# Do Fertilizer Subsidies Boost Staple Crop Production and Reduce Poverty Across the Distribution of Smallholders in Africa? Quantile Regression Results from Malawi.

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**Abstract**

*This study uses three waves of nationally representative household-level panel data from Malawi to estimate how receiving an additional kilogram of subsidize fertilizer affects maize production and the value of total crop output across the distribution of smallholder farm households. We use quantile regression and a correlated random effects estimator to deal with potential endogeneity of subsidized fertilizer. We then estimate the impact of subsidizing fertilizer at the 10%, 25%, 50%, 75%, and 90% of the maize production and value of total crop output distributions. Results from this study indicate that an additional kilogram of subsidized fertilizer contributes 2.61 additional kilograms to household maize production at the 90$^{th}$ percentile, but just 0.75 additional kilograms to maize production at the 10$^{th}$ percentile. Results also indicate that an additional kilogram of subsidized fertilizer has an effect of generating an extra US $0.80 at the 90$^{th}$ percentile of the value of total crop output distribution, but has no statistically significant effect at the 10$^{th}$ percentile of the distribution. These results raise the question of whether or not fertilizer subsidies can substantially boost maize production and reduce poverty at the same time, because the major returns from the subsidy program seem to accrue to households at the top of the maize production and value of total crop output distributions. Many households at the bottom of theses distributions seem unable to generate a substantial response from the subsidized fertilizer that they acquire.*

## Introduction

Subsidy programs that provide inorganic fertilizer to smallholder farmers at below-market rates are currently receiving a great deal of attention as a sustainable strategy to foster an African Green Revolution (Denning et al. 2009). Over the past several years numerous countries including Kenya, Tanzania, Uganda, Zambia, Senegal, Ghana, and Malawi have introduced or revived programs that provide inorganic fertilizer and often hybrid maize seeds to farmers below commercial market prices. Many believe that the gains from large scale subsidy programs are large. Official reports from Malawi indicate that the country increased maize production between 26 and 60 percent during the first four years of its subsidy program, which occurred during years of good rainfall (Dorward, Chirwa and Jayne 2010). Despite the potential benefits the costs of implementing large-scale fertilizer subsidy programs are high, and can increase substantially when fertilizer and fuel prices rise. For example, in 2008 Malawi spent roughly 70% of the Ministry of Agriculture's budget or just over 16% of the government's total budget subsidizing fertilizer and seed (Dorward and Chirwa 2011). In Zambia, 57% of total government spending on agriculture was devoted to fertilizer and maize subsidies in 2010, equivalent to 2% of the nation's gross domestic product (Nkonde et al., 2011; IMF, 2010). The high cost of fertilizer subsidy programs means that thorough evaluation of the benefits is warranted.

The stated goals of fertilizer subsidy programs are often to reduce poverty, and boost production of staple crops such as maize (Kelly, Crawford and Ricker-Gilbert 2011).[1] In practice, achieving both goals may be difficult because evidence from Africa suggests that returns to technologies such as hybrid seed and inorganic fertilizer are heterogeneous across a population of smallholders (Suri 2011; Duflo, Kremer and Robinson 2008). Furthermore, Marenya and Barrett (2009) demonstrate that poorer households generally farm plots with low soil organic matter, and households with low soil organic matter obtain little to no response when they apply inorganic fertilizer to maize on their fields.

This finding calls into question the rationale for providing subsidized fertilizer to households with a limited resource base as they may be unlikely to use fertilizer effectively.

Inefficiencies can also arise when more productive households are targeted to receive subsidized fertilizer. Findings from Malawi and Zambia suggest that better-off households are more likely to purchase fertilizer at commercial prices, and wealthier households displace a greater proportion of their commercial fertilizer purchases when they acquire subsidized fertilizer (Xu et al. 2009; Ricker-Gilbert, Jayne, and Chirwa 2011; Mason 2011). Ricker-Gilbert, Jayne, and Chirwa find that the poorest fifth of households in Malawi displace 18% of their commercial fertilizer purchases when they acquire subsidized fertilizer, while the richest fifth of households displace 30% of their commercial purchases when they acquire subsidized fertilizer. Therefore, the likelihood that impoverished households may not have the resource base to use fertilizer productively, combined with the probability that better-off and more productive households use subsidized fertilizer in place of some of their commercial purchases, raises the issue of how fertilizer subsidy programs can effectively boost production and reduce poverty at the same time.

The present article uses quantile regression with household-level panel data from Malawi to estimate the distributional effects of how receiving an additional kilogram of subsidized fertilizer in a particular year affects households' maize production in that year. Malawi makes for an interesting case study because since 2005/06 the country has implemented an innovative targeted input voucher program where the government distributes vouchers to selected farmers who meet certain criteria. Some of these selection criteria are observable to us as researchers and some are not. Under this program, targeted farmers can then redeem the vouchers in exchange for fertilizer at a reduced price. This study compliments and extends recent work by Ricker-Gilbert and Jayne (2011) that uses past quantities of subsidized fertilizer to measure how receiving subsidized fertilizer over a number of years affects household assets, maize and tobacco production, crop income, off-farm income and total household income in the current year at the conditional mean. The intent of the aforementioned study is to answer the question of whether subsidizing fertilizer over a number of years enabled small farmers to break out of a low input/low output poverty trap. The present study looks beyond the mean effect and estimates how receiving subsidized fertilizer in a given year affects households at the 10%, 25%, 50%, 75%, and 90% of the maize production, and value of total crop output distributions. In doing so, this study provides evidence to answer the question of whether or not fertilizer subsidy programs can effectively boost production and reduce poverty at the same time.

Measuring distributional effects of a program such as a large-scale fertilizer subsidy is important because in a context where household resource endowments vary, it is possible that estimates of a program's conditional mean effect can be misleading and may hide the true effect of a program across a population (Gamper-Rabindran et al. 2009). By comparing returns to subsidizing fertilizer at the mean with those across the maize production and value of total crop output distributions, this study can provide insight into whether a fertilizer subsidy program can both reduce poverty and enhance staple crop production at the same time. For the subsidy program to both reduce poverty and enhance staple crop production, the returns from subsidized fertilizer would need to be higher, or at the very least similar, at the lower end of the maize production and value of total crop output distributions as they are at the upper end of these distributions.

By investigating the distributional effects of the fertilizer subsidy program, this study adds an important dimension to the emerging literature on the impacts of fertilizer subsidy programs in Africa. Holden and Lunduka (2010) use plot-level data from households in central and southern Malawi to look at the impact of fertilizer subsidies on cropping decisions and fertilizer use efficiency. The authors find that maize area has decreased during the years of the subsidy while maize yield has increased over the same period. Chibwana, Fisher and Shively (2010) use plot-level data from two districts in the central region of Malawi. They find that the subsidy program causes the share of recipients' area planted to maize and tobacco (the crops targeted by the program) to rise, while causing the share of area planted to other crops to decline. Another study using experimental evidence from Kenya finds that offering small, time-limited fertilizer subsidies provided at harvest (while farmers have cash) can substantially increase fertilizer use the next season (Duflo, Kremer and Robinson 2009). The authors argue that small, timely discounts increase welfare more than large-scale fertilizer subsidies or *laissez-faire*.

The previous studies mentioned above only estimate conditional mean effects of fertilizer subsidy programs. Our study extends the literature by looking across the distribution of smallholders in order to quantify the extent of the program's heterogeneous benefits. This study also recognizes that fertilizer subsidies are not distributed randomly, so the amount of subsidized fertilizer acquired by households is potentially correlated with factors in the error term of the maize production and crop income models. Therefore dealing with biased estimates caused by subsidized fertilizer's potential endogeneity is an important part of this study's modeling effort. Unfortunately, first differencing or fixed effects estimators cannot be used in quantile estimation because they lead to the incidental parameters problem (Wooldridge 2010). Therefore the econometric estimation used in this article implements a correlated random effects (CRE) framework following Mundlak (1978) and Chamberlain (1984) to deal with potential correlation between covariates and unobserved heterogeneity in the empirical model.

Results from this study indicate that once potential endogeneity is controlled for, the returns to subsidized fertilizer are not symmetric across the maize production and crop income distribution. When estimated via supply response, we find that an additional kilogram of subsidized fertilizer contributes 2.43 additional kilograms to household maize production at the mean, 2.61 additional kilograms to household maize production at the 90$^{th}$ percentile but just 0.75 additional kilograms at the 10$^{th}$ percentile. Results from this study also indicate that an additional kilogram of subsidized fertilizer has no statistically significant mean effect on total value of crop output, an effect of US $0.80 at the 90$^{th}$

percentile of the value of crop output distribution, and no statistically significant effect at the 10th percentile of the distribution. These results raise questions about the possibility that fertilizer subsidies can substantially reduce poverty and boost staple crop production at the same time. The major returns from the subsidy program seem to accrue to households at the top of the maize production distribution, while many households at the bottom of the distribution seem to be unable to generate a substantial response from the subsidized fertilizer that they acquire.

**Fertilizer Distribution and Subsidies in Malawi**

Fertilizer subsidy programs have existed almost every year for decades in Malawi. However, after experiencing a drought-affected poor harvest in 2004/05, the Government of Malawi decided to greatly expand the scale of its targeted fertilizer subsidy program to promote maize and tobacco production. During the 2005/06 season coupons for around 131,000 metric tons of fertilizer (2.63 million 50kg bags) were distributed to farmers. The subsidy program cost US $48 million during the 2005/06 growing season (Dorward and Chirwa 2011).

The rains were good in 2005/06 and yields were high, making the subsidy program very popular. Consequently it was extended and further scaled up for the 2006/07 growing season. During that year the government procured and distributed 175,000 metric tons of fertilizer to farmers for maize and tobacco production. Coupons for subsidized maize seed were available as well. Coupon recipients paid the equivalent of US $6.75 for a 50 kg bag of fertilizer. The same 50 kg bag of fertilizer cost the government US $24.50 delivered at market, amounting to a subsidy rate of about 72% (Dorward and Chirwa 2011). Officially each household was eligible to receive two coupons good for two 50-kilogram bags of fertilizer at a discounted price. In reality, the actual amount of subsidized fertilizer acquired by households varied greatly. The program cost nearly US $85 million (Dorward and Chirwa 2011) with most of the bill being paid by the Malawian government and a minority by the UK's Department for International Development (DFID).

Fertilizer was also available for purchase from private suppliers at commercial prices during both the 2005/06 and 2006/07 growing season. Six private firms won the right to procure and distribute subsidized fertilizer through their retail networks. Farmers who received coupons could redeem them at participating retail stores along with US $6.75 to obtain their fertilizer. Retailers would then submit the coupon and receipt to the government for payment.

The subsidy program was scaled-up even further in 2007/08 when 216,500 metric tons of fertilizer was procured by the Malawian government at an estimated cost of nearly US $117 million. The government made 202,000 metric tons of subsidized fertilizer available in the 2008/09 season and spent an estimated US $265 million on the program. The higher cost was due to an increase in fertilizer prices and an expansion of the subsidy to smallholder tea and coffee crops (Dorward and Chirwa 2011). The private sector was excluded from distributing subsidized fertilizer in 2008/09, however a seed subsidy in that year did involve private retailers. The proportion of the fertilizer cost that was paid by the government increased to greater than 90% in 2008/09. Farmers were officially required to pay the equivalent of US $5.33 for a 50 kg bag of fertilizer that cost between US $40 to $70 at commercial prices.

Throughout the years of the subsidy's implementation, the process of determining who received coupons for fertilizer subsidies was subject to a great deal of local idiosyncrasies. At the regional level, coupons were supposed to have been allocated based on the number of hectares under cultivation. At the village level, subsidy program committees and the village heads were supposed to determine who was eligible for the program. In more recent years open community forums were held in some villages where community members could decide for themselves who should receive the subsidy. The general program eligibility criteria was that beneficiaries should be "full time smallholder farmers who cannot afford to purchase one or two bags of fertilizer at prevailing commercial prices as determined by local leaders in their areas" (Dorward et al. 2008). However, numerous unofficial criteria may have been used in voucher allocation, such as households' relationship to village leaders, length of residence, and social and/or financial standing of the household in the village. It is also possible that factors which are unobservable to us as researchers, such as soil quality or farm management ability may affect how much subsidized fertilizer a household receives. Therefore, we need to consider the fact that subsidized fertilizer is most likely endogenous in our models of maize production and value of total crop output.

## Empirical Model

Consider the following empirical supply response equation of factors affecting maize production and value of total crop output for household *i* in district *j* at time *t*:

1) $\mathrm{Y}_{ijt} = \alpha + \beta \mathrm{S}_{\mathrm{ijt}} + \sigma \mathbf{P}_{\mathbf{ijt}} + \delta \boldsymbol{\omega}_{\mathbf{ijt}} + \boldsymbol{\varsigma} \mathbf{X}_{\mathbf{ijt}} + \psi T_t + c_i + \mu_{ijt}$

where Y represents kilograms of maize produced by the household or total value of crop output. The quantity of subsidized fertilizer that a household receives in time t is represented by S. Subsidized fertilizer is regarded as quasi-fixed in this model because households are constrained as to how much fertilizer they can acquire at a reduced price. Therefore subsidized fertilizer enters into equation 1) as quantity acquired by household i in district j at time t. Output price for maize is represented by **P.** Input prices for commercial fertilizer and agricultural labor wage rates are represented by $\boldsymbol{\omega}$. The price of commercial fertilizer that the household faces is considered a variable input. Therefore it enters into the model in price form, as in a standard supply response equation. Including commercial fertilizer price controls for the impact that non-subsidized fertilizer has on maize production in year t. Other factors that affect maize production, such as use of hybrid maize seed, household demographics, assets, landholding, and rainfall are denoted by the vector **X**. Shocks that are observable to us as researchers such as death of household head or spouse, and rainfall are also included in **X**. Fixed production costs, such as availability of farm credit in the village, distance from the village to the nearest paved road, and distance from the village to the district market are also included in X. School attendance of the household head is also included in **X**, in order to partially proxy for management ability. Soil quality is also partially controlled in **X** by including dummy variables for whether or not the household had a plot with sandy, clay or mixed soil, and dummy variables for whether or not the household had plots that were flat or sloped during the first survey wave.[2] Year dummies are denoted by $T_t$ and $D_j$ denotes district-level dummies.

The error term in equation 1) has two components. First, $c_i$ represents the time constant unobserved factors that affect maize production and total value of crop output. Any factors affecting management ability not captured by the school attendance variable and any soil quality factors not captured in the soil composition and plot slope dummies end up in $c_i$. Second, $\mu_{ijt}$ represents the household-level time-varying shocks that affect maize production and total value of crop output. Subsequent sections will address how correlation between the covariates and $c_i$ are dealt with in this study.

**Estimation Framework**

The present study estimates equation 1) for maize production total value of crop output as linear models via quantile regression and compares those results with conditional mean estimates from OLS and first differencing (FD). The theory behind quantile regression was first developed by Koenker and Bassett (1978), and has since been used in various applications. Examples of quantile regression applications include wage distribution in the United States (Chamberlain 1994; Buchinsky 1994; Chay 1995), maternity factors affecting birth weight (Royer 2004; Abrevaya and Dahl 2008), and how clean water affects infant mortality rate (Gamper-Rabindran et al. 2009).

Quantile regression uses a least absolute deviation (LAD) estimator that minimizes the sum of absolute residuals rather than the sum of squared residuals as in OLS regression. As such quantile regression is less susceptible to extreme values in the sample than is OLS (Wooldridge 2010). Quantile regression allows us to see how subsidized fertilizer affects maize production and total value of crop output across the distribution of smallholder households. This enables us to address the question of whether or not fertilizer subsidy programs can significantly boost maize production for those at the bottom of the maize production distribution.

Quantile regression comes with an extra layer of complication over OLS because the LAD estimator is not a linear operator. Therefore dealing with inconsistent parameter estimates caused by correlation between covariates and the error term and the covariates is a bit more difficult than in estimation via OLS. The following section explains how we deal with potential endogeneity, so that we can identify a causal impact of subsidized fertilizer on the outcomes of interest in this study.

*Controlling for correlation between subsidized fertilizer ($S_{ijt}$) and unobserved heterogeneity ($c_i$)*

A challenge to obtaining consistent parameter estimates in this study is that the observed covariates such as $S_{ijt}$ may be correlated with the unobserved heterogeneity $c_i$ in the maize production and value of total crop output models. As mentioned previously, subsidized fertilizer is not distributed randomly. For example, it is possible that village leaders target the subsidy towards people who are better managers, or worse managers. In addition perhaps households with better soil quality, or worse soil quality were targeted to receive the subsidy. If management ability and/or soil quality affect maize production and value of total crop output e, and at the same time these factors are correlated with receiving subsidized fertilizer, then the coefficient estimate on β in equation 1) will be biased.

First difference and fixed effects regression techniques control for correlation between covariates and unobserved heterogeneity in OLS estimation. Unfortunately these estimation techniques are not available in this application. When there are many cross-sectional observations and few time periods parameter estimates suffer from the incidental parameters problem when using quantile regression, so they cannot be used in this application (Wooldridge 2010). Fortunately correlated random effects (CRE) estimators are available to deal with $c_i$ in the context of non-linear estimators (Mundlak 1978; Chamberlain 1984). Recently several studies have used a CRE related framework to control for unobserved heterogeneity using Quantile regression in a panel context. Abrevaya and Dahl (2008) use a framework related to CRE to estimate the effects of smoking and prenatal care on birth weights in the United States. Gamper-Rabindran et al. (2009) use a similar framework to estimate the effects of piped water on infant mortality in Brazil.

In this study we implement the CRE framework to control for $c_i$ in by including a vector of variables containing the means for household *i* of all time-varying covariates in equation 1). These variables, denoted as $\overline{\boldsymbol{X_i}}$ have the same value for each household in every year but vary across households (for more on the CRE framework in the context of Quantile regression, see Wooldridge 2010). We estimate equation 1) with $\overline{\boldsymbol{X_i}}$ included via Quantile regression in STATA. For the purpose of this study the unobservable time-varying shocks, $\mu_{ijt}$ in equation 1) is assumed to be i.i.d. normal (0, $\sigma^2$). Maintaining this assumption means that unobservable time-varying shocks that affect maize production and value of total crop output are uncorrelated with subsidized fertilizer. This assumption is maintained after conditioning on covariates such as assets, landholding, household demographics, and controlling for unobserved time-constant heterogeneity using the CRE procedure.

## Data

Data used in this study come from three surveys of rural farm households in Malawi. The first wave of data comes from the Second Integrated Household Survey (IHHS2), a nationally representative survey conducted during the 2002/03 and 2003/04 growing seasons that covers 26 districts in Malawi. The second wave of data comes from the 2007 Agricultural Inputs Support Survey (AISS1) conducted after the 2006/07 growing season. The budget for AISS1 was much smaller than the budget for IHHS2 and of the 11,280 households interviewed in IHHS2, only 3,485 of them lived in enumeration areas that were re-sampled in 2007. Of these 3,485 households, 2,968 were re-interviewed in 2007, which gives us an attrition rate of 14.8%.

The third wave of data comes from the 2009 Agricultural Inputs Support Survey II (AISS2) conducted after the 2008/09 growing season. The AISS2 survey had a subsequently smaller budget than the AISS1 survey in 2007, so of the 2,968 households first sampled in 2003 and again in 2007, 1,642 of them lived in enumeration areas that were revisited in 2009. Of the 1,642 households in revisited areas, 1,375 were found for re-interview in 2009, which gives us an attrition rate of 16.3% between 2007 and 2009.

We focus our analysis on the 1,375 households who were interviewed in all three surveys and the 1,593 households who were interviewed in just the first and second surveys. Since the CRE procedure is use, households who were only interviewed in wave 1 are not included in this analysis because those households have values for the household time averages, $\overline{\boldsymbol{X}_{\iota}}$, that are equivalent to their year t values, $X_{it}$. Ultimately after excluding households who did not plant in a particular season and those for whom no soil quality information is available, we end up with 6,817 observations in this unbalanced panel.

*Value of total crop output*

Value of total crop output is calculated in this study by taking the total value of all crops produced and subtracting from it the cost of renting land, purchasing seed, purchasing fertilizer, and hiring labor. Family labor input is not measured in the surveys so its cost (or opportunity cost) is not considered in this calculation. We also do not have data on payment for land that has been purchased by households.

*Fertilizer Prices*

Fertilizer prices used in the study are calculated as Malawian Kwacha per kilogram of commercial fertilizer. The price is an aggregation of Urea and Nitrogen/Phosphorus/Potassium (NPK) prices. These prices are based on what respondents in the survey say they paid for commercial fertilizer during the planting season from October to December. For those buying commercially we use the observed price that they paid, while for those who did not buy commercially we use the district median price to proxy for the price that the farmer faces for the input. Fertilizer prices are in real 2009 terms, which is calculated by dividing the nominal price by the CPI in Malawi.

*Labor Wage Rates*

Wage rates for labor hired by households on their plot are calculated as Malawian Kwacha per day of labor. In the survey we only have wage rates for hired in labor and have no way to value family labor other than to include a variable for adult equivalence as a proxy in our model. For those who hire in labor, we use the price that they pay, while for those who do not hire in labor, we use the district median price to proxy for the price that the farmer faces for the input. Labor wage rates are in real 2009 terms.

*Maize and Tobacco Prices*

Maize prices used in this study are calculated as the median district price received per kilogram by households in the survey. Tobacco prices are calculated as the median regional price received by households in the survey because there are fewer households who sell tobacco. These are observed prices received by households that directly affect maize production and crop income but may not be known to farmers at the time of planting. We make the assumption that farmers at planting time know the price they are going to receive at harvest time in order to use these prices in our maize production, and crop income models. Prices for maize and tobacco are in Malawian Kwacha per kilogram and are in real 2009 terms.

*Rainfall*

The rainfall variables come from district-level experiment station records. We include cumulative rainfall over the growing season to account for rainfall’s impact on production.

All other explanatory variables are constructed from the household surveys.

**Results**

Table 1 displays the results for factors affecting household-level maize production, estimated by supply response. The first column of table 1 presents the conditional mean estimates using Pooled OLS (POLS), and the columns to the right display the coefficient estimates at different points in the maize production distribution using Pooled Quantile Regression. Keep in mind that the Pooled OLS and Pooled Quantile estimates assume that all covariates are uncorrelated with unobserved heterogeneity, $c_i$ in equation 1). The conditional mean estimate of subsidized fertilizer is statistically significant at the 1% level in table 1 and indicates that an additional kilogram of subsidized fertilizer increases maize production by 3.96 kilograms on average. The mean effect of subsidized fertilizer is much higher than the median effect of 2.97, and is close to the marginal product estimate of 4.06 at the 75$^{th}$ percentile of the distribution. This results along with the rest of the results from the quantile estimation indicate that there is wide variation in the response to subsidized fertilizer across the maize production distribution. Households at the 10$^{th}$ percentile of the distribution only gain a 0.96 kg marginal increase in maize per unit of fertilizer, while households at the 90$^{th}$ percentile gain a marginal product of 4.48 kg per unit of fertilizer acquired.

The further households live from the main district market the lower their level of maize production. On average an additional kilometer from the district market reduces maize production by 1.37 kilograms on average and by 0.52 kilograms at the median. Households with higher assets also produce significantly more maize than do poorer households. The coefficient estimates on asset value indicate that a one percent increase in value of assets boosts maize production by 1.45 kilograms on average and by 0.68 kilograms at the median. Households with more land also produce more maize, as an additional hectare of land boosts maize production by 269 kilograms on average and by 110 kilograms at the median, *ceteris paribus*.

Table 2 also displays the results for factors affecting household-level maize production, but controls for correlation between covariates and unobserved heterogeneity using First Difference (FD) in conditional mean estimation, and Correlated Random Effects (CRE) in Quantile estimation. Two interesting findings emerge when comparing results for the marginal product of subsidized fertilizer in table 2 where unobserved heterogeneity is controlled and table 1 where it is not. First, once unobserved heterogeneity is controlled, the impact of subsidized fertilizer on maize production is much lower. Conditional mean estimates using FD demonstrate that on average each additional kilogram of subsidized fertilizer boosts maize production by 2.43 kilograms. This is significantly lower than the 3.96 kilogram average in table 1. The quantile regression results in table 2 are also significantly lower across the maize production distribution than they are for the pooled quantile regression results in table 1. The other important finding from table 2 is that households at the lower end of the maize production distribution obtain a significantly lower response to subsidized fertilizer than do households at the top end of the distribution. The mean response of 2.43 kg of maize per kg of fertilizer is higher than the median response of 2.04. Households at the 10$^{th}$ percentile of the maize production distribution obtain a marginal product of just 0.75 kg of maize per kg of fertilizer, compared to a response of 2.76 for households at the 75$^{th}$ percentile. It is also interesting to note that households at the 75$^{th}$ percentile of the maize production distribution obtain a higher response than households at the 90$^{th}$ percentile (2.61). The fact that households at the 90th percentile obtain a lower response than people at the 75th percentile could be attributed to the fact that households at the top of the maize production distribution likely hire in more labor and are engaged in production of other crops such as tobacco. Therefore these households may not be interested in the management effort required to obtain the high marginal return to fertilizer. Households further from the district market produce significantly less maize, while households with more assets and land produce significantly more maize.

Table 3 presents the pooled results for factors affecting household-level value of total crop output, where the covariates are considered to be uncorrelated with the unobserved heterogeneity. The first column indicates that the conditional mean impact of subsidized fertilizer on value of total crop output is 104 kwacha (US $0.69) per household on average. The mean return is also higher than the median return, as an additional kilogram of subsidized fertilizer boosts value of total crop output by 51 Kwacha (US $0.34) at the median. The quantile regression estimates for the effect of subsidized fertilizer on value of total crop output follow a similar pattern to those for maize production. Households at the bottom of the value of total crop output distribution get little to no return from subsidized fertilizer, but the return increases substantially as one moves up the distribution. Households at the 10$^{th}$ percentile of the value of total crop output distribution obtain an insignificant return from the subsidy, while households at the 90$^{th}$ percentile obtain a return of 185 Kwacha (US $1.23) per kilogram of subsidized fertilizer acquired. Households with higher assets and landholdings also generate higher value of total crop output, which is not surprising.

Table 4 also displays the results for factors affecting household-level value of total crop output, but controls for correlation between covariates and unobserved heterogeneity. First, the impact of subsidized fertilizer on value of total crop output is lower in table 4 compared to table 3, where unobserved heterogeneity is not controlled. The FD estimate in the first column indicates that once unobserved heterogeneity is controlled an additional kilogram of subsidized fertilizer does not produce a statistically significant mean impact on value of total crop output. The CRE Quantile regression estimates indicate that households at the 10$^{th}$ percentile do not obtain a statistically significant return from subsidized fertilizer. The return increases and becomes statistically significant however as we move up the value of total crop output distribution. The median return to a kilogram of fertilizer is 42 kwacha (US $0.28), while at the 90$^{th}$ percentile the return to a kilogram of subsidized fertilizer is 121 Kwacha (US $0.81). Assets and landholding also again have a positive and significant impact on value of total crop output across the distribution. There is also some evidence that higher maize and tobacco prices lead to higher value of total crop output, which is what one would expect *ex ante*.

**Conclusions**

Fertilizer subsidies are gaining support as a policy tool to foster a Green Revolution in Africa. The reported goals of fertilizer subsidy programs are often to reduce poverty and boost staple crop production among smallholder farmers (Kelly, Crawford and Ricker-Gilbert 2011). The present article uses three waves of nationally representative household-level panel data from Malawi to estimate how an additional kilogram of subsidized fertilizer affects maize production and value of total crop output across the distribution of smallholder farm households.

Results from this study demonstrate that it may in fact be difficult for subsidy programs to achieve the joint goal of reducing poverty and boosting staple crop production. Using quantile regression with a correlated random effects estimator to deal with endogeneity, we find that households at the 10$^{th}$ percentile of the maize production distribution obtain a response of just 0.75 kilograms of maize per kilogram of subsidized fertilizer acquired. Furthermore, a kilogram of subsidized fertilizer is found to produce no significant return to the value of total crop output at the 10$^{th}$ percentile of the distribution. Since the median commercial price of fertilizer was 133 Kwacha (US $0.88) in 2008/09, it is unlikely that using public funds to subsidize roughly 90% of the fertilizer cost for farmers is an effective strategy to reduce poverty, because households at the low end of the distributions obtain such small returns to subsidized fertilizer.

If the goal of the subsidy program is to boost staple crop production, then it may make sense to target people at the higher end of the maize production and value of total crop output distributions. Results from this study indicate that an additional kilogram of subsidized fertilizer boosts maize production by 2.76 kilograms at the 75$^{th}$ percentile of the maize production distribution, and by 2.61

kilograms at the 90th percentile of the distribution.  An additional kilogram of subsidized fertilizer boosts value of total crop output by just 44 kwacha (US $0.29) at the 75th percentile of the distribution, and by 121 kwacha (US $0.81) at the 90th percentile of that distribution.  Therefore, targeting more productive farmers in order to boost maize production seems like a logical strategy.   Evidence from this study suggests however, that farmers at the 90th percentile who produce the most maize do not get as high a marginal response to fertilizer as do households around the 75th percentile.  This could be because households at the 90th percentile hire in labor and grow other crops in addition to maize.  These households may use subsidized fertilizer on other crops such as tobacco, hence the lower marginal product of fertilizer on maize, but the higher return to value of crop output for people at the 90th percentile, compared with people at the 75% percentile.

If more productive households are targeted to receive the subsidy, governments should be aware that when wealthy, more productive households receive subsidized fertilizer they are likely to use it in place of some of their commercial fertilizer purchases (Xu et al. 2009; Ricker-Gilbert, Jayne, and Chirwa 2011; Mason 2011).  Crowding out reduces the amount of new fertilizer that enters the system and thus the ability of subsidy programs to boost staple crop production.

Ultimately if governments what to reduce poverty, targeting fertilizer subsidies to limited resource farmers who produce small quantities of maize is likely less effective than a cash transfer to these households.  This is because returns that limited resource households obtain from fertilizer are small, likely due to factors such as poor soil quality, and low management ability.   If governments want to use fertilizer subsidies to boost staple crop production then it makes sense to carefully target households who can obtain a positive return to inorganic fertilizer, but will be less likely to use the subsidized fertilizer in place of their commercial purchases.  Such households may be those smallholders who have between 1 to 2 hectares, have enough family labor to use the fertilizer and are located far from private input suppliers and thus have trouble accessing fertilizer on the commercial market.

**Endnotes**

[1] There may be other implicit goals associated with fertilizer subsidies, as governments distribute the fertilizer to gain political support among the rural population.   See Banful (2011), Holden and Lunduka (2010) for more discussion.

[2] Some households in the sample have more than one plot and for example one plot may be clay and one plot may be sandy soil.  Therefore we include dummy variables for each soil composition and slope category.  This soil quality information was only available in the first survey so households were assumed to have the same soil quality in all three waves of the survey.

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## Table 1: Pooled Quantile Regression Results for Maize Production Supply Response (in Kilograms)

| COVARIATES | POOLED OLS, CONDIDTIONAL MEAN ESTIMATION | | POOLED QUANTILE REGRESSION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10% | | 25% | | 50% | | 75% | | 90% | |
| | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value |
| Kg subsidized fertilizer acquired | 3.96*** | (0.00) | 0.96*** | (0.00) | 1.65*** | (0.00) | 2.97*** | (0.00) | 4.06*** | (0.00) | 4.48*** | (0.00) |
| =1 if farm credit organization in village | 21.70 | (0.50) | -2.63 | (0.75) | 9.96 | (0.40) | 9.41 | (0.43) | 23.28 | (0.22) | 55.92** | (0.02) |
| Distance to paved road, in km | -0.66 | (0.31) | -0.07 | (0.63) | 0.08 | (0.70) | 0.22 | (0.43) | 0.10 | (0.85) | 0.02 | (0.98) |
| Distance to main district market, in km | -1.37*** | (0.00) | -0.43*** | (0.00) | -0.59*** | (0.00) | -0.52*** | (0.00) | -0.73*** | (0.00) | -0.88 | (0.25) |
| log of real hh assets in 2009 kwacha | 145*** | (0.00) | 19*** | (0.00) | 40*** | (0.00) | 68*** | (0.00) | 108*** | (0.00) | 146*** | (0.00) |
| total landholding in hectares | 269*** | (0.00) | 32*** | (0.00) | 56*** | (0.00) | 110*** | (0.00) | 203*** | (0.00) | 446*** | (0.00) |
| log age of hh head | -5.84 | (0.85) | 0.67 | (0.90) | 2.87 | (0.71) | 0.96 | (0.92) | -7.11 | (0.70) | 0.62 | (0.99) |
| =1 if household head attended school | 90*** | (0.00) | 9.59 | (0.17) | 23.28*** | (0.00) | 29.07*** | (0.00) | 33.17** | (0.03) | 71.55*** | (0.01) |
| =1 if household headed by female | 89*** | (0.00) | 6.23 | (0.34) | 3.46 | (0.64) | 6.71 | (0.48) | 0.61 | (0.96) | 38.28*** | (0.01) |
| Log of adult equivalence in hh | 40 | (0.13) | 16.66*** | (0.00) | 16.28*** | (0.00) | 20.30*** | (0.00) | 22.68 | (0.13) | 37.90* | (0.07) |
| =1 if death in hh over past 2 years | -28 | (0.51) | -11.60 | (0.16) | -8.55 | (0.42) | 0.87 | (0.96) | 10.98 | (0.64) | -35.64 | (0.17) |
| Observed harvested hybrid mz price, dist level, real 2009 kwacha | 7.47 | (0.29) | -0.26 | (0.86) | -0.87 | (0.60) | -1.28 | (0.68) | -5.13 | (0.36) | -2.05 | (0.80) |
| Observed harvested tobacco pr., region level, real 2009 kwacha | 0.87 | (0.38) | 0.72*** | (0.01) | 1.59*** | (0.00) | 1.81*** | (0.00) | 2.59*** | (0.00) | 1.77 | (0.23) |
| Commercial fertilizer price kwacha/kg, real 2009 kwacha | 1.24* | (0.05) | 0.17 | (0.20) | 0.47 | (0.02) | 0.58*** | (0.00) | 0.48 | (0.25) | 1.55** | (0.04) |
| Ag. Labor wage rate Kwacha/day on hh plot, real 2009 kwacha | 0.10 | (0.17) | 0.01 | (0.64) | 0.00 | (0.93) | 0.05 | (0.09) | 0.15 | (0.13) | 0.29*** | (0.01) |
| cumulative rainfall over current growing season in cm | 0.02 | (0.75) | 0.02 | (0.39) | 0.00 | (0.85) | 0.00 | (0.90) | -0.03 | (0.45) | 0.08 | (0.34) |
| Average annual rainfall over previous 5 growing seasons, in cm | -0.55*** | (0.00) | -0.15*** | (0.01) | -0.25*** | (0.00) | -0.19*** | (0.01) | -0.29** | (0.02) | -0.34 | (0.16) |
| Std deviation of average long run rainfall | 0.05 | (0.83) | 0.04 | (0.51) | 0.10 | (0.14) | 0.13 | (0.16) | -0.13 | (0.49) | -0.18 | (0.51) |
| Intercept | -1,833*** | (0.00) | -228*** | (0.00) | -473*** | (0.00) | -746*** | (0.00) | -825*** | (0.00) | -1517*** | (0.00) |
| Soil quality dummy variables Included | Yes | | Yes | | Yes | | Yes | | Yes | | Yes | |
| Num. of Obs. | 6,817 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | |
| $R^2$ | 0.43 | | 0.09 | | 0.14 | | 0.21 | | 0.29 | | 0.35 | |

Note: *, **, *** indicates that corresponding coefficients are significant at the 10%, 5%, and 1% level respectively; models include district dummies district dummies and year dummies.

## Table 2: CRE Quantile Regression Results for Maize Production Supply Response (in Kilograms)

| | FIRST DIFFERENCE, CONDITIONAL MEAN ESTIMATION | | CORRELATED RANDOM EFFECTS QUANITLE REGRESSION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10% | | 25% | | 50% | | 75% | | 90% | |
| **COVARIATES** | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value |
| Kg subsidized fertilizer acquired | 2.43*** | (0.00) | 0.75*** | (0.00) | 1.11*** | (0.00) | 2.04*** | (0.00) | 2.76*** | (0.00) | 2.61** | (0.00) |
| =1 if farm credit organization in village | NA | NA | -5.64 | (0.51) | 12.15 | (0.23) | 5.29 | (0.64) | 17.19 | (0.32) | 44.63 | (0.19) |
| Distance to paved road, in km | NA | NA | -0.02 | (0.92) | 0.23 | (0.20) | 0.33 | (0.13) | -0.37 | (0.36) | -0.55 | (0.24) |
| Distance to main district market, in km | NA | NA | -0.32** | (0.02) | -0.63*** | (0.00) | -0.52** | (0.02) | -0.95*** | (0.01) | -1.18* | (0.07) |
| log of real hh assets in 2009 kwacha | 77*** | (0.00) | 11*** | (0.01) | 29*** | (0.00) | 52*** | (0.00) | 77*** | (0.00) | 94*** | (0.00) |
| total landholding in hectares | 240*** | (0.00) | 34*** | (0.00) | 50*** | (0.00) | 94*** | (0.00) | 179*** | (0.00) | 347*** | (0.00) |
| log age of hh head | NA | NA | -1.42 | (0.87) | 1.68 | (0.85) | 4.74 | (0.64) | -19.85* | (0.07) | -2.65 | (0.93) |
| =1 if household head attended school | NA | NA | 9.99 | (0.22) | 26*** | (0.00) | 29.40*** | (0.01) | 12.76 | (0.39) | 48.37* | (0.07) |
| =1 if household headed by female | 48 | (0.44) | 15 | (0.47) | -14 | (0.49) | -17 | (0.52) | -30 | (0.52) | -51 | (0.50) |
| Log of adult equivalence in hh | 53 | (0.11) | 18 | (0.12) | 18 | (0.14) | 27 | (0.14) | 32 | (0.21) | 59 | (0.13) |
| =1 if death in hh over past 2 years | 29 | (0.57) | -14 | (0.15) | -13 | (0.37) | 25* | (0.06) | 36 | (0.13) | 12 | (0.82) |
| Observed harvested hybrid mz price, dist level, real 2009 kwacha | 1.17 | (1.00) | -0.14 | (0.95) | -0.38 | (0.85) | -5.32** | (0.03) | -8.07* | (0.07) | -5.94 | (0.47) |
| Observed harvested tobacco pr., region level, real 2009 kwacha | 1.67** | (0.05) | 0.70*** | (0.01) | 1.47*** | (0.00) | 2.36*** | (0.00) | 3.02*** | (0.00) | 3.10*** | (0.01) |
| Commercial fertilizer price kwacha/kg, real 2009 kwacha | 1.46*** | (0.01) | 0.00 | (0.99) | 0.39* | (0.07) | 0.47 | (0.17) | 0.49 | (0.32) | 0.75 | (0.29) |
| Ag. Labor wage rate Kwacha/day on hh plot, real 2009 kwacha | 0.02 | (0.84) | 0.00 | (0.85) | -0.05 | (0.03) | -0.03 | (0.62) | -0.09 | (0.36) | -0.05 | (0.71) |
| cumulative rainfall over current growing season in cm | -0.03 | (0.62) | 0.04** | (0.03) | 0.02 | (0.29) | 0.03 | (0.24) | -0.02 | (0.71) | 0.11 | (0.30) |
| Average annual rainfall over previous 5 growing seasons, in cm | -0.56*** | (0.00) | -0.13** | (0.05) | -0.21*** | (0.00) | -0.18*** | (0.01) | -0.27** | (0.05) | -0.32 | (0.12) |
| Std deviation of average long run rainfall | -0.21 | (0.33) | 0.04 | (0.46) | 0.08 | (0.24) | 0.06 | (0.57) | -0.09 | (0.57) | -0.17 | (0.55) |
| Intercept | -7.87 | (0.95) | -42 | (0.86) | 122 | (0.74) | 383 | (0.30) | 566 | (0.37) | -1,010 | (0.41) |
| Soil quality dummy variables included | Yes | | Yes | | Yes | | Yes | | Yes | | Yes | |
| Number of Obs. | 4,045 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | |
| $R^2$ | 0.20 | | 0.10 | | 0.14 | | 0.22 | | 0.30 | | 0.38 | |

Note: *, **, *** indicates that corresponding coefficients are significant at the 10%, 5%, and 1% level respectively; models include district dummies, year dummies, and household time averages of all time-varying explanatory variables.

## Table 3: Pooled Quantile Regression Results for Value of Total Crop Output (in Real 2009 Kwacha)

| | POOLED OLS, CONDIDTIONAL MEAN ESTIMATION | | POOLED QUANITLE REGRESSION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10% | | 25% | | 50% | | 75% | | 90% | |
| COVARIATES | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value |
| Kg subsidized fertilizer acquired | 104*** | (0.00) | -4 | (0.43) | 21*** | (0.00) | 51*** | (0.00) | 83*** | (0.00) | 184*** | (0.00) |
| =1 if farm credit organization in village | -4,612*** | (0.00) | -1,115*** | (0.00) | -976*** | (0.00) | -1,303*** | (0.00) | -2,438*** | (0.00) | -2,070** | (0.03) |
| Distance to paved road, in km | -13 | (0.64) | 15* | (0.09) | 4 | (0.55) | 11 | (0.18) | 5 | (0.68) | 16 | (0.33) |
| Distance to main district market, in km | 20 | (0.28) | -10* | (0.09) | -5 | (0.14) | -5 | (0.37) | 0 | (0.99) | 4 | (0.77) |
| log of real hh assets in 2009 kwacha | 3,537*** | (0.00) | 72 | (0.35) | 697*** | (0.00) | 1,480*** | (0.00) | 2,368*** | (0.00) | 3,295*** | (0.00) |
| total landholding in hectares | 11,160*** | (0.00) | 801*** | (0.00) | 1,919*** | (0.00) | 3,969*** | (0.00) | 8,015*** | (0.00) | 15,095*** | (0.00) |
| log age of hh head | -2,707* | (0.06) | 504 | (0.10) | 85 | (0.76) | -69 | (0.84) | -791* | (0.08) | -1,589* | (0.10) |
| =1 if household head attended school | -830 | (0.55) | -119 | (0.59) | -95 | (0.66) | 223 | (0.46) | -149 | (0.81) | 731 | (0.46) |
| =1 if household headed by female | 468 | (0.62) | -281 | (0.39) | -123 | (0.64) | -428 | (0.15) | -699 | (0.17) | 198 | (0.74) |
| Log of adult equivalence in hh | 278 | (0.79) | 111 | (0.59) | 237 | (0.22) | 381 | (0.12) | 421 | (0.17) | -86 | (0.89) |
| =1 if death in hh over past 2 years | -838 | (0.59) | -572* | (0.06) | -295 | (0.34) | -241 | (0.50) | -90 | (0.88) | -895 | (0.31) |
| Observed harvested hybrid mz price, dist level, real 2009 kwacha | 890*** | (0.00) | 101 | (0.31) | 62 | (0.38) | 25 | (0.80) | -34 | (0.84) | 276 | (0.35) |
| Observed harvested tobacco pr., region level, real 2009 kwacha | 94** | (0.02) | 0 | (0.97) | 27*** | (0.01) | 30** | (0.03) | 30 | (0.16) | 76 | (0.15) |
| Commercial fertilizer price kwacha/kg, real 2009 kwacha | -30 | (0.24) | -39*** | (0.00) | -18** | (0.02) | 4 | (0.69) | 23 | (0.10) | 75* | (0.08) |
| Ag. Labor wage rate Kwacha/day on hh plot, real 2009 kwacha | -1 | (0.82) | -4*** | (0.01) | -3*** | (0.01) | -2 | (0.13) | -2 | (0.21) | 4 | (0.52) |
| cumulative rainfall over current growing season in cm | 7* | (0.07) | 1 | (0.17) | 1 | (0.39) | 1 | (0.47) | 2 | (0.25) | 4 | (0.17) |
| Average annual rainfall over previous 5 growing seasons, in cm | -6 | (0.53) | -1 | (0.62) | -6*** | (0.00) | -8*** | (0.00) | -7 | (0.11) | 1 | (0.92) |
| Std deviation of average long run rainfall | -7 | (0.40) | -2 | (0.40) | 0 | (0.95) | -1 | (0.80) | -8 | (0.14) | -12 | (0.18) |
| Intercept | -60,687*** | (0.00) | -723 | (0.86) | -4,059 | (0.18) | -7,728 | (0.14) | -8,792 | (0.26) | -43,138*** | (0.00) |
| Soil quality dummy variables included | Yes | | Yes | | Yes | | Yes | | Yes | | Yes | |
| Number of Obs. | 6,817 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | |
| $R^2$ | 0.28 | | 0.03 | | 0.06 | | 0.13 | | 0.22 | | 0.30 | |

Note: *, **, *** indicates that corresponding coefficients are significant at the 10%, 5%, and 1% level respectively; models include district dummies, and year dummies.

## Table 4: CRE Quantile Regression Results for Value of Total Crop Output (in Real 2009 Kwacha)

| | FIRST DIFFERENCE, CONDITIONAL MEAN ESTIMATION | | CORRELATED RANDOM EFFECTS QUANITLE REGRESSION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10% | | 25% | | 50% | | 75% | | 90% | |
| **COVARIATES** | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value | Coeff. | P-value |
| Kg subsidized fertilizer acquired | 49 | (0.34) | 3 | (0.54) | 17*** | (0.00) | 42*** | (0.00) | 44** | (0.05) | 121** | (0.02) |
| =1 if farm credit organization in village | NA | NA | -893*** | (0.01) | -1,086*** | (0.00) | -1,093*** | (0.00) | -2,278** | (0.00) | -2,623*** | (0.00) |
| Distance to paved road, in km | NA | NA | 11 | (0.34) | 7 | (0.41) | 14* | (0.05) | 3 | (0.80) | -5 | (0.85) |
| Distance to main district market, in km | NA | NA | -13** | (0.03) | -6 | (0.21) | -6 | (0.28) | -2 | (0.81) | 23 | (0.22) |
| log of real hh assets in 2009 kwacha | 3,056*** | (0.00) | 211* | (0.05) | 741*** | (0.00) | 1,436*** | (0.00) | 1,892*** | (0.00) | 2,675*** | (0.00) |
| total landholding in hectares | 10,889*** | (0.00) | 699** | (0.02) | 1,767*** | (0.00) | 3,434*** | (0.00) | 6,299*** | (0.00) | 13,365*** | (0.00) |
| log age of hh head | NA | NA | 394 | (0.10) | 115 | (0.64) | -378 | (0.12) | -984** | (0.02) | -1,251* | (0.08) |
| =1 if household head attended school | NA | NA | -131 | (0.62) | -39 | (0.87) | 319 | (0.14) | -264 | (0.55) | 797 | (0.15) |
| =1 if household headed by female | -3,107 | (0.27) | -442 | (0.58) | -390 | (0.49) | 223 | (0.63) | -770 | (0.45) | 89 | (0.95) |
| Log of adult equivalence in hh | 3,751* | (0.09) | 747* | (0.06) | 792** | (0.03) | 1,436*** | (0.00) | 2,906*** | (0.00) | 4,756*** | (0.00) |
| =1 if death in hh over past 2 years | 1,023 | (0.64) | -461 | (0.29) | -45 | (0.92) | 101 | (0.88) | 712 | (0.49) | -1,305 | (0.33) |
| Observed harvested hybrid mz price, dist level, real 2009 kwacha | 678* | (0.07) | 124 | (0.12) | 57 | (0.56) | -14 | (0.88) | -80 | (0.64) | 331 | (0.30) |
| Observed harvested tobacco pr., region level, real 2009 kwacha | 167*** | (0.00) | 2 | (0.87) | 31*** | (0.00) | 40*** | (0.00) | 69*** | (0.01) | 82 | (0.22) |
| Commercial fertilizer price kwacha/kg, real 2009 kwacha | -48 | (0.19) | -27*** | (0.01) | -13 | (0.24) | 15 | (0.20) | 32** | (0.02) | 101*** | (0.01) |
| Ag. Labor wage rate Kwacha/day on hh plot, real 2009 kwacha | 0 | (0.94) | -4** | (0.04) | -3** | (0.03) | -2 | (0.27) | -3 | (0.35) | -4 | (0.61) |
| cumulative rainfall over current growing season in cm | 11** | (0.03) | 2 | (0.10) | 1 | (0.44) | 1 | (0.15) | 4 | (0.13) | 8* | (0.07) |
| Average annual rainfall over previous 5 growing seasons, in cm | -20* | (0.05) | -3 | (0.20) | -7*** | (0.00) | -10*** | (0.00) | -6* | (0.09) | 4 | (0.66) |
| Std deviation of average long run rainfall | -6 | (0.47) | 1 | (0.60) | 1 | (0.79) | -3 | (0.34) | -9* | (0.06) | -18* | (0.07) |
| Intercept | 1,777 | (0.58) | 6,068 | (0.53) | 11,089 | (0.38) | 27,821* | (0.06) | 24,200 | (0.30) | -18,514 | (0.65) |
| Soil quality dummy variables included | Yes | | Yes | | Yes | | Yes | | Yes | | Yes | |
| Number of Obs. | 4,045 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | | 6,817 | |
| $R^2$ | 0.10 | | 0.03 | | 0.06 | | 0.14 | | 0.23 | | 0.31 | |

Note: *, **, *** indicates that corresponding coefficients are significant at the 10%, 5%, and 1% level respectively; models include district dummies, year dummies, and household time averages of all time-varying explanatory variables.