Amazing maize in Malawi: Input subsidies, factor productivity and land use intensification

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Input subsidies, factor productivity and land use intensification

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ABSTRACT. *The paper uses three years of household farm plot panel data (2006-2009), covering six districts in central and southern Malawi to assess factor productivity and farming system development under the input subsidy program. All farm plots of the households were measured with GPS. Maize production intensified in this period as maize area shares of the total farm size were reduced while input use intensity and yields increased. Yields of improved maize were significantly (+323 kg/ha) higher than for local maize. Improved maize seeds were used on only half of the maize plots that received subsidized fertilizer causing fertilizer use inefficiency*.

Key words: *Maize, Malawi, improved varieties, input subsidies, fertilizer use efficiency, land productivity, farming system changes.*

JEL:Q16, Q18.

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I. Introduction

Growing land scarcity in parts of Africa is making further land expansion difficult and therefore necessitating land use intensification under continuing population growth if self-sufficiency in food production is an objective. In fact, food imports have been on the increase due to rapid increase in urban populations and shift in demand towards rice and wheat, based on increasing imports (Jayne and Jones, 2010). Inequitable distribution of land within the smallholder sector combined with population growth pushes towards growing landlessness. Limited off-farm employment opportunities further threaten the food entitlements of the near landless and growing landless population. Higher international food and oil prices increase the cost of food import but also fertilizer prices have increased and made it more costly to intensify production.

The general perspective on cereal production in Sub-Saharan Africa (SSA) is that it has been stagnant or declining since 1970s (De Groote et al 2002; Minot et al. 2007) and it has been questioned why the Green Revolution (GR) did not bring sustainable yield increases to SSA. Production has increased at about the same rates as population growth and primarily through area expansion rather than through land use intensification (WDR 2008). The commonly identified reasons for its lack of success have been the high cost of fertilizer due to poor infrastructure, lack of water and irrigation infrastructure, low population density making area expansion rather than area intensification feasible and more profitable (Boserup 1965; Hayami and Ruttan 1971; Ruthenberg 1980), weak institutions relative to in countries where the GR succeeded (Minot et al. 2007; Lipton 2007).

However, there are also some GR successes in Africa. Maize has been the most successful crop in terms of adoption rates although these rates vary a lot across countries and over time (Byerlee and Heisey 1996; De Groote et al. 2002; Alene et al. 2009).

Maize is the most important staple food crop in Africa (Byerlee and Heisey 1996). This is particularly the case in Eastern and Southern Africa where it contributes 50% or more of calories provided by starchy staples (and over 80% in Malawi) and is the dominant crop in many of the farming systems (Byerlee and Heisey 1996). Maize production has also expanded at the expense of other cereal crops such as millet and sorghum and its share of cereal production has therefore increased. De Groote et al. (2002) also show that maize production and yields increased in East Africa, with yields of 1 ton/ha in 1960s to 1.5 tons/ha in the 1980s. They found, however, that the adoption process stalled in Kenya and Tanzania, while it expanded in Ethiopia in the 1990s but faced price collapses in 1997 and 2001 that affected adoption rates. Alene et al. (2009) found that adoption of improved maize varieties in West and Central Africa increased from less than 5% in the 1970s to 60% in 2005 and with significant poverty reduction effects.

Hybrid varieties (HYV) of maize were first developed for commercial farmers in Kenya, Zimbabwe and South Africa and were later adopted also by smallholders. Improved open-pollinated varieties (OPVs) were developed later and were intended for smallholders to allow them to recycle the seeds. Byerlee and Heisey (1996) estimated that 33-50% of the maize area was planted with improved maize in the middle of the 1990s. HYVs were estimated to have 30% higher yields and OPVs 14-25% higher yields than local maize.

Malawi experienced a rapid increase in the adoption of hybrid maize in the late 1980s after some flint-type HYVs were distributed and that had better storability properties than the dent-type

HYVs that were available before that (Kydd 1989; Smale et al. 1993). HYVs accounted for 50% of maize production in 1992 (Smale and Heisey 1994). However, the smallholder credit system collapsed after that after a couple of drought years in 1992 and 1994 combined with political promises to write off loan debt during the election year (1994) (Zeller et al. 1997). From the late 1990s the Starter Pack and the targeted input subsidy program came as a substitute for the credit program that collapsed in Malawi.

Malawi experienced how difficult it can be to be food deficient and dependent on food aid after severe droughts in 2004-2005. The country therefore embarked on a large scale input subsidy program to boost national maize production to reduce national and household food insecurity and dependency on food aid. The new policy was successful in increasing maize production and the country has for several years even produced a surplus of maize for export to neighboring countries (Dorward and Chirwa 2011).

Smallholder maize production in Malawi has been stimulated through a targeted input subsidy program in a context with land-scarce smallholders highly dependent on maize production to meet their staple food needs. Most households face limited access to off-farm employment and constrained access to input subsidies.

The rural population in Malawi constitutes 88% of the total population and the country has one of the highest rural population densities in Africa of about 2.3 persons per ha. The average farm size is about 1.12ha (SOAS 2008) making it very difficult to increase food production through area expansion. In this context land use intensification is imperative for agricultural development and food security. This study aims to investigate how successful the input subsidy program has been in achieving land use intensification. The specific objectives are to assess whether access to improved maize varieties and subsidized mineral fertilizer has; a) contributed to land use intensification through an increase in maize yields; b) enhanced land and fertilizer use efficiency; and d) affected maize area, maize area shares on farms and the integration of maize and other crops in the farming system.

These issues are investigated by use of farm household and plot level panel data from two districts in central Malawi (Kasungu and Lilongwe) and four districts in southern Malawi (Chiradzulu, Machinga, Thyolo and Zomba) for the years 2006, 2007 and 2009. The three years of data cover the period after the subsidy program was implemented and can therefore not provide a comparison with the situation before the program was introduced. However, the degree of exposure to the program varies across households because of its targeting characteristics causing some households to be rationed out. We draw on targeting errors in the program as one way of teasing out its impacts. We combine non-parametric and parametric methods in our analyses. The panel nature of the data allows us to use household fixed effects to control for unobservable household and farm characteristics that do not vary over time.

Byerlee and Heisey (1996) made an economic analysis of alternative maize technologies in Malawi assuming that hybrid maize with 145 kg fertilizer nutrients per ha would give a maize yield of 2400 kg/ha while local maize with 55 kg fertilizer nutrients per ha would give a maize yield of 750 kg/ha. We found that improved maize varieties on average gave 323 kg/ha more than local maize based on 1750 farm plot observations (where plot size was measured with GPS) over three years after controlling for differences in fertilizer use intensity and farm plot characteristics. The average yield for local maize was 1451 kg/ha and 1774 kg/ha for improved maize. About 50% of the maize plots receiving subsidized fertilizer and 75% of the plots not receiving subsidized fertilizer were planted with local maize, showing that fertilizer use efficiency in the subsidy program could have been substantially improved by ensuring that all households that received subsidized fertilizers also received a complementary amount of improved seeds. We demonstrate with lowess regressions between maize/fertilizer ratios and fertilizer/land ratios that improved maize outperforms local maize at lower fertilizer levels but also that the performance is poorer on plots receiving subsidies than on plots not receiving subsidies.

Recent studies in Malawi have shown that fertilizer subsidies have crowded out the demand for commercial fertilizer such that 1 kg of subsidized fertilizer resulted in 0.18-0.3 kg reduction in the demand for commercial fertilizer (Ricker-Gilbert and Jayne 2011). Holden and Lunduka (2012a) found that 1% increase in fertilizer use was associated with a 1.9% increase in manure use outside the subsidy program and a 0.6-1.7% increase in manure use with the subsidy program, thus the subsidy program does not crowd out organic manures. Chibwana et al. (2012) found a positive correlation between participation in the input subsidy program and the amount of land planted with maize in Malawi using cross-section data from two districts, suggesting that households with access to subsidies allocated less land to other crops. We are able to assess this finding using household and farm plot panel data from six districts in Central and Southern Malawi covering the years 2005/06, 2006/07 and 2008/09. Contrary to Chibwana et al. we find that the input subsidy program was associated with land use intensification in this period when the subsidy program was scaled up such that maize yields increased and the area share under maize declined significantly after controlling for selection associated with unobservable household and farm characteristics using household fixed effects. Furthermore, we find that intercropping of maize with other crops is more common on plots that received fertilizer than plots that did not receive fertilizer and the probability of intercropping increased with increasing land scarcity.

II. Data and methods of analysis

Data

Farm household and plot level data for the growing seasons 2005/06, 2006/07, and 2008/09 have been used. The survey covered 450 households in two districts in Central Malawi (Kasungu and Lilongwe) and four districts in Southern Malawi (Chiradzulu, Machinga, Thyolo, and Zomba) (Lunduka 2010). Some additional recall data for the production year 2007/08 were collected in the third round. Only 378 of the initial 450 households were found and interviewed in the third round.

About 89% of the Malawian population lives in Central and Southern Malawi. Our survey should therefore be fairly representative of a large share of the population in the most densely populated parts of the country.

Unlike the larger national farm household surveys in Malawi our survey included collection of plot level data by visiting and measuring each plot with a GPS. Plot sizes should therefore be fairly reliable and much more reliable than if one had to rely on households' own estimates of plot sizes. Another unique attribute of the survey, which is different from some other surveys in Malawi, is that we collected information from all plots of the households. The national surveys have collected information from only one plot, the maize plot of the households surveyed. Our data are therefore better suited to assess the whole cropping system of the households. Detailed data for all inputs and outputs from all plots allow us to study issues like input substitution, intercropping and land use intensification.

A farm plot was defined as an area of land with a unique cropping and management approach. This implied that each parcel was separated into plots if crop choice (and mix) varied across the parcel and input use varied significantly. We can therefore separate plots that did not use fertilizer, that used different maize varieties and that used different intercrops or were mono-cropped.

This gives a three round unbalanced panel of household and plot level data that can be used to assess the performance of the fertilizer subsidy program and improved maize seeds. The household and plot panel nature of the data allow us to control for observable and unobservable household and farm plot characteristics by using household fixed effects models. Access to improved seeds and subsidized fertilizers also varied within households over time.

Estimation

Propensity score matching on all maize plot observations was used to control for observable farm plot characteristics, input levels of fertilizer and manure, district and year dummies. The propensity score logit model results are presented in Appendix Table A1. The balancing requirement was satisfied. Kernel matching was used to compare yields of HYV and local maize by year and for all years jointly for the sample that satisfied the common support requirement.

Parametric regressions were used on the balanced sample of plot observations satisfying common support, using linear and Cobb-Douglas models with household fixed effects to control for unobservable household and farm characteristics that do not vary over time. The models are specified as follows;

$$(1)\quad Y_{pit} = a_0 + a_1 + a_2 H_{it} + a_3 L_{it} + a_4 S_{pit} + a_5 P_{pit} + a_6 F_{pit} + \hat{e}_{pit} + \hat{e}^{2}_{pit} + a_7 D_t + \mu_i + u_{pit}$$

Y_{pit} is the plot level land productivity per unit land, H_{it} is a vector of observable time-varying household characteristics (only included in some of the models) including sex and age of the household head, labour endowment, and value asset of endowments, L_{it} is a vector of farm characteristics including farm size and livestock endowment on the farm, S_{pit} is capturing plot level use of subsidized inputs (specified in the next paragraph), P_{pit} is a vector of farm plot characteristics including plot size, distance to plot from home, and observable land quality variables, P_{pit} is plot level fertilizer use intensity, $\hat{e}_{pit}$ is the error term from a fertilizer use intensity tobit model (control function approach including the error and squared error) to control for endogeneity of fertilizer use intensity, D_t represents two time period dummies, μ_i captures unobservable time-invariant household and farm characteristics and u_{it} is the random error component.

The problem with the subsidy variables is that they are endogenous. While a control function approach was used to control for endogeneity in the intensity of fertilizer use, a linear probability model with household fixed effects was used to predict the likelihood of households or plots receiving subsidized (coupon) fertilizer (including the unobserved household effect in the prediction). Four categories of observations for plots were derived:

a) Subsidy01: Have not received subsidy but was predicted to get
b) Subsidy11: Received subsidy and was predicted to get (used as “baseline”)
c) Subsidy10: Received subsidy and was not predicted to get
d) Subsidy00: Did not receive subsidy and was not predicted to get.

With clear targeting criteria based on household characteristics these four variables should capture errors of exclusion and errors of inclusion and we may expect systematic differences between these four groups and these differences may also have implications for the impacts. With unclear targeting criteria that vary across communities and years it is possible that such differences will be insignificant. Dorward and Chirwa (2011) and Holden and Lunduka (2012b) have shown that the targeting criteria, emphasizing targeting of resource-poor households, were not followed strictly and resource-poor households such as female-headed households were less likely to access subsidized inputs.

We do not know why some were more successful and others less successful in obtaining the subsidy coupons. Some insights may be obtained by correlating observable household characteristics with access to coupons. Unobservable household characteristics possibly affecting access include their social networks, position, influence, kinship ties, information available and decisions made by those responsible for the targeting. Actual targeting criteria may be different from the official targeting criteria which relate to poverty, vulnerability etc. Our method of classifying households and plots is pragmatic about what causes some households or plots to be recipients and others not as it “mines the data” including unobservable household characteristics (captured by household dummy variables). By predicting the probability of households and plots getting subsidies in each year, “errors of exclusion” were identified as those that were predicted (with probability higher than 50%) to receive but not having received subsidized fertilizer. Similarly, household or plots predicted not to get (with predicted probability less than 50%) but receiving were classified as “errors of inclusion” based on the actual pattern of distribution. The method allows different mechanisms to be at work in the distribution in each community. For example, a household that received coupons in 2 out of 3 years is more likely to be predicted as a recipient than one household that received coupons in only one or none of the years. Based on the “local standard” established over three years, the household that received coupons in two years is representing an “error of exclusion” in the third year when it did not receive, if it is predicted to receive with a probability higher than 0.5 in the year it did not receive.

A simple approach to assessing the impact of the program would be to measure:

i) Subsidy11 – Subsidy01: Impact of access for household predicted to receive subsidy

ii) Subsidy10 – Subsidy00: Impact of access for households predicted not to receive subsidy

This relies on the assumption that the approach allows us to remove differences due to unobserved heterogeneity. These effects will only be significant if the subsidy effect goes beyond the effect on fertilizer used efficiency.

Identification of these effects relies on there being variables included in the first stage that are excluded and with no direct effect in the second stage. We have not been able to identify any good instruments that we are confident can predict subsidy access without affecting the outcome (second stage error term). Rather we rely on our ability to control for endogeneity by use of household fixed effects and the predicted variables where non-linearities in addition may contribute to the identification. A better strategy rests on the ability to identify a household level time-varying variable that is correlated with subsidy access or fertilizer use while it is uncorrelated with the outcome of subsidy access or fertilizer use in a theoretical as well as empirical sense. Our inability to identify such variable(s) implies that our results need to be interpreted cautiously as correlations and only tentatively as impacts (under strong assumptions).

For improved maize we rely on the assumption that endogeneity in relation to access to such seeds was driven by the same factors as those for subsidized fertilizer and that the control function approach and predicted fertilizer subsidy use variables also have controlled for endogeneity in access to improved seeds. Our data indicate that “improved seed adoption” is by no means a one-way process for non-adopter to adopter during the time period for which we have data. The large majority of households have “adopted” hybrid maize in one or two out of the three years and for some of their plots only, possibly indicating that adoption to large extent is a question of access in a specific year and access in sufficient quantity. Our data are, however, not good enough to separate the supply and demand side factors associated with access and adoption. We leave this for future research.

The strength of our data and approach is that we have multiple observations from each household in each year with alternative maize varieties since access constraints cause partial adoption of improved maize within a year and switching in and out of improved maize over time for a large share of the sample, partly depending on more or less unreliable access to subsidized fertilizers and seeds in limited quantities.

The following model was used to identify factors that were significantly associated with maize area and maize area share of total farm size.

$$(2)\quad A_{it} = a_0 + a_1 S_{it} + a_2 L_{it} + a_3 H_{it} + a_4 D_t + \mu_i + u_{it}$$

A_{it} is the area under maize in ha or maize area share of total farm size of household i in year t. S_{it} is a vector for predicted and actual subsidy access at household level. The same method as used in the plot level analysis was applied at the household level. One basic hypothesis would be that access to subsidies increases the area under maize (Chibwana et al. 2012). An alternative hypothesis is that access to subsidies facilitates area intensification such that the maize area needed to meet subsistence requirements is reduced with access to subsidies. L_{it} is a vector of farm characteristics including farm size and livestock endowment on the farm. We expect maize area to increase with farm size but potentially to be reduced by livestock endowment if livestock compete for land and manure from livestock facilitate maize intensification. H_{it} is a vector of household characteristics including sex and age of the household head, labour endowment, and value of asset endowments. We expect the maize area to be higher for male headed households, households with higher labour endowment while the effect of other asset endowments is more uncertain. D_t represents two time period dummies, μ_i captures unobservable time-invariant household and farm characteristics and u_{it} is the random error component.

III. Descriptive Analysis

Table 1 presents average, p25, median, p75, and standard error of mean, maize yields in kg/ha by district for the sample maize plots covering the years 2005/06, 2006/07 and 2008/09, combining local, hybrid and open-pollinated varieties.

Table 1. Mean and quartile plot level maize yields in kg/ha by district

District	Mean	p25	p50	p75	se(mean)	N
Thyolo	2590.1	700.9	1678.3	3250.7	156.9	312
Zomba	1442.3	280.3	749.9	1555.6	93.9	477
Chiradzulu	1392.0	324.1	754.0	1649.3	106.1	316
Machinga	1399.4	163.1	457.4	980.9	172.1	226
Kasungu	1609.8	270.1	840.0	1755.2	114.8	414
Lilongwe	1761.0	397.3	1058.6	2041.0	116.3	385
Total	1688.6	325.6	854.5	1899.1	50.6	2130

Note: p50=median, se(mean)= standard error of mean, N= number of plots in sample.

Maize yields were substantially higher in Thyolo district than in the other districts. The median yield is particularly low and skewed (p75 < mean) in Machinga district. Figure 1 shows the yield distributions of hybrid and local maize for the matched sample of observations in natural logs of yields in kg/ha. The distribution of HYV yields are clearly higher than that of local maize but are also having a slightly higher tendency to have plots with total crop failure. The difference in yields between HYV and local maize may be due to difference in input use and this will be assessed below. The number of plots with OPV maize was too small to get reliable estimates of yield performance as compared to HYVs and local maize.

Table 2 shows the distribution of HYV and local maize across plots that received subsidized fertilizer ("FISP plots") and did not receive subsidized fertilizer by year. The % of FISP plots that were planted with HYV was 39% in 2005/06, 37% in 2006/07 and 43% in 2008/09 against 46, 52 and 54% for local maize. The remaining plots were planted with OPVs. These figures have implications for the fertilizer use efficiency under the subsidy program if we can show that fertilizer use efficiency is much higher for improved maize varieties than for local maize after having corrected for differences in fertilizer use intensity. About 50% of the plots receiving subsidized fertilizer have been planted with local maize.

Table 2. The distribution of plots by year, FISP subsidy access and type of maize grown

	Year and FISP plot dummy=1								
Number of plots	------	2005/06	-----	------	2006/07	------	------	2008/09	------
	0	1	Total	0	1	Total	0	1	Total
Local maize	706	161	867	748	221	969	534	245	779
Improved maize	324	188	512	208	208	416	123	205	328
% local maize	68.5	46.1	62.9	78.2	51.5	70.0	81.3	54.4	70.4
% hybrid maize	22.8	39.3	27.0	13.6	36.6	20.7	17.0	42.9	27.6
Total plots	1,030	349	1,379	956	429	1,385	657	450	1,107

Note: "FISP plot" is a plot that has received subsidized fertilizer

Figure 2 shows non-parametric (lowess) regressions for the relationship between maize/fertilizer ratios (in kg maize/kg total fertilizer) and fertilizer/land ratios (in kg/ha) for FISP plots planted with HYV and local maize. We see that HYV outperforms local maize at lower fertilizer intensity levels. Figures 3 and 4 provide non-parametric regression (lowess) of maize/fertilizer ratio vs. fertilizer/land ratio and kernel density maize-fertilizer ratio distributions by subsidy access. It is worrying to see that non-FISP plots demonstrated substantially higher fertilizer use efficiency given that a lower share of them were planted with HYVs. It points towards inefficient fertilizer use under the subsidy program.

The variation in maize area shares across districts is presented in Table 3. Maize area shares are largest in the southern part of Malawi (first four districts in the table) where also the median shares were substantially larger than the mean shares, indicating an even stronger dominance of maize on the smaller farms. Especially in Chiradzulu and Thyolo maize covered more than 90% of the area on the median farm.

Table 3. The maize area share of total farm size by district in the period 2006-2009

District	Mean	p50 (Median)	N
Thyolo	0.80	0.91	175
Zomba	0.73	0.80	260
Chiradzulu	0.87	0.99	152
Machinga	0.57	0.57	156
Kasungu	0.57	0.56	276
Lilongwe	0.61	0.60	250
Total	0.68	0.72	1269

Has there been any change in the maize area share from 2006 to 2009? Table 4 shows that there has been a substantial decline in the maize area share in this period as evidenced both by the mean and the median maize area shares. This may be due to the intensification of maize production as facilitated by the input subsidy program.

Table 4. Change in maize area share of total farm size from 2006 to 2009

Year	Mean	p50	N
2006	0.73	0.83	444
2007	0.67	0.70	437
2009	0.64	0.63	379
Total	0.68	0.72	1260

Figure 5 presents maize area shares by year (kernel density distributions) and shows the same falling trent in maize area shares. Figure 6 shows local polynomial regressions of maize area share by farm size and year. The maize area share falls with farm size and similarly over time for different farm sizes.

Figure 7 gives local polynomial regression lines for the probability that maize plots are intercropped by maize variety and Figure 8 the probability that fertilizer and unfertilized maize plots are intercropped by farm size. Intercropping of maize is more common the smaller the farm is and is more common for local maize than for hybrid maize. Surprisingly, intercropping of maize was also more common on fertilized than unfertilized maize plots. Figure 9 shows that fertilized HYV was also more commonly intercropped than unfertilized HYV and Figure 10 shows that maize plots where subsidized fertilizer had been used were more likely to be intercropped than maize plots where unsubsidized fertilizer had been used. The confidence intervals in the graphs support the significance of these findings. Parametric regression analyses follow to further assess the robustness of these results.

IV. Results and Discussion

Maize yields

In order to assess the maize yields for hybrid maize versus local maize, propensity score matching was used to identify plots with hybrid maize and local maize that had similar characteristics. The balancing property was ensured and the common support requirement was invoked before the matching comparison of yields was implemented. The propensity score matching results with the variables included in the propensity score are found in Appendix 1, Table A1. Farm plot characteristics and district dummies were included to control for biophysical variation. In addition, fertilizer use and manure use per ha were included in the propensity score to control for a likely bias due to higher fertilizer use on hybrid maize than on local maize as we were interested in finding the yield difference when input use and costs were approximately the same. Kernel matching was then applied to compare yields on plots with hybrid maize with plots of local maize. Standard errors were obtained by bootstrapping. Matching was done for all years together and for each year separately. The results are presented in Table 5.

The matching controls for systematic differences in soil type, slope, soil fertility, fertilizer use and manure use, plot size, distance to plots, and districts with respect to use of hybrid maize or local maize. When doing the matching without including the fertilizer use and manure use, the yield differences between hybrid maize and local maize were considerably larger (457 kg/ha for all years together) because more inputs are used on hybrid maize. Table 2 therefore gives a better measure of the yield response of hybrid maize versus local maize after controlling for the difference in input use. On average it was 323kg/ha for all years together.[1] The difference between 457 and 323 kg/ha should then be an estimate of the effect of higher input use on hybrid maize.

Table 5. The yields of hybrid maize vs. local maize as estimated by propensity score matching by year and for all years in six districts in central and southern Malawi.

Variable	2006	2007	2009	All years
Hybrid maize yield, kg/ha	1441.6	1845.6	2044.5	1773.7
Local maize yield, kg/ha	1116.5	1581.8	1681.3	1450.7
Average treatment effect on the treated (ATT), kg/ha	325.1	263.8	363.1	323.0
Bootstrapped standard error	158.3	214.9	179.9	110.3
t-value	2.053**	1.228	2.019**	2.928***
Number of treated observations	296	264	293	853
Number of control observations	288	325	281	897

Note: Kernel matching was used. Standard errors are bootstrapped with 400 replications. Hybrid maize is handled as the treatment and local maize as the control.

There is a positive yield trend for both hybrid maize and local maize from 2006 to 2009 with yields more than 600 kg/ha higher in 2009 than in 2006 for hybrid maize and with almost the same yield increase for local maize. The t-values show that the yield differences between hybrid and local maize were significant except in 2007. The results imply that hybrid maize does better than local maize, *ceteris paribus*, when we have controlled for observable heterogeneity. We cannot rule out bias due to unobservable heterogeneity,

[1] When the analysis was done only for plots with non-zero yield the average yield difference between hybrid and local maize was 347 kg/ha.

however. We apply parametric panel data methods to also control for such heterogeneity, see the following analyses.

The distribution of fertilizer in natural log kg/ha for the matched sample plot observations satisfying common support and all plots without matching and without controlling for differences in fertilizer use between hybrid and local maize are presented in Figures A1 and A2 in the Appendix. The matching has considerably reduced but not totally eliminated the difference in fertilizer use intensity between hybrid maize and local maize plots. Figure A2 shows clearly that much more local maize is grown without applying any fertilizer than is the case for hybrid maize.

Parametric linear models with household fixed effects controlling for time-invariant household and farm characteristics are presented in Table 6. The first model contains all maize plots and with dummy variables for HYV and OPV while the second model is for local maize and the third model includes improved maize varieties. A control function approach was used to control for endogeneity of fertilizer use including subsidy access. The coefficients on the HYV and OPV dummies indicate 160 and 114 kg/ha higher yields than for local maize but are not significant. The fertilizer use intensity variable was highly significant after controlling for endogeneity and one kg/ha extra fertilizer use increased maize yield by 2.9 kg/ha. The separate models for local maize and improved maize gave a marginal response of 2.2 kg maize/kg fertilizer for local maize and 3.4 kg maize/kg fertilizer for HYV. The year dummy variables show that average yields were 283 kg/ha higher in 2007 and 384 kg/ha higher in 2009 than in 2006. The positive trend in maize yields was clearer for improved maize where maize yields were 582 kg/ha higher in 2009 and 228 kg/ha higher in 2007 than in 2006.

Does access to fertilizer subsidies improve maize yields? Are those predicted to access subsidies more or less productive than those predicted not to access subsidized fertilizer? The Subsidy00 and Subsidy10 variables were significant (at 5% levels) and positive in the model with all maize plots and the model with improved maize varieties. This tells us that plots predicted not to receive subsidized fertilizer had yields of 426-544 kg/ha and 665-880 kg/ha higher than plots predicted to receive subsidized fertilizer in the models with all maize plots and improved maize plots respectively. This could indicate that subsidies were more likely to reach plots and farms and households that were less productive or access to subsidized fertilizer was likely to be less efficiently utilized than unsubsidized fertilizer, e.g. due to late delivery of subsidized fertilizer or more sloppy use of such (cheap) fertilizer.

Maize area and maize area share

Does access to fertilizer subsidies crowd out other crops and lead to increasing area under maize or does it lead to intensification of maize production and reduced area share of maize?

Two types of models were run to assess the determinants of maize area with alternative dependent variables; a) total maize area per farm; b) total maize area share of total farm size. Household fixed effects were used to control for time-invariant observable and unobservable household and farm characteristics. In addition time-varying endowment variables were included to assess how they were correlated with maize area. For the models with total maize area per farm the other asset variables were also in units per farm household. Table 7 provides the results.

Table 8 shows that maize area per farm is strongly positively correlated with farm size, livestock endowment and the labour force of the households while it was negatively correlated with the real value of other assets of the household. Older household heads tended to have smaller maize area. The maize area was significantly lower in 2007 and 2009 than in 2006. There is no indication that access to subsidies has resulted in an expansion of maize area. There are rather indications of the opposite. Better access to subsidies over time may be associated with intensified maize production and smaller maize areas as seen from the year dummies and the “Hhsubsidy10”-variable in the second model. Households that received, but were predicted not to receive subsidized fertilizer, had significantly lower maize area than the baseline household group (Hhsubsidy11) that was predicted to get and received fertilizer subsidy. This latter group did not have a significantly larger area than the two other household groups that did not receive input subsidies. The results seem to indicate that better access to fertilizers through the subsidy program has allowed intensification of maize production. This may also have been facilitated with the new planting system (the "Sasakawa" system) with 75 cm row spacing and 25 cm spacing of single seeds in the row (Denning et al. 2009).

Intercropping of maize

Parametric intercropping models were specified as panel logit models with household random effects. Fertilizer use intensity was specified with the control function approach using log-transformed fertilizer use and including the predicted error and squared error from a tobit model with household random effects. Models were run without and with the predicted subsidy access and actual subsidy access variables which were specified like in the maize yield models. The models are presented as the first two models in Table 8.

The models show that the probability of intercropping of maize was declining with farm size, was more likely for OPVs while HYVs were insignificant but with a negative sign (with local maize as the base). The probability of intercropping was increasing with fertilizer use intensity but was not significantly associated with the predicted subsidy and actual access to subsidy variables. The subsidy program and access to improved maize therefore does not lead to significantly less intercropping or more mono-cropping of maize.

Maize-fertilizer ratios

Given that the Farm Input Subsidy Program in Malawi is costly and more so due to rising fertilizer and oil prices, it makes sense not only to assess the program from the perspective of maximizing maize output per unit land. It also makes sense from a national perspective to maximize maize output per unit fertilizer given the severe financial constraints. We have therefore assessed factors associated with plot level maize-fertilizer ratios. Non-parametric findings have already been presented. The complementary parametric regressions are presented in Table 8 (last two models in the table). These maize-fertilizer ratio models are panel models with household fixed effects. The right hand side variables were specified as in the intercropping models in the same table. Only plots with positive fertilizer application rates were included in these models.

The results show that hybrid maize gave significantly higher maize-fertilizer ratios than local maize and OPVs (significant at 10% level) while the maize-fertilizer ratio reduces significantly with increasing fertilizer use intensity. These results may indicate that it is better to distribute smaller amounts of subsidized fertilizer per household, such as one 50 kg bag/household rather than the current standard of 100 kg/household and reach all households and ensure a wider distribution of improved seeds such that a much larger share of the fertilizer is combined with the more productive seed technology. Such an adjustment should be good both for efficiency, equity, national and household food security.

V. Conclusion

We have used household plot panel data for three years (2006, 2007, 2009) from the period after the Malawian targeted input subsidy program (FISP) was scaled up, covering six districts in central and southern Malawi to assess the access to improved maize seeds and subsidized or unsubsidized fertilizer. All farm plots of the households were measured and input use and outputs were recorded. We have assessed the land and fertilizer productivity of improved versus local maize and the effects on the farming system in terms of maize area share and extent of intercropping of maize.

The study revealed significant differences in yields across districts in Southern and Central Malawi. Maize yields were significantly higher in Thyolo (2590 kg/ha as average over the three years) than in other districts. Maize yields were particularly skewed in Machinga district (mean yield of 1400 kg/ha against a median yield of only 457 kg/ha). Hybrid maize yields were found to be significantly higher (about 320 kg/ha higher) than the yields of local maize also after controlling for differences in fertilizer and manure use (using propensity score matching). There was a significant positive trend in maize yields from 2006 to 2009 with an increase in mean yields of about 600 kg/ha from 1440 to 2040 kg/ha for hybrid maize and from 1120 to 1680 kg/ha for local maize. These findings illustrate that there is still a lot of room for maize yield improvement. The increase in maize yields was accompanied with reductions in maize areas and maize area shares during the study period. Our finding is contradicting the study by Chibwana et al. (2012) that found a positive correlation between maize area and fertilizer subsidy access using cross-section data from two districts in Malawi. Our larger data set with three years of panel data allow us to control for unobservable household and farm heterogeneity. We therefore think that our study provides more reliable findings on this issue. This implies that the subsidy program does not crowd out other crops but rather facilitates maize intensification while leaving more area for other crops. The program is therefore complementary with crop diversification. Furthermore, maize that received fertilizers was more likely to be intercropped than maize not receiving fertilizers. This is also contrary to claims that fertilizer subsidies lead to mono-cropping of maize (ref.). Shrinking farm sizes lead to more intercropping of maize and larger maize area shares on the farms and fertilizer access facilitates intensification and crop diversification through intercropping of maize.

Access to subsidized fertilizer had a significant positive effect on maize yields. However, the targeted households had significantly lower maize yields than those not targeted by the program, whether receiving subsidies or not. This was found by assessing the yields of households that had been erroneously excluded and included in the program based on our participation predictions. One explanation for this could be that the subsidy program targets resource-poor households that may be less efficient producers. On the other hand, other studies have shown that the Malawian subsidy program is less likely to reach poor households such as female-headed households (Dorward and Chirwa 2011; Holden and Lunduka 2012b) while relatively wealthier households are more likely to obtain subsidized inputs. We may question why such wealthier households are less efficient producers but we were unable to test alternative explanations for this with our data and therefore leave this issue for future research. Two possible explanations are that some of the subsidized fertilizer arrived too late, or less careful use of cheap fertilizers for those who have easy access to it because they are well connected, or a combination of these.

Another limitation of our study was that we only had data from good rainfall years. It is of high importance to investigate the performance of the improved versus local varieties under drought conditions, especially since some of the improved varieties are considered to be drought tolerant. With increasing fears for climate shocks and climate change it is crucial for a poor and drought-prone country like Malawi to develop more climate robust agricultural technologies and financial systems that can handle such shocks. The current shortage of foreign exchange makes the country and the subsidy program very vulnerable to such shocks. Future research should focus on how improved drought-tolerant maize varieties can be integrated with other climate-smart technologies in ways that enhance household and national food security in a financially sustainable way.

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Table 6. Maize productivity (linear) models: Household fixed effects models with control function approach for fertilizer use intensity

	All maize plots	Local maize	Improved maize
Hybrid seed dummy	160.389		-30.406
	(118.800)		(201.900)
Open-pollinated variety dummy	113.811 (146.410)		
Subsidy01	314.654	272.635	566.582
	(266.490)	(470.940)	(426.640)
Subsidy00	544.123**	509.690	879.902**
	(239.490)	(366.250)	(426.810)
Subsidy10	425.903**	369.687	664.648**
	(182.430)	(302.780)	(316.130)
Farm size in ha	-163.180	-43.497	-172.115
	(128.920)	(177.220)	(174.320)
Number of plots	74.006	-2.082	121.434
	(64.390)	(-86.430)	(99.780)
Fertilizer/ha	2.908****	2.247**	3.400****
	(0.470)	(0.920)	(0.560)
Error for fertilizer/ha	0.549)	0.161	0.513
	(0.380)	(0.550)	(0.650)
Error for fertilizer/ha, squared	0.000 (0.000)	0.001 (0.000)	-0.001 (0.000)
Plot characteristics	Yes	Yes	Yes
Year dummy for 2007	283.443**	443.192**	228.860
	(122.490)	(186.450)	(182.190)
Year dummy for 2009	384.158**	181.566	581.663**
	(163.000)	(268.800)	(266.410)
Constant	388.991	506.117	299.514
	(285.630)	(381.080)	(519.730)
Prob > chi2	0.000	0.000	0.000
Number of observations	1647	688	959
R-squared	0.306	0.382	0.31

Note: Models with household fixed effects and bootstrapped standard errors (400 reps.), re-sampling households. Standard errors in parentheses. Significance levels: *:10%, **:5%, ***:1%, ****:0.1%. Subsidy01: Plot not getting, predicted to get subsidized fertilizer, Subsidy11: Plot getting and predicted to get (omitted, used as baseline), Subsidy00: Not getting and predicted not to get, Subsidy10: Plot getting, predicted not to get subsidized fertilizer.

Table 7. Factors associated with maize area per farm and maize area share, household fixed effects models

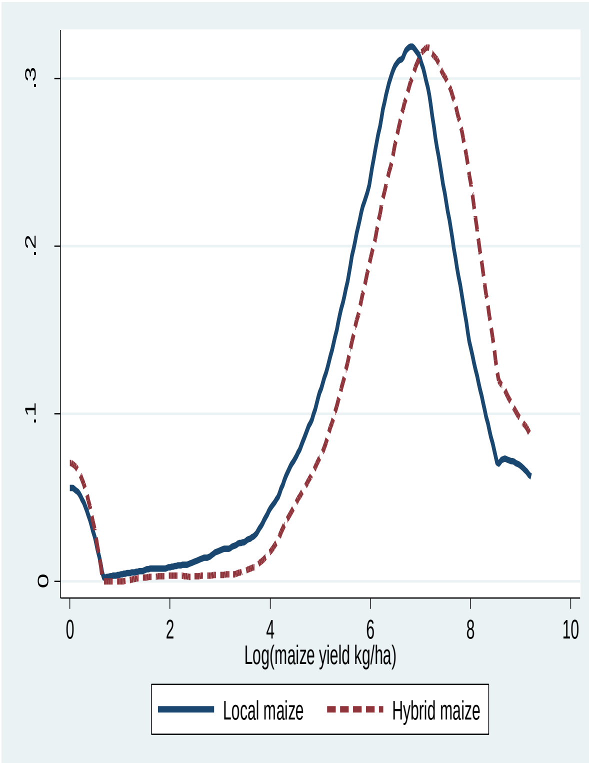
	Maize area in ha	Maize area share
Hhsubsidy01	-0.017	0.012
	(0.060)	(0.030)
Hhsubsidy00	-0.147	-0.035
	(0.090)	(0.040)
Hhsubsidy10	-0.166**	-0.081*
	(0.080)	(0.050)
Farm size in ha	0.487****	-0.054****
	(0.080)	(0.010)
Tropical livestock units	0.044***	0.017***
	(0.020)	(0.010)
Labour endowment	0.059**	0.013
	(0.020)	(0.010)
Quality of house	0.009	0.004
	(0.010)	(0.010)
Real asset value, 1000MK	-0.005***	-0.002*
	(0.000)	(0.000)
Sex of household head	-0.080	-0.045
1=male, 0=female	(0.060)	(0.040)
Age of household head	-0.005***	0.000
	(0.000)	(0.000)
Dummy for 2007	-0.085***	-0.070***
	(0.030)	(0.020)
Dummy for 2009	-0.140***	-0.089****
	(0.050)	(0.020)
Constant	0.262*	0.769****
	(0.150)	(0.080)
Prob > chi2	0.000	0.000
R-squared	0.513	0.073
Number of observations	1193	1193

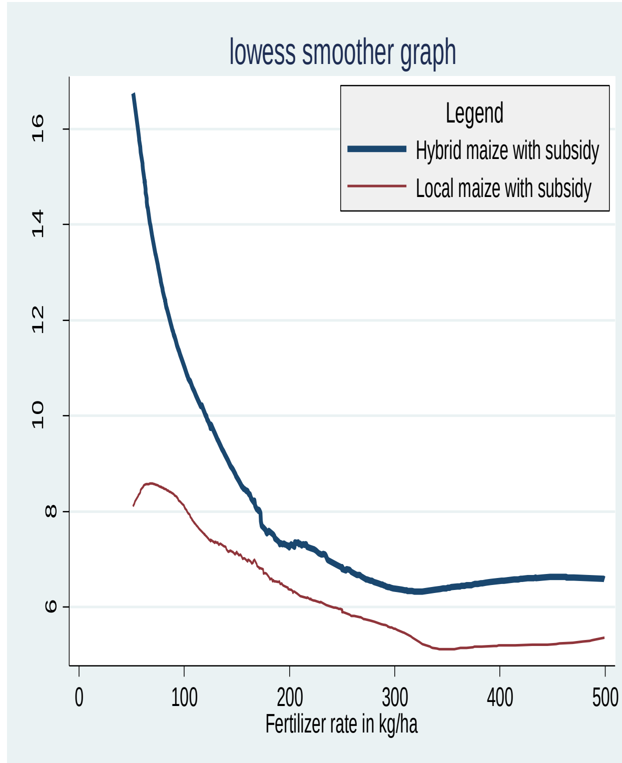
Note: Models with household fixed effects and bootstrapped standard errors (400 reps.), re-sampling households. Standard errors in parentheses. Significance levels: *:10%, **:5%, ***:1%, ****:0.1%. Hhsubsidy01: Household not getting, predicted to get subsidized fertilizer, Hhsubsidy11: Household getting and predicted to get (omitted, used as baseline), Hhsubsidy00: Household not getting and predicted not to get, Hhsubsidy10: Household getting, predicted not to get subsidized fertilizer.

Table 8. Factors associated with maize intercropping and maize-fertilizer ratios

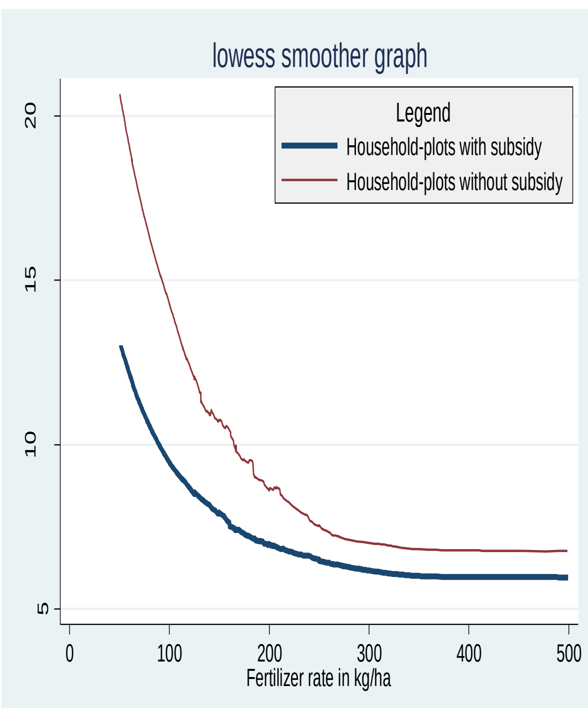
	Intercropping 1	Intercropping 2	Maize-fertilizer ratio 1	Maize-fertilizer ratio 2
Farm size in ha	-0.407*	-0.399*	-10.830	-11.180
	(0.210)	(0.220)	(7.020)	(7.370)
Hybrid maize dummy	-0.228	-0.231	5.900*	6.164*
	(0.220)	(0.230)	(3.410)	(3.620)
Open-pollinated variety	0.591*	0.589	-2.868	-3.182
dummy	(0.350)	(0.380)	(2.850)	(2.750)
Log of fertilizer use/ha	0.128***	0.114*	-12.898***	-14.074***
	(0.040)	(0.060)	(4.390)	(5.110)
Error fertilizer use eqn.	-0.150*	-0.129	4.283**	5.073*
	(0.080)	(0.090)	(2.030)	(2.630)
Error fertilizer use eqn.,	0.006	0.005	-0.596	-0.582
squared	(0.020)	(0.020)	(0.390)	(0.370)
Subsidy01		-0.197		-7.308
		(0.460)		(5.350)
Subsidy00		-0.373		-3.956
		(0.330)		(6.000)
Subsidy10		-0.408		2.642
		(0.300)		(1.840)
Plot characteristics	Yes	Yes	Yes	Yes
Year dummy variables	Yes	Yes	Yes	Yes
Constant	-0.537	-0.238	80.688****	87.270***
	(0.470)	(0.500)	(24.370)	(29.300)
Lnsig2u constant	1.142****	1.132****		
	(0.160)	(0.160)		
Prob > chi2	0.000	0.000	0.002	0.024
R squared			0.167	0.174
Number of observations	1686	1686	1129	1129

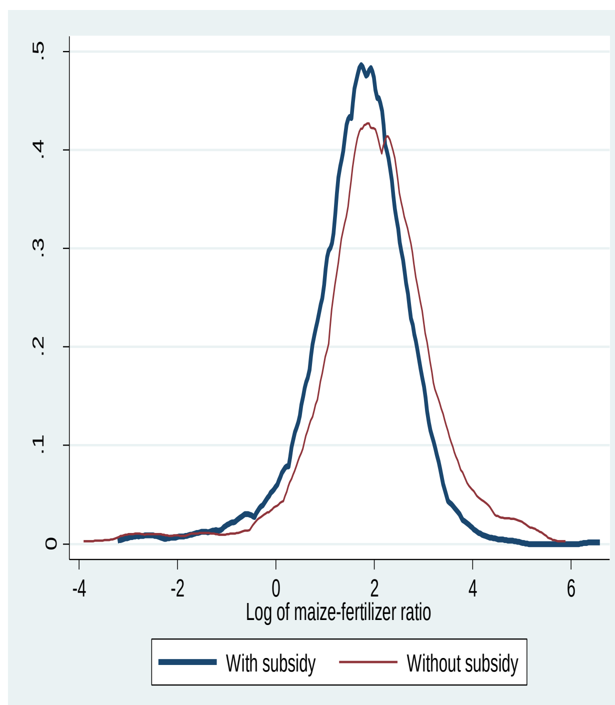
Note: Intercropping models are panel logit models with household random effects. Maize-fertilizer ratio models are panel models with household fixed effects. Subsidy01: Plot not getting, predicted to get subsidized fertilizer, Subsidy11: Plot getting and predicted to get (omitted, used as baseline), Subsidy00: Not getting and predicted not to get, Subsidy10: Plot getting, predicted not to get subsidized fertilizer. Control function approach used to control for endogeneity of fertilizer use and with bootstrapped standard errors (400 reps.), re-sampling households, in all models. Standard errors are in parentheses. Significance levels: *:10%, **:5%, ***:1%, ****:0.1%.



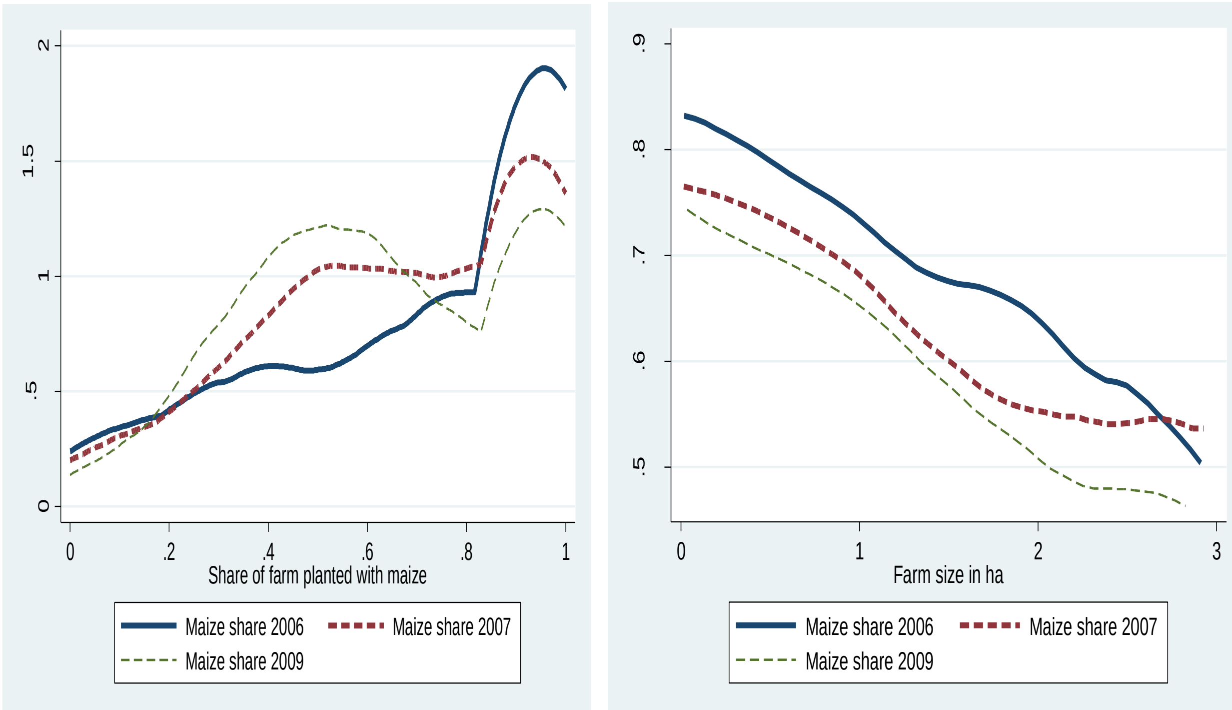


Figures 1 and 2. Maize yield distributions and maize-fertilizer ratios for local and hybrid maize

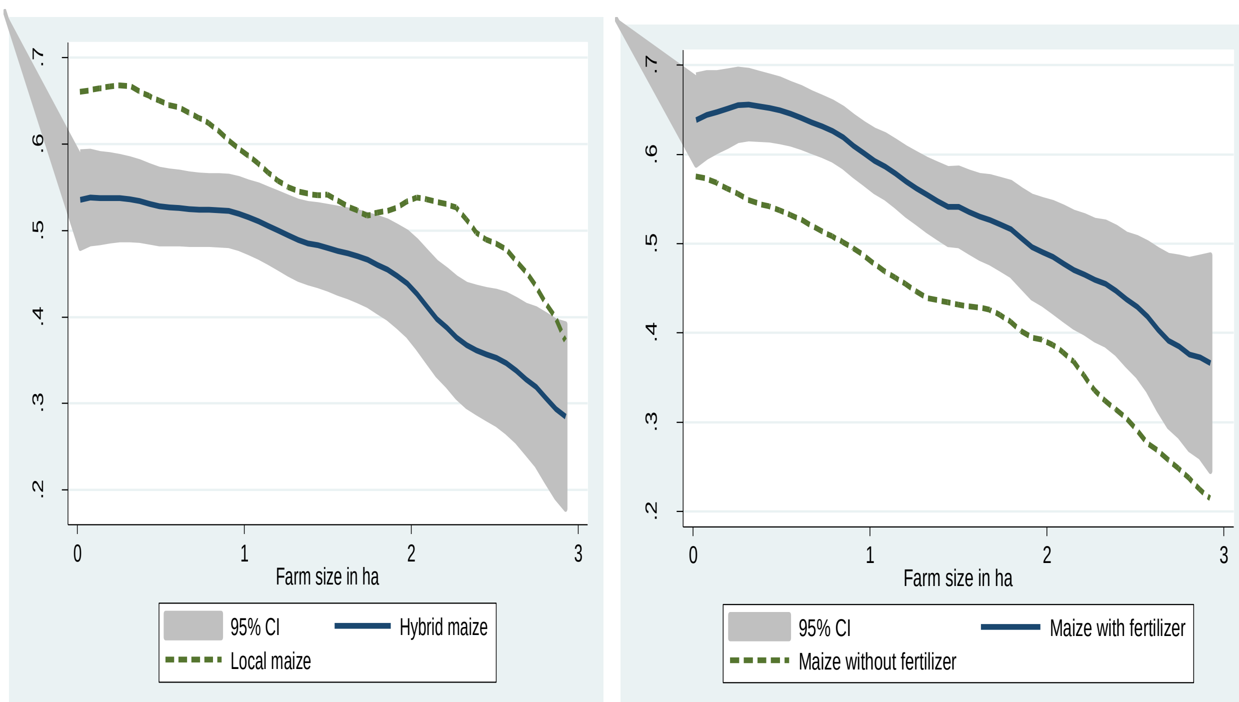




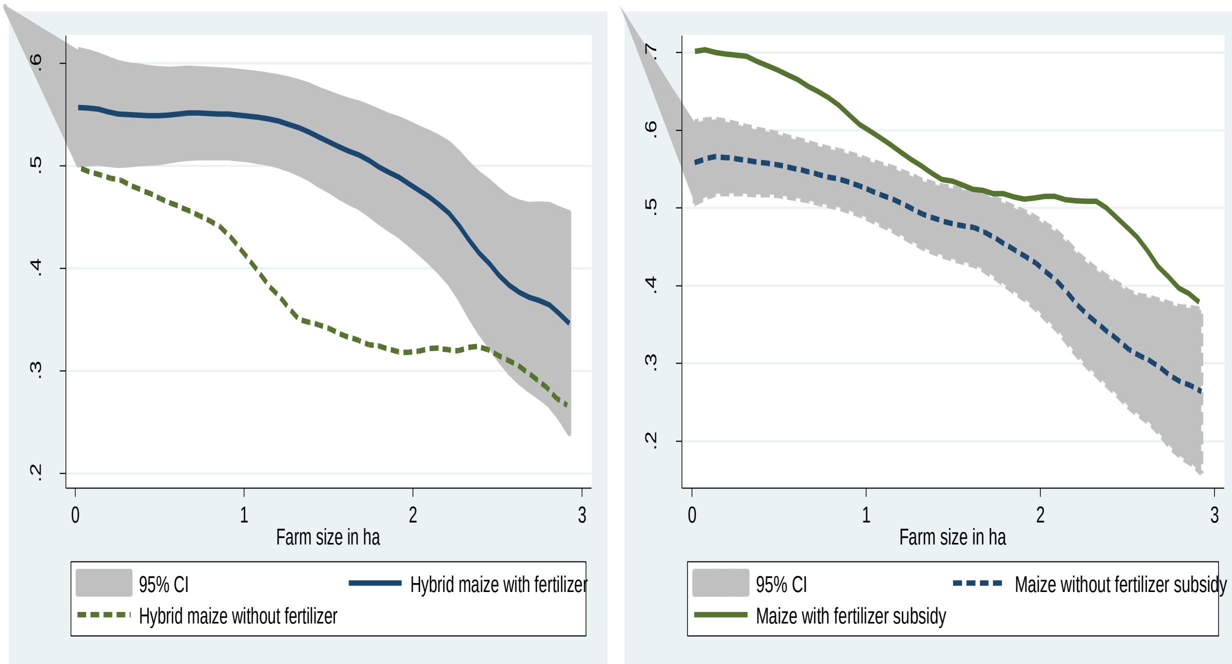
Figures 3 and 4. Non-parametric regression of maize/fertilizer ratio vs. Fertilizer/land ratio and maize-fertilizer ratio distribution by subsidy access



Figures 5 and 6. Maize area shares by year (kernel density distributions) and maize area share by farm size and year (local polynomial regressions)



Figures 7 and 8. The probability that maize plots are intercropped by maize variety and fertilizer use by farm size (Local polynomial regressions)



Figures 9 and 10. The probability that fertilized and unfertilized hybrid maize plots are intercropped and that plots receiving and not receiving subsidized fertilizer are intercropped, by farm size (Local polynomial regression)

Appendix

Table A1. Propensity score logit model for hybrid maize

Variable	Coef.	Std. Err.	z	P>z
Fertilizer/ha	0.00055	0.00011	5.060	0.000
Manure/ha	0.00002	0.00001	3.340	0.001
Plot area in ha	0.08495	0.06070	1.400	0.162
Distance to plot	-0.00002	0.00002	-0.930	0.351
Soil type 2	-0.13890	0.07062	-1.970	0.049
Soil type 3	-0.01683	0.09096	-0.190	0.853
Slope 2	0.01037	0.06429	0.160	0.872
Slope 3	-0.05454	0.13771	-0.400	0.692
Plot fertility 2	-0.27727	0.08237	-3.370	0.001
Plot fertility 3	-0.32531	0.09306	-3.500	0.000
Zomba district dummy	-0.66385	0.11235	-5.910	0.000
Chiradzulu district dummy	-0.45676	0.11609	-3.930	0.000
Machinga district dummy	-0.10821	0.13325	-0.810	0.417
Kasungu district dummy	0.17508	0.10965	1.600	0.110
Lilongwe district dummy	-0.10828	0.11548	-0.940	0.348
2007 year dummy	-0.15789	0.07051	-2.240	0.025
2009 year dummy	0.12967	0.07366	1.760	0.078
Constant	0.20332	0.14256	1.430	0.154

Note: the common support option has been selected. The region of common support is [.13387151, .89833362].

Description of the estimated propensity score in region of common support
Estimated propensity score

```
-------------------------------------------------------------
      Percentiles      Smallest
 1%       .1627748       .1338715
 5%       .1995951       .1344831
10%       .2280555       .1404542       Obs               1991
25%       .2986096       .1412285       Sum of Wgt.       1991

50%        .424458                      Mean          .4268864
                          Largest       Std. Dev.     .1537028
75%       .5364105       .8823209
90%       .6250805        .885017       Variance      .0236245
95%       .6852377       .8913599       Skewness      .2853332
99%       .8064283       .8983336       Kurtosis      2.479888
****************************************************
```

Step 1: Identification of the optimal number of blocks
Use option detail if you want more detailed output

****

The final number of blocks is 8
This number of blocks ensures that the mean propensity score
is not different for treated and controls in each blocks

****

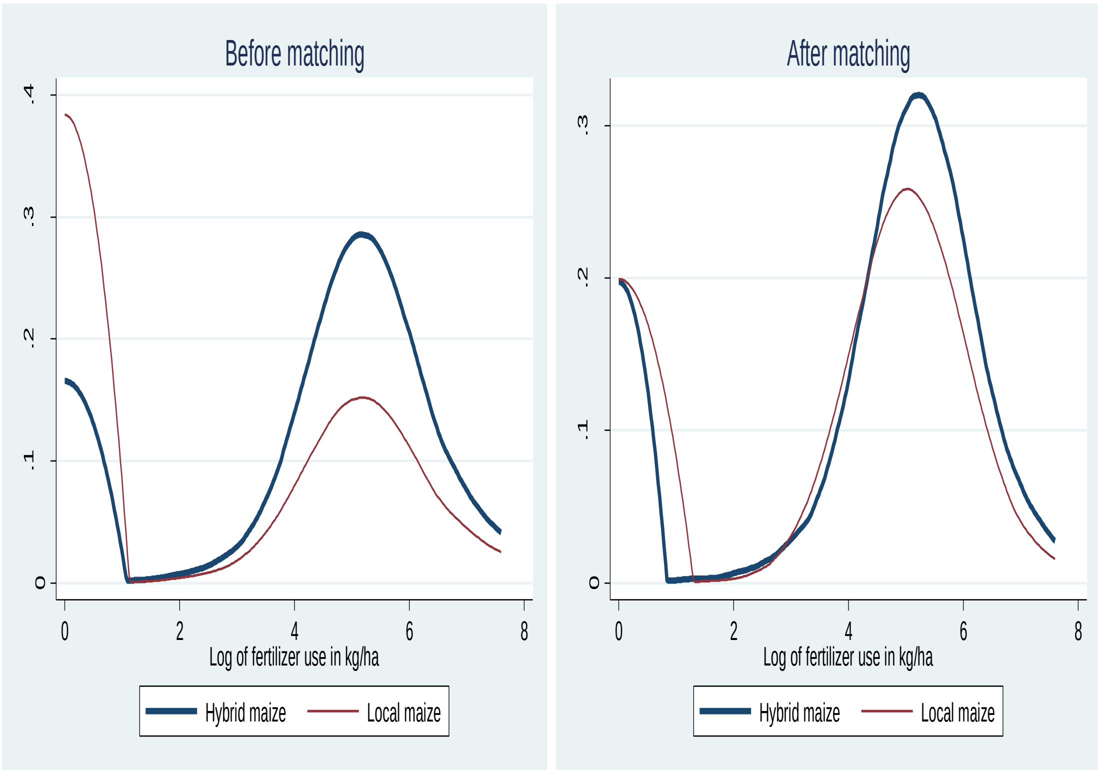
Step 2: Test of balancing property of the propensity score
Use option detail if you want more detailed output
****

The balancing property is satisfied

This table shows the inferior bound, the number of treated
and the number of controls for each block

Inferior of block of pscore	hyv 0	hyv 1	Total
.1338715	82	22	104
.2	163	36	199
.25	136	64	200
.3	265	115	380
.4	228	211	439
.5	176	232	408
.6	84	153	237
.8	4	20	24
Total	1,138	853	1,991

Note: the common support option has been selected



Figures A1 and A2. The fertilizer intensity distribution on plots with hybrid and local maize before and after propensity score matching satisfying the balancing and common support requirements

Table A3. Control function error model and Linear probability model for subsidy use

Tobit model with household random effects: Control function error model (Chamberlain-Mundlak)		**Linear probability model for subsidized fertilizer use at plot level with household fixed effects**	
	Fertilizer use		Subsidized fertilizer
	All plots	Age hhhead	-0.001
Maize plot dummy	74.212***		0.000
	-24.680	Sex hhhead	0.056
Average fertilizer price	-4.547****		-0.050
	-0.210	School years hhhead	0.005
Subsidy for maize	41.628*		0.000
dummy	-22.640	Male labour	-0.038**
Hybrid maize dummy	27.271		-0.020
	-19.310	Female labour	0.004
Age hhhead	2.535		-0.020
	-2.660	Children	-0.006
Age hhhead, squared	-0.044		-0.010
	-0.030	Quality of house	0.000
Sexhhhead	12.884		0.000
	-22.820	Real asset value	0.000
Male children	1.679		0.000
	-8.110	Livestock endowment	0.005
Female children	-8.141		-0.010
	-7.900	Farm size	-0.000****
Legumes plot dummy	-226.412****		0.000
	-37.660	Number of plots	-0.002
Root and tubers plot	-163.752****		-0.010
dummy	-45.410	Log plot area	0.405****
Other cereals plot	-189.111***		-0.040
dummy	-66.440	Plot distance	0.000
Tobacco or sugar	267.060****		0.000
plot dummy	-32.850	2.soiltype	-0.051**
Seed cost/ha	0.035****		-0.020
	0.000	3.soiltype	-0.114****
Pesticide cost/ha	0.023****		-0.030
	0.000	2.slope	0.023
Plot area in ha	-120.029****		-0.020
	-20.530	3.slope	0.073
Plot distance	3.185		-0.050
	-5.470	2.plotfertility	0.029
Mean male labour/ha	8.531		-0.030
	-5.480	3.plotfertilityy	-0.005

Mean female labor/ha	-0.839		-0.030
	-4.340	2007.year	0.060***
Mean real asset value	-5.071		-0.020
	-3.490	2009.year	0.155****
Mean livestock	-0.489		-0.020
endowment/ha	-2.850	Constant	0.304***
Mean farm size, ha	47.590****		-0.100
	-12.380	Prob > chi2	0.000
Deviation farm size	-24.176**	Number of obs.	3107
	-11.000		
Deviation livestock	0.821		
endowment/ha	-2.140		
Deviation male	2.632		
labor endowment/ha	-4.780		
Deviation female	9.793***		
labor endowment/ha	-3.590		
Deviation real asset	6.203***		
value	-2.350		
Plot characteristics	Yes		
_Idistrict_2	-113.657***		
	-35.660		
_Idistrict_3	-121.420***		
	-39.040		
_Idistrict_4	-214.441****		
	-42.950		
_Idistrict_5	-166.361****		
	-37.380		
_Idistrict_6	-162.969****		
	-37.020		
_Iyear_2007	15.017		
	-18.880		
_Iyear_2009	106.945****		
	-22.310		
Constant	266.515****		
	-74.630		
sigma_u	116.098****		
Constant	-11.790		
sigma_e	343.559****		
Constant	-6.480		
Prob > chi2	0.000		
Number of obs.	3193		

Two-sample Kolmogorov-Smirnov test for equality of distribution functions for maize-fertilizer ratios on plots receiving and not receiving subsidized fertilizer:

Smaller group	D	P-value	Corrected
0:	0.0096	0.944	
1:	-0.1462	0.000	
Combined K-S:	0.1462	0.000	0.000