Does Late Delivery of Subsidized Fertilizer Affect Smallholder Maize Productivity and Production?

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Selected paper prepared for presentation at the 2015 Agricultural& Applied Economics Association and Western Agricultural Economics Association Annual Meeting, San Francisco, CA, July 26-28, 2015

Abstract

Farm input subsidy programs have once again become a popular policy tool that many African governments use to improve agricultural productivity and address rural poverty. Zambia is one of the countries of Sub-Saharan Africa (SSA) that over the past decade has devoted a considerable share of its agricultural budget to the Farmer Input Support Program (FISP). Input subsidy programs have received considerable research attention in recent years. Unfortunately, the issue of late delivery of inputs under government subsidy programs has received little or no research attention even though it has been a longstanding problem in many countries, including Zambia. This paper examined the effects of late delivery of fertilizer on technical efficiency of smallholder maize producers and on foregone national maize output in Zambia. Using cross-sectional household survey data for the 2010/11 agricultural season, a plot-level maize yield response model was estimated using a Stochastic Frontier Approach (SFA) while controlling for the endogeneity of whether farmers received their FISP fertilizer on time. 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 FISP, we 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 family connections with village headmen/chiefs were more likely to receive fertilizer on time compared to other households.

1. Introduction

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. One of the stated goals of the Farmer Input Support Program (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 been a longstanding major challenge despite persistent calls by farmers and other stakeholders to correct this problem. 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 significantly affect national maize output and even maize price levels. However, to our knowledge, these issues have never been quantified in Zambia or any other country in SSA.

Box 1

Figure 1 depicts a maize field for a farmer in Choma District in Zambia and the challenges faced by many other farmers. 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 because of delays in acquiring FISP fertilizers, she 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 and applied on time with the first rains, while the section on the right shows the maize she planted when she eventually received inputs from FISP four weeks later. This photo illustrates how smallholder farmers in Zambia can be affected by late delivery of inputs from FISP.

Figure 1: Maize Field in Choma District
Source: Key informant from MAL (January, 22nd 2014)

According to data collected from the 8,839 households participating in the Rural Agricultural Livelihood Survey (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, 21.5% reported receiving their basal fertilizer late after the 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 November or early

December. Most farmers prepare land towards end of October in order to take advantage of the first rains. However, planting of seeds and fertilizer application can only be done when these inputs are readily available to the farmers.

According to agriculture field extension officers in Zambia, farmers are encouraged to apply fertilizer at two different stages; i) the first "basal" application is done at planting to encourage root growth. And Sangoi et al. (2007), indicate that 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. 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[1] 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 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 our knowledge no study has looked at its effects on foregone national maize production. Our study estimates the effect of late FISP delivery on the technical efficiency of farmers' maize production as well as on foregone national maize output. We define technical efficiency as the ability of a farm to produce the maximum possible output with the available combination of inputs. In most cases firms and farmers alike rarely operate at their technically efficient levels owing to weak management skills, lack of information, distance to major roads and many other factors.

Estimating the effects of late FISP delivery on national maize output is complicated by the possibility of indirect effects on output. For example, private fertilizer distributors have complained that late delivery of government-subsidized fertilizer create problems for the private sector to supply fertilizer on time 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, retailers often 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 government program fertilizer may have knock-on effects on the quantity and

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

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.
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). The studies highlighted 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 our 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 paper 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.

The remainder of this paper is organized as follows. Section 2 gives an overview of FISP; Section 3 describes the data used in the study. Section 4 describes the methods used to estimate the effect of late delivery of fertilizer on technical efficiency. We then present the study's main findings in section 5. The last section highlights the conclusions and policy recommendations that are drawn from this study.

2. Overview of the Farmer Input Support Program

In 2002, the Zambian government introduced the Fertilizer Support Program (FSP) and under this program, the beneficiaries[2] were entitled to 8 X 50kg bags of fertilizer[3] and 20kg bag of hybrid maize seed. However, in 2009 the Zambian government reduced the size of the input pack by half to increase the number of targeted beneficiaries and the program name was also changed to the Farm Inputs Support Programme (FISP). The input subsidy program has been scaled up since its inception 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. One of the challenges with the implementation of the program is serious delays in delivering of inputs to the farmers.

According to the FISP implementation guidelines (MACO 2010), inputs are supplied by private suppliers who are selected by the government through a tender process. Two types of fertilizer that are most commonly contained in the FISP: Compound D, a basal fertilizer to be applied at planting time, and urea, a top dress fertilizer to be applied at knee high (3 to 4 weeks after planting). Compound D contains 10% nitrogen and 20% phosphorous[4] while urea contains 46% nitrogen. 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). Compound D fertilizer is usually supplied by Nitrogen Chemicals of Zambia (NCZ) which is a state-owned company (Baltzer and Hansen 2011). Urea fertilizer is imported by two private fertilizer companies (Omnia fertilizer Zambia Limited and Nyiombo Investments Limited) who are typically awarded the contracts every year (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 points.
The delays in delivery of fertilizer 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 not 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 when there is a delay in approving the budget by the parliament, contracting the private suppliers to procure fertilizer would also be delayed. However, the fiscal year has since changed to run from 1st January to 31st December and government announces the budget by 31st of October, but delays in fertilizer procurement have still continued. According to MAL, 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 delivering fertilizer in more than one consignment in a particular area. Some farmers therefore receive their fertilizer earlier than others (personal communication, August 7, 2014).

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[2] 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.
[3] Fertilizer consists of four 50kg bags of Compound D basal fertilizer and four 50kg bags of Urea for top dressing
[4] Throughout this paper, we refer to phosphorous as a proxy for P_2O_5 found in Compound D fertilizer

3. 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 (IAPRI) 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 2010 Zambian census. The survey is statistically representative at the district level in Eastern Province and at the provincial level in all other provinces 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).

Of the 8,839 households that were interviewed, 48.9% (4,322 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, we narrow our focus to households that acquired fertilizer and had at least one maize field in the 2010/11 agricultural season. While fertilizer acquired through FISP can be used on various crops, the intended purpose of FISP is to increase maize production of the smallholder farmers. Since we 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 delivery of fertilizer under FISP.

We supplement the RALS data with other data from different sources. 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) now MAL (ZARI 2002).

4. Conceptual Framework and Methods

One assumption of production theory is that it presupposes full technical efficiency among producers in the sense that farms (firms) are assumed to be producing the maximum possible output for any combination of inputs. However, there exists a gap between the theoretical assumption of technical efficiency and reality hence the importance of measuring 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, we 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.

To estimate the effect of late delivery of FISP fertilizer on technical efficiency we use stochastic frontier production functions. Stochastic frontier analysis [5] (SFA) has been commonly used to measure relative efficiency on farm-level data. One major advantage of frontier production functions is their ability to estimate the level of technical efficiency of individual farms and also account for the sources of inefficiency that prevent farms 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. A stochastic frontier function incorporates a composite error term; a symmetric component that captures the random effects outside the control of the firm and a one-sided error term that reflects the inefficiency in production (Cullinane et al. 2006).

4.1 Empirical Model

Following the model specification by Battese and Coelli, (1995), the general stochastic production frontier can be expressed as;

$$Y_i^* = X'_i\boldsymbol{\beta} + V_i \qquad (1)$$

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 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 model is then written as;

$$Y_i = \alpha + X_i\beta + V_i - U_i \qquad (2)$$

[5] 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 one-sided error term (U_i) measures the extent to which observed output deviates from potential output given a certain level of inputs and technology. 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;

$$U_i = \delta Z_i + W_i \tag{3}$$

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). 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 assumed to be truncated normal which is denoted as $N^+(\mu_i, \sigma_u^2)$ but there are other distributional specifications which are outlined in detail by Greene (2008). The parameters in Eqns. (2) and (3) can be estimated using a one-step maximum likelihood estimation (MLE) which is generally proposed for simultaneous estimation of the stochastic frontier and the inefficiency effects. 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:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{\exp(x_i\beta + V_i - U_i)}{\exp(x_i\beta + V_i)} = e^{-U_i}$$
$$= e^{-(Z_i\delta + W_i)} \tag{4}$$

The technical efficiency estimates in Eqn. (4) 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) 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 (Suyantom et al. 2009).

Two functional forms are commonly used in the estimation of stochastic frontier models: Cobb-Douglas and Translog functional forms. The functional form for the stochastic frontier in this study was determined by testing the adequacy of the Cobb-Douglas relative to the less restrictive Translog. Since the two functional forms are nested the Likelihood Ratio (LR) was used to test the null hypothesis that the Cobb-Douglas production function is an adequate representation of the data[6].

A Translog production function is specified as:

$$\ln(Y_i) = \beta_0 + \sum_{i}^{n} \beta_i \ln X_1 + 0.5 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln X_i \ln X_j \; + \; v_i - u_i \tag{5}$$

[6] The null hypothesis that a Cobb-Douglas specification is an adequate representation of the data was rejected in favor of the Translog production function (*LR = 28.75, p-value= 0.000*).

4.1.1 Explanatory Variables

(i) Variables in the production frontier

Table 1 shows a list of all the variables used in the production frontier and in the inefficiency term. The variables included in the production frontier were collected at field level and some at community level. The unit of observation is the maize plot. Maize fields in Zambia are often intercropped with other crops however for the sample used for our analysis, only 2.3% of the fields (87 fields) were intercropped. Since the percentage of intercropped fields is very small we do not expect this to affect the yield estimations. To estimate the stochastic production function, inputs and output are in 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. 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 (Compound D and urea), nitrogen and phosphorus were used in fixed proportions. For the sample used in this study, nitrogen and phosphorus were highly correlated (linear correlation coefficient of 0.95) and therefore, both nutrients cannot be included in estimation. To estimate the maize response function we use the rate of nitrogen applied as an index since it is the most important nutrient in maize growth and is highly correlated with the level of phosphorus applied.

Besides knowing how much of each input the farmers used on a particular field, this study takes into account the different soil types in the various fields. The type and characteristics of soil is important in determining plant growth, nutrient intake (e.g. fertilizer) and level of output. Based on the soil characteristics, three dummy variables are used in this study. The three soil dummy variables [0, 1] include; acrisols, ferrasols, and a dummy for other soil types. A fourth soil category, the lixisols soil type, is subsumed in the intercept term. For more details on Zambian soil characteristics, see ZARI (2002). The soil types used in this study do not completely capture the variability in soil fertility conditions at field level, which often correlates with farm management practices. We 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 variable of whether or not a field is prone to soil erosion. These proxies partially mitigate the impact of differences associated with soil quality. We also control for soil acidity by including soil pH 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. The pH for neutral soils is used as a base (pH range of 5.5-7.1). The soil pH variables are not specific to the fields but are observed at community (standard enumeration area) level.

(ii) Variables in the inefficiency term

To explain the sources of inefficiencies among smallholder farmers, we use household and individual attributes such as; age, gender and education of household head; household size; variables measuring the distance from the farm to the nearest town and FISP collection point; extension services; landholding size and the 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). We also investigate the effects of gender on technical efficiency of maize farmers by including a dummy variable for the gender of the household head. 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). In addition to some of the variables that have been used in previous studies to measure the sources of inefficiency, we include a dummy variable denoting whether the farmer received fertilizer on time or not to evaluate its effect on technical efficiency.

Table 1: Descriptive statistics of variables in the production frontier and the inefficiency term

Variables	Percentile of the distribution					
	Mean	5	25	50	75	95
Variables in the production frontier						
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
N application rate (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]	0.05					
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)	0.57					
Soil erosion (=1)	0.15					
Manure or compost (=1)	0.10					
Variables in the inefficiency term						
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)	36.2	2	15	29	50	90
Value of productive assets (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

[7] Lixisols soil type is used as a base in this model

4.2 Dealing with possible endogeneity of timely receipt of subsidized fertilizer

Based on anecdotal reports in 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. 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 in the inefficiency term. We therefore use a control function (CF) approach to deal with the possible 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 3 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 the endogenous variable and W_i (for more details on control function approach see Imbens and Wooldridge 2007; Lewbel 2004). The reduced form model for timely receipt of fertilizer is modeled using a probit model and the probit 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. 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.

5. Results

Table 2 presents results from the reduced form probit model of factors influencing timely receipt of fertilizer from FISP. The coefficients presented in table 2 are the average partial effects computed using the Stata margins command. 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 similar to previous studies on input subsidy programs in Zambia and Malawi. The findings by Mason et al. (2013a) 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 in Malawi. The results presented in this study and the findings of Mason et al. (2013a) and Ricker-Gilbert et al. (2011) 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 2 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. The coefficients on the IVs, household head/spouse related to the headman or chief are positive and statistically significant. These findings are not surprising since traditional leaders are actively involved in the selection of beneficiaries and therefore distribution of fertilizer is likely to be targeted first towards their close relations. In order to test the strength of the IVs we look at the partial correlation of IVs in the reduced form model and the dependent variable fertilizer received late. The model yields a *p*-value of less than 1%, indicating that the IVs are partially correlated with the potentially endogenous variable.

Table 2: Socioeconomic factors influencing timely receipt of fertilizer from FISP

Independent variables	Average Partial Effects
Female HH Head (=1)	0.0182
	(0.0188)
Education of HH Head (years)	-0.0046**
	(0.0019)
Age of HH Head (years)	-0.0011**
	(0.0005)
Value of Productive Assets (ZMW)	0.00027***
	(0.0045)
Total landholding size (ha)	0.0037**
	(0.0015)
Distance to FISP collection point (Km)	-0.0003
	(0.0006)
Distance to the District town center (Km)	0.00066**
	(0.00023)
Household size (count)	-0.0087***
	(0.0025)
HH Head Related headman (=1)	0.0429***
	(0.0143)
HH Head is headman/woman (=1)	0.0530*
	(0.0280)
Spouse related to headman/woman (=1)	0.0083
	(0.0192)
Spouse related to the Chief (=1)	0.0485**
	(0.0240)
Extension service (=1)	0.0206
	(0.0167)
Observations	**3,844**
Pseudo R^2	**0.0921**

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

5.1 Estimated Results from Stochastic Frontier Model

The coefficients of the estimated Translog production function are not very informative *per se*; they must be transformed to determine the partial effect of each individual input in the production frontier.[8] Some of the variables that show a positive and statistically significant effect on maize yield include weeding, use of nitrogen and hybrid seed. Soil pH in the range of 4.4 and 5.5 also has a positive and significant effect on maize yield. Partial effects of dummy variables are derived as the difference in expected yields when the dummy variable changes from 0 to 1. The estimated partial effect for hybrid seed dummy is 0.237. Therefore, on fields where hybrid seed was used, maize yield was higher by 23.7% compared to fields where local seed varieties were used. Furthermore, fields that are prone to soil erosion had 3.2% lower yield compared to other fields, *ceteris paribus*. Soil acidity also had a significant effect on maize yield. Holding other factors constant, yields on fields where pH is in the range between 4.4 and 5.5 had 28.5% more yield than on fields where the pH was below 4.4.[9] The partial effects for the variables in the production frontier are presented in appendix 1.

a) Marginal and Average Product of Nitrogen

The marginal product (MP) and average product (AP) of nitrogen application plays an important role in the farmer's decision about use of fertilizer and we are also interested to model the expected maize yield response to nitrogen application. 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 Marginal Product of nitrogen is estimated as;

$$MP_N = TE * e_N * \frac{f(N)}{N} \qquad (6)$$

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. The estimated mean AP of nitrogen is 16.48 kg of maize per kilogram of nitrogen holding other variables constant. Table 3 shows the estimated MP and AP at various fertilizer application rates. As the rate of fertilizer application increases, both the MP and AP are decreasing. At the nationwide recommended application rate of 200kg Compound D and 200kg urea which is equivalent to 112kg of nitrogen per hectare, the estimated average and marginal products of fertilizer are 12.43kg and 7.9kg of maize per kg of nitrogen. These values are both below the estimated mean MP and AP for the sample used in this study. The official government-recommended fertilizer application rate in Zambia is beyond the rates used by majority of the smallholder farmers in Zambia.

[8] For the interested reader, the stochastic frontier function results are presented in Appendix 1.

[9] Soil acidity is inversely related to pH level, i.e., lower pH levels represent more acidic soils.

Table 3: Estimated MP and AP at different rates of nitrogen application

Percentiles for Nitrogen application rates	MP of Nitrogen (kg maize / kg N)		AP of Nitrogen (kg maize /kg N)	
	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

5.2 Estimated Technical Efficiency

Figure 2 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 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.

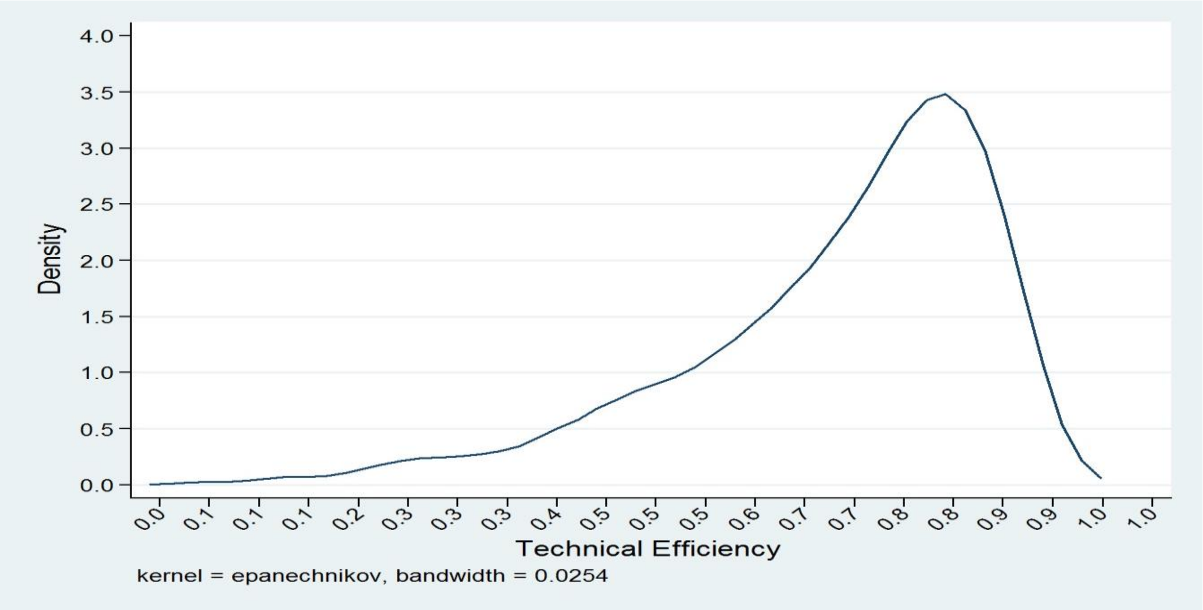

Figure 2: Probability density of technical efficiency estimates for farms participating in FISP
Source: Own calculations using RALS data

Figure 3 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.

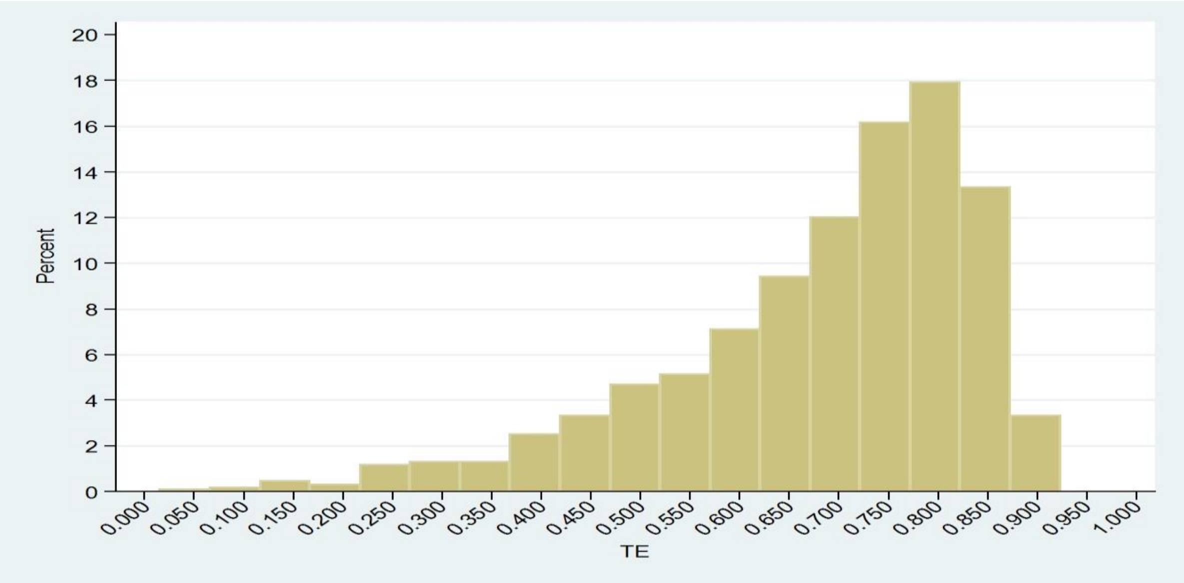

Figure 3**:** Histogram of Technical Efficiency for FISP recipients
Source: Own calculations using RALS data

5.3 Factors affecting Technical inefficiency

The coefficients of all the variables in the inefficiency term only indicate the direction of the effects that these variables have on technical inefficiency. 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 function. 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). Table 4 below presents the estimated marginal effects of each of the variables in the inefficiency term.

Table 4: Marginal Effects on Technical Inefficiency

Variables	Marginal Effects
FISP fertilizer late (=1)	0.042**
	(0.0006)
Age of Household Head (yrs.)	0.0015***
	(0.0001)
Education of Household head (yrs.)	-0.0005
	(0.00004)
Female head (=1)	0.0379**
	(0.0005)
Distance to the FISP collection point (Km)	0.0009**
	(0.0001)
Access to extension (=1)	-0.0561**
	(0.0004)
Distance to District town center (Km)	0.0005
	(0.0013)
Value of Productive assets	-0.0164*
	(0.0084)

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

The marginal 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. The estimated marginal effect is 0.042 and according to Wang (2002), $\frac{\partial E(\ln Y)}{\partial Fert\_Late} = -\frac{\partial E(U)}{\partial Fert\_Late}$. Therefore, a negative effect on technical efficiency translates into a decrease in yield (output) by 4.2%. 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 4 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 marginal effect on the variable fertilizer received late. It is also important to note that input use (seed and fertilizer) were 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 88.74 kg/ha respectively. Seeding rates were 24.74 kg/ha and 24.52 kg/ha for households that received fertilizer on time and those that received it late.

The two groups are therefore similar in terms of input use but what differentiates them is the timing of planting and fertilizer application hence resulting in yield difference of 4.2% due to late delivery of FISP fertilizer.

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.

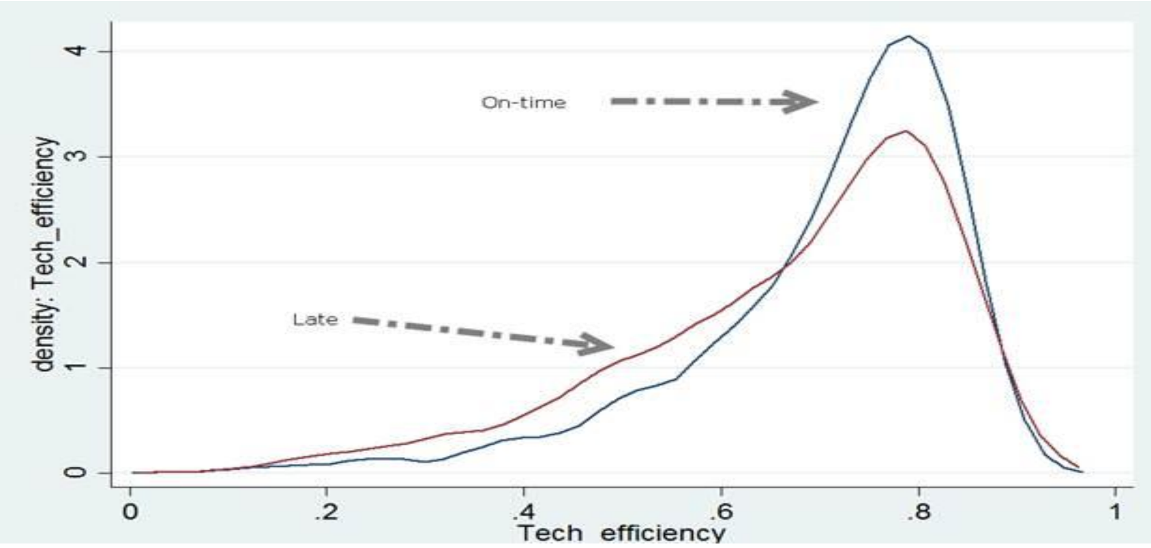

Figure 4: Technical Efficiency distribution for fields where fertilizer was received late and on time
Source: Own calculations using RALS data

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 4, age and gender of the household head both have a positive effect on technical inefficiency. 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 similar to 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 50th and 75th 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.

5.4 Foregone Maize Output Due to Technical Inefficiency and Late Delivery of Fertilizer

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

$$Potential\ Yield = \frac{Actual\ yield}{Technical\ Efficiency} \qquad (7)$$

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 frontier (potential) yield is 3.95 ton/ha. Therefore, with the given 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 technical efficiency of smallholder maize producers can increase maize output. As depicted in Figure 5 below, with the same nitrogen application rates that the maize farmers are currently using, maize yield can greatly increase by improving their technical efficiency. This can be achieved through farmers' involvement with extension agents and timely delivery of fertilizer from FISP.

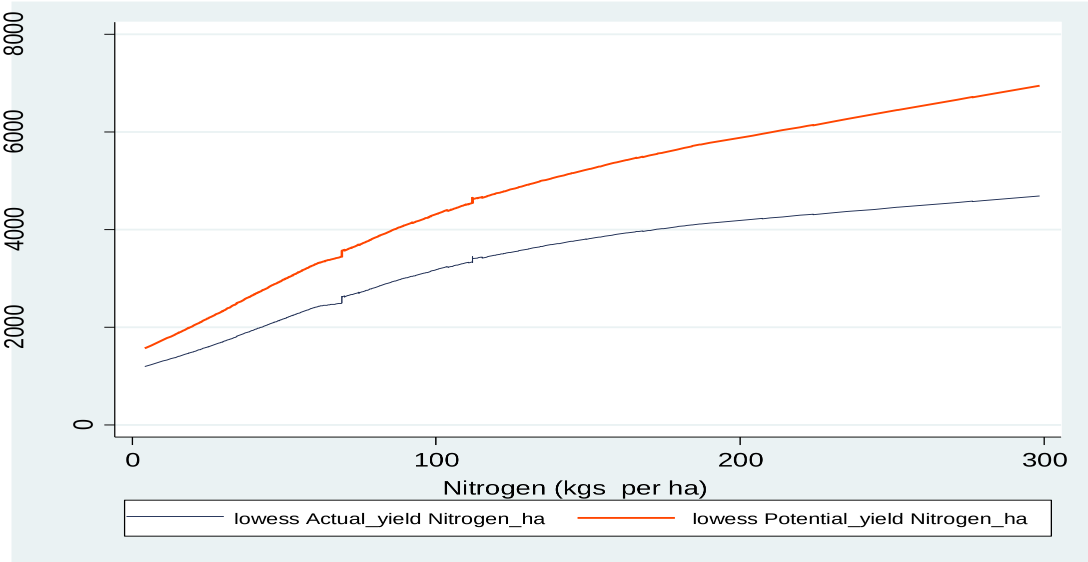

Figure 5: Graph of Yield vs. Nitrogen application rates
Source: Own calculations using RALS data

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

From the results presented in Table 4, the marginal effect of late delivery of fertilizer on yield is 4.2%. We also estimated the effect of late receipt of fertilizer from commercial traders on maize production. We then extrapolated the results to estimate the foregone national maize output due to late delivery of fertilizer. The foregone maize output due to late delivery of fertilizer can be estimated as:

$$\text{Foregone Mz}=0.042\left(\sum_{i=1}^{n} W_i Q_{FISP}\right)+0.032\left(\sum_{j=1}^{n} W_i\, Q_{Comm}\right)+0.042\left(\sum_{h=1}^{n} W_i Q_{BOTH}\right) \quad (8)$$

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 this formula, we estimate that the foregone national maize output due late delivery of FISP fertilizer is ***84,924 MT***. From the estimated equation, the biggest contribution of foregone maize output is from fields where households purchased fertilizer only from FISP amounting to ***34,566 MT***. While many factors determine the yield levels for different crops as evidenced from previous literature, we can conclude that timely availability of fertilizer also affects maize yield. The estimated loss in maize output adversely affects smallholder farm households who largely depend on maize production for their livelihoods, especially given that 78% of these households fall below the US$1.25/capita/day poverty line (Mason et al. 2013). 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 the achievement of such an important objective could be largely compromised if late delivery of inputs through the subsidy program is not quickly addressed.

6. Conclusion and Recommendations

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, using a reduced form probit model we determined the factors influencing timely receipt of fertilizer. We 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. Rationing occurs when the FISP fertilizer is delivered to a location in several truckloads or consignments. 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, we estimated the effect of late delivery of FISP fertilizer on technical efficiency and maize output. 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 our 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, we 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. 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 study. 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. 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.

We 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

Appendix

A1: Partial effects of the variable in the Stochastic Frontier Model

Variables in the Production Frontier	Partial Effects
Log of seed	0.1782**
	(0.0181)
Log of Nitrogen	0.2385***
	(0.1625)
Log of Weeding	0.0873***
	(0.0038)
Hybrid Seed (=1)	0.2372***
	(0.0284)
Manure or Compost (=1)	0.0414
	(0.0270)
Number of Stress period	-0.0487***
	(0.0156)
Soil Erosion (=1)	-0.0316*
	(0.0201)
Acrisols Soils (=1)	0.0632
	(0.0511)
Ferralsols Soils (=1)	0.0543
	(0.0395)
Other soil types (=1)	0.0431
	(0.0524)
Soil pH below 4.4 (=1)	-0.2891*
	(0.1630)
Soil pH between 4.5 and 5.5 (=1)	0.2847*
	(0.1609)
Tillage using a Plough (=1)	0.0030
	(0.0189)
Tillage before rains	-0.0003
	(0.0043)
Observations	**3,844**

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