Estimating the Enduring Effects of Fertilizer Subsidies on Commercial Fertilizer Demand and Maize Production: Panel Data Evidence from Malawi

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Abstract
Most studies of input subsidy programs confine their analysis to measuring contemporaneous program effects. This article estimates the potential longer run or enduring effects of fertilizer subsidy programs on commercial purchases of fertilizer and farmers' maize production over time. We use four waves of panel data on 462 farm households in Malawi for whom fertilizer use can be tracked for eight consecutive seasons between 2003/04 and 2010/11. Panel estimation methods are used to control for potential endogeneity of subsidized fertilizer. Farmers acquiring subsidized fertilizer in three consecutive prior years are found to purchase slightly more commercial fertilizer in the next year. This suggests a small amount of crowding in of commercial fertilizer from the receipt of subsidized fertilizer in prior years. Acquiring subsidized fertilizer in one year has a modest positive impact on increasing maize output in the same year. However, acquiring subsidized fertilizer in prior years generates no statistically significant effect on maize output in the current year. The findings indicate that potential enduring effects of the Malawi fertilizer subsidy programs are limited. Additional interventions that increase soil fertility are needed to raise maize to fertilizer response rates. Doing so can make using inorganic fertilizer more profitable and sustainable for smallholders in sub-Saharan Africa, and increase the efficiency of input subsidy programs.

Introduction

Input subsidy programs have re-emerged in recent years as major components of many African governments' agricultural development and food security strategies. An important rationale for the revival of subsidies for inorganic fertilizer and improved seeds is that they can help poor farmers break out of a low input/low output poverty trap (Dorward et al. 2004; Denning et al. 2009; Sachs 2012). This literature argues that subsidizing fertilizer for farmers over time can kick start growth processes that sustainably raise incomes and food security. However, to our knowledge this argument has yet to be empirically tested or verified.

With these considerations in mind, the present article addresses a major research and policy question associated with the potential impacts of input subsidies that largely remains unanswered to date. The question is whether or not the benefits of receiving subsidized fertilizer last only one season or whether they are of a more enduring nature? If the benefits of fertilizer subsidies are found to be one-off, lasting only one season, such programs may still be useful and financially sustainable if the contemporaneous benefits outweigh the costs. However, if the benefits last only one season, then the assertion that subsidizing farmers' fertilizer use over time will put them on a trajectory of sustained production growth and wealth accumulation would not be supported. In this case, questions about the sustainable impacts of an expenditure that accounts for a large share of many countries' agricultural budgets might be warranted. Conversely, if receipt of subsidized inputs in prior years has enduring long-term impacts on households' staple crop production, then this would give greater support for the argument that subsidies can kick-start sustained and enduring growth processes.

The present article uses four rounds of household-level panel data from Malawi collected between 2003/04 and 20010/11 to estimate the enduring or longer-run impacts of input subsidies on commercial fertilizer demand and maize production. In doing so two key hypotheses can be tested surrounding input subsidies in SSA, that have not been fully addressed by the growing literature on the topic. Hypothesis 1 is that households acquiring subsidized fertilizer in consecutive prior years do not purchase significantly more fertilizer on the commercial market in the future than do other households. Hypothesis 2 is that acquiring subsidized fertilizer in consecutive prior years has no significant effect on a household's maize production in the current year.

Hypotheses 1 and 2 are interrelated, because if input subsidies are going to help households sustainably break out of a low input low output poverty trap then subsidies have to ultimately help farmers use fertilizer more effectively, build up nutrients in the soil, and provide households with the resources to purchase fertilizer commercial in subsequent years. Hypothesis 1 measures the potential household wealth effect generated by input subsidies, and directly tests how subsidized fertilizer crowds out or crowds in commercial fertilizer use over time.[1] Previous studies investigating crowding out/in of commercial input demand from input subsidy programs have examined the issue as a static, current year phenomenon (see Xu et al. 2009; Ricker-Gilbert , Jayne, and Chirwa 2011; Mason and Jayne 2013; Liverpool-Tasie 2014; and Takeshima and Nkonya 2014 for fertilizer crowing out, and Mason and Ricker-Gilbert 2013 for seed crowding out). All of these studies find significant crowding out of commercial inputs from subsidy programs in the current year. The exception is Liverpool-Tasie who finds some evidence of crowding in of commercial fertilizer form a pilot program in Nigeria. However, the present article is the first to investigate this issue in a longer-run framework to determine whether households that acquire subsidized fertilizer in the past may purchase more or less commercial fertilizer in subsequent years.

Hypotheses 2 is tested by adapting a conceptual framework from the job-loss, and job- training literature. We follow Ashenfelter (1978), and Jacobson et al. (1993) to estimate a distributed lag model where current year and past year quantities of fertilizer enter as covariates in the maize production model. In addition to the wealth effect, input subsidies could potentially have two other enduring benefits. First, there could be a learning effect where household that acquire inorganic fertilizer at a reduced price are able to experiment and learn from using inorganic fertilizer over time. The learning effect could enable farmers to improve their fertilizer management and obtain higher response rates to fertilizer in the future. The other potential benefit from using subsidized fertilizer over time could come from a soil fertility effect. When inorganic fertilizer is applied to the soil some of the nitrogen and phosphorous from the input remain in the soil from one year to the next.

Most previous studies of the effects of input subsidy programs on crop production focus on the conditional mean effect in the current year (Holden and Lunduka 2010; Chibwana et al. 2014; Mason, Jayne, and Myers 2015). The general finding from empirical studies that use household-level data collected over the past 10 years in SSA is that input subsidies generate a statistically significant, but relatively modest contribution to maize yield in the current year. To our knowledge the only other study to investigate the enduring effect of input subsidies in SSA in any way is by Carter, Laajaj, and Yang (2014) in Mozambique. Households in that study are randomly given vouchers one time that allows the households to purchase subsidized fertilizer and seed at a reduced price. The authors estimate an intention to treat (ITT) effect that receiving the voucher contributes to household maize production and income in the current year, and for two additional years.

In addition to examining enduring crowding in/crowding out of commercial fertilizer by the subsidy, we extend the Carter, Laajaj, and Yang study by using 4 waves of panel data with 8 years of information on fertilizer use to investigate the channels through which input subsidies can affect maize production over a relatively long period of time. We also measure the effect of acquiring input subsidies in multiple prior years. This is an important contribution because most input subsidy programs in SSA almost always last for multiple years, so participant households acquire the benefit more than once.

Malawi is an important case study of input subsidy impacts because since 2005/06 the country has scaled up a large targeted subsidy program where the government distributes vouchers to selected farmers who meet certain criteria. Under this program, the targeted farmers can then redeem the vouchers in exchange for fertilizer and improved maize seed at a reduced price. The program received popular acclaim in a front-page New York Times article (Dugger 2007) and is widely be perceived as a litmus test for other countries in Africa. Between 5-16% of government spending in Malawi since 2005/06 has gone to funding input subsidies. Given the major opportunity cost involved, policy makers may want to better understand the potential enduring, and distributions effects of fertilizer subsidy programs on the lives of recipients.

When evaluating the impacts of fertilizer subsidies, it is essential to understand that they are not distributed randomly, so dealing with this issue is a major part of this article's modeling effort. Our identification strategy uses panel estimators along with presenting simple parsimonious specifications of the estimated model for factors affecting maize production in addition to fully specified models to deal with potential endogeneity likely caused by omitted variable bias.

Input Subsidies in Malawi

Input subsidy programs have existed almost every year for decades in Malawi. Prior to 2005/06 a relatively small subsidy program called Starter Pack and then called the Targeted Input Subsidy Program (TIP) were in place. 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 in 2005/06. The program was originally named the Agricultural Input Subsidy Program (AISP) and later the Farm Input Subisdy Program (FISP). Table 1 presents the quantiy of subsidized fertilizer and maize seed along with program costs for every year between 2002/03 to 2010/11, the years that pertain to the data used in the present study. Row 1 of the table shows how the quantity of subsidized fertilizer and seed distributed to smallholders in Malawi increased dramatically in 2005/06 and continued to climb to 202,000 metric tons in 2008/09 before declining to 161,000 metric tons in 2009/10 and 2010/11.

Farmers were allowed to acquire subsidized fertilizer from private sector retailers during the 2006/07 and 2007/08 growing season. Six private firms won the right to procure and distribute subsidized fertilizer through their retail networks. Row 2 of table 1 shows the amound ot subsidized fertilizer sold by the private sector over the nine relevant seasons. Farmers who received coupons could redeem them at participating retail stores along with their required contribution to obtain their fertilizer. Retailers would then submit the coupon and receipt to the government for payment. The private sector has been excluded from distributing subsidized fertilizer since 2008/09, but has been involved in the distribution and retailing subsidized maize seed. Row 3 of table 1 shows the quantity of maize seed that was included as part of the subsidy program from 2006/07 onwards. Farmers could choose between hybrid and open pollunated varieties (OPV) of improved maize seed.

Row 4 of table 1 also illustrates how the level of required beneficiary farmer contribution to the fertilizer subsidy in Malawi declined from 36% of the total cost in 2005/06 to 7% in 2010/11. Subsidized maize seed has always been available free of charge to participating farmers as part of the subsidy program other than in 2005/06, when maize seed was not part of the program. Row 5 of the table also shows how total cost of the program to the government increased between 2005/06 and 2008/09. Costs reached a high of US $241 million (row 5) and 16.2% of the national budget in 2008/09 (row 6), as global fossile fuel prices skyrocketed. Program costs declined in subsequent years as fossil fuel priced retreated towards earlier levels. Most of the bill for the subsidy program was paid by the Malawian government, and the rest was paid directly by the UK's Department for International Development (DFID). (For more background information on Malawi's FISP see Chirwa and Dorward 2013, and Lunduka et al. 2013).

[Table 1 Here]

Officially each household who participates in FISP is eligible to receive two coupons good for two 50-kilogram bags of fertilizer at a discounted price, and a coupon that can be redeemed for between 5-10 kilograms of improved maize seed. In reality, the actual amount of subsidized fertilizer acquired by households varied greatly. Figure 1 shows the percentage of households in our sample participating in the subsidy program, while Figure 2 shows the amount of subsidized and commercial fertilizer that the average household in Malawi from our sample acquires.

[Figure 1 Here]

[Figure 2 Here]

Throughout the subsidy program's implementation, the process of determining who received coupons for fertilizer subsidies was subject to a number of idiosyncrasies. Coupons, fertilizer and seed are officially allocated to regions and districts based on area cultivated and number of farm households. At the community-level subsidy program committees and the village heads are 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.

Originally the general program eligibility criteria were 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). From about 2008 onward "vulnerable households" were officially supposed to be targeted with priority given to resource poor households, including disabled, elderly, female and child headed households. Prior studies have shown that other factors were significantly associated with voucher allocation, such as households' relationship to village leaders, length of residence, and social and/or financial standing of the household in the village (Chibwana, Fisher, and Shively 2011; Ricker-Gilbert, Jayne and Chirwa 2011; Kilic, Whitney, and Winters 2015). It is also possible that factors which are unobserved to us as researchers, such as risk aversion or farm management ability may affect how much subsidized fertilizer a household receives. Therefore, we need to consider the fact that subsidized fertilizer may be endogeneous in our empirical models.

Data and Survey Design

Data used in this article come from four surveys of rural farm households in Malawi. The first wave of data come from the Second Integrated Household Survey (IHS2), a nationally representative survey conducted during the 2002/03 and 2003/04 growing seasons that covers 26 districts and 11,280 households 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. 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. 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 an attrition rate of 16.3% between 2007 and 2009.

The fourth wave of data comes from the 2011 Agricultural Inputs Support Survey IV (AISS4) collected by Wadonda Consulting after the 2010/11 growing season. The budget was again smaller than in previous rounds and of the 1,375 households that were surveyed in each of the first 3 rounds, 515 of them lived in enumeration areas that were revisited in 2011. Of the 515 households in revisited area, 462 of them were found for re-interview in 2011, which gives an attrition rate of 10.3 between 2009 and 2011. Since we are interested in measuring the potential enduring impacts of input subsidies over time, we need to confine our analysis to households interviewed in all four rounds between 2002/03 and 2010/11. Therefore we use the balanced panel of 462 households that were surveyed in each of the four survey waves conducted over 8 years. The sample is no longer nationally representative when the AISS4 data are included, but it covers 8 districts across all 3 regions of Malawi, and represents 8 major maize growing livelihood zones. This represents 77% of Malawi's rural households (Wadonda Consulting, 2011).

In each survey wave, respondents are asked a full set of demographic, production, income and asset questions that pertain to the years in which the survey takes place. Respondents are asked recall questions about the quantities of subsidized and commercial inputs they acquired in the years prior to the survey waves. For example, households are surveyed in 2006/07 and 2008/09, and during the 2008/09 survey a household is asked a recall question about fertilizer acquisition in 2007/08, a year with no survey. In total, this dataset provides us with the ability to track fertilizer use and other activities for the same households over eight years, which is a longer period of time than any other dataset in Malawi to our knowledge.

Controlling for potential attrition bias

The rate of attrition across the 4 waves of the sample is between 10.3-16.3% for households living in enumeration areas that were re-surveyed in subsequent rounds. This can potentially lead to biased coefficient estimates caused by households leaving the sample for non-random reasons. If the factors associated with households leaving the survey for non-random reason are correlated with time-constant unobserved heterogeneity in our models, then using an FD estimate removes this problem. However, attrition may still be correlated with time-varying errors. Fortunately, we have four waves of data, which allow for a formal test of attrition bias. The maize production model is estimated via a FD using the attrition bias test proposed in Wooldridge (2010, p. 837-838). Results of the test indicate that when all households surveyed in at least 2 waves are included, there is no statistically significant evidence of attrition bias (p-value on the selection indicator = 0.548). When we only include households in the enumeration areas sampled in all four waves, then we find marginal evidence of attrition bias (p-value on the selection indicator = 0.07). Therefore, for robustness purposes we estimate the linear maize supply response model using Inverse Probability Weights (IPW) and compare those results those where IPW is not used. Unfortunately IPW is not valid in non-linear models. However, observing the differences in linear models when IPW is used and when it is not provides a useful test for how attrition may affect coefficient estimates.[2] Results indicate that the coefficient estimates on the maize production model do not vary in any meaningful way between when IPW's are included and when they are not. However to ensure robustness, the linear maize production models are estimated with IPW's included, while the crowding in/out model does not include IPWs because the model is non-linear.

Conceptual Framework

The conceptual framework used in this article is adapted from the job training and job loss literature, where the event or treatment of interest is the year when an individual participates in a job training

(Ashenfelter 1978) or when the individual loses employment (Jacobson et al., 1993). This framework has been applied to the development literature that measures the impact of adult mortality due to HIV/AIDS on household income and well-being (Chapoto and Jayne 2008; Beegle 2005; Kirimi 2008). Figure 3 presents the conceptual relationship in our context of how a household's acquisition of subsidized fertilizer in year t may affect its production of maize in that year and in the future. The household has some level of maize production in t-j years before they acquire subsidized inputs (point a). Then in year t the recipient household receives a positive shock in the form of subsidized fertilizer and increases its maize production in that year t (point b). The size of the contemporaneous maize production effect is represented by the distance between points a and b in figure 1.

Findings of relatively small contemporaneous impacts from input subsidies on maize production is consistent with the current literature on the topic (Holden and Lunduka 2010; Chibwana et al. 2014; Mason, Jayne, and Myers 2015). The potentially more important question for determining the impacts of input subsidy programs, and the focus of this article, is what happens to household i's maize production in the years after the subsidy has been received. In years t+1 through t+j do households maintain their initial gain in maize production from *a* to *b*? Do they drop back to point *a* the following year? Or do they continue to grow to point c the next year and to point d after that? While theoretical arguments can and have been made to support both trajectories, these are ultimately empirical questions.

The measurement of impacts over time in our study is slightly more complicated than in earlier studies that use the same basic framework. In Malawi, the input subsidy program has occurred over multiple years, so household *i* could have received the treatment in more than one time period. Although households participating in the subsidy are officially supposed to receive 100 kilograms of fertilizer at a reduced price, the actual amount of subsidized fertilizer acquired by households varies from household to household and year to year. Therefore, we have to account for the fact that program participation occurs over time and need to be modeled as a continuous variable rather than a binary treatment as in Ashenfelter (1978) and Jacobson et al. (1993).

[Figure 2 Here]

As mentioned in the introduction, we conceptualize three main channels through which subsidized fertilizer acquired in one year may lead to increased maize production in the future. The first is through a learning effect, where household *i* has some base level of knowledge about how to use fertilizer in time t when it acquires subsidized fertilizer. If the household is able to acquire subsidized fertilizer at an extremely low price, then the household can experiment and learn how to use the fertilizer more effectively in year t with limited financial risk. This allows the farmer to build fertilizer management capital for future years.

The second channel through which acquiring subsidized fertilizer in one year may lead to increase maize production in the future is through a soil fertility effect. When fertilizer is applied to maize, some residual nutrients such as nitrogen and particularly phosphorous can be left over in the soil from one year to the next. The build-up of these extra nutrients can be thought of as soil capital and can be used to impact maize production in the future.

The third channel through which acquiring subsidized fertilizer in one year may lead to increase maize production in the future is through a wealth effect. If acquiring subsidized fertilizer enables household i to increase maize production in year t and subsequently increase its income in that year, this could in turn induce farmers to purchase more fertilizer from commercial sources during the following years. In addition, by lowering the price of fertilizer, acquiring subsidized fertilizer could help relieve the credit constraint for recipient househodls and enable them to purchase more fertilizer in the future.

To understand how the input subsidy program potentially generates a wealth effect and thus impacts commercial fertilizer use, it is important to note that the total quantity of fertilizer obtained by the household, denoted by *F,* consists of two parts: 1) the quantity of subsidized fertilizer *S* that a household acquires, and 2) the quantity of commercial fertilizer C that a household purchases, where *F = S + C.* Households that acquire some quantity of S may or may not use it in place of some or all of their commercial purchases. Therefore, subsidy program's impact on total fertilizer used by the household is a function of the following:

1) $\frac{\partial F}{\partial S} = \frac{\partial S}{\partial S} + \frac{\partial C}{\partial S} = 1 + \frac{\partial C}{\partial S}$

where the derivative $\frac{\partial C}{\partial S}$ represents the degree to which subsidized fertilizer affects commercial fertilizer use. If $\frac{\partial C}{\partial S} \leq 0$, subsidized fertilizer is said to "crowd out" or displace a household's commercial fertilizer purchases. Conversely, if $\frac{\partial C}{\partial S} \geq 0$ then subsidized fertilizer is said to "crowd in" a household's commercial fertilizer purchases. In addition, if $\frac{\partial C}{\partial S} = 0$, then subsidized fertilizer has no effect on a household's commercial fertilizer purchases. Considering the potential crowding out/in effect is essential for determining the effectiveness sof input subsidy programs, because it determines the extent to which subsidized fertilizer contributes to the total amount of fertilizer that ultimately ends up on farmers' fields. This can potentially increase maize production, income and food security.

Methods

Equation 2 operationalizes the model for testing potential crowding in or crowding out of commercial fertilizer by subsidized fertilizer in a longer-run framework. Consider commercial fertilizer purchases by household i at time t as a function of the following factors:

2) $\mathrm{C}_{it} = \Upsilon + \beta_0 \mathrm{S}_{\mathrm{it}} + \mathrm{S}_{\mathrm{it-j}} \beta_j + \mathrm{X}_{\mathrm{it}} \varsigma + \xi_{\mathrm{it}} б + R_{it} \rho + b_i + \mu_{it}$

Where S_{it} is the quantity of subsidized fertilizer that a household acquires at time t, and, and β_0 is the corresponding parameter. The possible enduring effect of acquiring subsidized fertilizer in multiple previous years on commercial fertilizer in the current year is represented by the sum of $\mathrm{S}_{\mathrm{it-j}}$; where *j= 1,* *2, 3.* The statistical significance and magnitude of the coefficient estimates on β_j tests the first hypothesis in this article, about whether or not subsidized fertilizer has a longer-run crowding out or crowding in effect on commercial fertilizer purchases.

The price of other inputs including agricultural labor wage rate, and maize seed prices and are denoted by the vector *X*, with corresponding parameter vector ς. The price of maize is also included in *X*. In Malawi, maize price is lowest just after harvest during the months of May, June and July, but increases steadily after harvest to a high in the months of January, February, and March when maize is scarce. Since most rural households in Malawi are net consumers of maize because they do not produce enough to meet their own consumption needs, most of them have run out of their own maize stocks by this time, and the next harvest is still several months away (Alwang and Seigel 1999; Dorward 2006). Therefore, we use the retail price of maize during this hungry season to proxy for the naive expectation for the retail maize price that maize deficit households would face as consumers in the coming year.

Household demographics and landholding are also denoted by *X.* Household landholding enters equation 2 as a quantity because it is regarded as quasi-fixed in this application given the under-developed state of land markets in Malawi. In addition, community factors such as whether or not the community has a farm credit organization, distance in kilometers to the nearest road, and distance in kilometers to the main district market are included in *X*.

Unexpected shocks that are observable to us as researchers such as death of the household head or spouse over the previous two years are denoted by ξ. Also included in ξ is a household's naieve expectation of rainfall in the coming year, proxied by 2 variables. The first variable is the average cumulative rainfall over the past 5 growing seasons. The second variable is the coefficient of variation over the past 5 years to control for expectations about rainfall risk. The corresponding parameter vector is denoted by б**.**

The error term in equation 2 has two components. First, b_i represents the time-constant unobserved factors that affect household commercial fertilizer purchases in year t. These unobserved factors may include farmer motivation and risk aversion of the household. Second, μ_{it} represents the time-varying shocks that affect C_{it}. These include factors such as conflicts among family members, or sickness of a family member that we cannot observe in our data (the error terms are given further treatment in the *identification strate*gy section).

Estimating enduring effects of subsidized fertilizer on maize output

After estimating the possible enduring effects on subsidized fertilizer on commercial fertilizer use we estimate the effect of subsidized fertilizer on area planted to maize and maize production using a household-level production function.[3] Equation 3 operationalizes the conceptual framework presented in figure 1, as follows:

3) $\mathrm{Y}_{it} = \alpha + \delta_0 \mathrm{F}_{\mathrm{it}} + \mathrm{F}_{\mathrm{it-j}} \delta_j + \mathrm{Z}_{\mathrm{it}} \alpha + e_i + v_{it}$

where Y represents maize production in kilograms produced by the household. In equation 3, F is decomposed in to two parts. First, F_{it} represent the quantity of inorganic fertilizer that a household acquires in the current year, t. The coefficient on the corresponding parameter δ_0 estimates the contemporaneous effect of an additional kilogram of fertilizer on maize area and maize production in that year. The second vector, F_{it-j}, represents the quantity of fertilizer that a household acquires in past years, *t-j*, where *j= 1, 2, 3*.[4] The sum of the individual coefficient estimates in the vector δ_j, provides an estimate of fertilizer's enduring effect on maize production, which allows us to test hypothesis 2 in this article. We also present an additional model, results of which are shown in appendix 1b, where the dependent variable is area planted to maize. This extra model is important because it provides evidence of whether or not increased production from subsidized fertilizer comes from increased area planted to maize or through yield increases.

The other covariates in the model estimated in equation 3 are denoted by the vector Z. These variables are expected to impact maize area and maize production on household plots. We include a dummy variable for whether or not a household owns goats or cattle, in order to control for soil quality. This variable is included as a proxy for whether or not a household has organic manure, and as such will give an indication of the quality of the soil on the household's plots. Evidence from Malawi suggests that there is a complementarity between inorganic fertilizer and organic manure use (Holden and Lunduka 2012), which can help maintain soil nutrients and increase output.[5]

In addition we also include a binary variable =1 if the household plants improved hybrid or open pollinated varieties (OPV) of maize, as opposed to traditional varieties. This variable controls for the effect that improved seeds have on maize production, as households that use improved varieties would be expected to have higher yields.[6] We also include the amount of land in hectares that a household has cultivation rights to as a covariate in Z.

We control for labor use and plot management in several ways. First, the average number of weedings on all household maize plots is included as a covariate in Z in the maize production equation.[7] Empirical evidence from Malawi suggests that the weed *striga* is a major inhibitor of maize, so more intensive weed management should facilitate higher output (Snapp et al. 2014). Second, the number of adult equivalents in the household is also included as a proxy for the amount of labor available on household plots. Third, we include a dummy variable=1 if the household is headed by a female, which controls for the possibility that female headed households are more likely to be labor constrained and have lower access to inputs than male headed households.

Observed shocks such as whether a household head or spouse has died in the past 2 years are also included in Z. In the maize production model we also include cumulative rainfall over the growing season to account for rainfall effects. In the maize area planted model, a household's naive expectation of rainfall in the coming year is proxied by including in the model the mean cumulative rainfall over the past 5 growing seasons, and the coefficient of variation of average rainfall over the past 5 years.

Similar to equation 2, the error term in equation 3 also has two components. The time constant unobserved factors that affect maize area and maize production are represented by e_i, while v_{it} represents the time-varying shocks that affect maize area and maize production.

Obtaining estimates of subsidized fertilizer's effect on maize area and maize production

Equation 3 provides an estimate of how the total quantity of inorganic fertilizer acquired by the household affects maize production. However, we know that households acquire fertilizer from commercial channels in addition to acquiring fertilizer from the subsidy program. Therefore, teasing out the effects of subsidized fertilizer takes an extra step. To do so we follow Mason and Smale (2013) to present this relationship as follows:

4) $\mathrm{Y}_{it} = \alpha + \delta_0 \mathrm{F}(\mathrm{S}_{\mathrm{it}} + C_{\mathrm{it}}) + \mathrm{F}(\mathrm{S}_{\mathrm{it-j}} + C_{\mathrm{it-j}})\delta_j + Z_{it}\varsigma + e_i + v_{it}$

where the production of *Y* is a function of *F*, which F = *S + C* by identity. Production of *Y* also depends on other factors, as explained in equation 3. Ignoring the time subscripts for simplicity, from equation 4 we can obtain the implicit effect of subsidized fertilizer, *S* on the production of *Y* through the following equation:

5) $\frac{\partial \mathrm{Y}}{\partial \mathrm{S}} = \frac{\partial Y}{\partial F} * \frac{dF}{dS} = \frac{\partial Y}{\partial F} * \left(\frac{\partial S}{\partial S} + \frac{\partial C}{\partial S}\right) = \frac{\partial Y}{\partial F} * \left(1 + \frac{\partial C}{\partial S}\right) = \delta * \left(1 + \frac{\partial C}{\partial S}\right)$

where the chain rule indicates that S affects Y through the effect of F on Y. This is denoted by the coefficient estimate, δ, which is multiplied by 1 + the crowding out/crowding in estimate $\frac{\partial C}{\partial S}$, obtained in equation 2. The coefficient estimates are obtained in Stata, and valid standard errors for this multi-step estimation process are computed via boostrapping.

Functional Form

The commercial fertilizer demand (crowding in/crowding out) model presented in equation 2 is estimated as a corner solution using a truncated normal hurdle (THN).[8] Commercial fertilizer demand takes on the properties of a corner solution because many households do not purchase commercial fertilizer as their optimal decision, so many observations have a zero value.[9] However, for those households that purchase commercial fertukuzer the quantity of commercial fertilizer they buy varies. Given the significant number of observations at 0, OLS may mis-estimate the conditional mean effect of crowding out (Wooldridge 2010). Following previous literature, the fertilizer purchase decision is estimated in two steps (Xu et al. 2009; Ricker-Gilbert, Jayne, and Chirwa 2011; Mason and Jayne 2013; Mason and Smale 2013). In the first step the household makes the binary decision whether or not to purchase commercial fertilizer. In the second step the household decides how much commercial fertilizer to purchase. Step 1 includes fixed costs such as distance to market and number of fertilizer dealers in a village that must be factored into a household's participation decision. These factors are not relevant in hurdle 2 once the participation decision has been made. Step 1 is estimated via a probit estimator, while step 2 is estimated via a truncated normal estimator.[10]

Identification Strategy

Using observational panel data vs. a randomized control trial (RCT)

Our goal is to estimate the impacts of Malawi's large-scale Farm Input Subsidy Program that has been occuring across the country since the 2005/06 season. The government of Malawi did not conduct a pilot or Randomized Control Trial (RCT) before scaling up the FISP, so we use observational panel data to conduct our evaluation of the program. Fortunately, our data set is longitudinal and follows the same households in Malawi over an eight year period, and the same households are surveyed at four points in time. Therefore, we are able to deal with the potential correlation between the amount of subsidized fertilizer a household receives and the error term using panel data methods. In addition, because we know how much subsidized fertilizer households receive in different years, we can deal with the fact that treatment is not constant, and that people receive differing quantities of subsidized fertilizer over time.

Several recent studies have estimated fertilizer use efficiency for smallholder African farmers in relation to an input subsidy using an RCT framework (see Duflo Kremer and Robinson 2008 in Kenya; Beaman et al. 2013 in Mali; and Carter Laajaj, and Yang 2014 in Mozambique). While these studies have relatively clean identification strategies due to their randomized design, they address specific case studies or pilot programs rather than large national subsidy programs that have been in place for many years, such as Malawi's FISP that we seek to evaluate. As most of these studies are implemented by researchers and non-governmental organizations (NGO) rather than government officials, the context between those studies and the present study is very different.

The following sub-sections present our strategy for dealing with the non-random nature of how subsidized fertilizer is distributed in Malawi.

Controlling for Unobserved Time-Constant Heterogeneity

Estimating equations 2 and 3 via Pooled OLS will yield inconsistent coefficient estimates if the time constant error terms denoted by b_i in equation 2 and e_i in equation 3 are correlated with the observed covariates in these models. For linear models such as the production function estimated in equation 3, potential correlation between e_i and the other covariates can be controlled by estimating the equations in first difference (FD) form. The FD estimator removes time-constant unobserved factors such as soil quality, risk aversion of the farmer, and motivation, represented by e_i from the model. Estimating equation 3 via FD requires the assumption of strict exogeneity where the covariates must be uncorrelated with Δv_{it} in all time periods.

FD regression is not an option when estimating the commercial fertilizer demand (crowding in/out) in equation 2, because the model is non-linear, and there are many cross-sectional observations and few time periods. In this situation, FD is subject to the *incidental parameters* problem (Wooldridge 2010). Fortunately, the Mundlak-Chamberlain (MC) device is available to deal with unobserved heterogeneity in this context (Mundlak 1978; Chamberlain 1984).[11] We implement the MC device to control for a possible correlation between b_i and observable covariates in equation 2 by including a vector of variables containing the means for household *i* of all time-varying covariates. The values of these variables are the same every year for a given household but vary across households (for more on the MC framework see Wooldridge, 2010). The MC device requires the strict exogeneity assumption, just like FD estimation.

Controlling for Correlation between subsidized fertilizer and Unobserved Time-Varying Shocks

After first-differencing, we also need to consider the fact that estimates of ΔS_{it} on commercial fertilizer purchases, and maize production will still be inconsistent if changes in subsidized fertilizer acquisition are correlated with unobserved time-varying shocks μ_{it} in equation 2. One way to address this issue is to use an instrumental variable (IV) strategy where the IV would be correlated with subsidized fertilizer acquisition, but uncorrelated with μ_{it} in the structural model. Given the difficulty in finding an exogenous IV, and the fact that using an endogeneous IV is likely worse than using no IV, especially if the IV is only weakly correlated with the potentially endogenous explanatory variable (Wooldridge, 2010, p. 108) we use deal with any potential left-over endogeneity using the following two strategies. First, since we hypothesize that any remaining endogeneity may becaused by omitted variables that could be correlated with household subsidized fertilizer acquisition, we include several household level shocks, such as i) average cumulative growing season rainfall over the past five years, ii) coefficient of variation on rainfall over the past five years, iii) current season rainfall (in the maize production model), and iv) a dummy variable =1 if the household head or spouse died over the past two years. Including important shocks such as rainfall and mortality in the model brings these factors out of the error term and removes concern that these unobservables are biasing our estimates. Second, we run the maize production model with a parsimonious specification where only subsidized fertilizer or total fertilizer are included as covariates in the models of interest using an FD estimator. Results indicate that the coefficient estimates on subsidized and total fertilizer are very similar in the parsimonious specificiation to the fully specified models that include all other controls in the main results of this article. This robustness check lends credibility to the fact that left over-time varying shocks due to omitted variables are not biasing the subsidized fertilizer coeffieints in our models. Nevertheless, though we give potential endogeneity of subsidized fertilizer rigorous treatment, we recognize that as with any observational study, full causal inference from our results cannot be conclusively asserted. To the extent that left-over unobservable factors such as higher ablity, motivation, intelligence and positive income shocks are positively correlated with subsidized fertilizer acquisistion as we might expect, the coeffieint estimates derived in this study could be thought of as upper bound estimates of FISP program impacts.

Controlling for possible resale of subsidized fertilizer

Households that acquire vouchers for subsidized fertilizer can potentially sell the voucher or sell the fertilizer after they redeem the voucher. Both of these possibilities can affect how we define our treatment and control group, and the estimates of program impacts. For this reason we compare the main results estimated in equation 3 where fertilizer acquisition in kilograms is the key program variable of interest, with results where the key program variable is defined as number of fertilizer vouchers that the household acquires (see appendix 2a and 2b).

The additional specification using number of fertilizer vouchers acquired by a household as the program variable of interest provides an estimate of the "eligibility" effect of receiving a voucher to participate in the FISP. The coefficient estimate is the intention to treat (ITT) effect, and the estimates generated by this specification will be unbiased only if 1) everyone who acquires a subsidized fertilizer voucher redeems it for the same amount of fertilizer (recall that 50 kilograms of fertilizer per voucher is the official amount), and 2) if people not acquiring a fertilizer voucher do not obtain subsidized fertilizer through any other channel (Imbens and Angrist 1994; Wooldridge 2010). This may be a strong assumption given evidence from Malawi indicating that farmers do in fact acquire subsidized fertilizer through resale (Holden and Lunduka, 2010). Regardless, we add this specification as a robustness check.

Table 2 shows that the correlation between number of vouchers received and kilograms of subsidized fertilizer acquired by households ranged from 0.277 in the 2007/08 season to 0.953 in the 2010/11 season. The correlation between vouchers and fertilizer receipt is higher in recent years, which is consistent with reports that the Malawi government tightened up its distribution of vouchers in more recent years. This was accomplished by forcing beneficiaries to register with the local extension staff and tying beneficiaries' voucher number identification to their voter identification. The results presented in appendix 2a and 2b where the treatment variable is number of subsidized fertilizer vouchers acquired are largely consistent with the main results of this article where the treatment variable is kilograms of subsidized fertilizer acquired.

[Table 2 Here]

Subsidized fertilizer applied to crops besides maize

It is possible that households can apply subsidized fertilizer to crops other than maize. However, the data suggests that the vast majority of fertilizer in Malawi goes to maize production. First, NPK and urea are the main fertilizers distributed as part of FISP and they are blended for maize cultivation. In the early years of the FISP tobacco fertilizer CAN was included, but due to low tobacco prices at that time some farmers applied tobacco fertilizer to maize. Second, the 2010/11 data used in this study indicates that of the 2,405 plots managed by households in the survey, 1,726 (72%) were fertilized. Of these 1,726 fertilized plots, 87% of them grew monocropped maize, or maize intercropped with something else. Conversely, only 13% of fertilized plots grew monocropped tobacco or intercropped tobacco, and less than 1% of fertilized plots (13 plots total) grew crops other than maize or tobacco. Considering the fact that maize is by far the most widely grown crop and the most fertilized crop in Malawi, in addition to the fact that increasing maize production is the primary goal of the FISP, it makes sense to focus the main impact of our analysis on maize production.

Results

Table 3 presents the data means and medians for variables used in this analysis by survey wave. The descriptive statistics are displayed for survey wave 1 collected during 2002/03 & 2003/04 (IHS2); wave 2 collected during 2006/07 (AISS1); wave 3 collected during 2008/09 (AISS2); and wave 4 collected during 2010/11 (AISS 4). The descriptive statistics are based on the 462 households for whom we have information in all 4 survey waves.[12]

Table 3 provides useful insights when looking across waves and when comparing the variables' means and medians in each year. Maize production at the household-level increases on average over time from 605 kilograms per household in wave 1 to 650, 716 and 818 kilograms per household in waves 2, 3 and 4. Area planted to maize remains relatively constant across the sample between 0.75 hectares and 0.81 hectares on average. There is a slight increase in average maize area between the pre-FISP survey wave 1 and the first FISP survey in wave 2.[13] Farm sizes in Malawi are very small and consequently area planted is very small. The median landholding does not change across waves, remaining at 0.81 hectares.

Input costs for fertilizer (NPK and urea), maize seed, and agricultural labor increase substantially between waves 2 and 3, but then decline in wave 4. This is also consistent with market level maize prices. Household size and demographic composition measured in adult equivalents stays roughly around four across waves.

[Table 3 Here]

Figure 1 presents descriptive results showing the percentage of the 462 panel households in the survey that acquire inorganic fertilizer from subsidized and commercial sources in each year. The figure indicates that the percentage of households acquiring subsidized fertilizer increases substantially between 2005/06 and 2006/07 when the FISP was first implemented. Between 75 to 84% of households in the sample acquired some quantity of subsidized fertilizer between 2006/07 and 2010/11. Figure 1 also indicates that the percentage of households using commercial fertilizer declines between 2005/06 and 2006/07 as the FISP was implemented and scaled up. However, in subsequent years the percentage of households purchasing some positive quantity of commercial fertilizer steadily increases between 2006/07 and 2010/11.

Figure 2 show the average kilograms of subsidized and commercial fertilizer acquired by panel households in each year. The figure shows a similar pattern to that of figure 1. Average kilograms of commercial fertilizer purchases decline between 2005/06 and 2006/07 as the FISP is implemented and scaled up. However, commercial purchases increase between 2006/07 and 2010/11. In total, Figures 1 and 2 provide *prima facia* evidence that household demand for commercial fertilizer has rebounded to pre-FISP levels in 2003/04, even as the FISP remains in effect. This would suggest that crowding out of commercial fertilizer may have been reduced in recent years, in contrast to findings from studies that analyzed the program in earlier years (Ricker-Gilbert et al. 2011).

Crowding out/in of commercial fertilizer by subsidized fertilizer

Table 4 presents the model results for factors affecting commercial fertilizer demand, estimated via double hurdle with the MC device. The key treatment variables of interest are the kilograms of subsidized fertilizer that a household acquires in year t-j. Column 1 presents the model results when j=0, and thus the coefficient estimates on the subsidized fertilizer variable represent the average partial effect for contemporaneous crowding in or crowding out. This specification is the same as previous studies that estimate crowding in/out of commercial fertilizer by the fertilizer subsidy program. The results indicate that the crowding out rate when the model is estimated contemporaneously is -0.286 on average (p-value=0.059). This suggest that that an additional 100 kilograms of subsidized fertilizer will only add 71.4 kilograms of new fertilizer to total fertilizer use because 28.6 kilograms of subsidized fertilizer will just take the place of commercial fertilizer. This estimate is in line, but slightly higher than earlier estimates of crowding out by Ricker-Gilbert, Jayne, and Chirwal (2011) at -0.22, Jayne et al. (2013) at -0.18, and Chirwa and Dorward (2013) who give a crowding out range of -0.15 to -0.21.

Columns 2, 3 and 4 of table 4 present the longer-run crowding in/out effects when subsidized fertilizer is lagged by year j, where j=1, j=2, and j=3 respectively. The statistical significance of these coefficients directly test hypothesis 1 in this article. Interestingly, in columns 2 and clumns 3 the t-1 lagged effect and the t-1 + t-2 join lagged effect from subsidized fertilizer is not statistically significant. However, in column 4 the cumulative lagged subsidized fertilizer effect from t-1 + t-2 + t-3 suggests that an additional kilogram of subsidized fertilizer acquired in each of the previous 3 years leads the average household to purchase 0.20 kilograms more commercial fertilizer in the current year (p-value=0.041).

One way to interpret this enduring effect is that giving the average household 100 kilograms of subsidized fertilizer in each of the previous 3 years would induce that household to purchase an additional 20 kilograms of commercial fertilizer in the current year. If one divides 20 by 300 (100 kilograms in each of the 3 previous years) the magnitude of the longer-run crowding in effect is 0.067. This is also a relatively small magnitude of crowding in but it suggests that the clear contemporaneous crowding out effect from subsidized fertilizer on commercial fertilizer appears to be partly mitigated by some crowding in of commercial fertilizer in past years.

Neither the contemporaneous nor the enduring crowding-in effects independently can give us a comprehensive program benefit-cost perspective. To do so, we must consider the cumulative multi-year effect of acquiring subsidized fertilizer in the current year and each of the previous years of program participation. Given the length of our panel data set, we have considered a maximum time frame of four years. We find a +0.20 enduring effect on the current year's commercial fertilizer demand resulting from a household obtaining a kilogram of subsidized fertilizer in years t-3, t-2 and t-1. The contemporaneous crowding out effect of between -0.15 and -0.30 in each of the previous three years should be added to the enduring effect to obtain the four-year cumulative crowding out effect.[14]

[Table 4 about here]

Impact of subsidized fertilizer on incremental maize production

Table 5 presents the regression results for factors affecting incremental maize production estimate via first differencing. Estimates on the fertilizer coefficients and the subsidized fertilizer coefficients in the parsimonious specifications in table 5 are very similar to those in the fully specified models. This suggests that the esitmates of subsidized fertilizer's impact on maize production are stable and not affected in any meaningful way by omitted variables that could potentially bias our results.

Column 1 of table 5 shows the contemporaneous effect of an additional kilogram of total fertilizer (kilograms of subsidized fertilizer + kilograms of commercial fertilizer) on maize production, while columns 2, 3, and 4 show the lagged effects. The statistical significance and magnitude of the estimates on the lagged effects answers hypothesis 2 about whether or not subsidized fertilizer has an enduring effect on maize production. The coefficient estimates from the contemporaneous model in column 1 indicate that an additional kilogram of fertilizer adds 1.40 kilograms to maize production on average (p-value=0.00). After accounting for crowding in/out of commercial fertilizer, we find that the effect of subsidized fertilizer on maize production shows that an additional kilogram of subsidized fertilizer leads to an additional 1.00 kilograms of maize production on average (p-value =0.00).

It seems that most of this increase in production comes from increased yields as Appendix 1b shows that the effects of subsidized fertilizer on area planted to maize is not statistically significant in the current year or in previous years in any of the specifications. Our results are somewhat different from Chibwana, Fisher, and Shively (2011) who find an increase in the share of maize area due Malawi's subsidy program. However, our results are somewhat consistent with Holden and Lunduka (2010), who find that households that acquire subsidized fertilizer plant a smaller total area to maize, suggesting some intensification. Our finding that yields increase rather than area expands due to subsidized fertilizer make sense as landholdings in Malawi are very small, 1.17 ha on average in the most recent year of our data, and few households have extra land to bring into cultivation.

Column 2 of table 5 presents the specification where fertilizer use from the previous season (t-q) is added to the model. In this specification, the coefficient estimate on the contemporaneous effect of fertilizer indicates that an additional kilogram of fertilizer boosts maize production by 1.26 kilograms on average (p-value=0.00). Subsidized fertilizer's effect on maize production is 1.07 on average after crowding out is accounted for (p-value=0.00). The one year lagged effect of fertilizer is found to be statistically insignificant.

Column 3 presents the results where kilograms of fertilizer is lagged up to 2 years, while column 3 presents results where kilograms of fertilizer is lagged up to 3 years. The results for both models are very similar for contemporaneous impacts, as an additional kilogram of fertilizer is found to increase maize yield by 1.55 kilograms on average in column 3 and by 1.58 kilograms on average in column 4, (in both models p-value=0.00). Subsidized fertilizer's current year effect on maize production is found to be 1.31 in column 3, and 1.46 in column 4 (in both models p-value<0.01). The two year lagged effect of fertilizer is found to be statistically insignificant in column 3, and the three year lagged effect is also found to be statistically insignificant in column 4. Therefore, the results from table 5 provide evidence in favor of hypothesis 2, that subsidizing fertilizer over one, two, or three previous years has no statistically significant enduring effect on maize production.

The other main factors that affect maize production have the expected sign. Households that plant improved seed (either hybrid or OPV varieties), produce significantly more maize than other households that do not (results are marginally significant in column 1 and approach statistical significance in other specifications). Households with more land produce significantly more than other households in the contemporaneous model in column 1. More rainfall during the growing season has a positive effect on maize output with results approaching statistical significance in columns 2 and 3.

[Table 5 Here]

Conclusions

This study is motivated by the need to better understand the potential enduring or longer run effects of fertilizer subsidy programs, which have been reinstated in many African countries as a means to increase fertilizer use and food production. Our analytical framework distinguishes between current year and longer run measures of crowding out and production effects of input subsidy programs. Nearly all existing analyses of subsidy program impacts to date are based on static, or contemporaneous effects. Theoretically, enduring effects can persist well into the future, but they may not necessarily do so. Ultimately the persistence of enduring effects is an empirical question.

This article uses 4 waves of panel data from Malawi that can track respondents' fertilizer use patterns for the previous 8 years going back from the 2010/11 season. We test 2 main hypotheses surrounding input subsides that remain largely unanswered to date. The first is that households acquiring subsidized fertilizer in multiple prior years do not purchase significantly more fertilizer on the commercial market in the future than do other households. This hypothesis is tested using a truncated normal hurdle model and measures how acquiring subsidized fertilizer in the current year and previous years affects commercial fertilizer demand in the current year. Our results reject hypothesis 1. The receipt of subsidized fertilizer in multiple prior years does significantly raise farmers' purchase of commercial fertilizer. However the effect is small, as an additional kilogram of subsidized fertilizer acquired in each of the previous 3 years causes the household to purchase 0.2 kilograms more commercial fertilizer in the current year, equivalent to an average annual crowding in rate of 0.067.

Moreover, we find no significant dynamic effects beyond one year, i.e., the impact of receiving the subsidy for three years in a row dissipates to insignificance after one season. Consistent with previous studies, we find evidence of statistically significant contemporaneous crowding out of commercial fertilizer from subsidized fertilizer in the same year of -0.286. The cumulative effect of subsidized fertilizer on commercial fertilizer demand over a four year period needs to be calculated by adding the positive enduring effect on commercial purchases in year t to the negative contemporaneous crowding out effect in each of the prior three years. When doing so, we find that, over the 4-year period in question, the receipt of 100kgs of subsidized fertilizer in each of the prior three years results in a cumulative reduction in commercial fertilizer purchases of between 25 and 70 kgs.[15]

The second null hypotheses, that the acquisition of subsidized fertilizer in multiple prior years has no significant effect on a household's maize production in future years, is largely upheld by this analysis. We find very little evidence to support the contention that Malawi's fertilizer subsidy program has had meaningful enduring effects on smallholders' maize production for the population sampled in our survey. Alternative model specifications also indicate that the effects do not last for more than one season after the program ends. These findings call into question whether receiving subsidized fertilizer over time generates major learning effects or soil fertility effects that can lead to higher maize to fertilizer response rates for subsidy recipients in the future. Potential reasons for limited learning effects are because fertilizer has been used extensively in Malawi for decades through subsidy programs, hence it is unlikely that many farm households are unfamiliar with its use, in contrast to other areas in the region where fertilizer use has been historically very limited. Potential reasons for limited soil fertility effects are related to growing research indicating that other soil quality features may pose binding constraints that limit the contribution of nitrogen-based fertilizers to maize production (e.g., Snapp et al, 2014). These contextual differences my explain why our results suggest limited enduring impacts from subsidized fertilizer in Malawi, while Carter et al. (2014) find evidence of higher response rates and enduring benefits from subsidized fertilizer in Mozambique, where fertilizer is much less commonly used.

While the enduring effects of subsidized fertilizer on maize production appear to be limited, we do find a statistically significant and small contemporaneous effect. Acquiring a kilogram of subsidized fertilizer in a particular year generates between 1.00 and 1.46 kilograms of maize produced in that year after accounting for contemporaneous crowding out of commercial fertilizer. Our finding of statistically significant, and low contemporaneous returns to fertilizer entirely consistent with other studies from Malawi that measure the returns to the FISP in terms of maize output per kilograms of fertilizer (Chibwana et al. 2014; Holden and Lunduka 2010). Our results suggest that the contemporaneous production effect from subsidized fertilizer works through intensification (increasing yields), as we find that the subsidy program has no significant effect on the area planted to maize. The result makes sense in Malawi as there is little unused area to be brought into cultivation in many parts of the country, so any increase in output would likely have to come at the intensive margin.

This relatively low rate of return from subsidized fertilizer to maize production indicates that there is very little possibility that the benefits of input subsidies in terms of maize output can cover their full implementation costs. Low benefit/cost ratios limit program sustainability, and raises the need for interventions that complement subsidies for inorganic fertilizer. For example, promoting practices such as maize rotations with legumes, conservation agriculture, organic manure and other soil fertility management strategies can help make soils more responsive to inorganic fertilizer over time (Giller and Cadisch, 1995; Snapp et al. 2014). Combining input subsidies with such practices, perhaps by making the subsidy program conditional on using one or more soil fertility management techniques, could be parts of a holistic strategy that would raise the contribution of input subsidy programs to agricultural productivity and food security in Malawi.

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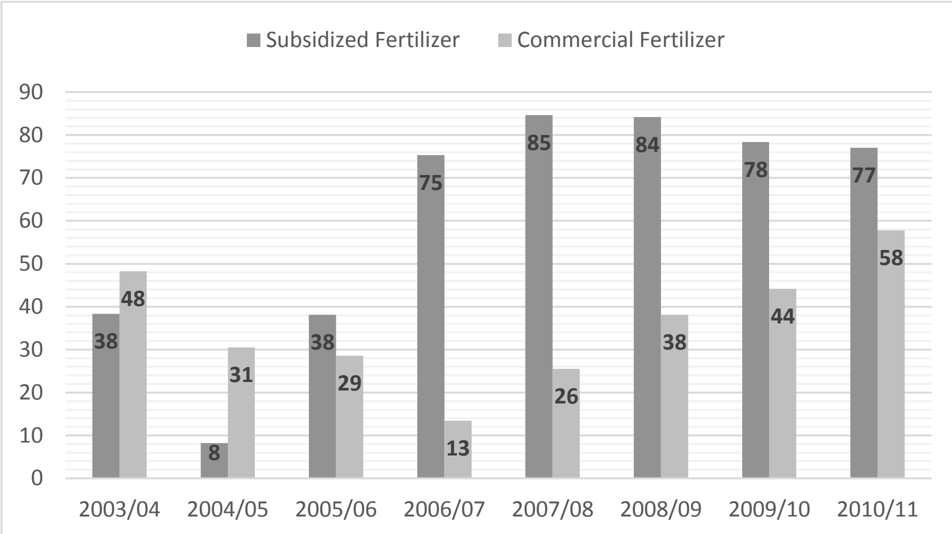
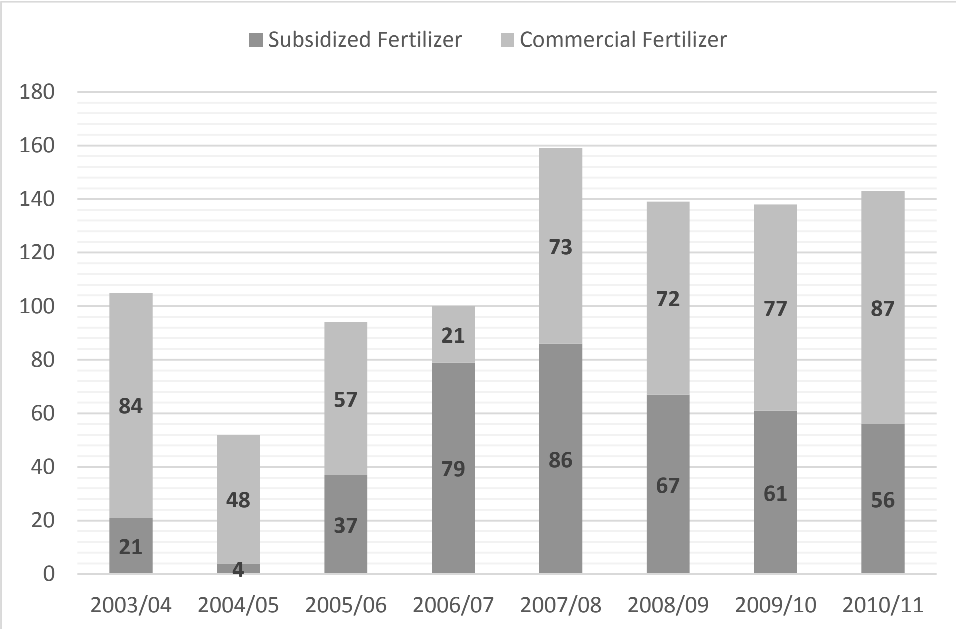
Figure 1. Percentage of Households Using Fertilizer by Year & Source



N=462 in each year

Figure 2. Average Kilograms of Fertilizer Used by Households, by Year & Source



N=462 in each year

Figure 3. Conceptual Relationship between Subsidized Fertilizer Acquisition and Household Maize Production Over Time

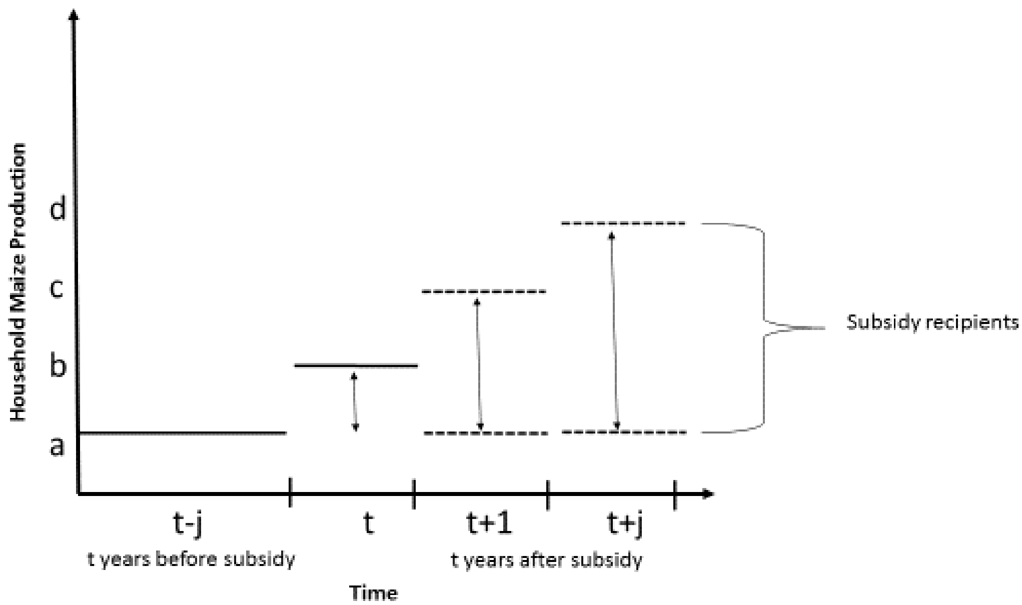


Table 1: Subsidized Input Supply and Cost by Year in Malawi (2002/03 – 2010/11)

	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
1) Total new subsidized fertilizer supplied ('000 mt)[¥]	35	22	54	131	175	217	202	161	161
2) Subsidized fertilizer sold at private retailers ('000 mt)[¥]	0.00	0.00	0.00	0.00	17.43	24.53	0.00	0.00	0.00
3) Subsidized maize seed supplied ('000 mt)[¥]	4.0	3.4	10.0	0.00	4.5	5.5	5.4	8.7	10.7
4) Percentage of total fertilizer cost paid by farmers[¥]	0.00	0.00	0.00	36	28	21	9	12	7
5) Total recorded program costs in '000,000 USD (less farmer redemption)[ƚ]	N/A	N/A	N/A	32.00	73.90	107.26	241.68	108.49	143.57
6) Program cost as percentage of national budget[ƚ]	N/A	N/A	N/A	N/A	6.8%	8.2%	16.2%	6.5%	8.0%

[¥] From Mason and Ricker-Gilbert 2013 p. 78; [ƚ] from Chirwa and Dorward 2013 p. 122-123

Table 2. Correlation Between Number of Vouchers and Kilograms of Subsidized Fertilizer Acquired (by Year)

Year	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	6 year average
Correlation	0.572	0.515	0.277	0.860	0.599	0.953	0.629

Note: N=462

Table 3: Descriptive Statistics (by Survey Wave)

	2002/03/04		2006/07		2008/09		2010/11	
Variables	mean	median	mean	median	mean	median	mean	median
maize production in kg	605	327	650	373	716	467	818	525
tobacco production in kg	15	0	58	0	106	0	97	0
maize area in ha	0.75	0.61	0.81	0.61	0.78	0.61	0.75	0.61
Kg commercial fertilizer yr t	77	0.00	18	0.00	60	0.00	74	15
Kg subsidized fertilizer yr t	19	0.00	76	50	66	50	54	50
Number of subsidized fertilizer vouchers yr t	0.40	0.00	1.28	1	1.28	1	1.06	1
=1 if household owns cattle or goats	0.31	-	0.29	-	0.35	-	0.35	-
avg number of weedings on maize plots	-	-	1.97	2.00	1.67	2.00	1.74	2.00
=1 if farm credit in village	0.33	-	0.33	-	0.32	-	0.27	-
distance to paved road in km	16.63	10.00	17.07	12.00	16.92	12.00	16.43	10.00
distance to main district market in km	39.13	30.00	39.06	30.00	39.53	32.00	38.71	30.00
=1 if HH plants improved maize seed	0.53	-	0.58	-	0.69	-	0.80	-
Household landholding in ha	1.07	0.81	0.98	0.81	1.12	0.81	1.17	0.81
age of HH head, first wave	46.30	44.00	45.53	43.00	44.78	42.00	44.24	41.00
=1 if HH head attended school, first wave	0.73	1.00	0.73	1.00	0.73	1.00	0.85	1.00
=1 if HH head is female	0.27	0.00	0.30	0.00	0.32	0.00	0.31	0.00
adult equivalents	3.68	3.52	3.95	3.72	4.16	3.92	4.17	4.08
=1 if head or spouse did in past year	0.02	0.00	0.04	0.00	0.03	0.00	0.05	0.00
retail maize price, last harvest, kwacha/kg, real	23	23	26	27	45	44	32	32
retail maize price, last hungry season, kwacha/kg, real	46	49	56	55	44	45	44	43
retail NPK and Urea price, kwacha/kg, real	73	72	93	91	160	153	97	100
agricutlural wage rate, kwacha/day, real	173	194	164	159	331	284	243	214
commercial seed cost, kwacha/kg, real	-	-	118	108	198	192	40	40
cumulative rainfall during growing season, in mm	798	758	830	815	770	756	935	936
Average growing season rainfall, past 5 years in mm	856	856	821	816	823	820	860	862
Coefficient of variation on average growing season rainfall, past 5 years in cm	0.14	0.14	0.12	0.12	0.11	0.12	0.99	0.94
kilograms of subsidized fertilizer distributed to district/ per rural hh	5.40	5.18	69.35	65.40	100.29	102.29	79.65	77.91

Note: N= 1,848 (462 observations per wave, balanced); real values are in 2011 Malawi Kwacha; US $1.00 = 151.55 Malawi Kwacha during 2010/11 (Chirwa and Dorward 2013).

Table 4: Factors Affecting Commercial Fertilizer Demand (Crowding out/Crowding in)

	(1)			(2)			(3)			(4)		
Dep. Var.: Kilograms of commercial fertilizer purchased	contemporaneous			year t-1			year t-2			year t-3		
Covariates	Coeff.		P-value	Coeff.		P-value	Coeff.		P-value	Coeff.		P-value
Kg subsidized fertilizer acquired in yr t	-0.286	*	(0.059)	-0.149		(0.283)	-0.158		(0.146)	-0.073		(0.456)
Kg subsidized fertilizer acquired in yr t-1				0.038		(0.245)						
Joint effect: (Kg subsidized fertilizer acquired in yr t-1 + t-2)[¥]							-0.021		(0.770)			
Joint effect: (Kg subsidized fertilizer acquired in yr t-1 + t-2 + t-3)[¥]										0.200**		(0.041)
Total land owned by household in ha	9.591	***	(0.016)	2.371		(0.714)	5.233		(0.452)	4.905		(0.460)
=1 if household headed by female	-17.629		(0.442)	-35.253		(0.257)	-34.373		(0.270)	-41.201		(0.175)
Household adult equivalents	16.747	**	(0.026)	6.109		(0.149)	6.300		(0.157)	8.152	*	(0.068)
=1 if household head or spouse died in last two years	-32.674		(0.416)	41.909		(0.221)	38.960		(0.315)	62.392	*	(0.060)
=1 if farm credit organization in village[†]	0.300		(0.921)	-0.382		(0.906)	0.165		(0.959)	-0.551		(0.843)
Distance to nearest paved road (in km)[†]	-0.110		(0.419)	-0.019		(0.887)	-0.016		(0.897)	-0.022		(0.841)
Distance to main district market (in km)[†]	0.005		(0.945)	0.001		(0.984)	-0.004		(0.955)	-0.023		(0.666)
Previous hungry season retail maize price kw/kg, real 2011 kwacha	3.331	*	(0.052)	-1.228		(0.596)	-1.079		(0.652)	-1.399		(0.530)
Ag. labor wage rate kw/day, real 2011 kwacha	0.030		(0.160)	0.010		(0.655)	0.013		(0.652)	0.004		(0.868)
Commercial price of NPK & Urea, kw/kg, real 2011 kwacha	0.259		(0.249)	0.161		(0.392)	0.135		(0.493)	0.281		(0.140)
Price of commercial seed kw/kg, real 2011 kwacha				0.270	**	(0.039)	0.269	**	(0.043)	0.201	*	(0.072)
Avg. rainfall over past 5 yrs (in mm)	-0.246		(0.468)	0.335		(0.509)	0.179		(0.677)	-0.340		(0.442)
CV of average past rainfall	213.043		(0.577)	-479.128		(0.343)	-423.093		(0.447)	-332.853		(0.475)
N		1,848			1,386			1,386			1,386	
R-squared (correlation squared)		0.537			0.619			0.624			0.810	

Note: models estimated via truncated normal hurdle, with Mundlak-Chamberlain device; coefficient estimates are average partial effects (APE); 20 observations drop when calculating APE's in column 2, 4 observations drop when calculating APE in column 3; models include time averages of all time-varying explanatory variables (APEs not shown); ***, **, * denotes that coefficients are significant at 1%, 5% and 10% level respectively; standard errors clustered at household level; [¥] inidicates that standard errors obtained via bootstrapping at 500 repetitions.

Table 5. Factors Affecting Maize Production

Dep. Var.: kilograms of maize produced	(1) contemporaneous		(2) year t-1		(3) year t-2		(4) year t-3	
Covariates	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)
kg of total fert. in yr t	1.53*** (0.000)	1.40*** (0.000)	1.33*** (0.002)	1.26*** (0.003)	1.61*** (0.000)	1.55*** (0.000)	1.65*** (0.000)	1.58*** (0.001)
kg of total fert. in yr t-1			-0.35 (0.220)	-0.37 (0.187)				
kg of total fert. in yrs (t-1 + t-2)[¥]					0.35 (0.370)	0.34 (0.414)		
kg of total fert. in yrs (t-1 + t-2 + t-3)[¥]							0.24 (0.595)	0.24 (0.601)
=1 if household owns cattle or goats		65.14 (0.177)		86.75 (0.130)		73.59 (0.200)		74.88 (0.196)
=1 if hh plants improved maize seed		115.28* (0.072)		110.97 (0.140)		105.2 (0.160)		102.23 (0.180)
number of weedings on maize plots		- -		43.11 (0.238)		44.61 (0.223)		43.69 (0.226)
Total land owned by household in ha		87.65** (0.047)		59.01 (0.266)		61.9 (0.199)		61.29 (0.208)
=1 if household headed by female		-10.36 (0.852)		19.3 (0.739)		21.94 (0.709)		21.55 (0.714)
Household adult equivalents		21.73 (0.201)		20.67 (0.351)		15.12 (0.484)		15.98 (0.464)
=1 if adult death in last 2 years		39.62 (0.795)		109.42 (0.426)		114.95 (0.409)		117.92 (0.394)
Cum. growing season rainfall (in mm)		0.15 (0.701)		0.56 (0.245)		0.74 (0.105)		0.74 (0.106)
Subsidized fertilizer indirect partial effect[¥]								
Kg sub. fert.in yr t	1.15*** (0.001)	1.00*** (0.000)	1.13** (0.021)	1.07** (0.029)	1.36*** (0.006)	1.31*** (0.009)	1.53*** (0.004)	1.46*** (0.007)
Kg sub. fert. in yr t-1			-0.36 (0.424)	-0.38 (0.385)				
Kg sub. fert. in yrs (t-1 + t-2)					0.31 (0.521)	0.31 (0.551)		
Kg sub. fert. in yrs (t-1 + t-2 + t-							0.18 (0.779)	0.18 (0.781)
Observations		1,386	924	924		924	924	924
R-squared		0.141	0.086	0.106		0.107		

Note: ***, **, * denotes that coefficients are significant at 1%, 5% and 10% level respectively; standard errors clustered at household level; all specifications include year dummies and a constant that are not shown; standard errors clustered at household level; [¥] inidicates that standard errors obtained via bootstrapping at 500 repetitions.

Appendix 1a. Reduced form Model of Subsidized Fertilizer Acquistion

Dep. Var. = Kilograms of subsidized inorganic fertilizer acquired			
Covariates	Coeff.		P-value
kilograms of subsidized fertilizer distributed to district/ per rural hh	0.33	***	(0.001)
=1 if farm credit organization in village[†]	3.51		(0.217)
Distance to nearest paved road (in km)[†]	0.17		(0.110)
Distance to main district market (in km)[†]	0.07		(0.156)
Total land owned by household in ha	4.43	***	(0.003)
=1 if household headed by female	4.05		(0.421)
Household adult equivalents	0.01		(0.991)
=1 if household head or spouse died in last two years	-0.07		(0.992)
Previous hungry season retail maize price kw/kg, real 2011 kwacha	-0.62		(0.150)
Commercial price of NPK & Urea, kw/kg, real 2011 kwacha	-0.07		(0.189)
Avg. rainfall over past 5 yrs (in mm)	0.15	**	(0.032)
CV of average past rainfall	-225	**	(0.016)
N		1,848	
R-squared		0.03	

Note: models estimated via tobit, with Mundlak-Chamberlain device; models include time averages of all time-varying explanatory variables and year dummies (coefficient estimates not shown); ***, **, * denotes that coefficients are significant at 1%, 5% and 10% level respectively; standard errors clustered at household level.

Appendix 1b. Factors Affecting Area Planted to Maize.

Dep. Var.: Area planted to maize in hectares	(1) contemporaneous		(2) year t-1		(3) year t-2		(4) year t-3	
Covariates	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)
kg of total fert. in yr t*100	0.062***(0.001)	0.028* (0.099)	0.053*** (0.003)	0.030* (0.050)	0.058*** (0.002)	0.036* (0.057)	0.057*** (0.003)	0.035* (0.069)
kg of total fert. in yr t-1*100			0.013 (0.116)	0.008 (0.222)				
kg of total fert. in yrs (t-1 + t-2)*100¥					0.025 (0.138)	0.021 (0.287)		
kg of total fert. in yrs (t-1 + t-2 + t-3)*100¥							0.026 (0.119)	0.025 (0.218)
=1 if household owns cattle or goats		0.662 (0.874)		0.038 (0.455)		0.035 (0.485)		0.035 (0.492)
=1 if hh plants improved maize seed		0.076** (0.022)		0.046 (0.183)		0.045 (0.189)		0.046 (0.181)
Total land owned by household in ha		0.326*** (0.001)		0.255** (0.010)		0.256***(0.009)		0.256***(0.009)
=1 if household headed by female		-0.009 (0.826)		-0.008 (0.869)		-0.008 (0.875)		-0.007 (0.879)
Household adult equivalents		0.016 (0.282)		0.023 (0.239)		0.021 (0.256)		0.021 (0.265)
=1 if adult death in last 2 years		0.037 (0.629)		-0.012 (0.902)		-0.011 (0.911)		-0.012 (0.900)
Avg cum. rainfall, past 5 seasons (in mm)		0.002*** (0.003)		0.001 (0.313)		0.001 (0.273)		0.001 (0.274)
CV. avg cum. rainfall, past 5 seasons		0.172 (0.832)		-0.273 (0.839)		-0.177 (0.897)		-0.161 (0.907)
Subsidized fertilizer indirect partial effect¥								
Kg sub. fert. in yr t*100	0.047***(0.009)	0.020 (0.171)	0.045 (0.056)	0.026 (0.161)	0.049** (0.029)	0.030 (0.141)	0.053** (0.026)	0.032 (0.148)
Kg sub. fert. in yr t-1*100			0.013 (0.377)	0.008 (0.516)				
Kg sub. fert. in yr (t-1 + t-2)*100					0.025 (0.276)	0.021 (0.392)		
Kg sub. fert. in yr (t-1 + t-2 + t-3)*100							0.031 (0.188)	0.026 (0.302)
Observations	1,386	1,386	924	924	924	924	924	924
R-squared	0.047	0.297	0.047	0.234	0.048	0.236	0.048	0.236

Note: ***, **, * denotes that coefficients are significant at 1%, 5% and 10% level respectively; standard errors clustered at household level; all specifications include year dummies and a constant that are not shown; standard errors clustered at household level; ¥ inidicates that standard errors obtained via bootstrapping at 500 repetitions.

Appendix 2a. Factors Affecting Area Planted to Maize (Subsidy Treatment Measured as Number of Fertilizer Vouchers Aquired)

	(1) contemporaneous		(2) year t-1		(3) year t-2		(4) year t-3	
Dep. Var.: Area planted to maize in hectares *Covariates*	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)
Number of fertilizer vouchers acquired in yr t	0.11***	0.05**	0.093***	0.05*	0.010***	0.07*	0.10***	0.08*
	(0.000)	(0.042)	(0.000)	(0.051)	(0.000)	(0.086)	(0.000)	(0.066)
Number of fertilizer vouchers acquired in yr t-1			0.02	0.03				
			(0.379)	(0.246)				
Number of fertilizer vouchers acquired in yrs (t-1 + t-2)					0.03	0.056		
					(0.238)	(0.138)		
Number of fertilizer vouchers acquired in yrs (t-1 + t-2 + t-3)							-0.02	0.030
							(0.671)	(0.647)
=1 if household owns cattle or goats		0.01		0.04		0.04		0.04
		(0.825)		(0.464)		(0.448)		(0.446)
=1 if hh plants improved maize seed		0.06**		0.03		0.02		0.02
		(0.048)		(0.415)		(0.469)		(0.455)
Total land owned by household in ha		0.33***		0.26**		0.26***		0.26***
		(0.001)		(0.010)		(0.004)		(0.004)
=1 if household headed by female		-0.01		-0.02		-0.02		-0.02
		(0.774)		(0.679)		(0.712)		(0.694)
Household adult equivalents		0.02		0.02		0.02		0.02
		(0.282)		(0.257)		(0.282)		(0.285)
=1 if household head or spouse died in last two years		0.02		-0.02		-0.01		-0.00
		(0.842)		(0.855)		(0.941)		(0.971)
Avg cumulative rainfall, past 5 growing seasons (in cm)		0.00**		0.00		0.00		0.00
		(0.020)		(0.553)		(0.672)		(0.643)
CV of avg cumulative rainfall, past 5 growing seasons (in cm)		0.24		-0.40		-0.18		-0.15
		(0.773)		(0.762)		(0.898)		(0.916)
Observations	1,386	1,386	924	924	924	924		924
R-squared	0.050	0.306	0.042	0.234	0.042	0.239		0.240

Note: P-values in parentheses; ***, **, * denotes that coefficients are significant at 1%, 5% and 10% level respectively; standard errors clustered at household level; all specifications include year dummies and a constant that are not shown; 1 fertilizer voucher = 50 kilograms of subsidized fertilizer officially.

Appendix 2b. Factors Affecting Maize Production (Subsidy Treatment Measured as Number of Fertilizer Vouchers Aquired)

Dep. Var.: Area planted to maize in hectares	(1) contemporaneous		(2) year t-1		(3) year t-2		(4) year t-3	
Covariates	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)	(parsimonious)	(full)
Number of fertilizer vouchers acquired in yr t	127.01***	99.45**	128.20***	110.40***	172.77***	160.87***	174.10***	161.68***
	(0.002)	(0.013)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Number of fertilizer vouchers acquired in yr t-1			-31.17	-38.48				
			(0.489)	(0.381)				
Number of fertilizer vouchers acquired in yrs (t-1 + t-2)					25.12	25.64		
					(0.632)	(0.636)		
Number of fertilizer vouchers acquired in yrs (t-1 + t-2 + t-3)							10.62	17.07
							(0.874)	(0.802)
=1 if household owns cattle or goats		93.42*		115.53*		120.10*		120.06*
		(0.083)		(0.086)		(0.079)		(0.079)
=1 if hh plants improved maize seed		98.66		91.93		84.56		84.80
		(0.111)		(0.223)		(0.265)		(0.259)
number of weedings on maize plots				44.48		44.12		44.01
				(0.253)		(0.254)		(0.253)
Total land owned by household in ha		131.26**		70.42		81.46*		81.03*
		(0.014)		(0.201)		(0.093)		(0.095)
=1 if household headed by female		-20.76		12.30		15.90		15.55
		(0.710)		(0.828)		(0.780)		(0.786)
Household adult equivalents		29.00*		20.50		17.90		17.85
		(0.089)		(0.329)		(0.390)		(0.390)
=1 if household head or spouse died in last two years		-54.92		78.32		103.45		104.65
		(0.726)		(0.541)		(0.433)		(0.429)
Cumulative rainfall over groing season (in cm)		0.19		0.54		0.60		0.60
		(0.619)		(0.245)		(0.190)		(0.190)
Observations	1,386	1,386	924	924	924	924	924	924
R-squared	0.031	0.060	0.027	0.044	0.035	0.055	0.035	0.055

Note: P-values in parentheses; ***, **, * denotes that coefficients are significant at 1%, 5% and 10% level respectively; standard errors clustered at household level; all specifications include year dummies and a constant that are not shown; 1 fertilizer voucher = 50 kilograms of subsidized fertilizer officially.

[1] Crowding out occurs when households that acquire subsidized fertilizer use it in place of commercial purchases that they otherwise would have made. Crowding in occurs when households that acquire subsidized fertilizer purchase additional commercial fertilizer with the savings.

[2] The IPW technique involves three steps: (i) use probit to measure whether observable factors in one wave affect whether a household is re-interviewed in the next wave; (ii) obtain the predicted probabilities (Pr_{it}) of being re-interviewed in the following wave; (iii) compute the IPW = ($1/Pr_{it}$) and apply it to all models estimated. For households originally sampled in the first survey (IHS2), the IPW for household i in the second survey (AISS1)=$1/Pr_{iAISS1}$. The IPW for being interviewed in the third survey (AISS2) = $1/(Pr_{iAISS1}*Pr_{iAISS2})$, while the IPW for being interviewed in the fourth survey (AISS4) = $1/(Pr_{iAISS1}*Pr_{iAISS2}* Pr_{iAISS4})$. (For more information on IPW see Wooldridge 2010). The IPW is multiplied by the sampling weights to account for the probability that a household is randomly selected for interview from the population.

[3] Household input use and production on maize plots are aggregated into a household level production function. We do this because fertilizer acquisition in years where no survey occurred are recorded as recall transactions at the household-level. Therefore, there would be no way to differentiate lagged fertilizer effects at the plot level to meaure possible enduring benefits. The average household in our sample had 1.44 maize plots in the first wave (2002/03) and 2.34 maize plots in 2010/11. Results are similar to those presented in this article when a plot level analysis is conducted measuiring only contemporaneous fertilizer use.

[4] We tested numerous lag structures for the fertilizer covariate, such as allowing j to vary from 1 to 5, and only including j=2, 3 in the model to account for longer than a one year enduring effect. Non of these alternative specifications generated statistically significant coefficient estimates on the lagged fertilizer covariates, so we focus on the specification presented in equation 3. Results from the alternative lag structures are available from the authors upon request.

[5] Additional heterogeneity in soil quality on household plots is controlled for by estimating the production function via household-level first difference. Doing so removes soil quality heterogeneity from the model to the extent that

it is time constant at the household and plot level. This estimation strategy is discussed in detail in the identification strategy section.

[6] While improved seed is part of the FISP program in Malawi, we focus our empirical estimation on fertilizer because it represents the vast majority of program expenditure. Malawi spent $600.47 million acquriring subsidized fertilizer between 2005/06 and 2010/11, compared to US $55.91 million spent acquiring maize seed over the same period (Chriwa and Dorward, 2013). Explicitly considering subsidized seed would complicate the analysis by introducing the need to deal with an additional potentially endogeneous variable. For these reasons we simply include the binary variable =1 if the household plants improved seed. From testing multiple specifications we find no evidence of a statistically significant interaction effect between hybrid seed and fertilizer.

[7] Number of weedings is not included as a covariate in the maize area planted equation because weeding occurs after planting.

[8] The TNH is a type of double-hurdle model.

[9] In our sample 60% of the observations do not purchase commercial fertilizer.

[10] The tobit model is another type of corner solution model that could potentially be used in this application. The TNH is different from the tobit because the TNH allows for different factors to potentially affect step 1 and step 2. In addition, the THN model allows for the same factor to affect step 1 and step 2 in different ways. The TNH can be compared to the tobit model using a likelihood-ratio test. In this article the LR test indicates that the tobit model is rejected in favor of the TNH at the 0.00 percent level. This indicates that the commercial fertilizer demand model should be estimated in two steps.

[11] The Mundlak-Chamberlain device is sometimes also referred to as correlated random effects (CRE).

[12] Because we lack data on lagged quantities of fertilizer before the first survey wave, the econometric analysis measuring the enduring effect of fertilizer on maize production in this article uses data from waves 2, 3, and 4 only.

[13] The increase in maize area likely comes from reduction in area planted to crops other than maize and tobacco as area planted to other crops declined from 0.11 ha in wave 1 to 0.05 ha in wave 3. Area planted to other crops rebounds to its pre-FSP level of 0.11 ha (numbers not shown in table 1).

[14] A contemporaneous fertilizer crowding out rate of -0.15 to -0.30 covers the range estimated in several studies including the present study along with Ricker-Gilbert, Jayne and Chirwa 2011; Jayne et al. 2013; and Dorward and Chirwa 2013.

[15] The lower bound estimate assumes a contemporaneous crowding out rate of -0.15, (-0.15*3 + 0.2) = -0.25; while the upper bound estimate assumes a contemporaneous crowding out rate of -0.30, (-0.30*3 + 0.2) = -0.70.