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Should Farm Input Subsidy Programs Target Poor or Non-Poor Farmers?

Evidence from Malawi's Farm Input Subsidy Program

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Abstract

This paper addresses the question of whether farm input subsidy programs should be targeted at non-poor farmers instead of poor farmers, using a two-wave, nationally representative panel data from Malawi. The question is addressed by estimating the net gain in maize yield for targeting non-poor farmers instead of poor farmers after accounting for the difference in inorganic fertilizer use efficiency and the difference in crowding-out of commercial fertilizer by subsidized fertilizer between the poor and non-poor farmers. Consumption expenditure is used to classify households into consumption poor and non-poor households, and an asset-based wealth index is used to classify households into asset poor and non-poor households. The difference in inorganic fertilizer use efficiency is estimated with a multilevel model of maize yield, and the difference in crowding out is estimated with a double hurdle model of demand for commercial, inorganic fertilizer. The results indicate that non-poor farmers are significantly more efficient in the use of inorganic fertilizer but have significantly higher levels of crowding out, compared to poor farmers. This suggests that there is a trade-off between targeting non-poor farmers and targeting poor farmers. However, further analysis of the trade-off indicates that targeting non-poor farmers instead of poor farmers, even after accounting for the difference in crowding out, would result in an overall gain in yield of 3.14 to 4.33 kilograms of maize per kilogram of nitrogen distributed by the subsidy program. Therefore, the productivity enhancing objective of Malawi's farm input subsidy program would be better served by targeting non-poor farmers instead of poor farmers.

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Introduction

Farm input subsidy programs have been the mainstay agricultural policy in many countries in Sub-Saharan Africa (SSA) since the 1960s (Kherellah et al., 2002; Jayne and Rashid, 2013). From the 1960s through the 1980s, the programs were implemented as universal (i.e. accessible to all farmers) and supported by international donors to help overcome market failures in farm input and financial markets (Jayne and Rashid, 2013). Although the universal subsidy programs succeeded in raising input use and food production, they were very expensive and thus caused significant fiscal and macro-economic problems (Banful, 2011; Dorward et al., 2008). The value of the output produced using subsidized inputs fell short of the costs of the programs in many SSA countries (Howard and Mungoma, 1997; World Bank, 2007; Jayne and Rashid 2013). Moreover, evidence suggests that the universal programs favored relatively wealthier, well connected and larger-scale farmers at the expense of smallholder, poor farmers (Banful, 2011).

Beginning in the early 2000s, targeted farm input subsidy programs (TFISPs) were introduced to address the shortcomings of the universal ones. TFISPs are supposed to: 1) target poor and vulnerable farmers who are otherwise not able to acquire inputs like inorganic fertilizer and improved seeds at commercial prices; 2) support the development of existing private input supply systems; and 3) devise appropriate exit strategies for the beneficiaries of the program (Morris et al., 2007; Baltzer and Hansen, 2011). Hence if properly implemented, TFISPs could be expected to be more economically efficient and have greater impacts on food production compared to the universal subsidy programs, albeit the cost of targeting is a counterweight.

The impact of TFISPs, like other targeted development programs, depends integrally on the effectiveness of the targeting process, the process used in identifying and reaching beneficiaries. Targeting plays a crucial role in that it determines the beneficiaries of the program, the amount of inputs they receive, and how the inputs are utilized. The eventual impacts of the program are therefore closely linked to the quality of the targeting process. Using two-wave panel data from Malawi, the goal of this study is to help improve the targeting of TFISPs by providing guidance for deciding on whether such programs should be targeted at poor or non-poor farmers.[1] The specific research question that this study seeks to answer is: *Do non-poor farmers use inorganic fertilizer more efficiently than poor farmers?* Efficiency is measured as kilograms of maize obtained per kilogram of nitrogen applied, otherwise known as nitrogen use efficiency (NUE). The steps involved in the empirical approach used in answering this question will help clarify issues such as whether the poverty and food security goals of TFISPs can be achieved together by estimating if poor farmers obtain the same NUE as non-poor farmers, and estimating whether crowding out varies significantly across poor and non-poor farmers. By answering these questions, the study provides an empirical standpoint for the targeting discourse that has in the past been based mostly on anecdotal evidence.

The decision of whether a subsidy should be targeted at poor or non-poor farmers depends on three main factors. The first factor is the objective of the programs. Officially, TFISPs in SSA have two main objectives: 1) increasing smallholder agricultural productivity and food production, to improve household food security and national food sufficiency; and 2) reducing poverty by increasing the income levels of beneficiaries. Though both are admirable, these objectives potentially have different implications for targeting. The objective of ensuring household food security and national food sufficiency suggests that the programs should be targeted at productive

[1] Targeting is made up of two processes: 1) identification of the targets, i.e., the category of people to be targeted, and 2) identification of the most appropriate method used in delivering the inputs to beneficiaries. The effectiveness of both processes are equally important in ensuring successful targeting. This study focusses on the first process, leaving the second process for future studies.

farmers in areas (regions, districts and communities) with high productivity potential. In theory, targeting productive farmers would maximize food availability not only for beneficiaries of the programs, but also for non-beneficiaries through the lowering of food prices as a result of increased production. The poverty reduction objective on the other hand suggests that the program should be targeted at poor farmers. Therefore, targeting poor farmers with the aim of achieving both the food security and the poverty reduction objectives, as most governments of SSA countries with TFISP are currently doing, suggests that poor farmers are implicitly assumed to be at least as productive as non-poor farmers. The validity or otherwise of this implicit assumption is critical for effective targeting of TFISPs. If poor farmers are at least as productive as non-poor farmers, both objectives can be achieved by targeting poor farmers. However, if non-poor farmers tend to be more productive than poor farmers, TFISPs would have to focus on either the food security objective or the poverty reduction objective because the target populations that maximize the achievement of both objectives do not coincide.

The second factor on which the decision to target TFISPs depends is the difference between poor and non-poor farmers in terms of the efficiency with which subsidized inputs are utilized. There is a long literature that suggests that poor farmers are efficient in the use of farm inputs in crop production. Schultz (1964) argued that because traditional farmers use mainly their own resources and are experienced in doing so, they are able to make the most efficient use of resources in their environment. Compared to non-poor farmers however, poor farmers may be less productive because non-poor farmers are usually better equipped to use complimentary inputs such as hired labor, pesticides, organic matter, and also have the ability to acquire or rent in plots of better soil quality. All of these advantages boost the efficiency with which inorganic fertilizer and other subsidized inputs can be used. Thus the assumption that poor farmers are at least as productive as non-poor farmers is an empirical matter.

The third factor governing the decision of whether TFISPs should be targeted at poor or non-poor farmers is the difference between poor and non-poor farmers in terms of the extent to which the use of subsidized farm inputs crowds out the demand for commercial farm inputs. Previous research reports that subsidized farm inputs crowd out commercial farm inputs (Mason and Jayne, 2013; Ricker-Gilbert et al. 2011; Xu et al., 2009). Such crowding out undermines the viability of the private sector and reduces the contribution of the fertilizer subsidy programs to total fertilizer use as well as the overall net impact of such programs on food production and levels of farm income (Dorward et al., 2008; Ricker-Gilbert, 2011; Shively and Ricker-Gilbert, 2013). By virtue of higher income, non-poor farmers are likely to purchase higher quantities of commercial fertilizer and are therefore likely to have higher levels of crowding out than poor farmers. The higher level of crowding out among non-poor farmers suggests a possible trade-off between targeting non-poor farmers and targeting to poor farmers, thereby undermining the propensity to target non-poor farmers.

Targeting of farm input subsidy programs in SSA has been widely discussed in the literature (Doward and Chirwa, 2013; Ricker-Gilbert and Jayne, 2012; Ricker-Gilbert and Jayne, 2016). However, many of these studies either provide a general discussion of the issues in targeting without any empirical analysis or discuss some aspects of targeting but go on to estimate some other impacts of farm input subsidy programs. Thus, the literature on empirical studies for which targeting farm input subsidy programs is the central focus is very sparse. Kilic et al. (2014), Houssou and Zeller (2010) and Basurta et al. (2015) are the main published studies that empirically addressed issues related to the targeting of farm input subsidy programs in SSA. Houssou and

Zeller (2011) assessed and compared the target, impact and cost-effectiveness of proxy means tests (an indicator-based targeting system) of universal and community-based targeting systems using quintile regressions and nationally representative data from Malawi's Second Integrated Household Survey (IHS2). The study finds that although the proxy means test is associated with relatively higher administrative costs, its overall benefits in targeting poor and smallholder farmers outweighs the cost involvements; and the proxy means test tends to be potentially more target, cost and impact efficient than the universal and community-based targeting systems.

Kilic et al. (2014) analyzed the overall performance of the decentralized targeting of Malawi's farm input subsidy program using nationally representative data of the 2009-10 agricultural season by decomposing the national targeting performance into district and community level components: inter-district, intra-district inter-community, and intra district intra-community components. The authors find that Malawi's farm input subsidy program is not poverty targeted and that the national government, districts, and communities are nearly uniform in their failure to target the poor, with any minimal targeting (or mis-targeting) overwhelmingly materializing at the community level.

Classifying farmers into kins and non-kins of chiefs (traditional leaders), Basurto et al. (2016) used a five-wave panel from Malawi to explore the trade-off between the informational/accountability advantages of decentralized targeting systems and its associated elite capture in the context of large-scale subsidy programs in Malawi decentralized to chiefs. The authors find evidence of elite capture and poverty-mistargeting for the subsidy programs considered; and also find that the poverty-mistargeting by chiefs is partly due to productive efficiency considerations. This study contributes to the targeting discourse by seeking to empirically estimate the overall gain in yield for targeting non-poor farmers instead of poor farmers, after accounting for the potential difference in input use efficiency and crowding out across poverty groups.

The results of the present study indicate that non-poor farmers are significantly more productive than poor and ultra-poor farmers, but crowding out of commercial fertilizer by subsidized fertilizer also tends to be significantly higher among non-poor farmers, suggesting a trade-off between targeting non-poor farmers and targeting poor farmers. Further analysis of the trade-off however indicates that targeting non-poor farmers instead of poor farmers, after accounting for the significant differences in productivity and crowding out, will result in an overall yield gain of 3.136kg per kilogram of nitrogen when poverty is measured by consumption expenditure or 4.330kg per kilogram of nitrogen when poverty is measured using the asset-based wealth index

Background: Targeting of Malawi's Farm Input Subsidy Program

In terms of scope and coverage, Malawi's targeted farm input subsidy program (FISP) is perhaps the most well-known TFISP in Africa. It currently provides inorganic fertilizers and improved maize and legume seeds to over 50% of rural, smallholder farmers at hugely subsidized prices (about 95% subsidy). Each beneficiary is entitled to 50kg of Urea; 50kg of NPK 23:21:0; 5kg of improved maize seed or 10kg of open pollinated variety maize seed; and a kilogram of legume seed (Kilic et al., 2014). Beneficiaries receive coupons that are to be redeemed for inputs at subsidized prices at participating retailers who in turn redeem the coupons to the government, receiving the full commercial price minus the subsidized price. The coupons are distributed to beneficiaries in a decentralized manner. Officials of the Ministry of Agriculture and Food Security (MoAFS) allocate coupons to districts and Extension Planning Areas (EPAs) where representatives are subsequently mandated to redistribute the coupons to selected villages and communities within the district and EPAs. Community leaders and local authorities of the selected villages and communities are then authorized to identify and distribute the coupons to beneficiary households using a predefined criterion. The predefined criteria involve “resource-poor” Malawians who own a piece of land and are resident in the village/community, with special consideration to guardians looking after physically challenged persons, child-headed, female-headed and orphan-headed households (MoAFS, 2009; Chirwa et al. 2011). According to Dorward and Chirwa (2013), the criteria for the distribution of coupons to districts and EPAs is “very opaque” although it is supposed to be in line with a number of household characteristics.

Among other things, the difficulty in clearly establishing measures for applying these criteria and the fact that eligible households exceed the number of available coupons results in community leaders and village authorities not consistently applying the set criteria. Hence coupon allocation at both the district/EPA and village/community levels may be based on unofficial criteria such as political support at the district level; and relationship to community leaders and local authorities, length of residence, and social and/or financial status of households at the community level (Banful, 2011; Ricker-Gilbert et al., 2011). Accordingly, studies suggest that “resource poor” households have not been consistently targeted. Studies on participation in FISP reveal that subsidized inputs do not always get to the intended beneficiaries (Ricker-Gilbert et al., 2011; Chibwana et al., 2012; Kilic et al., 2014; Houssou and Zeller, 2011; Dorward et al., 2008). Ricker-Gilbert et al. (2011) and Chibwana et al. (2012) observed that male-headed households and relatively wealthier farmers, rather than female-headed households and poor farmers, are more likely to access subsidized inputs. Kilic et al. (2014) report that neither the poor nor the rich are exclusively targeted by the program, but rather the middle of the income distribution if there is any targeting at all. The program's coverage and leakage rates[2] of 35% and 65% respectively in 2004/2005; 46% and 54% respectively in 2006/07; and 57.9% and 52%[3] respectively in 2009/10 also lend credence to the shortcomings in the targeting process (Kilic et al., 2014; Houssou and Zeller, 2011; Dorward et al., 2008).

The weaknesses in the targeting process has likely undermined the impacts of FISP on productivity, staple food prices and poverty. Although evidence (Holden and Lunduka, 2010; Chibwana et al. 2012) suggests that FISP has had a positive impact on maize productivity, given the size, scope and cost of the program, the effect is only modest when comparing the benefits of the program against the costs (Ricker-Gilbert et al., 2013). The modest effect of the program on maize productivity can, *inter alia,* be linked to the weaknesses in the targeting process with the possible explanation being that participation of farmers who could make efficient use of the subsidized inputs was limited. FISP, like other large-scale farm input subsidy programs, is expected to significantly reduce the retail price of staple crops and thus improve the welfare of consumers, but perhaps due to the modest effect on maize productivity, Ricker-Gilbert et al. (2013) observed that, on average, doubling the size of FISP reduced the retail maize price by only 1.2% to 2.5%. Poverty appears not to have been significantly impacted by the program probably because of its poor targeting system. Since the inception of FISP, the national absolute poverty rate decreased only marginally (only 1.3 percentage points between 2004/05 and 2010/11) while

[2] The coverage rate of a targeted development program is the proportion of beneficiaries who are eligible for the program (poor farmers, in the case of FISP); and the leakage rate is the proportion of beneficiaries who are ineligible (non-poor farmers, in the case of FISP).

[3] The coverage and leakage rates were 57.9% and 52%, respectively, in 2009/10 when predicted poverty was used as the measure of resource poverty. When resource poverty was defined in terms of asset ownership (or land holding), however, the coverage and leakage rates were estimated to be 50.7 (49.6%) and 56.8% (56.7%), respectively (Kilic et al., forthcoming).

income inequality, as measured by the GINI coefficient, exacerbated - increasing from 0.39 to 0.45 over the same period (Kilic et al. 2014; NSO, 2012).

Conceptual Framework

General Framework

The estimation of the overall gain in yield for targeting non-poor farmers instead of poor and ultra-poor farmers after accounting for the potential difference in input use efficiency and crowding out is conceptualized as follows. Let p_1 and p_0 be two groups of farmers, with farmers in group p_0 being poorer than those in group p_1. For instance, when comparing non-poor and poor households, p_1 and p_0 will denote non-poor and poor farmers respectively; but when comparing poor and ultra-poor households, p_1 represents poor farmers while p_0 represents ultra-poor farmers. Let $\Delta NUE_{p1,p0}$ be the difference in NUE between the average farmer in group p_1 and the average farmer in group p_0. In other words, $\Delta NUE_{p1,p0}$ represents the potential, gain in yield per kilogram of nitrogen obtained by targeting the average farmer in group p_1 instead of the average farmer in group p_0.

Targeting the average farmer in group p_1 instead of the average farmer in group p_0 will result in a potential, additional crowding out effect. Let this potential, additional crowding out effect be represented by $\Delta CO_{p1,p0}$. Because a crowding out estimate is generally an indication of the reduction in total fertilizer use resulting from access to subsidized fertilizer, $\Delta CO_{p1,p0}$ can also be interpreted as the potential, additional reduction in total fertilizer use that results from targeting the average farmer in group p_1 instead of the average farmer in group p_2. This potential reduction in total fertilizer use ultimately leads to a potential reduction in yield. Using the notations and variables defined above, the potential reduction in yield is given by $[(\Delta CO_{p1,p0}) * NUE_{p0}]$. Based on these estimates, the overall net gain in yield for targeting the average farmer in group p_1 after accounting for the potential difference in *NUE* and crowding out between farmers in groups p_1 and p_0 is expressed as:

$$NG_{yield,p1} = \{[\Delta NUE_{p1,p0}] - [(\Delta CO_{p1,p0}) * NUE_{p0}]\} \quad (1)$$

With this estimate, the decision is to target FISP at farmers in group p_1 if $NG_{yield,p1}$ is (significantly) positive; otherwise, FISP should be targeted at farmers in group p_0. The following two sub-section lay out the framework for measuring $\Delta NUE_{p1,p0}$ and $\Delta CO_{p1,p0}$ respectively.

Framework for Measuring $\Delta NUE_{p1,p0}$

In order to measure $\Delta NUE_{p1,p0}$, we measure maize yield is a function of several factors:[4]

$$Y = f[N(P), X, H, C] \quad (2)$$

where Y is maize yield in kilograms per hectare, N is the rate of nitrogen (from inorganic fertilizer) application; X is a vector of other plot-level agronomic inputs including the quantity of seeds sown, the amount of labor used on the plot, whether or not the plot is planted to a hybrid maize variety etc. H is a vector of household-level variables such as adult-equivalent household size, dependency ratio etc. that are likely to affect maize production. C is a vector of climatic variables including rainfall and temperature. A full list of the variables in each of the vectors is presented in table 1. The extent to which nitrogen application affects maize yield is hypothesized to depend on the poverty status of households, *P*. The idea is based on the premise that better-off households are better equipped to use complimentary inputs such as hired labor, pesticides, organic matter; and also have the ability to rent in plots of better soil quality, all of which boost nitrogen use efficiency.

[4] We focus on estimating maize production since it is the main staple crop in Malawi (cultivated by about 90% of smallholders on 70% of their farm plots), and it is the focus crop of the FISP.

Accordingly, the poverty status of households, P is modeled as nitrogen-facilitating input – an input that boost the extent to which nitrogen affects yield – in the production of maize.

Framework for Measuring $\Delta CO_{p1,p0}$

In order to measure $\Delta CO_{p1,p0}$, the potential difference in crowding out between poverty groups *p1 and p0*, following Ricker-Gilbert et al. (2011), the basic Sing, Squire and Strauss (1986) household model is used to derive the demand for commercial fertilizer for a rural agricultural household. In developing countries like Malawi where credit and labor markets are imperfect, and where households face high levels of risks because of high weather variability and other shocks, households' consumption and production decisions are likely to be non-separable. This implies that a household's desired level of input use in crop production is affected by its socio-demographic characteristics. In the presence of a large-scale farm input subsidy program like FISP, the demand for commercial fertilizer is also likely to be affected by the amount of subsidized fertilizer that a household receives. Other factors such as transaction cost, output price of agricultural goods, and the amount and quality of land available to farmers are also likely to affect households' decisions to participate in the commercial fertilizer market. It is hypothesized in this study that the extent to which the amount of subsidized fertilizer affects the demand for commercial fertilizer depends on the poverty status of households. In a setting where the demand for commercial fertilizer by a non-separable household is affected by the amount of subsidized fertilizer access, and the effect of subsidized fertilizer depends on the poverty status of households, consider the following equation:

$$F = f[S(P), P_c, P_a, T, Z, A] \qquad (3)$$

Where F and S are respectively the quantity of commercial and subsidized fertilizer accessed by the household; P is household poverty status; P_c and P_a are prices of commercial fertilizer and the agricultural good produced respectively; T represents a vector of factors such as distance to road and urban centers that determine the fixed transfer costs associated with the use of commercial fertilizer; Z is a vector of household characteristics; and fixed quantity of land is represented by A.

Empirical Models

Empirical Model for Estimating $\Delta NUE_{p1,p0}$

The effect of household poverty status on nitrogen use efficiency, $\Delta NUE_{p1,p0}$, is estimated by specifying the yield function in equation (2) with a two-level multilevel model. A household fixed effects model has also been considered to check the robustness of the estimates. A multilevel model is used because it allows for the explicit expression of nitrogen use efficiency as a function of household poverty status; and such an expression is of particular interest in this study. In addition to this, the use of multilevel model has two other advantages. First, it accounts for the hierarchical structure in the dataset – plots are nested within households – by modeling the variations at all levels of the hierarchy (plot and household levels) and by accounting for the intra-household correlation that is likely to result from the fact that plots belonging to the same household share the same management and related conditions. The existence of such a hierarchy in the data has implications for statistical validity and should therefore not be ignored (Goldstein, 1995; Elhorst, 2014; Carrado and Fingleton, 2011). Second, the multilevel model distinguishes (explicitly) between plot-level and household-level covariates in the model by allowing for the coefficients of the plot-level variables to vary within households. This is particularly important in this study because of the interest in understanding the how nitrogen use efficiency vary across poor and non-poor households.

For yield on plot i, belonging to household h, the model at the various level of the hierarchy is specified as:

Plot-level model

$$Y_{ih} = \beta_{0h} + \beta_{1h}N_{ih} + X_{ih}\beta_x + \varepsilon_{ih} \quad (4)$$

where Y_{ih} is yield; N_{ih} is nutrient application rate; X_{ih} is a vector of other plot-level variables affecting maize yield; and ε_{ih} represents the plot-level error term. β_{0h} is the random intercept, varying across households, but has the same value for individual plots belonging to household *h*. β_{0h} therefore measures the mean yield for plots in household h. β_{1h} is the random slope for the nitrogen variable which varies across households. β_x is a vector of fixed coefficients for the other plot-level variables, where the subscript x represents the corresponding plot-level variable in vector X_{ih}. Unlike the nitrogen use efficiency (β_{1h}), these coefficients are fixed because their variation across households is not of any particular interest in this study.

Household-level model

The study hypothesizes that variability in the nitrogen use efficiency (β_{1h}) depends on the poverty status of households (P_h); and the variability in the random intercept (β_{0h}) is explained by other household level variables (H_h). Thus, in the household-level model, equations (5a) and (5b), the nitrogen use efficiency and the random intercept are expressed as:

$$\beta_{1h} = \beta_{10} + \beta_{1p}P_h + U_{1h} \quad (5a)$$

$$\beta_{0h} = \beta_{00} + H_h\alpha_{0m} + U_{0h} \quad (5b)$$

where β_{1p} is the effect of household poverty status on nitrogen use efficiency i.e. $\Delta NUE_{p1,p0}$. β_{00} and β_{10} are the household-level group effect for the intercept and nitrogen use efficiency (i.e. the mean yield and nitrogen use efficiency) respectively; and household-specific variation around these values are represented by U_{0h} and U_{1h} respectively. α_{0m} represents the contribution of the other household variables to the variation in the random intercept, where the subscript *m* represents the corresponding household-level variable in the vector H_h.

Full model

Substitution of equations (5a) and (5b) into equation (4) results in the full hierarchical model which is given by:

$$Y_{ih} = \beta_{00} + \beta_{10}N_{ih} + \beta_{1p}(P_h * N_{ih}) + X_{ih}\beta_x + H_h\alpha_{0m} + (U_{0h} + U_{1h}N_{ih} + \varepsilon_{ih}) \quad (6)$$

β_{1p} represents $\Delta NUE_{p1,p0}$; and the terms in bracket, $(U_{0h} + U_{1h}N_{ih} + \varepsilon_{ih})$, represent the total error term in the full model — ε_{ih} from the plot level, and U_{0h} *and* $U_{1h}N_{ph}$ from the household level.

Empirical Model for Estimating $\Delta CO_{p1,p0}$

In order to estimate $\Delta CO_{p1,p0}$, the difference in the crowding out of commercial fertilizer by subsidized fertilizer across poverty groups, the conceptual model in equation (3) and the error term are specified as follows:

$$C_{it} = \gamma S_{it} + X_{it}\beta + \varepsilon_{it} \quad (7a)$$

$$\varepsilon_{it} = a_i + \mu_{it} \quad (7b)$$

where C and S are quantities of commercial and subsidized fertilizers acquired by household *i* in time *t*. γ represents the parameter that captures the extent to which subsidized fertilizer crowds out commercial fertilizer. X_{it} is a vector of other variables that affect the demand for commercial fertilizer; and β is a vector of the corresponding parameters. X_{it} consists of such variables as price of commercial fertilizer at the time of planting, real price of maize in the past lean season, distance to the nearest road, a soil quality index, average rainfall in the past year and household socio-demographic characteristics listed in table 1. The error term, ε_{it}, is made up of two components: unobserved time-invariant factors (a_i) and unobserved time-varying factors which affect the demand for commercial fertilizer. The unobserved time factors consist of such factors as the management ability of farmers; and the unobserved time-varying factors consists of factors such as health shocks and political turmoil.

$\Delta CO_{p0,p1}$ can be estimated using two approaches. The first approach involves interacting the subsidized fertilizer variable with the variable measuring the poverty status in equation (7a), and finding out whether the coefficient on the interaction term is significantly different from zero. The second approach involves estimating equation (7a) without the interaction term, generating the partial effect of the subsidized fertilizer for each household, and then using a simple t-test to test whether the partial effect varies significantly across poverty groups. The second approach is adopted in this study because, as the next section discusses, the subsidized fertilizer variable is potentially endogenous, implying the first approach would require multiple instrumental variables which are not easy to come by.

Potential Endogeneity of Subsidized Fertilizer in a Demand for Commercial Fertilizer Model

As described earlier, coupons to be redeemed for subsidized inputs are not distributed randomly to beneficiaries; hence unobservable factors that affect farmers' participation in the commercial fertilizer market such as political turmoil, weather and health shocks could influence the amount of subsidized inputs that a household receives. As such, the quantity of subsidized inputs that a household receives is likely to be endogenous in a commercial fertilizer equation. This implies that, in terms of the empirical models, S_{it} could be potentially correlated with a_i and/or μ_{it}. Failure to control for such correlations could potentially result in inconsistent estimates of crowding out.

This study uses the Mundlak-Chamberlin device to account for the potential correlation between S_{it} and a_i, and the control function approach (CF) to account for the correlation between S_{it} and μ_{it} (Mundlak, 1978; Chamberalain, 1984). The Mundlak-Chamberlin device is used instead of household fixed effects because many farmers in Malawi do not use fertilizer in crop production, so the data take on properties of non-linear corner solutions. The implementation of the Mundlak-Chamberlin device involves the inclusion of a vector of variables consisting of the household-level means of time-varying covariates. The CF approach in this case involves estimating a reduced form model of quantity of subsidized fertilizer acquired and including the residuals from this model as an additional explanatory variable in the commercial fertilizer model. The significance or otherwise of the coefficient on this additional explanatory variable tests and corrects for the potential correlation between S_{it} and μ_{it}.

The CF approach requires an instrumental variable in the reduced form model of subsidized fertilizer. The instrumental variable should strongly correlate with S_{it} but be uncorrelated with μ_{it} in the commercial fertilizer model when the other covariates are controlled for. Following Ricker-Gilbert et al. (2011), the number of years that the household head has been living in the community is used as the instrumental variable. This variable is used because it represents a "sociopolitical capital" that could affect the quantity of subsidized fertilizer received by a household (Ricker-Gilbert et al., 2011). Also, after conditioning on other covariates, it is unlikely that the number of years that the household head lived in a village would correlate with unobserved time-varying factors in the commercial fertilizer model.

The reduced form model in the CF approach is specified as a Tobit model. A Tobit model is used because the subsidized fertilizer variable is a corner solution outcome – there are many zeros in the subsidized fertilizer variable due to the fact that only about 50% of households receive subsidized fertilizer each year. The commercial fertilizer demand variable is also a corner response outcome but instead of a Tobit model, the demand model for commercial fertilizer is specified with a double-hurdle model proposed by Cragg (1971).[5] The DH model is used in order to account for the possibility that factors affecting the farmer's decision to participate in the fertilizer market may be different from those that affect the quantity purchased of commercial fertilizer once the decision to participate has been made. The double-hurdle model also allows the same factors to affect the decision to participate in the market and the quantity purchased differently. The decision to participate in the commercial fertilizer market is modeled in hurdle 1 while the quantity purchased of fertilizer is modeled in hurdle 2 once the decision to participate has been made.

The unconditional PE of the subsidized fertilizer coefficient are derived from the DH model for each household in the sample. A simple student t-test is subsequently used to determine whether there is a significant difference in PE across poverty groups.

[5] The Tobit model is nested within the double hurdle because unlike the double hurdle model, it requires that the decision to participate in the commercial fertilizer market and the amount purchased are determined by the same process. The choice between the two models is usually based on a Likelihood Ratio (LR) test.

Classification of Households into Poverty Groups

Households are classified into poverty groups in two ways: first using consumption expenditure and second using an asset-based wealth index.[6] Both consumption expenditure and the assert-based wealth index serve as proxies for the long-term economic status of households. The theoretical underpinning of using both variables as measures of long-term economic status of households has been established in the literature (Deaton and Muellbauer, 1980; Deaton 1997; Deaton and Zaidi, 1999; Filmer and Pritchett, 2001). Both measures are used for the classification of households into poverty groups in order to consider all the possible empirically proven ways (expenditure and asset ownership) by which the poverty status of households may be expressed.

The consumption expenditure variable represents aggregate annual expenditure on food and non-food products. The food expenditure component was constructed by adding up expenditure on all food items consumed by the household at home and away from home over the past seven days. The non-food expenditure component consists of expenditure on utilities such as kerosene and electricity, health, transport, communications, recreation, education, furnishing, personal care, durable assets and housing. A more elaborate description of the construction of the consumption expenditure variable can be found World Bank (2013). Using the official poverty and ultra-poverty lines of MKW 85,852 and MKW 53,262, respectively, households are classified into non-poor, poor and ultra-poor households.

Following Filmer and Pritchett (2001), the asset-based wealth index is measured as a linear index generated from indicators of household asset ownership and housing condition using principal-components analysis (PCA) to derive weights. PCA is a statistical technique used to

[6] Consumption expenditure and asset-based wealth index are chosen over income for the poverty classification because both variables reflect smoothing and are easier to measure than income in rural settings.

extract from a group of variables a few orthogonal linear combinations of the variables that capture the common information most successfully. The first principal component of the asset and housing condition indicators is the linear index that captures the largest amount of information, so this study uses that as the measure of wealth. Filmer and Pritchett (2001) demonstrate the construction and internal validity of this index as a measure of wealth.

The assets included in the construction of the index include ownership of mortar, bed, table, chair, fan, air conditioner, radio, CD or cassette player, television, sewing machine, stove, refrigerator, washer, bicycle, motorbike or vehicle, drum, sofa, coffee table, cupboard, lantern, desk, clock, iron, computer, satellite dish, solar, generator and cellphone. The housing condition included in the construction of the index include the material (permanent or not) of which the dwelling, outer walls, roof and floor are made of; the source of lighting (electricity or otherwise) in the house; the source of water (pipe or otherwise); the kind of toilet facility (water closet or otherwise); number of rooms in the house; and number of rooms per capita. Following Filmer and Pritchett (2001) and Dzanku (2015) households within the top 60% of the distribution of the wealth index are classified as non-poor, and those within the bottom 40% are classified as poor. Using the same logic, households with the bottom 16% are classified as ultra-poor.[7]

Data and Sample Selection

The study uses the two-wave Malawi Integrated Household Panel Survey (IHPS) data collected by the collected by the National Statistical Office of Malawi (NSO) with support from the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA)

[7] In order to test the sensitivity of the estimates to the benchmarks used for the asset poverty classifications, we also classified farmers into quintiles of the wealth index. The conclusions from the results based on the quintile classification are similar to the those based on the asset poverty classification. The results for the quintile classifications are available upon request.

program. The survey for the first wave of the dataset covered 3,247 households (hereafter baseline households) in the 2009/2010 agricultural year. The sampling was representative at the national, regional and urban/rural levels. The survey for the second wave of the dataset was conducted in the 2012/2013 agricultural year and attempted to track and resample all the baseline households as well as individuals (projected to be at least 12 years) that split-off from the baseline households between 2010 and 2013 as long as they were neither guests nor servants and are still living in mainland Malawi. Once a split-off individual was located, the new household that he/she formed or joined was also brought into the second wave. In all, a total of 4,000 households were traced back to 3,104 baseline households. An overwhelming majority, 76.80%, of the 3,104 baseline households did not split over time; 18.49% split into two households; and rest (4.70%) split into 3-6 households. Considering the 20 baseline household that died in their entirety between 2010 and 2013 and the fact that 4,000 households could be traced back to 3,104 baseline households, the dataset has an overall household attrition rate of only 3.78%.

The study dropped all non-agricultural households (580 and 845 households in the first and second waves respectively), as well as urban agricultural households (370 and 438 households in the first and second waves respectively). The urban agricultural households were dropped because farming in Malawi is predominantly rural. In order to avoid reverse causality in the maize production function, all the households for which questions about their food and non-food consumption were asked after the harvesting of agricultural products were also dropped. In the end, a panel of 1,667 households (2,472 maize plots), 771 households (1,127 maize plots) in the first wave and 896 household (1,347 maize plots) in the second wave was used for the analyses.

Attrition bias in the data could not be tested because there are no regression-based tests for attrition when fixed effects or MC devise models are used with a panel of only two wave – a panel of more than two-waves are required for such tests (Wooldridge, 2010; Mason and Smale, 2013). That notwithstanding, the study is confident that attrition bias is not likely to be a concern because as indicated earlier, the attrition rate is only 3.78% at the household level.

Results

Descriptive Statistics

The descriptive statistics of the key variables used in the study are presented in tables 1 and 2. Table 1 presents the descriptive statistics for the pool sample and for the 2010 and 2013 sub-samples while table 2 compares the descriptive statistics across poor and non-poor farmers in both 2010 and 2013 survey years. The average maize yield was 1,272 kg/ha in 2010 but increased significantly to 1,574 kg/ha in 2013. The nitrogen application rate (47.58 kg/ha in 2010) and the proportion of plots planted to hybrid maize seeds (39.70%) did not change significantly over time. Hence the increase in maize yield is likely not attributable to increased use of modern inputs, and rainfall and temperature remained relatively constant between waves. The difference in yield may be partly attributable to the 35% increase in the proportion of plots on which organic fertilizer was applied, the 25% increase in labor utilization, and the 18% increase in seed application rate. The increase in yield could also be due to farmers becoming more experienced in the use of inputs in maize production.

Using the asset poverty classification, the estimates shows that, in 2010, 58.30% of farmers were non-poor, 20.40% were poor and 21.30% were ultra-poor; and this proportions did not change significantly between 2010 and 2013. Across poverty groups, the estimates indicate that maize yield of non-poor households is significantly greater than that of poor farmers in both years. In

2013 for instance, maize yield for asset non-poor farmers (1,804.31 kg/ha) was about 44% higher than that of non-poor farmers. The difference in yield between the non-poor and poor farmers can be attributed to non-poor farmers using significantly more inorganic fertilizer and having a higher level of compliance with fertilizer (both nitrogen and total fertilizer) recommendations than poor farmers.

The average quantity of subsidized fertilizer acquired by households was on average 41.76kg in 2010 and increased slightly (though not statistically different) to 44.62kg in 2013. The quantity of commercial fertilizer, however, increased significantly from 143.79kg in 2010 to 184.70kg in 2013. Table 2 shows that non-poor farmers acquired significantly more subsidized and commercial fertilizer than poor farmers. This estimate corroborates previous studies on access to subsidized inputs which reported that non-poor farmers are more likely to access, and acquire higher quantities of, subsidized inputs than poor farmers (Chibwana et al, 2012; Ricker-Gilbert et al., 2011). In 2013 for instance, non-poor farmers acquired 25% and 90% more subsidized and commercial fertilizer respectively than poor formers. The fact that non-poor farmers acquired significantly more commercial fertilizer than poor farmers provides an indication that crowding out of commercial fertilizer by subsidized fertilizer is likely to be higher among non-poor farmers than it would be among poor farmers.

Effect of Poverty Status on Nitrogen Use Efficiency ($\Delta NUE_{p1,p0}$)

Results of the multilevel model of the effect of the poverty status of farmers on nitrogen use efficiency (NUE) are presented in tables 3 and 4, and in tables A1 and A2 in appendix B.[8] A

[8] For a robustness check, results of the household fixed effects model are also presented in table A3. Results from this model are quite similar to the results of the multilevel model.

likelihood ratio test shows that the multilevel model chosen for this analysis fits the data better than a linear model. The estimates indicate that, as expected, nitrogen application has a positive and significant effect on maize yield. In general, non-poor farmers have significantly higher NUE than poor and ultra-poor farmers irrespective of how poverty is measured (consumption expenditure or asset ownership). Using the two-category (poor/non-poor) consumption poverty classification, the estimates indicate that NUE for poor farmers is 3.38 kg lower than that of their non-poor counterparts (table 3, column 2); and using the three-category (ultra-poor/poor/non-poor) consumption poverty classification, the NUE for ultra-poor and poor farmers is 4.47kg and 3.02kg respectively lower that the NUE of non-poor farmers (table 3, column 3).

The difference in NUE across asset poverty groups follow a similar pattern. Based on the two-category asset poverty classification, the NUE of poor farmers is 4.93kg lower than the NUE of non-poor farmers; and based on the three-category asset poverty, NUE of ultra-poor and poor farmers is 6.84 kg and 3.51 kg respectively lower than that of non-poor farmers (table 4, columns 2 and 3). In terms of asset quintiles, the estimates indicate that the NUE of farmers in the fifth quintile is significantly greater than the NUE of the lower quintiles (table 4, columns 4).

The fact that non-poor farmers are remarkably more productive (have much higher NUE) than poor and ultra-poor farmers suggests that the productivity and food security objective of FISP would be better served by targeting non-poor farmers; but the potential difference in crowding out across poverty groups ought to be considered before this suggestion can be made. The following section addresses the potential difference in crowding out across poverty groups.

Crowding Out of Commercial Fertilizer by Subsidized Fertilizer

The Average Crowding Out Estimate

Table 6 presents the double hurdle model of the factors that influence demand for commercial fertilizer. The coefficients in hurdle 1 of the table are conditional Average Partial Effects (APEs) obtained using the *margins* command in Stata. In order to account for the first-stage reduced form estimation of access to subsidized fertilizer, the corresponding p-values are obtained via bootstrapping with 250 repetitions. The residuals from the reduced form equation of access to subsidized fertilizer is significant at the 1% level in hurdle 1, indicating that subsidized fertilizer is endogenous in the participation model of commercial fertilizer. The coefficient on the subsidized fertilizer variable in hurdle 1 is negative and significant, indicating that the quantity of subsidized fertilizer that a household received reduces the household's probability of participating in the commercial fertilizer market. The p-value of the residuals in hurdle 2 is 0.90, suggesting that subsidized fertilizer is not endogenous in the commercial fertilizer model once the decision to purchase has been made. Hence the residual is dropped from hurdle 2. The APEs and the p-values in hurdle 2 are obtained using the *margins* command in Stata.

The estimates in hurdle 2 indicate that once the decision to purchase fertilizer in the commercial market has been made, a kilogram of subsidized fertilizer reduces the quantity demanded of commercial fertilizer by 0.5kg, all things being equal. This estimate indicates that subsidized fertilizer crowds out commercial fertilizer, corroborating the findings of previous studies on crowding out (Ricker-Gilbert et al., 2011). Using the partial effects and likelihood functions of hurdles 1 and 2, the unconditional APE of subsidized fertilizer is estimated to be -0.86. The -0.86 APE is the overall crowding out effect, implying that each kilogram of subsidized fertilizer that a household acquires reduces the household's demand of commercial fertilizer by -

0.86 kg, all things being equal. The -0.86 kg crowding out estimate obtained in this study is higher than the -0.22 kg estimated by Ricker-Gilbert et al. (2011). Because this study followed the same methodological approach as Ricker-Gilbert et al. (2011), the higher crowding out estimate found in this study suggests that crowding out has increased substantially over time. The increase in crowding out could have resulted from an increase in demand for commercial fertilizer that has grown in Malawi over the past ten years, and is now quit high (Ricker-Gilbert and Jayne 2017; Sheahan and Barrett 2014).

Effect of Poverty Status on Crowding Out, $\Delta CO_{np,p}$

Table 7 presents estimates of crowding out (unconditional APEs) across the various poverty groups; and the difference in the crowding-out estimates across the various poverty groups are presented in table 8. Generally, the crowding out estimates for non-poor households is significantly higher than it is for poor and ultra-poor households. This is expected because non-poor farmers, as the descriptive statistics indicated, purchase significantly larger quantities of commercial fertilizer than poor households. Using the two-category consumption poverty classification, the estimates indicate that crowding out is 0.045 kg (5.4%) higher among non-poor households than it is among poor households; and using the three-category consumption poverty classification, crowding out among non-poor household is 0.034 kg (4.5%) and 0.069 kg (8.6%) greater than the estimates among poor and ultra-poor households respectively. The estimates also show that crowding out among poor households is 0.035 kg (4.3%) greater than ultra-poor households.

The variation in crowding out across asset poverty groups follows in a similar but more pronounced pattern. Based on the two-category asset poverty classification, crowding out is 0.130 kg (16.6%) higher for non-poor households than it is for poor households. In terms of the three-category asset poverty classification, crowding out among non-poor households is 0.095 kg (11.6%) and 0.163 kg (21.8%) greater than the estimate among poor and ultra-poor households. The above results suggest that targeting poor farmers would reduce crowding out, and consequently increase total fertilizer use.

Overall Net Gain in Yield for Targeting the Average Non-poor Farmer $\left(NG_{yield,p1}\right)$

This section presents the results of the overall net gain in yield for targeting the average non-poor farmer after accounting for the potential difference in NUE and crowding out between non-poor and poor households. It is clear from the variation of NUE and crowding out across poverty groups and their implication for targeting that there is a trade-off between targeting productive farmers (non-poor farmers, as the NUE estimates indicate) and targeting to reduce crowding out (poor farmers, as the crowding out estimates indicate). Targeting productive farmers will help serve the food security objective better but results in significantly higher levels of crowding out; while targeting to reduce crowding out in order to ensure higher overall fertilizer use results in lower levels of NUE and hence lower crop output. This study further examines the trade-off by estimating the overall net gain in yield when FISP is targeted at the average non-poor farmer after accounting for the differences in NUE and crowding out across the poor and non-poor farmers. The estimates required for this exercise and the results of the exercise are presented in tables 9 and 10 respectively. The estimates indicate that between any poverty groups, the overall net gain for targeting the better off farmers is positive and significant. For instance, using the two-category poverty classification, the overall net gain in yield for targeting consumption non-poor and asset non-poor farmers instead of their poor counterparts is 3.136kg and 4.330kg per kilogram of nitrogen respectively, after accounting for the difference in NUE and crowding out between poor and non-poor farmers. Using the three-category poverty classification, the overall gain in yield for targeting consumption non-poor and asset non-poor farmers instead of their ultra-poor counter parts is 4.170kg and 6.404kg respectively. Comparing poor to ultra-poor farmers, the estimates further show that the overall net gain in yield for targeting poor farmers instead of ultra-poor farmers is also positive and significant. This implies that although a significantly higher crowding out would be incurred when FISP is targeted at non-poor farmers, the productivity gain in targeting such farmers outweighs the additional crowding out effect. Thus, overall, the food security goal of FISP would be better served if the program were targeted at non-poor farmers.

Conclusions and Policy Recommendations

Targeted farm input subsidy programs have become major development policies in many Sub-Saharan African (SSA) countries. Like other targeted development programs, the success of TFISPs depends integrally on the effectiveness of the targeting process used in identifying and reaching beneficiaries. Targeting plays a crucial role in that it determines the beneficiaries of the program, the amount of inputs they receive, and hence how the inputs are used. The eventual impacts of the program are therefore closely linked to the quality of the targeting process. Notwithstanding that, the weight of the empirical evidence suggests that targeting of most TFISPs in SSA has not been effective. The goal of this study has been to provide guidance for determining the category of farmers that should be targeted in order to maximize the benefits of TFISPs using a two-year panel data from Malawi. Specifically, the study estimated the overall gain in productivity for targeting non-poor farmers instead of poor and ultra-poor farmers after accounting for differences in input use efficiency and crowding out across poverty groups. The study also investigated how nitrogen use efficiency and crowding out of commercial fertilizer by subsidized fertilizer vary between poor and non-poor farmers. Farmers were classified into poverty groups – non-poor, poor and ultra-poor – using consumption expenditure and a wealth index computed from household asset ownership. The consumption expenditure and the wealth index used in the poverty classification can be computed using information that can easily be collected from households.

The results indicate that non-poor farmers are significantly more productive than poor and ultra-poor farmers irrespective of whether poverty is measured by consumption expenditure or by the asset-based wealth index. The study also found that crowding out of commercial fertilizer by subsidized fertilizer is significantly higher among non-poor farmers than it is among poor and ultra-poor farmers. After accounting for these differences in productivity and crowding out across poverty groups, the study found that, on average, the overall net gains in yield for targeting consumption non-poor and asset non-poor farmers instead of their poor counterparts are 3.136kg and 4.330kg per kilogram of nitrogen. Comparing non-poor to ultra-poor farmers, the overall gains in yield for targeting consumption poor non-poor and asset non-poor farmers instead of their ultra-poor counterparts are 4.12kg and 6.40kg per kilogram of nitrogen.

These results have two key implications for the targeting of FISP and other TFISPs in SSA. First, since poor farmers are significantly less productive than non-poor farmers after accounting for crowding out, the two goals of FISP – increasing productivity and through that improving household and national food security by increasing food production, and reducing poverty by increasing household income – can hardly be achieved together by targeting poor farmers. The study therefore recommends that FISP and other TFISPs be focused on a single objective of increasing productivity. Second, the results reveal that there is a trade-off between targeting for increased productivity and targeting to reduce crowding out. Further analysis of the trade-off suggests that the overall net gain in yield for targeting the average non-poor farmer instead of the average poor farmer is positive and significant. Hence the study also recommends that FISP and other TFISPs should be targeted at non-poor farmers with the primary objective of increasing productivity and food security.

References

Baltzer, K. and H. Hansen. 2011. "Agricultural input subsidies in Sub-Saharan Africa". Evaluation Department, Ministry of Foreign Affairs of Denmark.

Banful, A. 2011. "Old Problems in the New Solutions? Politically Motivated Allocation of Program Benefits and the New Fertilizer Subsidies." *World Development* 39(7):1166–76.

Basurto, P., Dupas, P., and Robinson, J. 2016. "Decentralized and Efficiency of Subsidy Targeting: Evidence from Chiefs in Rural Malawi." *Unpublished document*

Chamberlain, G. 1984. Panel Data. In *Handbook of Econometrics*, vol. 2, ed. Z. Grilliches and M. D. Intriligator, 1247–1318. Amsterdam: North-Holland.

Chibwana, C., M. Fisher, and G. Shively. 2012. "Cropland Allocation Effects of Agricultural Input Subsidies in Malawi." *World Development* 40 (1):124–133.

Chirwa, E., M. Matita, P. Mvula and A. Dorward. 2011. "Impacts of the Farm Input Subsidy Programme in Malawi." Paper prepared for Malawi Government / DFID Evaluation of Malawi Farm Input Subsidy Programme, School of Oriental and African Studies, University of London.

Corrado, L and Fingleton, B. Multilevel Modelling with Spatial Effects. Discussion paper, SIRE-DP-2011-13, Scottish Institute for Research in Economics.

Cragg, J. G. 1971. Some Statistical Models for Limited Dependent Variables with Application to the Demand for Durable Goods. *Econometrica* 39(5): 829–844.

Deaton, A. and J. Muellbauer. 1980. Economics and Consumer Behavior. Cambridge, UK: Cambridge University Press. Deaton, A. and S. Zaidi. 1999. "Guidelines for Constructing Consumption Aggregates for Welfare Analysis." Working Paper 192, Princeton University Research Program in Development Studies, Princeton, NJ.

Deaton, A. 1997. The Analysis of Household Surveys. Washington, DC: Johns Hopkins University Press.

Dorward, A., E. Chirwa, V. Kelly, T. Jayne. 2008. Evaluation of the 2006/7 Agricultural Input Supply Programme, Malawi. Report, School of Oriental and African Studies (SOAS), Wadonda Consult, Michigan State University, and Overseas Development Institute (ODI), undertaken for the Ministry of Agriculture and Food Security, Government of Malawi.

Dorward, A. and Chirwa, E. 2013. "Targeting in the Farm Input Subsidy Programme in Malawi: Issues and Options." Working Paper 066, Futures Agriculture.

Dzanku, Fred, M. 2015. “Household Welfare Effects of Agricultural Productivity: A Multidimensional Perspective from Ghana”. *Journal of Development Studies,* 51 (9), 1139–1154

Elhorst, J.P. 2014. Spatial Econometrics from Cross-Sectional Data to Spatial Panels. Springer Briefs in Regional Science.

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

Goldstein, H. 1995. Multilevel statistical model, 2nd edn. Arnold (Oxford University Press), London.

Holden, S., and R. Lunduka. 2010. “Too Poor to Be Efficient? Impacts of the Targeted Fertilizer Subsidy Program in Malawi on Farm Plot Level Input Use, Crop Choice and Land Productivity.” Unpublished document, Department of Economics and Resource Management, Norwegian University of Life Sciences.

Houssou N. and Zeller, M. 2010. “Targeting the Poor and Smallholder Farmers: Empirical Evidence from Malawi.” *Quarterly Journal of International Agriculture* 49 (4), 341-358.

Houssou N. and M. Zeller, M. 2011. “To Target or not to Target? The cost, benefits and impacts of indicator-based targeting. *Food Policy* 36, 626-636.

Howard, J., Mungoma, C., 1997. Zambia’s stop-and-Go maize revolution. In: Byerlee, D., Eicher, C. (Eds), Africa’s Emerging Maize Revolution, Lynn Rienner Publishers, Colorado.

Jayne, T.S. and Rashid, S. 2013. “Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence”. *Agricultural Economics*, 44: 547-562

Kilic, T., E. Whitney and P. Winter. 2013. “Decentralized Beneficiary Targeting in Large-Scale Development Programs: Insights from the Malawi Farm Input Subsidy Program.” Unpublished document.

Malawi National Statistical Office (NSO). 2012. Malawi Second Integrated Household Survey (IHS3) 2010-2011. Basic Information Document, Zomba, Malawi.

Marenya, P. P. and C. B. Barrett. 2009. "Soil quality and fertilizer use rates among smallholder farmers in western Kenya." *Agricultural Economics* 40 (5): 561-572.

Malawi Ministry of Agriculture and Food Security (MoAFS) .2009. “2009-2010 farm input subsidy program implementation guidelines.” Lilongwe, Republic of Malawi.

Mason, N. and Smale, M. 2013. “Impacts of subsidized hybrid seed on indicators of economic well-being among smallholder maize growers in Zambia.” *Agricultural Economics* 44: 1-12

Mason, N.M. and Jayne, T.S. 2013. Fertilizer Subsidies and Smallholder Commercial Fertilizer Purchases: Crowding Out, Leakage and Policy Implications for Zambia. Journal of Agricultural Economics, Vol. 64, No. 3, 558-582.

Morris, M., V. A. Kelly, R. J. Kopicki and D. Byerlee. 2007. "Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines." The World Bank, Washington, DC.

Mundlak, Y. 1978. On the Pooling of Time Series and Cross Section Data. *Econometrica* 46:69–85.

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): 26–42.

Ricker-Gilbert, J., and T.S. Jayne. 2017. "Estimating the Enduring Effects of Fertilizer Subsidies on Commercial Fertilizer Demand and Maize Production: Panel Data Evidence from Malawi." *Journal of Agricultural Economics* 68(1):70-97.

Ricker-Gilbert, J., T. Jayne and G. Shively. 2013. "Addressing the "Wicked Problem" of Input Subsidy Programs in Africa." *Applied Economics Perspectives and Policy* 35 (2): 322-340.

Ricker-Gilbert, J., N. M. Mason, F.A. Darko and Tembo, S.T. 2013. "What are the Effects of Input Subsidy Programs on Maize Prices? Evidence from Malawi and Zambia." *Agricultural Economics* 44: 1-16.

Schultz, Theodore W. (1964) Transforming Traditional Agriculture (New Haven, London: Yale University Press).

Sheahan, M., and C.B. Barrett. 2014. "Understanding the Agricultural Input Landscape in sub-Saharan Africa. Recent Plot, Household, and Community-Level Evidence." World Bank Policy Research Working Paper 7014. Washington D.C., USA.

Shively, G.E., and J. Ricker-Gilbert. 2013. "Measuring the Impacts of Agricultural Input Subsidies in Sub-Saharan Africa: Evidence from Malawi's Farm Input Subsidy Program." Policy Brief Vol 1, Issue 1. Global Policy Research Institute, Purdue University.

Singh, I., L. Squire, and J. Strauss. 1986. *Agricultural Household Models*. Baltimore: Johns Hopkins University Press.

Wooldridge, J.M., 2010. Econometric Analysis of Cross Section and Panel Data, Second Edition. MIT Press, Cambridge, MA.

World Bank. 2007. World Bank Assistance to Agriculture in sub-Saharan Africa: An IEG Review. Independent Evaluation Group, World Bank, Washington, DC.

Xu, Z. Z. Guan, T.S. Jayne and R. Black. 2009. "Factors Influencing the Profitability of Fertilizer Use on Maize in Zambia." *Agricultural Economics* 40: 437-446.

Table 1: Descriptive Statistics by Survey Year

	Pooled		Year = 2010		Year = 2013	
	Mean	Stan dev.	Mean	Stan dev.	Mean	Stan dev.
Maize yield (Kg/ha)	1,437.46	1,077.30	1,272.17	936.82	1,573.89***	1,169.14
Nitrogen application rate (Kg/ha)	46.35	45.79	47.58	45.00	45.34	46.42
Non-poor (consumption)	63.80	0.48	63.20	0.48	64.30	0.48
Poor (consumption)	25.20	0.43	24.90	0.43	25.40	0.43
Ultra-poor (consumption)	11.00	0.32	11.90	0.33	10.30	0.31
Non-poor (asset)	58.30	0.49	58.30	0.49	58.20	0.49
Poor (asset)	20.00	0.40	20.40	0.40	19.70	0.40
Ultra-poor (asset)	21.70	0.40	21.30	0.40	22.10	0.40
Below recommended N application rate (1/0)	78.50	0.42	78.40	0.42	78.60	0.41
Above recommended N application rate (1/0)	14.90	0.36	15.20	0.37	14.50	0.35
Applied basal fertilizer on time (1/0)	29.70	0.46	36.50	0.49	24.10***	0.44
Fertilizer used is basal fertilizer	50.20	0.50	47.40	0.50	52.40**	0.50
Applied organic fertilizer (1/0)	16.00	0.36	13.40	0.33	18.10**	0.38
Seed rate (Kg/ha)	25.72	21.81	22.99	25.42	27.96***	17.95
Used hybrid seed (1/0)	37.70	0.49	39.70	0.49	36.00	0.48
Pure stand (1/0)	48.10	0.50	53.50	0.50	43.60***	0.50
Plot size (ha)	0.42	0.26	0.43	0.25	0.40**	0.27
Labor (days)	132.74	94.55	116.92	80.07	145.80***	103.88
Soil is of good quality (1/0)	45.80	0.50	44.70	0.50	46.60	0.50
Soil is of fair quality (1/0)	41.30	0.49	41.70	0.49	40.90	0.50
Plot is sloppy (1/0)	46.70	0.50	47.00	0.50	46.30	0.50
Plot is swampy (1/0)	15.80	0.36	16.40	0.37	15.30	0.36
Soil is sandy clay (1/0)	53.80	0.50	52.50	0.50	54.80	0.50
Plot show signs of erosion (1/0)	39.00	0.49	40.20	0.49	38.10	0.48
Female plot manager (1/0)	30.40	0.45	27.20	0.44	33.00**	0.46
Age of plot manager (years)	41.78	15.39	40.96	15.23	42.45*	15.49
Years of education of plot manager	4.85	3.86	4.88	3.84	4.82	3.88
African Adult Male Equivalent	3.87	1.63	3.79	1.58	3.94**	1.67
Dependency ratio (%)	121.53	95.66	124.36	98.01	119.19	93.63
Distance to boma (Km)	38.85	27.49	52.61	27.92	27.49***	21.48
Avg. 12-month total rainfall(mm) for July-June	825.56	80.86	828.55	87.84	823.10**	74.31
Annual Mean Temperature (°C * 10)	215.78	17.76	216.53	18.14	215.17	17.42
Quantity of subsidized fertilizer acquired (Kg)	43.29	41.51	41.76	41.12	44.62	41.84
Quantity of commercial fertilizer acquired (Kg)	164.92	228.93	143.79	203.91	184.70***	248.20

***, ** and * implies significant difference between 2010 and 2013 at the 1%, 5% and 10% levels respectively

Table 2: Descriptive Statistics by Survey Year by Poverty Status

	2010		2013	
	Non-poor	Poor	Non-poor	Poor
Maize yield (Kg/ha)	1,432.90***	1,047.21	1,804.31***	1,253.14
Nitrogen application rate (Kg/ha)	55.39***	36.66	55.83***	30.73
Below recommended N application rate (1/0)	72.95***	86.00	72.39***	87.35
Above recommended N application rate (1/0)	20.25***	8.23	19.62***	7.45
Applied basal fertilizer on time (1/0)	37.9	34.44	24.72	23.30
Applied inorganic fertilizer twice (1/0)	81.99***	70.86	80.25***	58.67
Fertilizer used is basal fertilizer	55.79***	35.62	62.01***	39.14
Applied organic fertilizer (1/0)	14.65	11.69	19.36	16.32
Seed rate (Kg/ha)	21.40*	25.22	27.76	28.24
Used hybrid seed (1/0)	44.23***	33.41	37.84	33.33
Pure stand (1/0)	54.92	51.52	44.74	41.94
Plot size (ha)	46.28***	39.36	43.65***	35.74
Labor (days)	111.20**	124.93	144.24	147.98
Soil is of good quality (1/0)	50.32***	36.88	46.79	46.42
Soil is of fair quality (1/0)	39.18	45.33	42.07	39.33
Plot is not flat (1/0)	45.65	49.00	47.80	44.33
Plot is swampy (1/0)	17.31	15.24	16.06	14.25
Soil is sandy clay (1/0)	53.04	51.67	55.56	53.83
Plot show signs of erosion (1/0)	39.98	40.47	36.73	39.89
Female plot manager (1/0)	24.81	30.44	29.65**	37.70
Age of plot manager (years)	42.22***	39.19	44.79***	39.19
Years of education of plot manager	5.79***	3.62	5.60***	3.74
African Adult Male Equivalent	3.964***	3.53	4.09***	3.73
Dependency ratio (%)	117.03**	134.60	110.32***	131.55
Distance to boma (Km)	53.83	50.91	27.90	26.92
Avg 12-month total rainfall(mm) for July-June	833.08***	822.22	824.13	821.67
Annual Mean Temperature (°C * 10)	217.01	215.84	214.46	216.16
Quantity of subsidized fertilizer acquired (Kg)	47.07***	34.41	48.97***	38.88
Quantity of commercial fertilizer acquired (Kg)	180.81***	87.94	220.89***	116.49

***, **, * imply significant difference between non-poor and poor farmer

Table 3: Impact of (consumption) Poverty on Nitrogen Use Efficiency

(Dependent variable = maize yield (kg/ha))

VARIABLES	Non-poor vs poor	Non-poor vs poor vs ultra-poor
Nitrogen application rate (Kg/ha)	8.718***	8.739***
	(1.450)[a]	(1.450)
Nitrogen application rate squared	0.006	0.006
	(0.011)	(0.011)
Poor * nitrogen application rate	-3.376***	-3.019***
	(0.922)	(1.013)
Ultra-poor * nitrogen application rate	--	-4.465***
		(1.351)
Below recommended nitrogen application rate (1/0)	96.495	91.500
	(106.668)	(107.305)
Above recommended nitrogen application rate (1/0)	-204.521	-202.685
	(124.744)	(124.431)
Applied basal fertilizer on time (1/0)	158.702***	159.430***
	(57.534)	(57.476)
Applied organic fertilizer (1/0)	223.656***	223.318***
	(62.183)	(62.242)
Seed rate (Kg/ha)	3.716***	3.737***
	(1.080)	(1.081)
Used hybrid seed (1/0)	71.598	71.286
	(44.931)	(44.918)
Pure stand (1/0)	-128.015***	-129.637***
	(43.270)	(43.270)
Plot size (ha)	-1,121.032***	-1,117.205***
	(267.271)	(267.280)
Plot size squared	504.382***	500.586***
	(192.800)	(192.381)
Labor (days)	1.088***	1.079***
	(0.297)	(0.298)
Soil is of good quality (1/0)	199.826***	198.950***
	(59.526)	(59.630)
Soil is of fair quality (1/0)	173.052***	172.211***
	(56.097)	(56.224)
Plot is sloppy (1/0)	-31.560	-32.681
	(43.348)	(43.396)
Plot is swampy (1/0)	-62.787	-62.827
	(61.095)	(61.061)
Soil is sandy clay (1/0)	53.839	55.267
	(44.481)	(44.512)
Plot show signs of erosion (1/0)	25.718	24.967
	(53.417)	(53.486)
Female plot manager (1/0)	-121.001**	-120.232**
	(51.803)	(51.837)
Age of plot manager (years)	0.152	0.134
	(1.666)	(1.667)

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 3: Cont'd

VARIABLES	Non-poor vs poor	Non-poor vs poor vs ultra-poor
Years of education of plot manager	27.977***	27.783***
	(6.975) [a]	(6.974)
African Adult Male Equivalent	38.665**	39.349**
	(19.066)	(19.117)
Dependency ratio (%)	0.303	0.298
	(0.294)	(0.295)
Household received extension service for production	69.447	68.195
	(47.410)	(47.446)
Distance to boma (Km)	-0.218	-0.239
	(0.916)	(0.916)
Tropic-warm/semi-arid	266.211***	264.337**
	(102.891)	(102.819)
Tropic-warm/sub-humid	-68.112	-71.668
	(96.586)	(96.518)
Tropic-cool/semiarid	73.843	73.098
	(109.004)	(108.743)
Average 12-month total rainfall(mm) for July-June	1.290***	1.302***
	(0.373)	(0.374)
Annual Mean Temperature (°C * 10)	-6.620***	-6.595***
	(2.065)	(2.063)
Year (2013)	192.640***	191.052***
	(49.355)	(49.390)
Constant	684.163	678.523
	(602.950)	(601.835)
Observations	2,474	2,474
Number of groups	1,072	1,072

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 4: Impact of (asset) Poverty on Nitrogen Use Efficiency

(Dependent variable = maize yield (kg/ha))

VARIABLES	Non-poor vs poor	Non-poor vs poor vs ultra-poor
Nitrogen application rate (Kg/ha)	9.511***	9.538***
	(1.487) [a]	(1.484)
Nitrogen application rate squared	0.004	0.005
	(0.011)	(0.011)
Poor * nitrogen application rate	-4.926***	-3.505***
	(0.915)	(1.116)
Ultra-poor * nitrogen application rate	--	-6.843***
		(1.101)
Below recommended nitrogen application rate (1/0)	102.801	120.223
	(102.802)	(102.842)
Above recommended nitrogen application rate (1/0)	-221.822*	-223.171*
	(120.590)	(121.086)
Applied basal fertilizer on time (1/0)	175.645***	176.226***
	(57.819)	(57.598)
Applied organic fertilizer (1/0)	215.521***	216.975***
	(62.129)	(61.885)
Seed rate (Kg/ha)	3.727***	3.754***
	(1.070)	(1.074)
Used hybrid seed (1/0)	75.965*	76.576*
	(44.729)	(44.691)
Pure stand (1/0)	-128.170***	-129.149***
	(43.278)	(43.183)
Plot size (ha)	-1,153.045***	-1,163.643***
	(268.805)	(268.448)
Plot size squared	513.263***	521.923***
	(189.674)	(189.264)
Labor (days)	1.109***	1.114***
	(0.297)	(0.297)
Soil is of good quality (1/0)	201.091***	200.991***
	(60.077)	(60.162)
Soil is of fair quality (1/0)	171.225***	170.074***
	(57.112)	(57.035)
Plot is sloppy (1/0)	-26.440	-26.292
	(43.096)	(43.089)
Plot is swampy (1/0)	-61.347	-58.271
	(61.022)	(60.906)
Soil is sandy clay (1/0)	47.631	48.339
	(44.346)	(44.249)
Plot show signs of erosion (1/0)	29.441	31.667
	(53.112)	(53.031)
Female plot manager (1/0)	-132.546**	-128.822**
	(52.167)	(52.054)
Age of plot manager (years)	-0.669	-0.724
	(1.649)	(1.643)

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 4: Cont'd

VARIABLES	Non-poor vs poor	Non-poor vs poor vs ultra-poor
Years of education of plot manager	25.102***	24.144***
	(6.952) [a]	(6.941)
African Adult Male Equivalent	27.262	26.967
	(19.290)	(19.264)
Dependency ratio (%)	0.288	0.294
	(0.293)	(0.292)
Household received extension service for production	65.813	63.811
	(47.025)	(46.911)
Distance to boma (Km)	-0.315	-0.210
	(0.915)	(0.917)
Tropic-warm/semiarid	305.713***	319.041***
	(103.392)	(103.225)
Tropic-warm/subhumid	-45.435	-40.194
	(96.005)	(96.263)
Tropic-cool/semiarid	106.661	111.840
	(109.019)	(109.620)
Avg 12-month total rainfall(mm) for July-June	1.293***	1.317***
	(0.372)	(0.371)
Annual Mean Temperature (°C * 10)	-7.223***	-7.364***
	(2.052)	(2.041)
Year (2013)	192.316***	193.375***
	(49.049)	(48.989)
Constant	883.356	870.003
	(598.315)	(598.819)
Observations	2,474	2,474
Number of groups	1,072	1,072

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 5: Factors Influencing the Quantity of Subsidized Fertilizer Acquired by Households[b]

	Average Partial Effects (APE)
Years household head has lived in village during first survey	0.191***
	(0.067)[a]
Wealth index	-0.302
	(1.801)
Total landholding (ha)	4.032
	(2.915)
Dependency ratio (%)	-0.004
	(0.034)
Household head is female (1/0)	0.435
	(9.877)
Distance to nearest road (Km)	0.433
	(1.391)
Distance to nearest population center of +20,000 people	0.181
	(0.814)
Real price of nitrogen at the time of planting (MKW/ha)	0.064
	(0.047)
Real price of maize during lean season before planting (MKW/ha)	0.317
	(0.228)
12-month total rainfall (mm) in July-June, starting July 2009	0.027
	(0.027)
Central region	-1.654
	(4.867)
Southern region	21.705***
	(8.295)
Soil quality index	-0.249
	(3.063)
Year (2013)	32.456*
	(17.473)
Observations	1,667

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
[b] Based on the tobit estimator

Table 6: Double-Hurdle Models of Factors Influencing Demand for Commercial Fertilizer Demand (subsidized fertilizer treated as endogenous)

VARIABLES	**Hurdle 1** Probability of participating in commercial fertilizer market Estimator: Probit	**Hurdle 2** Demand for commercial fertilizer upon participation Estimator: Truncated Normal
Quantity of subsidized fertilizer acquired by household (kg)	-0.003***	-0.501**
	(0.000) [a]	(0.233) [a]
Residual from reduced form equation	0.007***	--
	(0.002)	--
Wealth index	-0.018	-4.488
	(0.020)	(8.753)
Landholding (ha)	0.095***	28.025
	(0.032)	(20.461)
Dependency ratio (%)	0.000	-0.202
	(0.000)	(0.282)
Household head is female (1/0)	0.162	-41.636
	(0.115)	(67.510)
Distance to nearest road (Km)	0.007	-13.252***
	(0.016)	(4.328)
Distance to nearest population center with +20,000 people	0.001	-4.022
	(0.008)	(2.683)
Real price of nitrogen at the time of planting (MKW/ha)	0.000	0.860*
	(0.001)	(0.470)
Real price of maize during lean season before planting (MKW/ha)	-0.000	0.882
	(0.003)	(1.693)
12-month total rainfall (mm) in July-June, starting July 2009	0.000	-0.202
	(0.000)	(0.199)
Central region	-0.121**	-31.668
	(0.057)	(35.543)
Southern region	-0.044	4.278
	(0.131)	(67.484)
Soil quality index	-0.002	14.491
	(0.119)	(17.003)
Year (2013)	0.246	188.872
	(0.230)	(127.476)
Observations	1,667	646

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. [a] Standards errors in hurdle 1 were obtained via bootstrapping at 250 repetitions to account for first-stage estimation. The coefficients in both hurdles were obtained using *margins* command in Stata.

Table 7: Average Partial Effects (APE) of Subsidized Fertilizer on Commercial Fertilizer Demand across Different poverty Groups

	Consumption poverty	**Asset poverty**
Poverty category 1		
Non-poor	-0.874***	-0.911***
	(0.170)[a]	(0.178)
Poor	-0.830***	-0.781***
	(0.153)	(0.145)
Poverty category 2		
Non-poor	0.874***	-0.911***
	(0.170)	(0.178)
Poor	0.840***	-0.817***
	(0.156)	(0.150)
Ultra-poor	0.805***	-0.748***
	(0.149)	(0.142)

*** implies significant at 1% level. [a] Values in parenthesis are standard errors obtained via bootstrapping at 250 repetitions. The mean APE is -0.858 for the entire sample.

Table 8: Difference in Crowding Out Estimates Across Poverty Groups

	Consumption poverty	Asset poverty
Poverty category 1		
Non-poor vs Poor	-0.045***	-0.130***
	(5.422%) [a]	(16.645%)
Poverty category 2		
Non-poor vs Poor	-0.034**	-0.095***
	(4.048%)	(11.628%)
Non-poor vs Ultra-poor	-0.069***	-0.163***
	(8.571%)	(21.791%)
Poor vs Ultra-poor	-0.035 *	-0.069***
	(4.348%)	(9.225%)

***, **, and * imply significant difference at 1%, 5% and 10% levels respectively. [a] Values in parenthesis are estimates of percentage difference in crowding out.

Table 9: Estimates of $\Delta \boldsymbol{NUE}_{\boldsymbol{p1,p0}}$, $\Delta \boldsymbol{CO}_{\boldsymbol{p1,p0}}$ and $\boldsymbol{NUE}_{\boldsymbol{p0}}$ Across Poverty Groups

	Consumption poverty			Asset poverty		
	$\Delta NUE_{p1,p0}$	$\Delta CO_{p1,p0}$	NUE_{p0}	$\Delta NUE_{p1,p0}$	$\Delta CO_{p1,p0}$	NUE_{p0}
Poverty category 1						
Non-poor vs Poor	3.376***	-0.045***	5.342	4.926***	-0.130***	4.585
Poverty category 2						
Non-poor vs Poor	3.019***	-0.034**	5.720	3.505***	-0.095***	6.033
Non-poor vs Ultra-poor	4.465***	-0.069***	4.274	6.843***	-0.163***	2.695
Poor vs Ultra-poor	1.445	-0.035*	4.274	3.337***	-0.069***	2.696

***, **, and * imply significant difference at 1%, 5% and 10% levels respectively.

Table 10: Estimates of $\boldsymbol{NG_{yield,p}}$

	Consumption poverty	Asset poverty
Poverty category 1		
Non-poor vs Poor	3.136***	4.330***
	(0.123)	(0.144)
Poverty category 2		
Non-poor vs Poor	2.825***	2.932***
	(0.111)	(0.134)
Non-poor vs Ultra-poor	4.170***	6.404***
	(0.186)	(0.214)
Poor vs Ultra-poor	1.295*	3.151**
	(0.009)	(0.116)

*** implies significant at 1% level. [a] Values in parenthesis are standard errors obtained via bootstrapping at 250 repetitions.

Appendix A

Table A1: Impact of (consumption) Poverty on Nitrogen Use Efficiency

Dependent variable = maize yield (kg/ha)

	Poor vs non-poor vs ultra-poor	Quintiles of consumption expenditure: 4th quintile omitted	3rd quintile omitted	2nd quintile omitted
Nitrogen application rate (Kg/ha)	5.719***	8.442***	8.928***	6.064***
	(1.675) [a]	(1.662)	(1.656)	(1.711)
Nitrogen application rate squared	0.006	0.003	0.003	0.003
	(0.011)	(0.011)	(0.011)	(0.011)
Non-poor * nitrogen application rate	3.019***	--	--	--
	(1.013)	--	--	--
Ultra-poor * nitrogen application rate	-1.445	--	--	--
	(1.425)	--	--	--
First quintile * nitrogen application rate	--	-3.109**	-3.596**	-0.731
	--	(1.320)	(1.409)	(1.291)
Second quintile * nitrogen application rate	--	-2.378*	-2.865**	--
	--	(1.248)	(1.307)	--
Third quintile * nitrogen application rate	--	0.487	--	2.865**
	--	(1.326)	--	(1.307)
Fourth quintile * nitrogen application rate	--	--	-0.487	2.378*
	--	--	(1.326)	(1.248)
Fifth quintile * nitrogen application rate	--	1.212	0.725	3.590***
	--	(1.208)	(1.370)	(1.338)
Below recommended nitrogen application rate (1/0)	91.500	94.233	94.233	94.233
	(107.305)	(106.842)	(106.842)	(106.842)
Above recommended nitrogen application rate (1/0)	-202.685	-196.010	-196.010	-196.010
	(124.431)	(124.068)	(124.068)	(124.068)
Applied basal fertilizer on time (1/0)	159.430***	155.490***	155.490***	155.490***
	(57.476)	(57.731)	(57.731)	(57.731)
Applied organic fertilizer (1/0)	223.318***	222.701***	222.701***	222.701***
	(62.242)	(62.721)	(62.721)	(62.721)
Seed rate (Kg/ha)	3.737***	3.727***	3.727***	3.727***
	(1.081)	(1.081)	(1.081)	(1.081)
Used hybrid seed (1/0)	71.286	73.391	73.391	73.391
	(44.918)	(44.711)	(44.711)	(44.711)
Pure stand (1/0)	-129.637***	-127.311***	-127.311***	-127.311***
	(43.270)	(43.416)	(43.416)	(43.416)
Plot size (ha)	-1,117.205***	-1,115.696***	-1,115.696***	-1,115.696***
	(267.280)	(267.941)	(267.941)	(267.941)
Plot size squared	500.586***	496.523**	496.523**	496.523**
	(192.381)	(193.110)	(193.110)	(193.110)
Labor (days)	1.079***	1.088***	1.088***	1.088***
	(0.298)	(0.297)	(0.297)	(0.297)
Soil is of good quality (1/0)	198.950***	202.057***	202.057***	202.057***
	(59.630)	(59.687)	(59.687)	(59.687)
Soil is of fair quality (1/0)	172.211***	173.044***	173.044***	173.044***
	(56.224)	(56.404)	(56.404)	(56.404)
Plot is sloppy (1/0)	-32.681	-31.084	-31.084	-31.084
	(43.396)	(43.488)	(43.488)	(43.488)
Plot is swampy (1/0)	-62.827	-65.357	-65.357	-65.357
	(61.061)	(60.789)	(60.789)	(60.789)
Soil is sandy clay (1/0)	55.267	54.359	54.359	54.359
	(44.512)	(44.690)	(44.690)	(44.690)
Plot show signs of erosion (1/0)	24.967	26.643	26.643	26.643
	(53.486)	(53.462)	(53.462)	(53.462)
Female plot manager (1/0)	-120.232**	-115.662**	-115.662**	-115.662**
	(51.837)	(51.684)	(51.684)	(51.684)
Age of plot manager (years)	0.134	0.028	0.028	0.028
	(1.667)	(1.667)	(1.667)	(1.667)

[a] Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A1: Cont'd

	Poor vs non-poor vs ultra-poor	Quintiles of consumption expenditure		
		4th quintile omitted	3rd quintile omitted	2nd quintile omitted
Years of education of plot manager	27.783***	27.197***	27.197***	27.197***
	(6.974) [a]	(7.019)	(7.019)	(7.019)
African Adult Male Equivalent	39.349**	41.661**	41.661**	41.661**
	(19.117)	(19.140)	(19.140)	(19.140)
Dependency ratio (%)	0.298	0.318	0.318	0.318
	(0.295)	(0.294)	(0.294)	(0.294)
Household received extension service for production	68.195	72.840	72.840	72.840
	(47.446)	(47.069)	(47.069)	(47.069)
Distance to boma (Km)	-0.239	-0.187	-0.187	-0.187
	(0.916)	(0.918)	(0.918)	(0.918)
Tropic-warm/semiarid	264.337**	263.274**	263.274**	263.274**
	(102.819)	(102.957)	(102.957)	(102.957)
Tropic-warm/sub-humid	-71.668	-73.191	-73.191	-73.191
	(96.518)	(96.749)	(96.749)	(96.749)
Tropic-cool/semiarid	73.098	71.527	71.527	71.527
	(108.743)	(109.431)	(109.431)	(109.431)
Avg 12-month total rainfall(mm) for July-June	1.302***	1.295***	1.295***	1.295***
	(0.374)	(0.374)	(0.374)	(0.374)
Annual Mean Temperature (°C * 10)	-6.595***	-6.599***	-6.599***	-6.599***
	(2.063)	(2.060)	(2.060)	(2.060)
Year (2013)	191.052***	190.778***	190.778***	190.778***
	(49.390)	(49.586)	(49.586)	(49.586)
Constant	678.523	668.890	668.890	668.890
	(601.835)	(602.027)	(602.027)	(602.027)
Observations	2,474	2,474	2,474	2,474
Number of groups	1,072	1,072	1,072	1,072

[a] Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A2: Impact of (asset) Poverty on Nitrogen Use Efficiency

Dependent variable = maize yield (kg/ha)

VARIABLES	Poor vs non-poor vs ultra-poor	Quintiles of consumption expenditure		
		4th quintile omitted	3rd quintile omitted	2nd quintile omitted
Nitrogen application rate (Kg/ha)	6.033***	9.226***	7.933***	6.027***
	(1.671) [a]	(1.593)	(1.714)	(1.661)
Nitrogen application rate squared	0.005	0.003	0.003	0.003
	(0.011)	(0.011)	(0.011)	(0.011)
Non-poor * nitrogen application rate	3.505***	--	--	--
	(1.116)	--	--	--
Ultra-poor * nitrogen application rate	-3.337***	--	--	--
	(1.294)	--	--	--
First quintile * nitrogen application rate	--	-6.521***	-5.228***	-3.321**
	--	(1.245)	(1.314)	(1.293)
Second quintile * nitrogen application rate	--	-3.200**	-1.907	--
	--	(1.310)	(1.284)	--
Third quintile * nitrogen application rate	--	-1.293	--	1.907
	--	(1.182)	--	(1.284)
Fourth quintile * nitrogen application rate	--	--	1.293	3.200**
	--	--	(1.182)	(1.310)
Fifth quintile * nitrogen application rate	--	2.725**	4.018***	5.924***
	--	(1.279)	(1.382)	(1.420)
Below recommended nitrogen application rate (1/0)	120.223	116.223	116.223	116.223
	(102.842)	(101.653)	(101.653)	(101.653)
Above recommended nitrogen application rate (1/0)	-223.171*	-223.898*	-223.898*	-223.898*
	(121.086)	(120.661)	(120.661)	(120.661)
Applied basal fertilizer on time (1/0)	176.226***	182.258***	182.258***	182.258***
	(57.598)	(57.297)	(57.297)	(57.297)
Applied organic fertilizer (1/0)	216.975***	209.230***	209.230***	209.230***
	(61.885)	(61.685)	(61.685)	(61.685)
Seed rate (Kg/ha)	3.754***	3.721***	3.721***	3.721***
	(1.074)	(1.074)	(1.074)	(1.074)
Used hybrid seed (1/0)	76.576*	69.989	69.989	69.989
	(44.691)	(44.856)	(44.856)	(44.856)
Pure stand (1/0)	-129.149***	-131.991***	-131.991***	-131.991***
	(43.183)	(43.101)	(43.101)	(43.101)
Plot size (ha)	-1,163.643***	-1,188.183***	-1,188.183***	-1,188.183***
	(268.448)	(267.446)	(267.446)	(267.446)
Plot size squared	521.923***	522.911***	522.911***	522.911***
	(189.264)	(188.044)	(188.044)	(188.044)
Labor (days)	1.114***	1.132***	1.132***	1.132***
	(0.297)	(0.295)	(0.295)	(0.295)
Soil is of good quality (1/0)	200.991***	200.042***	200.042***	200.042***
	(60.162)	(60.221)	(60.221)	(60.221)
Soil is of fair quality (1/0)	170.074***	173.017***	173.017***	173.017***
	(57.035)	(56.999)	(56.999)	(56.999)
Plot is sloppy (1/0)	-26.292	-27.196	-27.196	-27.196
	(43.089)	(42.546)	(42.546)	(42.546)
Plot is swampy (1/0)	-58.271	-59.931	-59.931	-59.931
	(60.906)	(60.637)	(60.637)	(60.637)
Soil is sandy clay (1/0)	48.339	48.416	48.416	48.416
	(44.249)	(43.999)	(43.999)	(43.999)
Plot show signs of erosion (1/0)	31.667	30.423	30.423	30.423
	(53.031)	(52.886)	(52.886)	(52.886)
Female plot manager (1/0)	-128.822**	-134.549***	-134.549***	-134.549***
	(52.054)	(51.683)	(51.683)	(51.683)
Age of plot manager (years)	-0.724	-1.228	-1.228	-1.228
	(1.643)	(1.629)	(1.629)	(1.629)

[a] Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A2: Cont'd

		Quintiles of consumption expenditure		
	Poor vs non-poor vs ultra-poor	4th quintile omitted	3rd quintile omitted	2nd quintile omitted
Years of education of plot manager	24.144***	20.660***	20.660***	20.660***
	(6.941) [a]	(7.087)	(7.087)	(7.087)
African Adult Male Equivalent	26.967	26.243	26.243	26.243
	(19.264)	(19.263)	(19.263)	(19.263)
Dependency ratio (%)	0.294	0.314	0.314	0.314
	(0.292)	(0.291)	(0.291)	(0.291)
Household received extension service for production	63.811	61.877	61.877	61.877
	(46.911)	(46.657)	(46.657)	(46.657)
Distance to boma (Km)	-0.210	-0.190	-0.190	-0.190
	(0.917)	(0.915)	(0.915)	(0.915)
Tropic-warm/semiarid	319.041***	322.959***	322.959***	322.959***
	(103.225)	(102.844)	(102.844)	(102.844)
Tropic-warm/sub-humid	-40.194	-49.845	-49.845	-49.845
	(96.263)	(96.163)	(96.163)	(96.163)
Tropic-cool/semiarid	111.840	108.331	108.331	108.331
	(109.620)	(110.156)	(110.156)	(110.156)
Avg 12-month total rainfall(mm) for July-June	1.317***	1.293***	1.293***	1.293***
	(0.371)	(0.371)	(0.371)	(0.371)
Annual Mean Temperature (°C * 10)	-7.364***	-7.489***	-7.489***	-7.489***
	(2.041)	(2.042)	(2.042)	(2.042)
Year (2013)	193.375***	191.503***	191.503***	191.503***
	(48.989)	(48.766)	(48.766)	(48.766)
Constant	870.003	974.413	974.413	974.413
	(598.819)	(598.939)	(598.939)	(598.939)
Observations	2,474	2,474	2,474	2,474
Number of groups	1,072	1,072	1,072	1,072

[a] Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A3 Household Fixed Effects of Impact of (asset) Poverty on Nitrogen Use Efficiency

(Dependent variable = maize yield (kg/ha))

VARIABLES	Non-poor vs poor	Non-poor vs poor vs ultra-poor	Quintiles of wealth index
Nitrogen application rate (Kg/ha)	7.509***	7.444***	9.587***
	(1.795)	(1.801)	(2.160)
Nitrogen application rate squared	-0.004	-0.002	-0.003
	(0.013)	(0.013)	(0.013)
Poor * nitrogen application rate	-2.840**	-1.511	--
	(1.174)	(1.350)	
Ultra-poor * nitrogen application rate	--	-4.524***	--
		(1.642)	
First quintile * nitrogen application rate	--	--	-6.608***
			(2.078)
Second quintile * nitrogen application rate	--	--	-3.701*
			(2.021)
Third quintile * nitrogen application rate	--	--	-2.770
			(1.913)
Fourth quintile * nitrogen application rate	--	--	-2.759*
			(1.614)
Below recommended nitrogen application rate (1/0)	11.453	27.604	22.229
	(94.367)	(95.955)	(96.713)
Above recommended nitrogen application rate (1/0)	-160.867	-165.339	-172.509
	(120.664)	(119.119)	(120.257)
Applied basal fertilizer on time (1/0)	155.689	157.686	155.558
	(94.644)	(95.923)	(94.724)
Applied organic fertilizer (1/0)	170.894**	172.179**	167.035**
	(66.428)	(66.584)	(67.923)
Seed rate (Kg/ha)	3.613***	3.660***	3.634***
	(1.155)	(1.170)	(1.190)
Used hybrid seed (1/0)	31.536	32.937	35.014
	(52.075)	(51.223)	(51.430)
Pure stand (1/0)	-200.941***	-202.059***	-205.604***
	(60.236)	(60.369)	(59.512)
Plot size (ha)	-2,083.328***	-2,092.950***	-2,094.284***
	(437.279)	(436.727)	(439.132)
Plot size squared	999.366***	1,010.714***	1,005.612***
	(286.754)	(285.072)	(287.256)
Labor (days)	1.105***	1.102***	1.088***
	(0.375)	(0.377)	(0.377)
Soil is of good quality (1/0)	122.552*	119.094*	114.371*
	(63.425)	(64.169)	(64.402)
Soil is of fair quality (1/0)	215.178***	208.327***	205.228***
	(59.752)	(60.294)	(60.421)
Plot is sloppy (1/0)	-46.090	-47.303	-44.864
	(54.328)	(54.401)	(54.665)
Plot is swampy (1/0)	-112.265	-110.937	-116.446
	(84.602)	(83.805)	(83.471)
Soil is sandy clay (1/0)	-29.934	-29.668	-24.925
	(57.893)	(58.064)	(57.873)
Plot show signs of erosion (1/0)	24.750	24.975	25.467
	(83.398)	(82.835)	(81.752)
Female plot manager (1/0)	-153.693	-150.987	-156.415*
	(93.758)	(93.097)	(91.184)
Age of plot manager (years)	1.238	1.173	1.046
	(2.806)	(2.806)	(2.793)

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A3: Cont'd

VARIABLES	Non-poor vs poor	Non-poor vs poor vs ultra-poor	Quintiles of wealth index
Years of education of plot manager	17.695	17.041	15.436
	(15.102)	(14.819)	(14.751)
African Adult Male Equivalent	53.904	55.127	54.521
	(44.296)	(44.483)	(44.183)
Dependency ratio (%)	0.443	0.445	0.437
	(0.399)	(0.396)	(0.397)
Household received extension service for production	-37.639	-41.063	-41.255
	(71.063)	(70.092)	(68.846)
Distance to boma (Km)	-2.392*	-2.267	-2.238
	(1.373)	(1.384)	(1.375)
Tropic-warm/semiarid	10.531	45.961	115.574
	(349.590)	(350.001)	(346.544)
Tropic-warm/subhumid	592.044	632.323	565.182
	(495.457)	(499.451)	(472.718)
Tropic-cool/semiarid	-497.594**	-460.148**	-438.071**
	(210.675)	(211.017)	(208.667)
Avg 12-month total rainfall(mm) for July-June	4.223*	4.163*	4.200*
	(2.173)	(2.166)	(2.161)
Annual Mean Temperature (°C * 10)	-19.563*	-19.418*	-19.726*
	(10.882)	(10.975)	(11.362)
Year (2013)	155.173**	156.160**	153.007**
	(62.982)	(62.649)	(61.904)
Constant	17.695	17.041	15.436
	(15.102)	(14.819)	(14.751)
Observations	2,474	2,474	2,474
Number of groups	1,072	1,072	1,072

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1