrogen is estimated as;

$$MP_N = TE * e_N * \frac{f(N)}{N} \qquad (6.6)$$

Where; e_N is the estimated elasticity of output with respect to nitrogen. The mean estimated MP of nitrogen is 10.52kg of maize per kilogram of nitrogen. While the estimated mean AP of nitrogen is 16.48 kg of maize per kilogram of nitrogen holding other variables constant. Table 9 shows the estimated MP and AP at various nitrogen application rates for fields where households reported to have received fertilizer late and on time. As the rate of fertilizer application increases, both the MP and AP are decreasing. At the nationwide recommended rate of fertilizer application (112kg of nitrogen per hectare at 75th percentile) both the average and marginal product of fertilizer are below the estimated mean AP and MP for both groups. The recommended rate is way above the rates used by majority of the smallholder farmers in Zambia.

Table 9: Estimated MP and AP at different rates of nitrogen application

Percentiles for Nitrogen rates	**MP of Nitrogen (kg/kg)**		**AP of Nitrogen (kg/kg)**	
	Fertilizer Late	Fertilizer on Time	Fertilizer late	Fertilizer on time
25th (56kg/ha)	8.96	8.94	18.37	18.39
50th (84 kg/ha)	7.34	7.40	14.53	14.65
75th (112kg/ha)	6.44	6.42	12.41	12.45
90th (140kg/ha)	5.81	5.96	11.29	11.03

6.4 Technical Efficiency

In this section, I present the findings on the factors affecting technical efficiency of smallholder farmers in Zambia. I begin by discussing the estimated technical efficiency scores and then later look at the variables that have a significant effect on technical efficiency.

Figure 8 below is the probability density of technical efficiency estimates for smallholder farms that received fertilizer from FISP and has a distribution which is skewed to the left. The estimated is average technical efficiency is 68.2% and the mode is 80%. The efficiency scores vary widely from 1.5% to 92.3% with standard deviation of 15.7%. The estimated MPs above vary with technical efficiency scores. Therefore, the MPs at the mode technical efficiency are 18% higher than at the mean technical efficiency.

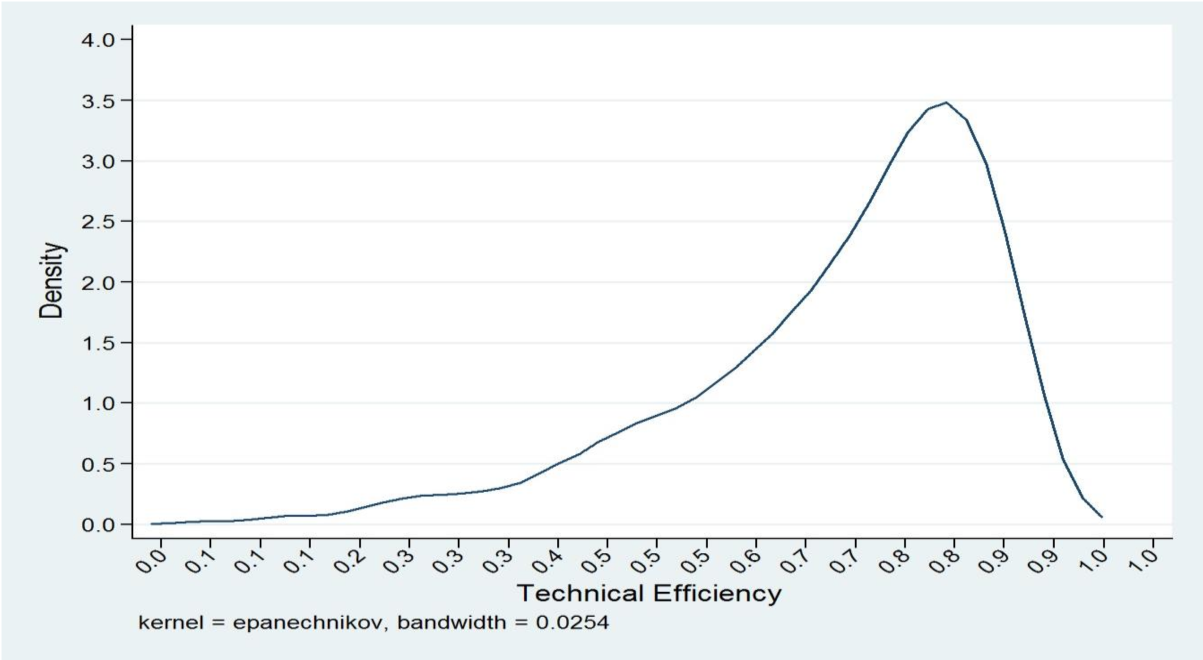

Figure 8: Probability Density of Technical Efficiency for Farms Participating in FISP

Source: Own calculations using RALS data 2012

Figure 9 below shows the distribution of predicated technical efficiency for the smallholder maize farms in Zambia who participated in the farmer input support program. The distribution shows that the modal technical efficiency for the farms is approximately 80%. And the graph suggests that there is potential for improving technical efficiency of the smallholder farms. On less than 1% of the fields had a mean TE below 20%. The estimated mean TE is comparable with the estimates from other African countries. For example, Kibaara and Kavoi (2012) found a mean TE of 49% with efficiency scores varying from 8.04% to 98.3% among maize producers in Kenya. Similarly, Seyoum et al. (1998) estimated the technical efficiency of maize producers in Ethiopia and found the mean technical efficiency of 79% while in the case of Malawi, Darko and

Ricker-Gilbert (2013) found the average profit efficiency score of 46.33% with values ranging from 0.13% to 87.8% among maize producers.

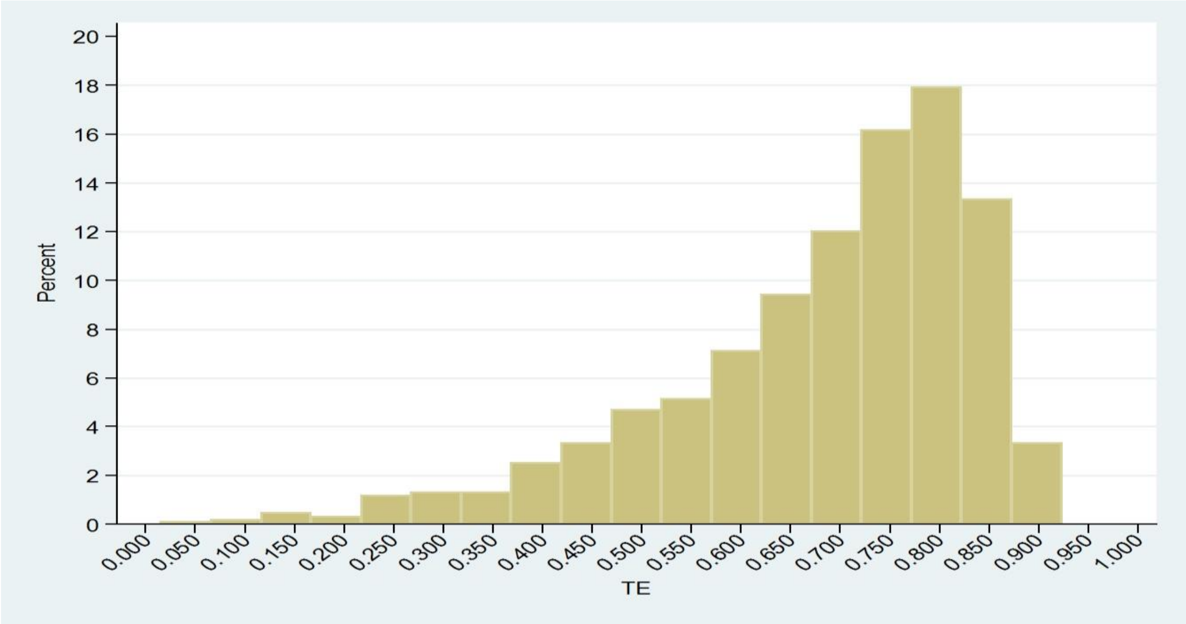

Figure 9: Histogram of Technical Efficiency for FISP recipients

Source: Own calculations using RALS data 2012

With regard to the variables in the inefficiency term presented in Appendix 2, the variable of interest fertilizer received late has a positive and significant effect on technical inefficiency. However, the coefficient on fertilizer received late (Fert_Late) like all other coefficients in the inefficiency term only indicates the direction of the effects that these variables have on inefficiency levels. Where a negative coefficient estimate shows that the variable reduces technical inefficiency and vice versa (Amsler et al. 2013). Quantification of the marginal effects of these variables on technical inefficiency is possible by partial differentiation of the technical inefficiency predictor with respect to each variable in the inefficiency term.

The post estimation for sfcross command in Stata 12 allows to compute the partial effects of the exogenous variables (Z's) on technical inefficiency using the predict marginal command (Belotti et al. 2012). The marginal effects obtained using Belotti et al. (2012) method gives the marginal effects of the Z variables on the mean and variance of inefficiency using the approach proposed by Wang (2002). The estimated partial effects are presented in Table 10 below. The definitions of the variables presented in Table 10 are in Appendix 1.

Table 10: Partial effects on inefficiency evaluated at the sample mean

Variable	**Average Partial effects**	**Standard errors**
Marginal effects on $\boldsymbol{E}\ (\boldsymbol{U_i})$		
Fert_Late	0.042**	(0.0006)
Age_HH	0.0014***	(0.0001)
Education	-0.0005	(0.00004)
Female head	0.0379**	(0.0005)
Distance_FISP	0.0009**	(0.0001)
Access_extension	-0.0561**	(0.0004)
Distance_DistriCenter	0.0005	(0.0013)
Prod_Assets	-0.0164*	(0.0084)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The estimated partial affects in Table 10 presents the effect of the exogenous variables on both technical efficiency and maize out (Y) and according to Wang (2002), $\frac{\partial E(\ln Y)}{\partial Fert\_Late} = -\frac{\partial E(U)}{\partial Fert\_Late}$.

From Table 10, the partial effect on the fertilizer received late variable indicates a positive and significant effect on technical inefficiency. This implies that receiving fertilizer late increases the level of technical inefficiency of smallholder farmers by 4.2%. The partial effect on the variable fertilizer received late, translates into a decrease in output by 4.2%. Therefore, households that received fertilizer late tend to produce 4.2% less maize than a household that received fertilizer on time. Recall that the overall objective of this study is to determine the effect of late delivery of subsidized fertilizer on technical efficiency and maize production. And from the estimated results, delivering fertilizer late to the farmers has a negative effect on their level of technical efficiency thereby reducing maize yield by 4.2%, *ceteris paribus.*

Figure 10 below shows the distribution of technical efficiency for the households that received fertilizer on time and for those that received it late. The mean technical efficiency for households that received fertilizer on time and those that received it late is 71% and 66.9% respectively. Holding other factors constant, households receiving fertilizer on time are 4.1% more efficient than households receiving fertilizer late. The difference in the mean technical efficiency between the two groups is approximately equal to the estimated partial effect on the variable fertilizer received late. It is also important to note that input use (seed and fertilizer) were slightly similar for households that received fertilizer on time and those that received it late. The average nitrogen application rates for households that received fertilizer on time and those that received it late is 86.79 kg/ha and 90.74 kg/ha respectively. Whereas seeding rate was 24.74 kg/ha and 24.52 kg/ha for households that received fertilizer on time and those that received it late respectively. The two groups are therefore similar in terms of input use but what differentiates them is the timing of planting and timing of fertilizer application hence resulting in yield difference of 4.2% due to late delivery.

Timing of fertilizer application has been emphasized in agronomy literature. According to the study by Jones and Jacobsen (2003), proper timing of fertilizer application reduces nutrient losses and can maximize both yield and nutrient use efficiency thereby increasing net profit for the producer. Recall that for the two types of fertilizers commonly used in Zambia, the main nutrient is nitrogen. The goal of timing nitrogen application in maize is to ensure adequate supply of nitrogen when the crop needs it and nitrogen stress at any time during the plant's life will lead to a reduction in potential yield (Scharf and Lory 2006). The cited studies underscore the importance of timing of fertilizer application in order to optimize yield and profitability while minimizing nitrogen losses due to late fertilizer application.

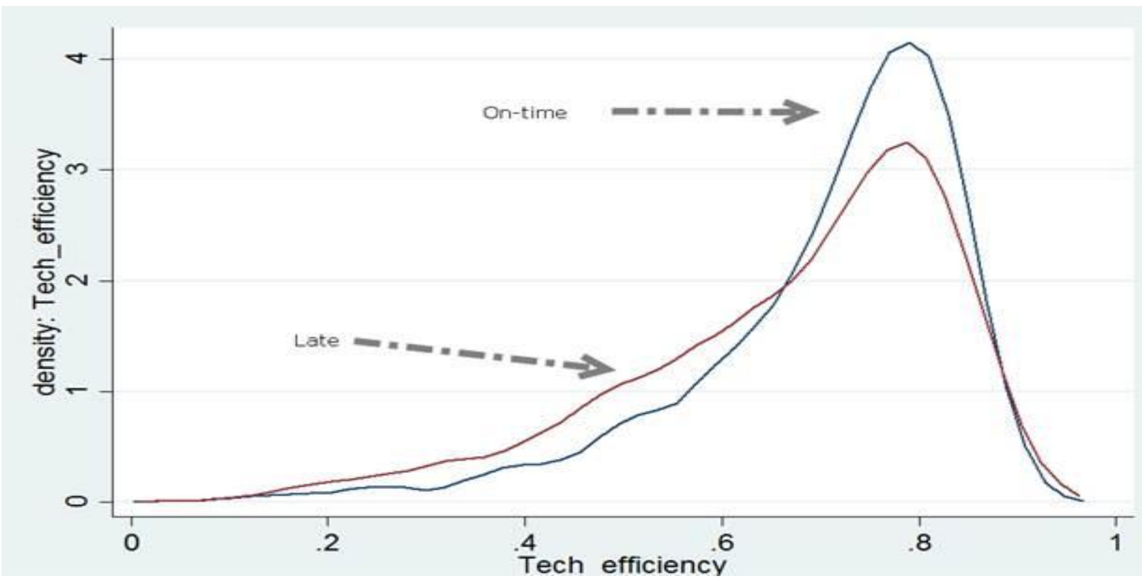

Figure 10: Technical Efficiency for fields where fertilizer was received late and on time

Source: Own calculations using RALS data 2012

Other variables that have shown a significant effect on the technical efficiency of smallholder farms include age and gender of the household head, access to extension services, household assets and distance to the FISP collection points. It should be noted from the onset that some of the variables that affect technical efficiency of the farmers are beyond the farmers control and hence there are very little measures that can be done to change that (e.g. age and gender of the household head). From Table 10, age and gender of the household head have a positive effect on the level of technical inefficiency of the farmers. The results imply that younger and male farmers are more likely to show a higher technical efficiency in maize production than older and female farmers. The partial effect on the variable age of the household is 0.0014 which translates into a decrease in maize output by 0.14%. At the mean age (i.e. 47 yrs.) of the household head, technical efficiency decreases by 6.6 percentage point. As the head of the household gets older, technical efficiency in maize production decreases. Therefore, increases in age tend to be counterproductive leading to an increase in technical inefficiency. Similarly, the partial effect of female head variable implies that a household with a female head tends to produce 3.79% less maize than a household with a male head. The results are consistent with existing literatures on the effects of age and gender on technical efficiency (Wang 2002; Liu and Myers 2008). Other things being equal, younger farmers are more technically efficient in maize production than older farmers. For older farmers, uncertainty in production increases with age.

The results further indicate that been one kilometer closer to the FISP collection point would increase yield and technical efficiency by 0.15%. At the 50^{th} and 75^{th} percentile for distance to the FISP collection points (i.e. at 2km and 5km from FISP collection point) technical efficiency decreases by 0.18 and 0.45 percentage points respectively. Furthermore, the partial effect on the extension variable shows a negative and significant effect on technical inefficiency. This indicates that households that are involved with extension agents tend to be technically efficient in maize production. Obtaining information from extension agents through field demonstrations affects the farming practices and therefore, access to extension services increases yield and technical efficiency by 5.61%. The variable value of productive assets has a marginal effect of 0.016 and it is statistically significant at 10% level with a negative sign. The results suggest that 1,000 ZMW increase in the value of productive assets increases maize yield by 1.64 percentage point holding other factors constants. Lastly, the variable education shows that one more school year would increase yield by 0.05% however, education is not statistically different from zero.

CHAPTER 7: ESTIMATING THE FOREGONE MAIZE OUTPUT

In this section I will discuss the foregone maize production resulting from late delivery of fertilizer. Based on the predicated technical efficiency and marginal effect of late delivery of fertilizer, I can estimate how much maize is lost due to technical inefficiency as well as due to late delivery of fertilizer.

7.1 Estimating Potential Yield (Frontier yield)

Given the estimated technical efficiency scores for the individual farm plots, potential yield can be estimated for each field following the formula proposed by (Battese 1992).

$$Potential\ Yield = \frac{Actual\ yield}{Technical\ Efficiency} \qquad (7.1)$$

The predicated mean technical efficiency score is 0.682 (68.2%) and the weighted average yield for the observed sample is 2.86 ton/ha. Using the formula above the estimated potential (frontier) yield is 3.95 ton/ha. Therefore, with the same level of inputs the Zambian smallholder farmers are capable of producing 3.95 ton/ha of maize by moving to the frontier. The total loss in maize yield due to technical inefficiency is equivalent to 1.09 ton/ha. The results suggest that improving the technical efficiency levels of smallholder maize producers can increase maize yield. This can be achieved through farmers' involvement with extension agents and timely delivery of inputs from FISP.

Figure 13 below shows the potential yield and actual yield at a given level of fertilizer application. This graph depicts that with the same fertilizer application rates that smallholder farmers are currently using; maize yield can greatly increase by moving to the frontier.

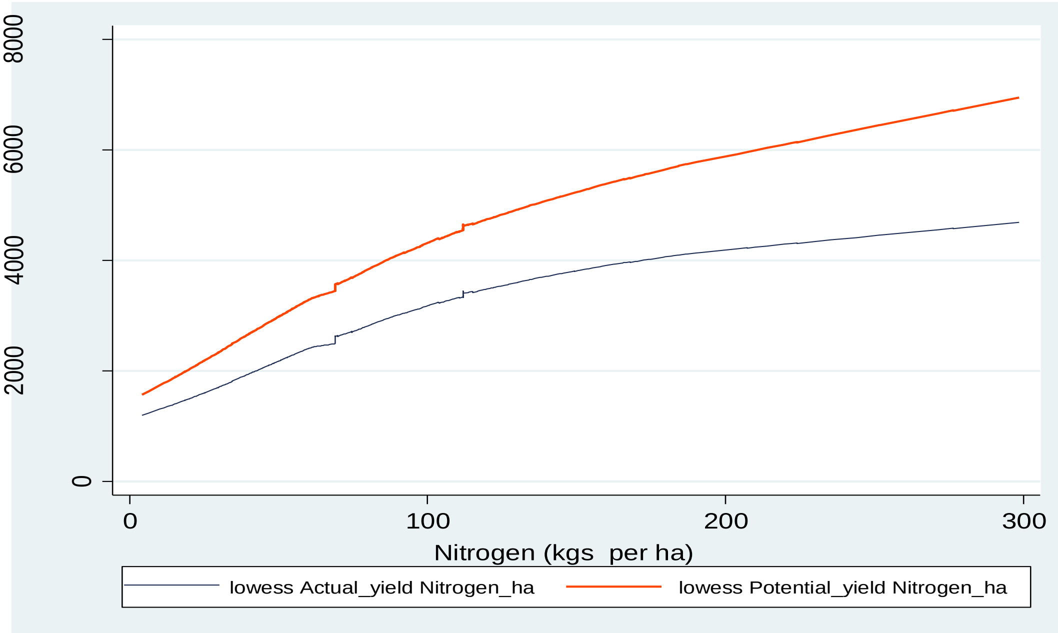

Figure 11: Graph of Yield vs. Nitrogen application rates

Source: Own calculations using RALS data 2012

7.2 Magnitude of the Loss in Maize Output due to Late Delivery of Fertilizer

The preceding section describes the overall lose in crop yield due to technical inefficiency resulting from various exogenous factors. In this section I will focus on determining the loss in maize output resulting from delivering fertilizer late. From the results presented in Table 10, the effect of late delivery of fertilizer on yield has a magnitude of 4.2%. I therefore extrapolate the results to estimate the foregone national maize output due to late delivery of FISP fertilizer. The foregone maize output due to late delivery of fertilizer can be estimated as:

$$Foregone\ Mz = 0.042\left(\sum_{i=1}^{n} W_i Q_{FISP}\right) + 0.032\left(\sum_{j=1}^{n} W_i Q_{Comm}\right) + 0.042\left(\sum_{h=1}^{n} W_i Q_{BOTH}\right) \qquad (7.2)$$

Where; Mz is foregone national maize output; W_i are sampling weights for the data used in this study; Q_{FISP} is the total maize output in Kgs on fields where households got fertilizer from FISP only; 0.042 is the estimated partial effect of late delivery of FISP fertilizer on maize yield/output; 0.032 is change in maize output for households that got commercial fertilizer late; Qcomm is the total maize output in Kgs on fields where households got fertilizer from commercial traders only and Q_{BOTH} is the total maize output on fields where households got fertilizer from both FISP and commercial traders.

Using Eqn. (7.2) the estimated foregone maize output due late delivery of fertilizer from FISP is 84,924 MT. Holding other factors constant, if fertilizer from FISP was delivered on time, the total national maize output would have increased by 84,924 MT. While we do acknowledge that there are a number of factors that determine the yield/output levels for different crops as evidenced from previous studies, for this study we can conclude that timely availability of fertilizer has an effect on maize yield/output. The estimated loss in maize output has adverse effects for smallholder farm households who largely depend on maize production for their livelihoods. And given that 78% of these households fall below the US$1.25/capita/day poverty line (Mason et al. 2013a). Reducing rural poverty and enhancing food security has been an important objective for FISP as stipulated in MACO (2010) since its inception. But, the findings from this study suggest that achievement of such an important objective could be largely compromised if late delivery of inputs through the subsidy program is not quickly addressed.

CHAPTER 8: SUMMARY AND CONCLUSION

Late delivery of inputs under agricultural input subsidy programs is a widespread issue in Sub-Saharan Africa. If applied sufficiently late, fertilizer may not contribute optimally to crop yields. Using cross-sectional household survey data from Zambia, this study provides insights on the effects of late delivery of fertilizer from the Farm Inputs Support Programme (FISP) on the technical efficiency of maize production of smallholder farmers. Three main objectives were addressed. Firstly, I sought to determine whether late delivery of FISP is random with respect to recipients or whether there are household and individual characteristics that affect the timely receipt of fertilizer from the government. I found wealthier households, as measured by landholding size and value of productive assets, were more likely to receive FISP fertilizer on time compared to poor households. These findings extend previous studies from Zambia and Malawi showing that wealthier households are more likely to receive subsidized inputs than poorer farmers; my study shows even among recipients, wealthier recipients are more likely to receive their inputs first. Rationing occurs when the FISP fertilizer is delivered to a location in several truckloads or consignments. While the data I used did not quantify the extent of "lateness" among recipients, a nationally-representative study the following year (2011/12) did show that FISP fertilizer was commonly received by households between three and eight weeks after the optimal planting date.

The findings also indicate that if the household head or the spouse is either related to the village headman or chief, the likelihood of receiving fertilizer on time increases significantly by roughly 4.5 and 5.3 percentage points, respectively. Given that roughly 77% of FISP recipients received their consignment on time, those with blood connections to the headman or chief are 5.8% and

6.8% more likely to obtain their fertilizer on time. Furthermore, households living closer to the FISP collection points are somewhat more likely to receive their fertilizer on time than households that are farther away.

Secondly, I estimated the effect of late delivery of FISP fertilizer on technical efficiency and maize output. I estimated a maize yield response function by incorporating technical inefficiency using the stochastic frontier production function approach outlined by Battese and Coelli (1995). The findings show that farms who indicated they received fertilizer late had a reduction in maize output, holding other factors constant, by 4.2%. This contrasts with Xu et al. (2009b) who had previously estimated the reduction for Zambian smallholders at 11% using two period panel data for the 1999/2000 and 2002/2003 farming seasons. However the sample was drawn from all smallholders, not only FISP recipients.

The literature review discussed the challenge of determining what constitutes "late delivery". During the survey, the respondents were asked whether fertilizer from a particular channel (government or private) was available to them when they needed it. Agronomists, in setting up experiments and making recommendations, typically describe post planting application dates in terms of the stage of plant growth beginning with the number of plant leaves. This serves as an indicator of target rates of nitrogen uptake. In a two-year randomized agronomic trial at three sites, Walsh (2006) delayed first applications to V6, to V10 (10 leaves, or about five weeks post planting), and to VT compared to all nitrogen at planting and various combinations of at planting and V6 or V10. The results were variable across treatments and year with range of five to 10 percent reduction in yield averaged across the V6 to VT treatments.

The reduction for this study is less than a previous Zambian study and for a single designed study with treatments consistent with the study objective. This suggests that my estimate of the reduction in maize yield resulting from late fertilizer delivery may be a lower threshold, with results in the 4 to 8 percent range, holding the total fertilizer applied constant, being in the plausible range.

Thirdly, I estimate the foregone maize production resulting from late delivery of FISP fertilizer. The foregone maize output was estimated by extrapolating the results from the stochastic frontier. I determine that by delivering fertilizer late, the government is causing maize farmers to harvest roughly 84,924 MT less maize at the national level than they would if all FISP fertilizer were delivered on time. If valued at the government's maize purchase price of USD250/MT, the foregone maize production is equivalent to USD 21.2 million. According to Jayne and Rashid (2013), the cost of the input subsidy program for Zambia in 2010 was USD 99.8 million. Therefore, the loss in maize production due to late delivery of fertilizer is approximately 21.2% of the total cost of the FISP program.

It is also important to mention that late delivery of fertilizer can affect maize production in other indirect way such as crop choice, land cultivated, labor allocation. However, estimating the impact of late delivery on such outcomes is beyond the scope of this thesis. Including the indirect effects of late delivery of fertilizer would increase the foregone maize outcome and therefore, the estimated 84,924 MT presents a lower bound for foregone maize output.

For the past decade late delivery of inputs to the farmers has been a perennial problem and little has been done to correct the situation. This study provides evidence that late delivery of inputs affect crop yield due to delays in application of fertilizer. The input subsidy program has often created uncertainties among smallholder farmers and private fertilizer retailers due to delays in input delivery. One way that government can improve timely delivery of FISP inputs is through an e-voucher system. Sitko et al. (2012) have extensively discussed how the e-voucher system works. If the e-voucher coupons can be distributed two to three months before the beginning of the farming season this can give farmers ample time to source inputs from the local agro-dealers in readiness for planting. Another advantage of the e-voucher system is that it will enable government to eliminate some of the costs that are incurred under the current system. As shown in Figure 2, there are costs associated with selecting the private suppliers through a tendering process, local transportation as well as storage and these costs can be eliminated if government had to implement the e-voucher system. The e-voucher system can also encourage the private sector to participate in input distribution and stock inputs early before planting time.

This study also provides additional information beyond the scope of the objectives, including the distribution of technical efficiency among Zambian maize farmers and the impact of other factors besides late delivery on their technical efficiency. The distribution of technical efficiency is significantly negatively skewed; the estimated average technical efficiency is 68.2% and the mode is 80%. Twenty five percent are greater than 80% efficient and 50% are greater than 72.5% efficient. However, there are factors that affect the level of technical efficiency that are beyond the farmer's control. For example, the findings indicate that age and gender of the household head negatively affects the level of technical efficiency among smallholder maize producers. Access to agricultural information and distance to the FISP collection points have a significant impact on technical efficiency and these are inputs to the system that are under the control of the government.

Furthermore, the findings show that receiving fertilizer late reduces the level of technical efficiency and maize output by 4.2%. On average, households that received fertilizer late had a reduction both in their level of technical efficiency and maize output. Similarly, households living farther away from the FISP collection points were on a lower level of technical efficiency compared to households living closer to the collection points. Also having access to agriculture information through extension services can improve the level of technical efficiency of smallholder farmers. I can therefore conclude from the above findings that smallholder maize producers can improve their efficiency in production acquiring fertilizer on time and having access to agriculture extension services. Efforts by the Zambian government to address the problem of late delivery of fertilizer and also decentralize the collection points for FISP fertilizer can effectively contribute to improving technical efficiency of smallholder farmers.

APPENDICES

Appendix 1: Description of variables in the production function

Table 11 : Variable Definitions

VARIABLES	Definition	Level of observation
lnseed	Log of kg/ha of seed applied	Field
LnNitrogen	Log of kg/ha of nitrogen applied	Field
lnWeed	Log of number of weeks for first weeding	Field
Seed_squared	Squared log of seed	Field
Nitrogen_squared	Squared Log of nitrogen	Field
Seed_NitrogenFert	Log of nitrogen-Log of seed	Field
Weed_squared	Squared log of weeding	Field
Seed_Stress	Log of seed-number of stress periods	Field
Hybrid	1= Hybrid seed, 0= local variety	Field
Manure_compost	1= Manure or compost used on the field, 0 = none	Field
MoistureStress	Proportion of 20-day periods when rainfall was less than 40 mm during the main growing season	Cluster
soil_erosion	1 = field prone to soil erosion 0 = none	Field
Acrisols	1= Acrisols soil, 0 = otherwise	SEA
Ferralsols	1 = Ferralsols , 0 =otherwise	SEA
Other_soils	1= Other soil types 0 = otherwise	SEA
pHbelow4.4	1= pH below 4.4, 0 =otherwise	SEA
pHbetween4.4_5.5	1 = pH between 4.4 and 5.5, 0 = otherwise	SEA
Tillage_Ploughing	1 = Tillage with a plough, 0 = otherwise	Field
Tillage_before rains	1 = Tillage before the rains, 0 = otherwise	Field
Fert_late	1= Fertilizer received late, 0 = otherwise	Household
Age_HH	Age of household head (years)	Household
EduHead	Education of household head (years)	Household
Femalehead	1= Female head, 0 = otherwise	Household
Distan_FISPColPoint	Distance to the FISP collection point (Km)	Household
Acces_ext	1= Accessed extension services, 0 = otherwise	Household
Dist_townCenter	Distance to district town center (Km)	Household
Prod_Assets	Value of productive Assets	Household
Residuals	Residuals from reduced form equation	Household
Prov	Each province included as a dummy	Household

Appendix 2: Stochastic Frontier Model Results

Table 12 : Econometrics Results From Stochastic Frontier Model

VARIABLES	**Translog**	**Cobb Douglas**
Constant	5.594***	5.516***
	(0.513)	(0.106)
lnseed	0.465**	0.165***
	(0.226)	(0.024)
LnNitrogen	0.312**	0.445***
	(0.163)	(0.017)
lnWeed	-0.087***	-0.001
	(0.024)	(0.016)
Seed_squared	-0.114	
	(0.072)	
Nitrogen_squared	0.045	
	(0.039)	
Seed_NitrogenFert	-0.016	
	(0.044)	
Weed_squared	0.127***	
	(0.026)	
Seed_Stress	0.066***	
	(0.024)	
Hybrid	0.237***	0.244***
	(0.028)	(0.028)
Manure_compost	0.041	0.039
	(0.027)	(0.027)
MoistureStress	-0.238***	-0.036***
	(0.076)	(0.013)
soil_erosion	-0.032**	-0.035*
	(0.020)	(0.020)
Acrisols	0.063	0.064
	(0.051)	(0.051)
Ferralsols	0.054	0.048
	(0.039)	(0.039)
Other_soils	0.043	0.049
	(0.052)	(0.053)
pHbelow4.4	-0.262*	-0.278*
	(0.163)	(0.165)
pHbetween4.4_5.5	0.285*	0.281*
	(0.161)	(0.162)
Tillage_Ploughing	0.003	0.005
	(0.018)	(0.017)
Tillage_before rains	-0.026	-0.028
	(0.024)	(0.023)

Table 12 (Cont'd)

Provincial Dummies (Central Base		
Copperbelt	-0.0249	-0.0324
	(0.0409)	(0.0412)
Eastern	0.0869*	0.0582*
	(0.0351)	(0.0346)
Luapula	-0.0522	-0.0734*
	(0.0444)	(0.0441)
Lusaka	-0.1909***	-0.2102***
	(0.0512)	(0.0510)
Muchinga	0.1443***	0.1377***
	(0.0445)	(0.0447)
Northern	0.0384	0.0283
	(0.0379)	(0.03808)
North Western	0.0621	0.0636
	(0.0472)	(0.0468)
Southern	-0.0901**	-0.1029***
	(0.0369)	(0.0361)
Western	-0.1818**	-0.1851***
	(0.0582)	(0.0361)

Table 12 (Cont'd)

Variables in the inefficiency term μi	Translog	Cobb Douglas
Constant	5.5223***	5.5157***
	(0.5306)	(0.1055)
Fert_late	0.1409**	0.1306**
	(0.0595)	(0.0604)
Age_HH	0.0080***	0.0077***
	(0.0020)	(0.0020)
EduHead	-0.0033	-0.0046
	(0.0069)	(0.0070)
Femalehead	0.1857**	0.1908**
	(0.0736)	(0.0743)
Distan_FISPColPoint	0.0044**	0.0044**
	(0.0019)	(0.0019)
Acces_ext	-0.1396**	-0.1347**
	(0.0626)	(0.0635)
Dist_townCenter	-0.0013	-0.0012
	(0.0009)	(0.0009)
Prod_Assets	-0.0227*	-0.0252*
	(0.0140)	(0.0142)
Num_members	0.0060	0.0050
	(0.0093)	(0.0094)
Residuals	0.8264**	0.8994**
	(0.3982)	(0.4027)
Constant	-2.3137***	-2.1978***
	(0.6227)	(0.6024)
Sigma	-1.966***	-2.197***
Sigma_u	1.116	1.068
Sigma_v	0.374***	0.394
Number Observations	**3,792**	**3,792**
Log-likelihood	2,874.04	2,912.03

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

REFERENCES

REFERENCES

Allah Wasaya. 2011. "Improving Maize Productivity through Tillage and Nitrogen Management." *African journal of Biotechnology* 10 (82) (December 19).

Alvarez, A. 2004. "Technical Efficiency and Farm Size: a Conditional Analysis." *Agricultural Economics* 30 (3) (May): 241–250.

Amsler, Christine, Peter Schmidt, and Wen-Jen Tsay. 2013. *A Post-Truncation Parameterization of Truncated Normal Technical Inefficiency*. Institute of Economics, Academia Sinica, Taipei, Taiwan. http://econweb.umd.edu/~davis/eventpapers/SchmidtPost.pdf.

Baltzer, Kenneth, and Henrik Hansen. 2011. *Agriculture Input Subsidies in SSA.pdf*. Ministry of Foreign Affairs of DenMark.

Battese, George E. 1992. "Frontier Production Functions and Technical Efficiency: a Survey of Empirical Applications in Agricultural Economics." *Agricultural Economics* 7 (3): 185–208.

Battese, George E., and Tim J. Coelli. 1995. "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data." *Empirical Economics* 20 (2): 325–332.

Belotti, Federico, Silvio Daidone, Giuseppe Ilardi, and Vincenzo Atella. 2012. "Stochastic Frontier Analysis Using Stata." *CEIS Tor Vergata Research Paper Series* 10: 12.

Chirwa, Ephraim W. 2007. *Sources of technical efficiency among smallholder maize farmers in southern Malawi*. Nairobi: African Economic Research Consortium.

Coelli, Timothy J., Dodla Sai Prasada Rao, Christopher J. O'Donnell, and George Edward Battese. 2005. *An Introduction to Efficiency and Productivity Analysis*.

Cullinane, Kevin, Teng-Fei Wang, Dong-Wook Song, and Ping Ji. 2006. "The Technical Efficiency of Container Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis." *Transportation Research Part A: Policy and Practice* 40 (4) (May): 354–374.

Darko, Francis Addeah, and Jacob Ricker-Gilbert. 2013. “Economic Efficiency and Subsidized Farm Inputs: Evidence from Malawi Maize Farmers.”

Duflo, Esther, Michael Kremer, and Jonathan Robinson. 2011. “Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya.” *American Economic Review* 101 (6) (October): 2350–2390.

Greene, William H. 2008. “The Econometric Approach to Efficiency Analysis.” *The Measurement of Productive Efficiency and Productivity Growth*: 92–250.

Hammad, HAFIZ MOHKUM, Ashfaq Ahmad, Aftab Wajid, and JAVAID Akhter. 2011. “Maize Response to Time and Rate of Nitrogen Application.” *Pak. J. Bot* 43 (4): 1935–1942.

Henningsen, Arne. 2014. “Introduction to Econometric Production Analysis with R (Draft Version).” http://files.itslearning.com/data/ku/103018/teaching/lecturenotes.pdf.

IAPRI. 2012. “Indaba Agricultural Policy Research Institute (IAPRI), 2012. The 2012 Rural Agricultural Livelihoods Survey: Interviewer’s Instruction Manual.” IAPRI, Lusaka, Zambia.

Imbens, G, and J Wooldridge. 2007. “Control Function and Related Methods. NBER Summer Lecture Series 6” Michigan State University.

Jacoby, Hanan G. 1998. “Access to Markets and the Benefits of Rural Roads: a Nonparametric Approach.” *Washington DC: World Bank, Working Paper* 2028.

Jayne, T.S., and Shahidur Rashid. 2013. “Input Subsidy Programs in sub-Saharan Africa: a Synthesis of Recent Evidence.” *Agricultural Economics* 44 (6) (November): 547–562.

Jones, Clain, and Jeff Jacobsen. 2003. “Fertilizer Placement and Timing.” *MSU Extension Service, Nutrient Management Module* (11).

Kibaara, B. W., and M. M. Kavoi. 2012. “Application of stochastic frontier approach model to assess technical efficiency in Kenya’s maize production.” *Journal of agriculture, science and technology* 14

Kumbhakar, Subal C., Soumendra Ghosh, and J. Thomas McGuckin. 1991. “A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in US Dairy Farms.” *Journal of Business & Economic Statistics* 9 (3): 279–286.

Lewbel, Arthur. 2004. “Simple Estimators for Hard Problems: Endogeneity in Discrete Choice Related Models.” *Unpublished Manuscript, Http://www2. Bc. Edu/lewbel*.

Liu, Yanyan, and Robert Myers. 2008. “Model Selection in Stochastic Frontier Analysis with an Application to Maize Production in Kenya.” *Journal of Productivity Analysis* 31 (1) (September 23): 33–46.

MACO. 2009. “FISP_implementation_manual_0910.pdf.”

MACO. 2010. “Farmer Input Support Programme Implementation Manual, 2010/2011 Agricultural Season”. MACO, Lusaka Zambia.

Mason, Nicole M., T.S. Jayne, and Rhoda Mofya-Mukuka. 2013. “Zambia’s Input Subsidy Programs.” *Agricultural Economics* 44 (6) (November): 613–628.

Mason, Nicole M., and Melinda Smale. 2013. “Impacts of Subsidized Hybrid Seed on Indicators of Economic Well-being Among Smallholder Maize Growers in Zambia.” *Agricultural Economics* 44 (6) (November): 659–670.

Masterson, Thomas. 2007. *Productivity, Technical Efficiency, and Farm Size in Paraguayan Agriculture*. Working papers//The Levy Economics Institute

McWilliams, Denise A., Duane Raymond Berglund, and G. J. Endres. 2010. “Corn Growth and Management Quick Guide.” http://lib.ndsu.nodak.edu/repository/handle/10365/9112.

Park, Hun Myoung. 2009. *Regression Models for Ordinal and Nominal Dependent Variables Using SAS, Stata, LIMDEP, and SPSS*. Working Paper.

Ricker-Gilbert, J., and T. S. Jayne. 2015. “What Are the Dynamics Effects of Fertilizer Subsidies on Commerical Fertilizer Demand and Maize Production? Panel Data Evidence from Malawi.” *International Development Working Paper, Michigan State University East Lansing, Mi*.

Ricker-Gilbert, J., T. S. Jayne, and E. Chirwa. 2011. “Subsidies and Crowding Out: A Double-Hurdle Model of Fertilizer Demand in Malawi.” *American Journal of Agricultural Economics* 93 (1) (January 27): 26–42.

Ricker-Gilbert, Jacob. 2013. “Wage and Employment Effects of Malawi’s Fertilizer Subsidy Program.” *Agricultural Economics* (September)

Sangoi, Luis, Paulo Roberto Ernani, and Paulo Regis Ferreira da Silva. 2007. “Maize Response to Nitrogen Fertilization Timing in Two Tillage Systems in a Soil with High Organic Matter Content.” *Revista Brasileira De Ciência Do Solo* 31 (3): 507–517.

Sawyer, John E. 2008. “Nitrogen Application Timing, Forms, and Additives.” http://www.agronext.iastate.edu/soilfertility/info/Gulf06PP.pdf.

Scharf, Peter, and John Lory. 2006. “Integrated Pest Management: Best Management Practices for Nitrogen Fertilizer in Missouri”. College of Agriculture, Food and Natural Resources, University of Missouri-Columbia.

Seyoum, E. T., G. E. Battese, and E. M. Fleming. 1998. “Technical Efficiency and Productivity of Maize Producers in Eastern Ethiopia: a Study of Farmers Within and Outside the Sasakawa-Global 2000 Project.” *Agricultural Economics* 19 (3): 341–348.

Sitko, Nicholas J., Richard Bwalya, Jolly Kamwanga, and Mukata Wamulume. 2012. “Assessing the Feasibility of Implementing the Farmer Input Support Programme (FISP) Through an Electronic Voucher System in Zambia”. IAPRI, Lusaka, Zambia.

Suyanto, Ruhul A. Salim, and Harry Bloch. 2009. “Does Foreign Direct Investment Lead to Productivity Spillovers? Firm Level Evidence from Indonesia.” *World Development* 37 (12) (December): 1861–1876.

Vetsch, Jeffrey A., and Gyles W. Randall. 2004. “Corn Production as Affected by Nitrogen Application Timing and Tillage.” *Agronomy Journal* 96 (2): 502–509.

Van de Walle, Nicholas. 2001. *African Economies and the Politics of Permanent Crisis, 1979-1999*. Cambridge University Press.

Walsh, Olga S. 2006. “Effect of Delayed Nitrogen Fertilization on Corn Grain Yields”. Oklahoma State University. https://shareok.org/handle/11244/9381.

Wang, Hung-Jen. 2002. “Heteroscedasticity and Non-monotonic Efficiency Effects of a Stochastic Frontier Model.” *Journal of Productivity Analysis* 18 (3): 241–253.

Wang, Hung-Jen, and Peter Schmidt. 2002. "One-step and Two-step Estimation of the Effects of Exogenous Variables on Technical Efficiency Levels." *Journal of Productivity Analysis* 18 (2): 129–144.

Wooldridge, Jeffrey M. 2010. *Econometric Analysis of Cross Section and Panel Data*. 2nd ed. Cambridge, MA: MIT Press.

World Bank. 2010. "Impact Assessment of the Fertilizer Support Program." http://citeseerx.ist.psu.edu/viewdoc/download?

Xu, Zhiying, William J. Burke, Thomas S. Jayne, and Jones Govereh. 2009a. "Do Input Subsidy Programs 'crowd in' or 'crowd Out' Commercial Market Development? Modeling Fertilizer Demand in a Two-channel Marketing System." *Agricultural Economics* 40 (1) (January): 79–94.

Xu, Zhiying, Zhengfei Guan, T.S. Jayne, and Roy Black. 2009b. "Factors Influencing the Profitability of Fertilizer Use on Maize in Zambia." *Agricultural Economics* 40 (4) (July): 437–446.

ZARI. 2002. "Zambia Agricultural Research Institute (ZARI):'Maize Production Guide.' Publication Prepared by the Soils and Crops Research Branch, Ministry of Agriculture and Cooperatives." MACO, Lusaka Zambia.

ZNFU. 2008. *Zambia National Farmers Union (ZNFU): Position Paper on the Fertilizer Support Program (FSP)*. Lusaka Zambia: ZNFU.