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Abstract

This study used a three-year panel dataset for 350 Malawian farm households to examine the potential for widespread adoption of drought tolerant (DT) maize varieties, a technology that holds considerable promise for helping smallholder farmers in SSA adapt to drought risk. Regression results revealed that DT maize cultivation increased substantially from 2006 to 2012, with the main driver being the Malawi Farm Input Subsidy Program. Some other key factors related to adoption were having recently experienced drought and farmer risk aversion. As far as yield performance, improved maize varieties performed significantly better than local maize during the 2011/12 drought year. However, DT maize did not perform significantly better than other improved maize varieties used in Malawi, which is in contradiction to results from on-station and on-farm trials (e.g., Magorokosho et al. 2010; Setimela et al., 2012). A plausible explanation is that farmers had inadequate training or experience to move towards the yield potentials of the DT maize varieties. Expansion of agricultural extension activities may be required to help farmers achieve the DT maize yield potentials and, subsequently, improve farmer resilience to drought.

Key words: Improved maize varieties, drought, drought tolerance, input subsidies, maize yields, agricultural adaptation, risk aversion.

JEL codes: Q12, Q18.

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1. Introduction

Agricultural development in sub-Saharan Africa (SSA) faces unprecedented challenges, due to changes in demand for food, market conditions, and climate. The Intergovernmental Panel on Climate Change (IPCC 2014) predicts that, under medium scenarios, mean annual temperature over extensive areas of Africa will be 2°C higher during the middle of the 21st Century than during the late 20th Century. Despite uncertainty about future changes in rainfall in SSA (IPCC 2014), climate change models consistently predict increased incidence of drought (Li et al. 2009). Increasing temperatures and changes in precipitation are expected to adversely affect biodiversity, amplify existing stress on water supplies, exacerbate the vulnerability of agricultural systems, and increase the burden of a range of climate-related health outcomes (IPCC 2014).

Climate change is not being superimposed on a static world (Burke and Lobell 2010). African farmers already adapt to climate variability by switching to different crops and by diversifying their cropping systems (Deressa et al. 2009); by selling physical assets, such as livestock (Kinsey et al. 1998); by migrating to gain access to land or employment (Dillon et al. 2011); by diversifying into non-farm wage employment (Porter 2012); and by increasing their reliance on natural resources (Fisher et al. 2010). However, the magnitude and speed of the predicted changes in climate suggest that the farm-level measures used to cope with climate variability in the past will not be sufficient adaptations in the future. Large public and private investments in crop breeding, irrigation infrastructure, and safety nets (e.g., micro-insurance) will be needed to meet the food needs of the growing human population – in SSA and in the rest of the world (Burke and Lobell 2010).

The present paper focuses on recent advances in maize research that hold promise for helping African farmers adapt to drought. Maize is the most important food crop in SSA, where it is almost completely rainfed and, therefore, dependent on the region's increasingly erratic precipitation. Around 40% of Africa's maize-growing area faces occasional drought stress in which yield losses are 10-25%. Around 25% of the maize crop suffers frequent drought, with losses of up to half the harvest (CIMMYT 2013). To reduce vulnerability and improve food security, the Drought Tolerant Maize for Africa (DTMA) project has developed more than 160 drought tolerant (DT) maize varieties, since 2007. DT maize varieties can produce about 30% of their potential yield after six weeks of water stress, before and during flowering and grain-filling stages (Magorokosho et al. 2010). They have the same input (e.g., chemicals, labor) requirements and seed costs as non-DT commercial varieties. Through national agricultural research systems and private seed companies, new DT varieties have been tested in field and on-farm trials, involving farmers in 13 SSA countries. In on-farm trials, DT maize varieties have matched or exceeded the yields of widely sown commercial seed when rains are good, and have had 20–30% higher yields under moderate drought conditions (CIMMYT 2013).

The potential higher yields of DT maize can substantially benefit smallholder farm households in SSA, through improved food security and increased net returns. By decreasing the vulnerability of farm households to drought-related harvest failure, DT varieties also reduce the need for harmful post-failure coping strategies, such as borrowing, reducing food consumption, sale of household assets, or taking children out of school. Two recent assessments of DT maize adoption in Africa, based on the economic surplus method, predicted large positive impacts of increasing average yields and reducing yield variability. Kostandini et al. (2013) estimated that, by 2016, adoption of DT maize could generate between US$362 million and US$590 million in cumulative benefits to producers and consumers in the 13 DTMA project countries. For the same countries, La Rovere et al. (2014) estimated economic benefits of US$907 million under conservative yield gains, and US$1,535 million under optimistic yield gains.

The present study addresses two knowledge gaps related to the potential of DT maize for drought risk mitigation in SSA. First, there has been insufficient research on demand for DT maize. The realization of expected benefits of DT maize depends on adoption of the new DT maize varieties by SSA farmers, which has only been studied for the case of 200 farm households in Borno State, Nigeria (Tambo and Abdoulaye 2013). The Nigeria case study suggests considerable farmer demand for DT varieties, but the literature on adoption of improved crop varieties by smallholder farmers in SSA indicates an uneven record: incidents of widespread adoption (Alene et al. 2009) are mixed with examples of low rates of adoption and lack of sustained use of seemingly advantageous farm technologies (Kijima et al. 2011; Suri 2011).

By 2011, the year of the present study, 15 DT maize varieties had been released to Malawian farmers.[1] The cultivation of these maize varieties by smallholder farmers has been viewed by Malawi observers as a way to free land for other crops, thereby promoting crop diversification, reduce the impact of drought, and increase farmer market participation. Our survey data show that four of the released DT maize varieties were cultivated by sampled farmers. We

[1] Of the 15 DT maize varieties released by 2011, eight were developed by the International Maize and Wheat Improvement Center (CIMMYT): Chitedze4, CAP9001, MH27, MH28, PAN53, SC719, ZM309, and ZM523. The remaining seven DT maize varieties (MH26, PHB30G19, SC403, SC627, ZM421, ZM521, ZM621, and ZM623) were developed by other private or public research institutions and have been promoted by CIMMYT and the International Institute for Tropical Agriculture (IITA) under the DTMA project.

estimate demand and levels of adoption of these varieties and estimate regression models to reveal the determinants of DT maize uptake in Central and Southern Malawi. Our study, similar to the work of Jain et al. (2015), employs a modeling approach that accounts for the many factors that simultaneously influence a farmer's decision to cultivate DT maize, an approach rarely used in the adaptation literature.

A second knowledge gap we address is that although the yield advantage of DT maize for African farmers has been repeatedly predicted from on-station and on-farm trials (e.g., Magorokosho et al. 2010; Setimela et al., 2012), these trials range from highly to moderately controlled settings and do not sufficiently replicate farmer conditions. Furthermore, the number of farmers in the trials has been small, for example only 49 households across eight countries in Setimela et al. (2012), and farmers were chosen by extension agents and may therefore represent progressive rather than average farmers. Our 2011/12 data for 350 farm households in six Malawi districts allows for assessment of how the DT maize varieties compare in terms of yield with other improved and local varieties under a range of farmer characteristics, farmer management, agro-ecologies, and drought vs. non-drought conditions. As highlighted by Jain et al. (2015), a limitation of previous research is the common assumption that any weather-induced change made by farmers and other decision makers is adaptive or beneficial. More research is needed to examine whether changes made by decision makers in response to climate variability are in fact beneficial to the individual and her/his household.

Malawi is a useful setting for the present study for several reasons: maize, the staple crop, has high importance for national and household food security, drought risk exhibits considerable spatial variability, and DT maize adoption has potential to bring about substantial reduction in food insecurity. Our study provides information on the likely effects of scaling up the distribution of DT maize varieties in drought and normal years, and helps to identify future priorities in crop breeding, agricultural extension, and infrastructure that hold promise for stimulating adoption. Furthermore, we assess how exposure to previous drought shocks and farmers' risk aversion affect adoption of DT maize.

2. Data and Study Context

2.1. The farm household survey

Data for this study come from a farm household survey with an original sample of 450 households located in two districts in Central Malawi (Kasungu and Lilongwe) and four districts in Southern Malawi (Chiradzulu, Machinga, Thyolo and Zomba) that were interviewed in 2006, 2007, 2009, and 2012. In the 2012 survey, we managed to find and re-interview 350 of the original households. Households had been randomly sampled within each Enumeration Area (EA) following the Integrated Household Survey of 2004, conducted by Malawi's National Statistical Office. Two (in Thyolo, Chiradzulu and Machinga districts) or three (Zomba, Kasungu and Lilongwe districts) EAs were randomly sampled and at least 30 households were randomly sampled from each of the EAs (Lunduka 2009). As in the earlier years, the 2012 survey included collection of detailed farm plot level data with GPS-measurement of plot sizes. A plot was defined as a uniform crop stand that received homogenous "input treatment" (Holden and Lunduka 2012). Unlike the former large national surveys that typically collected data from one plot per household and relied on farmers' own assessment of plot size and farm size, we measured (with GPS) and collected data for all plots of the sample households. Our data should therefore suffer less from measurement error than the past larger surveys.

In this study we present results utilizing the three year panel (2006, 2009, 2012) as well as expanded models for 2012 when we had access to additional variables that help us better understand the mechanisms of DT maize adoption. The 2012 data also includes a substantial amount of recall information from the 2010/11 and the 2009/10 seasons as well for variables that we thought would be quite easy for the households to remember.

2.2. Exposure to dry spells at the study sites

We now assess the extent of exposure to dry spells among the sampled households and compare exposure across districts and recent years. We were in advance informed that there were widespread dry spells in the 2011/12 season, and the survey asked respondents whether or not they had experienced dry spells during the last three years (Table 1). There is obviously a subjective element in assessment of dry spell exposure. We did not force a special definition of the term onto the respondents but simply asked them about their own perceptions.

Table 1 shows that 74% of the sampled households were exposed to a dry spell in the 2011/12 season compared to only 18% and 9% in the previous two years. The aggregate measure indicates that, on average, 80% were exposed to a dry spell at least once during the last three years. Kasungu district appears to have had lower exposure to dry spells in recent years, as only 26% perceived that they had been exposed to a dry spell in the 2011/12 season and only 40% perceived that they had been exposed to such an event at least once the last three years. By contrast, survey results indicate relatively high exposure to dry spells in Chiradzulu and Thyolo districts: all of the sampled households in these districts reported a dry spell at least once in the last three years. Another way to measure dry spell exposure with the survey data is with information on maize replanting. Table 1 provides district-level information on the percent of sampled households that replanted after experiencing a dry spell in 2011/12. As indicated by the table, the dry spell caused many households (43%) to replant maize due to crop failure, with the bulk of replanting occurring in December 2011. There is some agreement between measures of drought exposure reported in

Table 1. Specifically, by both measures Kasungu district households were least exposed to dry spells, while Thyolo district households were most exposed. In section 5 of the paper, we use farmer reported exposure to the 2011/12 dry spell (Table 1) to assess the impacts on maize yields of different types of maize using our farm plot level data.

3. Assessing Farmer Demand for DT Maize

3.1. Maize variety use and preferences

In the 2011/12 agricultural season, 173 of the 351 sampled households received hybrid maize seed through the Malawi Farm Input Subsidy Program (FISP), 15 households received open pollinated (OPV) maize seed, and 34 households received legume seed. FISP, which has been implemented since 2005/06, targets approximately 50% of farmers in the country to receive subsidized fertilizer for maize production, with additional vouchers for tobacco fertilizers and improved maize seed (Lunduka et al. 2013). Table 2 reports the most common maize varieties that households said they received through the subsidy program during the last three production years, distinguishing between DT and other improved maize varieties. The data suggest the FISP has played an important role in diffusing DT maize to Malawian farmers, especially in 2009/10. Between 69 and 82% of sampled farmers that received a coupon for maize seed reported that they redeemed their coupon for a DT maize variety. It is not possible to state that this distribution represents the demand for maize varieties, as supply side factors related to what was available in the depots for distribution with the input subsidy coupons may be more important for what households received than their own preferences.

Table 3 gives an overview of preferred maize varieties that households stated they would have used if they had good access to fertilizers and if they did not have access to fertilizer, again distinguished by DT and non-DT improved maize. The data indicate high farmer demand for the DT maize varieties, particularly for SC403, and this is the case with good and poor fertilizer access. The popularity of SC719 is impressive given the variety is rather new, released in 2008, but farmers do not prefer the variety without good fertilizer access. To questions about unmet demands for improved maize seed, farmer responses show that the most commonly grown varieties are also the ones that most often people have failed to obtain. Supply constraints therefore appear to constrain adoption of the most popular varieties, although the severity of this constraint appears to have reduced in recent years: 81% of surveyed farmers stated that availability of improved maize varieties has improved over the last three years.

Respondents were also asked why they prefer some varieties over others. Farmers with good access to fertilizer expressed a strong preference for high yielding maize varieties, while those with poor fertilizer access most commonly mentioned a preference for varieties having reasonable yields without fertilizer application. Early maturity was also a desirable trait, and the most popular variety, SC403, is a very early maturing variety. But other popular varieties, SC627 and SC719, are medium and long duration varieties. Among the sampled households, less than 3% of respondents expressed a preference for drought tolerance. This might reflect a misunderstanding of what drought tolerance is and a misconception that drought tolerant varieties have lower yields than other improved maize varieties.

4. Estimation Strategy

We outline below the estimation strategy to assess factors associated with DT maize adoption and its performance relative to local maize and other improved maize varieties. This requires controlling for differences in fertilizer use intensity on the different maize varieties as well as other observable and unobservable factors that may be correlated with adoption, intensity of input use, and maize productivity.

4.1. DT maize adoption

A farmer's decision to grow DT maize is influenced by many supply and demand factors, which we represent with regression models based on the three-year panel dataset and the 2011/12 cross-sectional data. The three-year panel model is specified as follows:

1) $$DT_{ipt} = \alpha_0 + \alpha_1 R_{vt} + \alpha_2 D_{it} + \alpha_3 Rp_{ipt} + \alpha_4 S_{ipt} + \alpha_5 T_t + \alpha_6 P_{ipt} + \alpha_i + \varepsilon_{ipt} .$$

In equation 1), dependent variable DT_{ipt} is a dummy variable for whether or not household i grew DT maize on plot p in year t. R_{vt} is a vector of variables capturing weather conditions (annual rainfall, deviation of rainfall from normal (coefficient of variation - CV%)) in the farm household's village v. D_{it} indicates the household experienced a dry spell occurred in that specific year, according to the farmer. Rp_{ipt} is a binary variable indicating if the drought was so severe that the household had to replant the crop. S_{ipt} is a dummy for whether the household received subsidized inputs and used them on the plot. The FISP has been a major supplier of DT and other improved maize varieties in Malawi, and the complementary Agricultural Sector-Wide Approach – Support Program (ASWAP-SP) has since 2009 disseminated information about new maize varieties through a country-wide system with lead farmers and demonstration trials. Maize seed is otherwise available through commercial providers of agricultural inputs. T_t denotes year-specific dummies and captures the trend in DT maize adoption from 2006 to 2012. P_{ipt} controls for observable farm plot characteristics such as soil type, slope, fertility status, plot size and distance to plot from home. α_i captures unobservable time-invariant characteristics of households and farms such as managerial ability and unobservable land quality. We use household random effects and fixed effects specifications to test the sensitivity of the results to these alternative specifications. The household fixed effects approach is the best tool we have to control for selection bias related to access to subsidized inputs.

The 2011/12 dataset includes several important variables that are not part of the three-year panel dataset, allowing for an expanded model:

$$\text{2a) } DT_{ip} = \alpha_0^* + \alpha_{11}^* D_i^{2012} + \alpha_{12}^* D_i^{2011} + \alpha_{13}^* D_i^{2010} + \alpha_2^* Rp_{ip} + \alpha_{31}^* DTsub_i + \alpha_{32}^* \varepsilon(DTsub_i)_i + \alpha_4^* NS_i + \alpha_5^* crra_i + \alpha_6^* P_{ip} + \alpha_7^* G_i + \alpha_8^* AS_i + \alpha_9^* D_v + \alpha_i + \nu_{ip}$$

$$\text{2b) } DTsub_i = \delta_0 + \delta_1 NA_i + \delta_2 D_v + \varepsilon_i$$

Many of the explanatory variables in equation 2a) are the cross-section equivalents of the explanatory variables in equation 1), but there are several important additions. The rainfall and rainfall variability variables do not vary within villages and are therefore dropped since we use village fixed effects. We make use of recall data for exposure to drought shocks in 2011 (D^{2011}) and 2010 (D^{2010}) to see whether such exposure has stimulated adoption of DT maize varieties. We also include another shock variable (NS_i) which captures the number of shocks other than drought the household experienced over the period 2009-2012, such as deaths or serious sickness in the family. Such shocks may affect both the ability and willingness to adopt. We have also included the estimated variable $crra_i$ which is the relative risk aversion coefficient estimated using risk experiment data from the same households (Holden 2014)[2]. If DT maize is perceived as risk-reducing but perhaps not as high-yielding as other improved maize varieties, we may expect that more risk averse households are more eager to adopt DT maize. The G_i captures gender of household head and *ASi* captures whether households have been exposed to the ASWAP-SP

[2] Holt and Laury (2002) type of hypothetical and monetary experiments were used and a structural model with a constant relative risk aversion coefficient utility function was used combining the hypothetical and monetary experiments.

program that has promoted conservation agriculture including demonstrations of DT maize varieties in on-farm demonstration trials throughout the country by 2012.

In equation 2a), the explanatory variable for receipt of subsidized DT maize ($DTsub_i$) is potentially jointly determined with the dependent variable, i.e. $DTsub_i$ may be endogenous, since the selection of DT maize beneficiaries under FISP was not random but was guided by targeting criteria and influenced by local and regional politics (Holden and Lunduka 2013; Lunduka et al. 2013). To avoid biased coefficient estimates due to endogeneity in the DT maize seed access under FISP, we employ a control function approach to test and control for endogeneity bias: a regression model, in which the dependent variable was $DTsub_i$ and the explanatory variables are described below. Equation 2b) is the first stage for the control function approach. The residuals from estimation of 2b) are included with $DTsub_i$ as explanatory variables in equation 2a). The statistical significance of the residuals provide a test for endogeneity of the DT maize subsidy variable.

As in a two-stage instrumental variables model, the control function approach requires inclusion of at least one variable in the input subsidy equation that is not in the DT maize adoption equation. For this reason, a dummy variable for households having non-agricultural business income (*NA*) is used as instrument. Households with non-agricultural business income may be less likely to access subsidies and therefore DT seed through FISP. We see no particular reason why having non-agricultural business should make households more or less interested in adopting DT maize. We test the statistical validity of this by also including the instrumental variable in the adoption equation in one specification. If the instrument is insignificant in the adoption model but significant in the subsidy equation, and if the error term from the first stage model is significant in the adoption model, then endogeneity is an issue and is corrected for with the control function approach. Village fixed effects are also used to capture possible cross- village differences in the distribution of DT seeds through the subsidy program that allow for non-linear identification.

4.2. Maize yield impact

We seek to evaluate the yield performance of DT maize relative to other improved maize varieties and local maize, for the drought year 2011/12. While on-station and on-farm trials suggest a sizable yield advantage, there has been no complementary research to measure DT yield performance with farm household survey data. While we have three years of data we only utilize the household fixed effects from the three-year maize yield models to control for the unobserved household and farm characteristics in the following models for 2011/12[3]. It is the performance under the drought conditions in 2011/12 that we are particularly interested in.

To assess the yield performance of the different maize varieties in the drought year 2011/12, we have specified models where we have controlled for endogeneity related to access to DT maize varieties through the subsidy program, for access to subsidized fertilizer through the subsidy program, for unobservable factors that can affect commercial demand for fertilizer, and for unobservable household ability and farm land quality characteristics. The included error terms come from equation 2b above and from three models that are available from the authors upon request. We control for the unobservable household ability and farm land quality with the fixed effects extracted from the three year plot panel model for maize yields as explained above[4]. We have in addition to the annual rainfall, rainfall deviation from a normal year, and 2012 dry spell dummy, also included lagged drought dummy variables for the two previous years and a dummy

[3] The three-year panel model results are available from the authors upon request.
[4] The three-year panel model did not give any significant difference in yield between the maize varieties. One of the reasons may be that this model is too rigid as it requires many coefficients to be constant over time while soil characteristics and fertilizer may give different responses under varying weather conditions. For example, clay soil may conserve moisture in a dry year but be associated with waterlogging in a wet year. Separate models run for each year revealed this kind of differences. These models are available from the authors upon request.

for whether the 2011/12 drought was so severe that the crop failed totally and had to be replanted. We have not included village fixed effects in these models as these are highly correlated with the drought variables and the rainfall variables that also do not vary within villages.

$$3)\ Y_{ip}^{Ha} = \lambda_0 + \lambda_1 DT_{ip} + \lambda_2 LM_{ip} + \lambda_3 R_{vt} + \lambda_4 D_i^{2012} + \lambda_5 DT_{ip} * D_i^{2012} + \lambda_6 LM_{ip} * D_i^{2012} + \lambda_7 P_{ip} + \left(\lambda_8 E_{ip} + \lambda_9 \hat{v}\left(E_{ip}\right) + \lambda_{10}\alpha_i\right) + \xi_{ip}$$

In model 3 it is particularly the DT maize and local maize (LM) dummy variables and their interactions with the dry spell drought in 2011/12 that we are interested in, while controlling for farm plot characteristics (land quality). We have specified models without and with the maize variety and drought interaction variables. Models were run without and with endogenous variables (E_{ip}) such as source of access to DT maize as well as log-transformed subsidized and commercial fertilizer, including their error terms from separately run models to control for their endogeneity (control function approach) and unobserved household heterogeneity[5]. The other variables in equation 3 are as specified in relation to equation 2a.

5. Results and Discussion

5.1. DT maize adoption

The adoption model results are presented in Tables 4 and 5. Table 4 shows the adoption trend from 2006 to 2012, which indicates a substantial increase in the adoption of DT varieties over this time period. Results also indicate that the increase in adoption was strongly associated with FISP. The model with household fixed effects, which controls better for unobservable

[5] This was done by including the household fixed effects extracted from the three-year panel model for maize productivity.

household and farm characteristics, reveals a more significant effect of the subsidy program on DT adoption.

Table 5 provides a more comprehensive analysis of factors associated with DT maize adoption in the 2011/12 season. As mentioned earlier, we used a control function approach to handle sample selection related to receiving DT maize through FISP and non-agricultural business was the instrumental variable left out in the second stage regressions. The first model in Table 4 is the first stage model, the second model in Table 4 includes the instrument in the second stage to assess statistical validity. As shown, non-agricultural business income was significant at 5% level and with a negative sign in the first model, and the instrument was not significant at standard test levels in the second model, while the error term from the first stage model was significant at 5% level and with negative sign. Our control function approach therefore appears to work. We used four different specifications of the second stage. The first included the instrument as a test for its statistical validity, the second excluded the instrument, the third included the ASWAP-SP variables as well as the household fixed effects from the three-year maize productivity models as controls for unobservable farmer ability and farm land quality, and the fourth included the average annual rainfall and rainfall deviation variables as well. The household fixed effects variable was insignificant. This indicates that farmers that were more productive (e.g., due to unobservable ability or better land quality) were not more or less likely to adopt DT maize.

The dummy variable for receiving DT maize through the subsidy program was highly significant (at 0.1% level) and with a positive sign. The receivers of DT maize through the subsidy program were 78% more likely to use DT maize. This is very strong evidence that the FISP was a strong driver that encouraged DT maize adoption in the country.

We wanted to explore whether the Agricultural Sector-Wide Support Programme (ASWAP-SP) which has expanded dissemination of improved maize varieties and conservation programs had started to make a visible impact on DT maize adoption in our study areas. Findings do not indicate a significant impact of the program on DT maize adoption in our sample, but this may reflect that the program only has been operational since 2009 and has expanded gradually to new areas.

Next, we assessed whether exposure to drought shocks in previous years (2010 and 2011) affected DT adoption. Earlier drought shocks may have given farmers experience or interest in adopting DT varieties. Results show that exposure to drought shocks in 2010 was associated with significantly (at 5% level) higher adoption of DT maize varieties. Farmers with such exposure were 18% more likely to plant DT maize. This result was robust to alternative specifications.

We also tested the effects of the 2012 drought and of this drought causing households to have to replant their maize crop. While the 2012 drought dummy had no significant effect on DT maize adoption, the replanting dummy was significant (at 5% level) and with a positive sign. Those who had to replant their maize crop were 8% more likely to use DT maize when they replanted their crop.

A measure of relative risk aversion, based on experimental data, was included in the model. If DT maize is perceived to reduce production risk, we expect that more risk averse farmers are more likely to adopt DT maize. Our results support this. The variable was significant at 10% level and with positive sign in all three specifications. A one unit change in the constant relative risk aversion coefficient was associated with a 16% increase in the adoption of DT maize. This indicates that the awareness of DT maize as a risk-reducing technology has started to make its impact on maize variety adoption in Malawi.

5.2. DT maize yield impact

Table 6 presents the results for the test of the DT maize varieties versus local maize and other improved maize varieties using the maize yield data from 2012 when a severe dry spell occurred early in the rainy season in much of the country. We assessed the performance of the different maize varieties in areas affected and unaffected by the dry spell. Robustness checks were included by running models without and with the interaction of maize variety and drought, and without and with a set of endogenous variables and controls for their endogeneity, using a control function approach. The first model in Table 6 included the dummies for DT maize and local maize (LM) without interacting them with exposure to drought in 2012. The second and fourth of these models included endogenous variables and error terms for control of endogeneity and the household fixed effects variable extracted from the three-year model. The third and fourth models included the maize variety dummy variables as well as their interactions with the 2011/12 drought dummy variable to more specifically test how DT maize performed under drought conditions compared to other improved maize varieties and local maize. The control function approach involved including three error terms; one for access to DT maize through the subsidy program, the second for access to subsidized fertilizer, and the third for access to commercial fertilizer.

The first two models in Table 6 indicate that local maize had significantly lower yield than DT maize and other improved maize varieties, but DT maize did not give yields that were significantly better than the other improved maize varieties. With inclusion of endogenous variables and additional controls this main result did not change except the coefficient on local maize was slightly reduced and its level of significance was reduced from 1% level to 5% level.

With inclusion of the variety and drought interaction variables models Y3 and Y4 show that again the local maize performed significantly poorer than DT maize and other improved maize varieties, while DT maize did not do significantly better or worse than other improved maize varieties. This result is robust to exclusion or inclusion of endogenous variables and additional controls for endogeneity and household unobservables.

6. Conclusions

Maize is the main staple food crop for rural smallholder households that dominate Malawi's countryside. The crop is highly susceptible to drought, and climate variability and climate change threaten household and national food security. Several drought tolerant (DT) maize varieties have recently been developed and disseminated to farmers in Malawi and other SSA countries, and there is urgent need to evaluate the merits of these promising technologies for drought risk mitigation. The present paper is among the first to measure the degree of adoption and evaluate, under farmer conditions, the yield advantage of DT maize technologies under moderate drought conditions. The study employed cross-sectional and panel data for 350 farm households residing in six districts of Central and Southern Malawi for such investigation, with focus on the 2011/12 production season in which widespread drought occurred in Malawi.

Our analysis of DT maize adoption revealed that adoption of DT maize has expanded substantially from 2006 to 2012. The main driver of this adoption was the subsidy program (FISP) which has distributed free seeds in addition to highly subsidized fertilizer to smallholder households since 2005/06. However, we also found that lack of access to commercial seeds constrained the adoption of DT maize varieties. About 35% of the households stated that they were unable to obtain the most preferred maize variety in the 2011/12 season. The most popular varieties were the most commonly grown DT varieties, showing that there is room for further expansion of such varieties. Exposure to an earlier drought (in 2010) was associated with significantly higher demand for DT maize in 2012, suggesting that the farmer's decision to start cultivating DT maize was partly in response to climatic variability. Likewise, more risk averse households had a significantly higher demand for DT maize.

As far as yield performance, improved maize varieties performed significantly better than local maize during the 2011/12 drought year. However, DT maize did not perform significantly better than other improved maize varieties used in Malawi, which is in contradiction to results from on-station and on-farm trials (e.g., Magorokosho et al. 2010; Setimela et al. 2012). Findings suggest that, for farmers who moved from cultivating local to DT maize, this change was adaptive, that is it conferred significant benefit in maize yield. But the change from cultivation of non-DT improved maize to DT improved maize did not appear to offer any benefit in maize yield.

The finding of no yield advantage of DT improved maize over non-DT improved maize was not predicted, given the results of on-station and on-farm trials. We caution readers to draw conclusions until more evidence on the issue is available. There could be several reasons for this and more research is needed before a robust conclusion can be drawn regarding the additional yield benefits of DT maize compared to other maize varieties under alternative agroclimatic and socioeconomic conditions. One plausible explanation is that farmers had inadequate training or experience to move towards the yield potentials of the DT maize varieties. Expansion of agricultural extension activities may be required to help farmers achieve the DT maize yield potentials and, subsequently, improve farmer resilience to drought. For now, continuation of the FISP will ensure continued cultivation of the DT maize varieties which have commonly been featured under the input subsidy program. As farmers gain experience with these varieties it will be important to track the yields of DT maize in farmers' fields to observe if yields increase and eventually exceed those of the non-DT varieties. Finally, it is important to recognize that while our study focused on DT maize for adaptation, there are many proven agricultural adaptations for promoting household food security in Malawi and elsewhere, for example cultivation of drought tolerant crops such as cassava and pigeon pea. However, the recent serious flood in the country illustrates the limitations of any crop or crop variety as protection against extreme weather conditions.

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Table 1. Drought exposure of sampled households in the last three years, by district

District	Percent reporting drought, by year				Percent that replanted in 2011/12
	Drought at least once last 3 years	Drought in 2011/12	Drought in 2010/11	Drought in 2009/10	
Thyolo	100	98	24	11	62
Zomba	97	95	13	4	61
Chiradzulu	100	100	58	18	33
Machinga	85	81	23	11	49
Kasungu	40	26	10	6	16
Lilongwe	81	73	7	12	40
Total	80	74	18	9	43

Source: Own survey data.

Table 2. Maize varieties received as a percent of those receiving free maize seed under the FISP, by year

Maize variety	2011/12, %	2010/11, %	2009/10, %
Received improved maize seed	50.7	54.1	51.9
DT improved maize varieties	68.9	70.1	81.9
SC403 – Kanyani	34.4	39.0	42.3
SC627 – Mkango	25.0	23.7	24.7
SC719 – Njovu	2.2	0.5	2.2
ZM523 – Demeta (OPV)	6.7	5.3	7.7
ZM623	0.6	1.6	5.0
Other (not DT) improved maize varieties	30.3	29.0	18.3
Decap	0.6	1.1	0
DK8033	7.2	9.5	8.8
DK8053	13.9	5.3	3.3
DK8067	0.6	0	0
DK8071	0.6	0	0
DK9089	0.6	0	0
MH18	2.2	4.2	0.6
MH19	0.6	3.2	0.6
MH41	0.6	0.5	0
Pannar 43	2.8	0.5	4.4
SC407	0.6	4.7	0.6

Source: Own survey data.

Table 3. Preferred types of maize and varieties with good access and no access to fertilizer

Name of variety	With good access to fertilizer, %	Without fertilizer access, %
DT maize varieties	74.1	62.4
SC403 – Kanyani	35.9	34.1
SC627 – Mkango	22.1	20.8
SC719 – Njovu	15.0	5.8
ZM535	1.1	1.7
Other improved maize varieties	32.4	30.1
DK8033	9.1	9.8
DK8052	0.7	
DK8053	7.6	5.2
DK8071	0.7	0.6
DK9089	0.4	
MH18	8.3	13.3
MH19	0.4	
MH41	1.1	
Pannar 43	2.2	1.2
Pioneer	1.5	
SC407	0.4	

Table 4. Linear probability models for DT adoption with household-farm plot panel from 2006, 2009 and 2012 (maize plots).

	Village FE & Household RE	Household FE
Annual rain, mm	0.000	0.000
	(0.000)	(0.001)
Rain deviation, CV%	-0.002	-0.002
	(0.002)	(0.008)
Drought_2012	-0.050	-0.025
	(0.088)	(0.087)
Replant_2012	-0.007	0.009
	(0.070)	(0.076)
Fertilizer subsidy, dummy	0.038*	0.056**
	(0.022)	(0.026)
Year 2009, dummy	0.188****	0.199****
	(0.025)	(0.029)
Year 2012, dummy	0.464****	0.440****
	(0.069)	(0.066)
Farm plot characteristics	Yes	Yes
Village FE	Yes	
Household FE	No	Yes
Constant	-0.175	-0.027
	(0.214)	(0.828)
Wald chi	342.279	
F-value		18.146
Prob > chi2	0.000	0.000
Observations	1744	1744
R-squared		0.239

Note: Dependent variable is a dummy for drought tolerant maize variety grown on the plot. Land quality controls include soil type, slope, and soil fertility classes. Significance levels: *: 10%, **: 5%, ***: 1%, ****: 0.1%. Robust standard errors.

Table 5. DT maize adoption models with control function approach for access to DT maize through the subsidy program, 2012 data.

	1.stage IV	CF1	CF2	CF3	CF4
Drought_2012, dummy		-0.069	-0.074	-0.078	-0.047
		(0.063)	(0.063)	(0.069)	(0.065)
Drought_2011, dummy		0.022	0.019	0.011	0.006
		(0.047)	(0.046)	(0.051)	(0.049)
Drought_2010, dummy		0.182**	0.182**	0.188**	0.172**
		(0.085)	(0.083)	(0.090)	(0.084)
Replant_2012 after dry spell, dummy		0.078**	0.083**	0.089**	0.102***
		(0.034)	(0.034)	(0.035)	(0.035)
Received DT maize through subsidy		0.795****	0.785****	0.778****	0.793****
program (DTsub)		(0.090)	(0.087)	(0.082)	(0.065)
Error term for received DT maize		-0.162**	-0.154**	-0.148**	-0.170***
through subsidy program model		(0.069)	(0.066)	(0.071)	(0.053)
Number of shocks, 2009-2012		0.029	0.030	0.025	0.031*
		(0.021)	(0.021)	(0.021)	(0.019)
Relative risk aversion coefficient		0.154*	0.148*	0.145	0.064
		(0.089)	(0.088)	(0.095)	(0.076)
Failed to get preferred maize variety,		-0.023	-0.019	-0.020	-0.038
dummy		(0.038)	(0.038)	(0.037)	(0.036)
Sex of household head=female, dummy		-0.053	-0.056	-0.056	-0.071**
		(0.036)	(0.037)	(0.038)	(0.035)
Familiar with ASWAP-SP				-0.028	-0.019
				(0.029)	(0.025)
Seen ASWAP-SP demonstration plots				-0.021	0.003
				(0.047)	(0.041)
Unobservables control (HHFE)				-0.000	-0.000
				(0.028)	(0.024)
Average annual rainfall					-0.000
					(0.000)
Rainfall deviaton (CV%)					-0.002
					(0.003)
Farm plot characteristics		Yes	Yes	Yes	Yes
Instrumental variable:					
Non-agricultural business, dummy	-0.083**	0.045			
	(0.038)	(0.035)			
Village FE	Yes	Yes	Yes	Yes	No
Constant	0.175**	-0.278	-0.247	-0.174	0.113
	(0.084)	(0.197)	(0.189)	(0.220)	(0.309)
Wald chi	138.367	1038.092	1088.975	1084.655	501.552

Prob > chi2	0.000	0.000	0.000	0.000	0.000
Rho	0.000	0.639	0.639	0.640	0.640
Observations	582	489	489	483	483

Note: Dependent variable: Dummy for use of DT maize at plot level. Linear probability models with household random effects. Selection bias in relation to obtaining DT maize through the subsidy program is tested for with a Control Function approach using visit by extension staff and having non-agricultural business as instruments. The robustness of the results is tested by alternatively including instruments in second stage to test their statistical validity and by control for unobservables as follows: Control for unobservable household and farm characteristics is included as the household fixed effects extracted from a three-year panel model for maize productivity (Unobservables control (HHFE)). DT varieties include SC403, SC627, SC719, ZM521, ZM523 and ZM621. Significance levels: *: 10%, **: 5%, ***: 1%, ****: 0.1%. Standard errors are bootstrapped by resampling households, with 400 replications.

Table 6. Cobb-Douglas Maize yield models 2012 without and with variety*drought interactions and control function approach to test and control for endogeneity in subsidy access, seed access and fertilizer use.

	Y1	Y2	Y3	Y4
DT maize varieties	-0.033	0.082	0.185	0.167
	(0.123)	(0.122)	(0.268)	(0.226)
Local maize	-0.307***	-0.282**	0.182	0.125
	(0.099)	(0.126)	(0.247)	(0.253)
Drought in 2012	-0.215	-0.183	0.084	0.031
	(0.211)	(0.202)	(0.273)	(0.279)
DT maize*Drought_2012			-0.252	-0.083
			(0.300)	(0.240)
Local maize*Drought_2012			-0.577**	-0.477*
			(0.268)	(0.264)
Farm plot characteristics	Yes	Yes	Yes	Yes
Weather data	Yes	Yes	Yes	Yes
Endogenous variables +controls	No	Yes	No	Yes
Wald chi	181.579	473.469	187.463	520.094
Prob > chi2	0.000	0.000	0.000	0.000
Rho	0.427	0.245	0.437	0.257
Observations	494	489	494	489

Note: Dependent variable: Log of maize yield in kg/ha. Controls: Household fixed effects from 3-year panel models (models Y2 and Y4), error terms from DT maize access through subsidy program, access to subsidized fertilizer, and demand for commercial fertilizer. Significance levels: *: 10%, **: 5%, ***: 1%, ****: 0.1%. Standard errors in parentheses are robust in models Y1 and Y3 and bootstrapped by resampling households, with 400 replications in models Y2 and Y4.

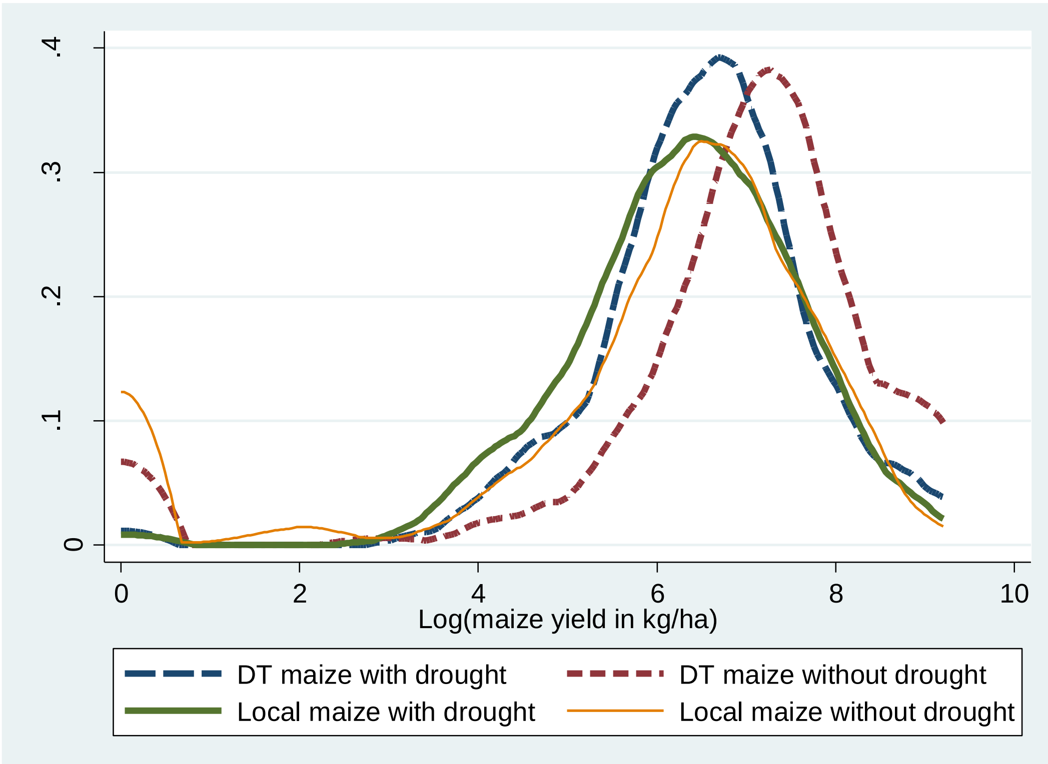

Figure 1. Maize yield distributions for DT maize and Local maize with and without drought in 2012, based on farm plot level data.

Appendix. Overview of variables in 3-year panel and 2012 extended data

Table A1. List of variables for 3-year panel

Variable	Obs	Mean	Std. Dev.	Min	Max
Log(Maize yield in kg/ha+1)	1719	6.000	2.371	0	9.210
Soil type	1978	1.932	.692	1	3
Slope	1970	1.453	.610	1	3
Plot fertility	1994	2.071	.633	1	3
Annual rain, mm	2013	911.766	248.720	334.3	1359
Rain deviation, CV%	2013	-.263	21.383	-57.999	33.91
Fertilizer subsidy access, dummy	1924	.549	.498	0	1
Log(Fertilizer use intensity in kg/ha+1)	1719	3.602	2.378	0	6.686
DT maize, dummy	2023	.197	.398	0	1
Local maize (LM), dummy	2023	.402	.490	0	1
Drought_2012, dummy	2023	.220	.415	0	1
Replant_2012, dummy	2023	.106	.308	0	1
DT maize*Drought_2012	2023	.098	.298	0	1
LM maize*Drought_2012	2023	.105	.307	0	1
Log(Plot size in ha)	1719	-1.341	.942	-5.988	4.285

Table A2. List of 2012 variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Grow DT maize on plot, without SC627	591	.305	.4606	0	1
Received DT through subsidy program, without SC627	591	.225	.418	0	1
Grow DT maize on plot, with SC627	591	.455	.498	0	1
Received DT through subsidy program, with SC627	591	.387	.488	0	1
Log(plot size in ha)	591	-1.392	.896	-4.82	2.10
Log(plot distance)	584	5.589	2.10	0	9.68
Subsidized fertilizer access, dummy	593	.408	.492	0	1
Failed to get preferred maize variety	593	.302	.459	0	1
Drought_2011, dummy	511	.217	.413	0	1
Drought_2010, dummy	511	.078	.269	0	1
Drought_2012, dummy	593	.803	.398	0	1
Replant_2012, dummy	593	.381	.486	0	1
Sex of household head=female, dummy	587	.588	.493	0	1
Relative risk aversion coefficient	586	1.740	.282	.99	2.21
Number of shocks 2009-12	591	1.645	.867	0	4
Unobservables household-farm (HHFE)	737	.049	.751	-4.57	4.43
Familiar with ASWAP-SP	513	2.165	.878	1	3
Seen ASWAP-SP demonstration trials	593	.359	.480	0	1
Soil type (1=sand, 2=loam, 3=clay)	593	2.029	.658	1	3
Slope (1=flat, 2=slight, 3=steep)	591	1.457	.633	1	3
Plot fertility (1=very fertile, 2=average, 3=infertile)	590	1.920	.520	1	3
Weed infestation (1=high, 2=medium, 3=low)	591	1.782	.652	1	3
Log(Tropical livestock units)	591	.298	.421	0	3.463
Non-agricultural business, dummy	582	.442	.497	0	1
DT maize error term (used in CF models)	582	-.165	.405	-.967	.841