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Adoption of Drought Tolerant Maize Varieties under Rainfall Stress in Malawi

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Abstract

We examine adoption of drought tolerant (DT) maize varieties using a four-round panel dataset from six districts in Malawi. There is an increase in adoption of DT maize from 3% in 2006 to 43% in 2015 in our data. We focus on the effect of past drought exposure on adoption and the likelihood of DT maize being distributed under the Farm Input Subsidy Programme (FISP). Results show that past exposure to drought increases the probability of DT maize seed being distributed through FISP. Farmers who accessed maize seed subsidy coupons and were previously exposed to late season dry spells are more likely to use the seed subsidy coupon to redeem DT maize seed. The likelihood of adoption and adoption intensity (area under DT maize) are positively influenced by previous early season dry spells and access to seed subsidy. Previous late season droughts also positively affect adoption intensity. On the other hand, area share under DT maize is positively correlated with early season dry spells and past exposure to late season dry spells but negatively related to seed subsidy. FISP in Malawi appears to have stimulated adoption of DT maize directly through subsidy and indirectly through generating farmers' experiences of the performance of DT varieties under drought conditions.

Keywords: *drought exposure*; *drought tolerant maize adoption*; *farm input subsidy programme*; *Malawi*; *Mundlak-Chamberlain*.

JEL classifications: *O13, O33, Q18, Q56*.

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1. Introduction

Weather shocks such as droughts and floods undermine crop yields and aggregate production thereby reducing food availability and agricultural incomes (Davies *et al.*, 2009; Kassie *et al.*, 2009; Pauw *et al.*, 2011). Farm households' failure to adapt to climate change could aggravate the negative effects and can inhibit further investment and economic growth (Nangoma, 2007; Kato *et al.*, 2011; Kassie *et al.*, 2015). Weather shocks can cascade through low production to food insecurity and local and national economic disruption (Devereux, 2007). The problem is particularly serious among smallholder farmers in sub-Saharan Africa (SSA), who are repeatedly exposed to weather extremes but with limited adaptation options. For example, Malawi has experienced several weather shocks during the last two decades that have led to severe crop losses, infrastructure damage and occasional displacement of people (Nangoma, 2007; Pauw *et al.*, 2010). The most recent shocks include the droughts of 2001/02, 2004/05 and 2011/12 (Nangoma, 2007; Denning *et al.*, 2009; Holden and Fisher, 2015; Msowoya *et al.*, 2016) and the 2014/15 flash floods early in the growing season and droughts thereafter.

Investing in agricultural production methods to boost farmers' resilience against weather shocks is a key strategy to reduce negative impacts (Davies *et al.*, 2009; Pangapanga *et al.*, 2012). In a country like Malawi and most countries in the SSA region, with poor or missing markets for insurance and credit and limited off-farm employment opportunities, adoption of agricultural management strategies that reduce production risks is an important option for smallholder farmers (Kassie *et al.*, 2015). Drought tolerant (DT) maize is one potential technology that has the capacity to help smallholders adapt to drought risks. It is estimated that DT maize can produce up to 30% of their potential yield after 6 weeks of water stress, before and during flowering and grain-formation (Magorokosho *et al.*, 2009). It is also estimated that DT maize can give a yield advantage of up to 40% over other maize varieties in severe drought environments (Tesfaye *et al.*, 2016).

We examine the adoption of DT maize among smallholder farmers in Malawi, focusing on how past exposure to dry spells affects adoption and the probability that DT maize is included in the seed subsidy programme. The paper combines household panel data spanning 9 years from 2006 to 2015 and daily rainfall data from 2003 to 2015 from Malawi's Department of Climate Change and Meteorological Services. Previous studies across several countries in SSA identify several major factors affecting adoption of DT maize varieties, including: unavailability of improved seed; inadequate information; lack of resources; high seed prices (Fisher *et al.*, 2015). Other authors report farming experience with DT maize, access to DT seed and awareness of DT maize varieties as key drivers of adoption in Nigeria (Idrisa *et al.*, 2014; Radda, 2015; Awotide *et al.*, 2016). In Malawi, Holden and Fisher (2015) and Holden and Quiggin (2017a) identify the Farm Input Subsidy Programme (FISP), recent droughts and farmer risk aversion as the major drivers of adoption.

Building on these findings, our paper extends the empirical analysis of Holden and Quiggin (2017a) in several ways. First, while Holden and Quiggin reported FISP as a major driver of DT maize seed adoption, we examine how past exposure to droughts affects the probability that DT seed was included and distributed through FISP. We also examine how past exposure to dry spells affects use of DT seed, conditional on access to subsidised DT seed. Second, Holden and Quiggin combined experimental data to derive prospect theory parameters with cross-sectional survey data from 2012 and perception data on lagged exposures to weather shocks (drought). In contrast, we use four rounds of household panel data to assess changes in DT adoption over the period 2006–2015, which includes substantial variation in rainfall shocks, and controlling for (stable) household preferences. We construct a more independent dry spell variable using measured daily rainfall data as opposed to farmers' perception/memory of recent droughts. We define a dry spell as a period of 5–15 days with a total rainfall of less than 20 mm following a rainy day of at least 20 mm.[2] Using this definition, we identified the length (days) of the longest dry spell in each of the survey years, namely 2006, 2009, 2012 and 2015, and the previous three seasons of each survey year.

We hypothesise that the length of dry spells should have a positive effect on adoption of DT maize in later years (assuming farmers have learnt that DT maize performs better than other maize varieties). To learn about the relative performance, farmers need to be able to observe the performance of alternative varieties under those growth conditions. Conversely, lack of recent droughts may reduce the likelihood of adopting DT maize. Areas with higher average rainfall are less likely to have droughts or have longer growing seasons and this may reduce the probability of farmers planting early-maturing DT maize varieties.

Our third difference from the Holden and Quiggin (2017a) is that we disaggregate the dry spell variable into early season and late season dry spells. The early dry spells cover a period between December and early January that coincides with planting time while late dry spells coincide with maize grain formation between February and early March. DT maize performs relatively better than other maize varieties in case of late season droughts. Exposure to late droughts may have revealed this to farmers who have seen this on their own or neighbouring farms. Our expectation is that exposure to late droughts is more likely to have a significant positive effect on adoption of DT maize among farmers that have observed this through exposure to late droughts in earlier years. Such exposure, in combination with the FISP, should enhance adoption of DT maize.

1.1. Maize varieties in SSA

Maize varieties cultivated in the SSA region are classified into three major categories: traditional/local, hybrid and open pollinated variety (OPV) (Lunduka *et al.*, 2012; Abate *et al.*, 2017). The hybrids and OPVs are improved varieties whose breeding programme dates back to the 1930s in Zimbabwe (Magorokosho, 2007) and 1940s in Malawi (Mason and Ricker-Gilbert, 2013). The locally bred hybrid (LH7) in Malawi was first distributed in 1959 (Cromwell and Zambezi, 1993). Since then over 1,700 varieties have been released between 1950 and 2014 across countries in SSA, of which 68% are hybrids and 32% OPVs. As of 2014, improved maize occupied 57% of the land area under maize production in SSA (Abate *et al.*, 2017). The hybrid maize varieties are high yielding while OPVs are early maturing, compared with local varieties, hence providing farmers with yield advantage (Lunduka *et al.*, 2012). However, local varieties are still popular among farm households, despite proliferation of hybrids and OPVs, because of favourable processing and consumption traits such as taste,

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[2]Personal communication (18 February 2016) with Charles L. Vanya (Principal Meteorologist with the Department of Climate Change and Meteorological Services).

storability, poundability, high flour-to-grain ratios and lower requirements for inorganic fertiliser (Smale *et al*., 1995; Denning *et al*., 2009; Lunduka *et al*., 2012). Thus, while hybrids and OPVs have production advantage over local varieties, they do not yet have the consumption attributes that farm households prefer in local maize.

Considering the subsistence nature of most smallholder farmers who produce mainly for own consumption, and non-separable household production and consumption decisions, farmers face a trade-off between planting improved maize varieties with good production attributes and a local variety with preferred consumption characteristics. Farmers tend to adopt a portfolio of maize varieties combining both traditional and improved (Smale *et al*., 1995; Lunduka *et al*., 2012). Smale *et al.* (1995) reported risk aversion, future utility prospects of the variety and rationing in input supply markets or credit as some of the reasons for joint production of local and modern varieties. Abate *et al.* (2017) report adoption rates of 32% hybrids; 23% OPVs; 46% local in SSA. Farmers weigh options as to whether to allocate more land to high yielding varieties with poor post-harvest attributes or put more weight on post-harvest attributes at the expense of high yields. With the apparent recent increase in droughts, farmers not only weigh high yielding against post-harvest characteristics, but also drought tolerance as a hedge against droughts.

1.2. Drought tolerant maize variety

Drought tolerant maize seed became an integral component in breeding programmes across SSA countries during the late 1990s because of recurrent droughts (Bänziger *et al*., 2006). The programme received support from the International Maize and Wheat Improvement Centre (CIMMYT) and International Institute of Tropical Agriculture (IITA) with the launch of the Drought Tolerant Maize for Africa (DTMA) project in the mid 2000s. The project supported production and dissemination of DT maize varieties in 13 countries in SSA. Over 200 varieties were released before the project phased out in December 2015. The project was implemented jointly with national agricultural research systems who were responsible for seed delivery with support from public and private seed companies (Setimela *et al*., 2013; Wawa, 2016).

In Malawi, as of December 2015, 18 DT maize varieties (15 hybrids and 3 OPVs) were released under the DTMA project. There are also other varieties developed outside the DTMA project that have been certified as drought tolerant by maize breeders (Abate, 2015; Holden and Fisher, 2015). The Government of Malawi includes DT seed in the FISP, making it more accessible (Lunduka *et al*., 2012; Holden and Fisher, 2015). FISP beneficiaries are officially entitled to two 50-kg bags of fertiliser and either one 2-kg bag of hybrid maize seed or a 4-kg bag of OPV seed (Ricker-Gilbert and Jones, 2015).

2. Theoretical Framework, Model Specification and Estimation Strategy

2.1. Theoretical framework

Production under uncertainty can be presented as a state-contingent production function as proposed by Chambers and Quiggin (2000) and Quiggin and Chambers (2006). The model assumes y distinct outputs, x distinct inputs and s possible states of nature. A farm household allocates input $x \in \Re_{+}^{X}$ and chooses state contingent output

$y \in \Re_{+}^{S*Y}$. before the state of nature is revealed (*ex ante*), where; $\Re_{+}$ implies that x and y are positive real numbers. Inputs are then fixed and output produced *ex post* (Quiggin and Chambers, 2006). If the household chooses output y and state of nature s is realised then the observed output is y_s.

The technology can then be summarised as T = [(x,y): x can produce y]. Given p_y as output price and p_x as the price of inputs, we can express the technology as a cost function $C(p_x,y) = \min[p_x x{:}(x,y) \in T]$, or as a demand function $x(p_x,y) = \operatorname{argmin}[p_x x{:}\,(x,y) \in T]$. Assuming a simple case of two states of nature, one of which is unfavourable, the farmer's interest is to maximise output (y). The producer's problem is choice under uncertainty whereby state one is unfavourable if and only if output $y_1 < y_2$. We may distinguish between inputs that are risk-complementary or risk-substituting in this kind of setting. If a shift from a state-contingent output vector y to a riskier output y' leads to an increase in demand for an input x_j that is $x_j(p_x,y) < x_j(p_x,y')$, then input x_j is risk-complementary, otherwise it is a risk-substitute if $x_j(p_x,y) > x_j(p_x,y')$ (Holden and Quiggin, 2017b). An increase in probability of a less favourable state will lead to an increased share of risk-substituting inputs in the input mix for a given expected output.

Given that the farmer's objective is to maximise expected utility [EU(.)] from output y under the expected utility theory, the adoption decision of alternative inputs can be modelled as an optimal land allocation problem (Ding *et al*., 2009). Since smallholder farmers are price takers, and prices are assumed to be non-random, the only source of uncertainty is climatic risk. An individual farmer will allocate a mix of inputs to maximise expected utility from output (y). The farmer's optimal land allocation problem can therefore be specified as $\underset{X}{\mathrm{Max}}\, \mathrm{E}[\mathrm{U}(\pi)] = \mathrm{MaxEU}[p_y y - p_X(X)]$. Our hypothesis is that experience of droughts will increase the likelihood of adopting DT maize. On the other hand, other improved maize (OIM) varieties are considered risk-complementary because they are optimal only under normal rainfall.

However, the farmer's adoption decision will not only be affected by production factors but also consumption characteristics of the seeds. The risk-averse farmer is likely to adopt a portfolio of maize varieties to meet both production and consumption needs (Smale *et al*., 1995; Lunduka *et al*., 2012). DT maize will be preferred for early maturing and drought tolerant traits but is low yielding compared to other improved hybrids under normal rainfall, while local maize varieties will be chosen for consumption traits. The key question is the land area allocated to each variety. We first model the farmer's decision on whether to adopt DT maize varieties as a binary decision and then model the decision on area (ha) and area share allocated to DT maize varieties.

2.2. Model specification

The farmers' decision to adopt DT maize can be modelled using the latent variable approach (Wooldridge, 2014). The choice is based on the seed's characteristics and weather expectations for that season (Ding *et al*., 2009), and maximising utility implies partial adoption and farmers choosing a portfolio of seeds. Both market imperfections and household circumstances mean that production and consumption decisions are inseparable. The seed demand functions are therefore based on both wealth (consumption) and production characteristics. We therefore model the adoption decision of DT maize as follows:

$$\mathrm{DT}_{it} = \alpha_0 + \alpha_1 R_{dt} + \alpha_2 S_{it} + \alpha_3 M_{it} + \alpha_4 H_{it} + \alpha_5 P_{it} + \alpha_6 T_{it} + \alpha_i + \varepsilon_{it} \quad (1)$$

where DT_{it} is the dependent variable representing the adoption of DT maize by household i in year t. R_{dt} is a vector of variables capturing rainfall stress in the farmer' district d. Lagged dry spell variables are included to capture adaptive expectations of farmers on rainfall pattern for the forthcoming season. S_{it} is a dummy for access to the FISP package of seed and fertiliser subsidies.

M_{it} represents market factors, including distance to agricultural markets (km) and the real price of inorganic fertiliser. H_{it} denotes household characteristics such as education (years), age (years) and sex (1=female) of household head, male and female labour (adult equivalent/ha), off-farm labour (adult equivalent/ha), household size (number of persons), tropical livestock units (TLU) and asset values in Malawi Kwacha (MK). P_{it} controls for observable farm characteristics such as farm size (ha) and number of plots. T_{it} represents year dummies with 2006 as base year. α_i captures unobservable time-invariant characteristics of households and plots such as time-invariant observable and unobservable preferences, managerial ability and land quality. ε_{it} is a normally distributed error term.

2.3. Estimation strategy

Parameters in equation (1) are estimated using the Mundlak-Chamberlain (MC) models with a Control Function (CF) approach (Mundlak, 1978; Chamberlain, 1984; Wooldridge, 2010). In this MC framework, we include means and deviations of all household and farm characteristics. We model the adoption decision as a binary (zero/one) decision, using a probit estimator (Wooldridge, 2010). For adopters, the second hurdle (decision) is how much land area (ha) to plant with DT maize varieties. We use a Tobit estimator to account for those who do not adopt DT maize, assuming normal distribution of the error term, ε_{it}, (that is $\varepsilon_{it}|X_{it} \sim \mathrm{Normal}(0,\sigma^2)$) (Tobin, 1958). Finally, we model the area share planted with DT maize varieties, using a fractional probit estimator to constrain the predicted value between zero and one (Wooldridge, 2011).

2.4. Attrition bias, sample selection and endogeneity

Estimation of equation (1) can suffer from attrition bias due to non-random loss of sample households between the first and subsequent waves. Following Wooldridge (2010) we test whether attrition is random, and the results give evidence of attrition bias. Fortunately, with proper adjustments, unbiased estimation is possible even with high attrition. Using the MC device, for instance, allows us to control for time-constant unobservable factors that affect attrition. On the other hand, attrition bias due to observables can be controlled using an inverse probability weighting (IPW) approach (Fitzgerald *et al.*, 1998; Wooldridge, 2010). IPW is, however, not available for our non-linear models.

Another problem in this model could be sample selection bias and endogeneity due to non-random access to FISP by the households. To control for sample selection and endogeneity bias, we use a two-step control function (CF) approach (Petrin and Train, 2010; Wooldridge, 2011). In the first step, S_{it} is written as a function of all exogenous variables entering the adoption model and the instruments that do not enter the adoption equation:

$$S_{it} = \alpha_0 + \alpha_i X_{it} + \beta_i Z_{it} + \varepsilon_{it}, \quad (2)$$

where Z_{it} are instrumental variables (IV) that can affect access to FISP but have no direct impact on adoption. Our choices for IV are: the number of children residing in the household; whether the area has a Member of Parliament (MP) from the ruling party, which can influence access to FISP based on previous studies (e.g. Holden and Lunduka, 2012; Mason and Ricker-Gilbert, 2013).

We estimate two separate probit reduced form equations for seed subsidy and fertiliser subsidy as a first stage in this procedure and observe the significance of the instruments. If the instruments are jointly significant and hence relevant we then predict the error terms from each equation that are used to create control functions ($\bar{\mu}_{it}$ and $\bar{\gamma}_{it}$). Equation (2) is also used to test the first hypothesis on whether recent droughts result in an increase in the probability that DT maize was distributed related to the seed subsidy program. Having ascertained appropriateness of the instruments, we compute residuals ($\bar{\mu}_{it}$ and $\bar{\gamma}_{it}$) from both reduced form equations to include in the structural equation. The structural equation is thus estimated as:

$$DT_{it} = \alpha_0 + \alpha_1 R_{dt} + \alpha_2 S_{it} + \alpha_3 M_{it} + \alpha_4 H_{it} + \alpha_5 P_{it} + \alpha_6 T_{it} + \alpha_7 \bar{\mu}_{it} + \alpha_8 \bar{\gamma}_{it} + \alpha_i + \varepsilon_{it} \quad (3)$$

3. Data and Descriptive Statistics

3.1. Data

We use four-round panel data from six districts in Malawi, namely Chiradzulu, Kasungu, Lilongwe, Machinga, Thyolo and Zomba. The initial sample of 450 households was drawn in 2006 following the 2004 Integrated Household Survey Two (IHS 2) (Lunduka, 2009). In 2009, 378 were resurveyed while 350 were resurveyed in both 2012 and 2015. Dropping households with invalid observations leaves 449 households in 2006, 373 in 2009 and 345 in 2012 and 2015 (Table 1). Our primary unit of analysis is the farm household. The household panel data are combined with daily rainfall data from the Department of Climate Change and Meteorological Services from 2003 to 2015, which allows us to generate dry spell variables that include lags for the past three seasons of each survey year. We use three seasons as the basis for farmers' expectations and experience in comparing the performance of alternative maize varieties under varying rainfall patterns. For previous early dry spells, the third season coincides with the early dry spell for the survey year, hence we limit the lags for the early dry spells to the past two seasons.

In Table 2 we show adoption of DT maize disaggregated according to access to seed subsidy. Adoption was measured as whether farmers reported buying and using a DT maize variety. We consider both buying the seed through FISP or commercially at market price. The results show that adoption of DT maize varieties increased from 3% in 2006 to 43% in 2015. It is interesting however to notice that adoption of DT maize outside FISP is very low.

Table 2 suggests some correlation between adoption of DT maize seed and possession of seed subsidy coupons. However these results also show that while seed subsidy may contribute significantly to adoption of DT seed, some adopters buy the seed commercially. The seed subsidy package contains hybrid and OPV seed coupons, which are both DT and non-DT seed so farmers have an option to redeem either DT or

Table 1
Number of households (HHs) and plots by study area (district)

	2006		2009		2012		2015		Total	
District	HHs	Plots	HHs	Plots	HHs	Plots	HHs	Plots	HHs	Plots
Thyolo	61	105	47	137	47	135	47	168	202	545
Zomba	86	181	82	158	77	137	79	270	324	746
Chiradzulo	53	117	39	104	35	97	34	123	161	441
Machinga	56	87	43	142	46	156	43	156	188	541
Kasungu	97	166	90	337	79	325	79	329	345	1,157
Lilongwe	96	173	72	178	61	157	63	224	292	732
Total	449	829	373	1,056	345	1,007	345	1,270	1,512	4,162

Table 2
DT maize seed adopters by seed subsidy beneficiaries

		Received seed subsidy coupon		
Year	Adopted DT	No	Yes	Total
	No	67%	30%	97%
2006	Yes	1%	2%	3%
	Total	68%	32%	100%
	No	53%	23%	75%
2009	Yes	14%	11%	25%
	Total	66%	34%	100%
	No	32%	28%	60%
2012	Yes	14%	26%	40%
	Total	46%	54%	100%
	No	23%	34%	57%
2015	Yes	12%	32%	43%
	Total	34%	66%	100%

non-DT maize seed. Lunduka *et al*. (2012) reported that 98% of the beneficiaries preferred hybrid seed, with Holden and Fisher (2015) finding 69–82% redeeming DT maize seed.

3.2. Descriptive statistics of dependent and explanatory variables

Table 3 shows the descriptive statistics for the dependent and independent variables. The dependent variables are 'adoption' equal to one if the household bought and used DT maize variety, and zero otherwise, 'maize area' (ha) allocated to DT maize and 'area share' under DT maize varieties. The key explanatory variable in this paper is 'dry spells'. The results show that, on average, the longest early dry spell lasted 9.3 days in 2006, 9 days (2009), 7 days (2012) and 5.7 days in 2015. In previous years to the survey year, farmers were exposed to the longest early dry spells in 2004 with an average of 10 days, while the longest late dry spell was in 2005 with an average of 13 days. We expect early dry spells in survey years to affect adoption as early warning

Table 3
Definitions and summary statistics of variables by year

Variable	2006	2009	2012	2015	Total
Adoption of DT maize, dummy	0.03	0.24	0.40	0.44	0.26
Area under DT maize (ha)	0.02	0.10	0.15	0.17	0.10
Area share under DT (%)	0.02	0.12	0.15	0.17	0.11
Longest early dry spell, days	9.27	9.10	6.96	5.71	7.89
1 year Lag longest early dry spell, days	8.04	7.12	6.68	4.90	6.78
2 years Lag longest early dry spell, days	12.61	10.44	11.68	6.19	10.40
1 year Lag longest late dry spell, days	10.08	8.01	10.55	7.66	9.13
2 years Lag longest late dry spell, days	9.61	6.54	8.02	10.33	8.66
3 years Lag longest late dry spell, days	7.95	9.42	7.97	10.68	8.94
3 year lag of average rainfall in mm	5.24	6.17	5.60	5.53	5.62
Seed subsidy, dummy	0.23	0.34	0.54	0.66	0.43
Fertiliser subsidy, dummy	0.45	0.53	0.72	0.69	0.59
Distance to agricultural market (km)	4.00	4.30	4.23	4.21	4.18
Fertiliser real price (MK[1]/Kg)	59.92	75.68	131.38	135.23	97.38
Age of household head (years)	41.40	46.21	50.74	48.85	46.42
Sex of household head, dummy (1 = female)	0.25	0.22	0.25	0.35	0.26
Education of household head (years)	7.04	5.10	5.12	5.29	5.73
Household size	5.28	5.33	5.28	5.62	5.37
Male labour force (adult equiv./ha)	2.47	3.75	3.53	4.13	3.41
Female labour force (adult equiv./ha)	2.28	3.56	3.19	3.78	3.14
Off-farm labour (adult equiv./ha)	0.14	0.21	0.35	0.24	0.23
Tropical livestock units (TLU)	1.08	1.47	1.11	0.50	1.05
Asset value (MK[1])	3,352	4,102	2,488	5,985	3,940
Farm size (ha)	0.80	1.10	0.97	1.09	0.98
Number of plots	1.85	2.80	2.92	3.68	2.74
Number of children in a household	3.29	2.81	2.77	2.82	2.95
Member of parliament from ruling party	0.52	0.40	0.46	0.47	0.47

Notes. [1]Values in Malawi Kwacha (MK) are deflated with consumer price index using 2010 prices.

of potential drought and/or a short rainy season. On the other hand, we expect previous exposure to late droughts to affect adoption through risk aversion. Also included in Table 3 are seed and fertiliser subsidy variables and household and farm-level factors. The ‘farm size’ (ha) variable is a total of all the plots cultivated by the household in a particular year. To enhance accuracy, all the plots were measured with a Global Positioning System (GPS) device.

4. Results and Discussion

4.1. Impact of recent droughts on DT seed distribution through FISP

Table 4 presents results for access to seed and fertiliser subsidy and use of DT maize seed conditional on seed subsidy access. All the models are estimated using the MC framework. We include variables, ruling party Member of Parliament (MP) and number of children in the households, in seed subsidy and fertiliser subsidy models as instruments to compute residuals for the structural equations for the second

Table 4

Factors affecting access to seed and fertiliser subsidy coupons and use of DT seed conditional on seed subsidy access

Variables	Seed subsidy coupon	Fertiliser subsidy coupon	Redeemed DT seed conditional on seed subsidy access
Longest early dry spell (days)	*0.04***	*0.01*	*0.05*
	(0.02)	*(0.02)*	*(0.03)*
1-year lag longest early dry spell (days)	0.00	0.05***	0.05*
	(0.02)	*(0.02)*	*(0.03)*
2-years lag longest early dry spell (days)	–0.01	0.01	0.04
	(0.02)	*(0.02)*	*(0.03)*
1-year lag longest late dry spell (days)	–0.03**	–0.05****	0.01
	(0.01)	*(0.01)*	*(0.02)*
2-years lag longest late dry spell (days)	0.08****	0.03	0.09***
	(0.02)	*(0.02)*	*(0.03)*
3-years lag longest late dry spell (days)	0.05****	0.03**	0.03
	(0.01)	*(0.01)*	*(0.02)*
3-years lag average rainfall (mm)	0.11**	0.28****	–0.20**
	(0.05)	*(0.05)*	*(0.08)*
Distance to agricultural markets (km)	0.03	0.06***	0.00
	(0.02)	*(0.02)*	*(0.03)*
Fertiliser price (MK)	–0.00****	–0.00****	–0.00**
	(0.00)	*(0.00)*	*(0.00)*
Year 2009, dummy	0.27**	-0.02	1.83****
	(0.14)	*(0.13)*	*(0.32)*
Year 2012, dummy	1.14****	1.00****	2.08****
	(0.14)	*(0.15)*	*(0.31)*
Year 2015, dummy	1.05****	0.61***	2.03****
	(0.18)	*(0.19)*	*(0.34)*
Ruling party member of parliament	0.24**	0.29**	
	(0.12)	*(0.12)*	
Number of children in a household	-0.05	-0.01	
	(0.05)	*(0.05)*	
Constant	–2.98****	–2.65****	–3.44****
	(0.51)	*(0.55)*	*(0.86)*
Prob > chi^2	0.000	0.000	0.000
Rho	0.06	0.11	0.04
Observations	1,506	1,506	641

Notes. Significance levels *10%, **5%, ***1%, ****0.1%. The mean and deviation of household and farm characteristics are included in this MC framework but are left out of the table to save space. The full table can be accessed through the online Appendix at the publisher's website.

hypothesis. The variable ruling party MP is positive and significant suggesting that the area whose Member of Parliament is from the ruling party is more likely to access seed and fertiliser subsidy coupons. With respect to exposure to recent dry spells, there is a positive correlation with DT seed distribution and use. Two- and three-year lags of longest late season dry spells are positive and significant on the probability that the household received seed subsidy coupons. Further, 1-year lag of early season dry spells and 2-year lag of late season dry spells significantly increase the likelihood that the household used the seed subsidy coupon to redeem drought tolerant maize seed. On the other hand, 3-year lag of average rainfall (mm), a proxy for rainfall distribution is associated with less likelihood of a household using the seed subsidy coupon to redeem DT maize seed.

These results suggest that areas that have been exposed to more droughts in recent years are more likely to choose and redeem DT maize seed in the Farm Input Subsidy Package. Our results also suggest that farmers who were previously exposed to late dry spells are more likely to use the maize seed subsidy coupon to redeem DT maize seed varieties. Although the Government of Malawi tries to match seed varieties with appropriate agro-ecological zones and with farmer preferences (from demonstration trials), it does not relate varieties to recent weather experience.

4.2. Impact of recent droughts on adoption and adoption intensity of DT maize seed varieties

Table 5 presents our adoption results, estimated with the MC device with a control function (CF) approach. The three columns are: (i) DT adoption (Probit), (ii) area (ha) under DT maize (Tobit); (iii) area share allocated to DT maize varieties (Fractional Probit). The fertiliser subsidy residual is significant in area and area share models while the seed subsidy residual is significant in the area share model. Thus, we reject exogeneity of fertiliser subsidy and seed subsidy variables in these models[3] and deduce, therefore, our CF approach is appropriate.

The results show that the likelihood of adoption of drought tolerant maize varieties is positively correlated with a 2-year lag of longest early dry spells and seed subsidy access, but there is negative correlation with 3-year lag of average rainfall. Intensity of adoption measured as area (ha) under DT maize is positively correlated with 1-year and 2-year lag of early longest dry spells, 2-year and 3-year lag of longest late dry spells and seed subsidy but inversely related to 1-year lag of late dry spells and fertiliser subsidy. Area share under DT maize has a positive and significant relationship with early longest dry spell and 2-year and 3-year lag of late dry spells but is negatively correlated with seed subsidy access.

This positive impact of early dry spells can be explained by the fact that early drought acts as a warning to farmers of a potential drought season so that farmers are more likely to increase area share under maize varieties that are drought tolerant. Another possible explanation is that early drought signifies a short rainy season, so that previous exposure increases the likelihood of adopting early maturing maize varieties to fit into the growing season as Malawi has a unimodal type of rainy season. Although other hybrids are also early maturing, the 2012 experience shows that most farmers opt for DT early maturing maize varieties (Holden and Fisher, 2015) such as SC403 (*Kanyani*) which matures within 90 days after planting. Such varieties are not only drought tolerant but also suitable for replanting after an early drought.

For late droughts, the positive impact of 2-year and 3-year lags suggest that farmers respond to previous late droughts by adopting technologies that hedge against resulting yield losses. These results suggest that farmers are influenced by previous exposure to droughts. The most important advantage of DT maize is its performance over

[3]We failed to reject exogeneity of seed subsidy and fertiliser subsidy variables for the adoption model hence we re-estimated the model excluding residuals.

Table 5
Factors affecting adoption and adoption intensity of DT maize varieties

Variables	DT adoption (Probit)	DT area (Tobit)	DT area share (Fractional Probit)
Longest early dry spell (days)	*0.03*	*0.00*	*0.02***
	(0.02)	*(0.01)*	*(0.01)*
1-year lag longest early dry spell (days)	0.03	0.02**	–0.01
	(0.02)	*(0.01)*	*(0.01)*
2-years lag longest early dry spell (days)	0.05**	0.03***	0.00
	(0.02)	*(0.01)*	*(0.00)*
1-year lag longest late dry spell (days)	0.01	–0.03**	0.00
	(0.01)	*(0.01)*	*(0.00)*
2-years lag longest late dry spell (days)	0.03	0.02*	0.04***
	(0.02)	*(0.01)*	*(0.01)*
3-years lag longest late dry spell (days)	0.02	0.02**	0.02***
	(0.02)	*(0.01)*	*(0.01)*
3-years lag average rainfall (mm)	–0.13**	0.11*	–0.02
	(0.06)	*(0.06)*	*(0.04)*
Seed subsidy, dummy	0.56***	0.25***	–0.48**
	(0.12)	*(0.05)*	*(0.20)*
Fertiliser subsidy, dummy	–0.16	–0.51***	0.29
	(0.12)	*(0.19)*	*(0.19)*
Distance to agricultural markets (km)	0.00	0.02	–0.01
	(0.02)	*(0.02)*	*(0.01)*
Fertiliser price (MK)	–0.00**	–0.00**	0.00
	(0.00)	*(0.00)*	*(0.00)*
Year 2009, dummy	1.65***	0.56***	0.29***
	(0.19)	*(0.08)*	*(0.07)*
Year 2012, dummy	1.95***	1.04***	0.44***
	(0.20)	*(0.19)*	*(0.09)*
Year 2015, dummy	2.12***	0.92***	0.56***
	(0.22)	*(0.13)*	*(0.12)*
Error from seed subsidy		0.43**	–0.33*
		(0.19)	*(0.19)*
Error from fertiliser subsidy			0.55***
			(0.20)
Constant	–3.10***	–2.18***	–0.80***
	(0.59)	*(0.59)*	*(0.23)*
Prob > chi^2	0.000	0.000	0.000
Rho	0.08	0.000	
Observations	1,506	1,506	1,505

Notes. Significance levels *10%, **5%, ***1%, ****0.1%. Standard errors are bootstrapped with 400 replications, resampling households. The mean and deviation of household and farm characteristics are included in this MC framework but are left out of the table to save space. The full table can be accessed through the online Appendix.

other maize varieties under rainfall stress before and during the flowering period for maize, as reported by Magorokosho *et al*. (2009). If farmers' experience is in line with this, then more adoption will follow in years after early droughts where DT and other maize varieties were planted and their relative performance could be assessed.

However, the negative impact of 1-year lag of late dry spells on DT area is unexpected and not easily explained.

The findings overall suggest that the more severe (longer) the dry spells, the more the farmers become aware of the risks associated and hence a need to adopt DT seed. These results are consistent with our expectations and the findings of Holden and Fisher (2015) and Holden and Quiggin (2017a) that farmers who have been exposed to drought previously are more likely to adopt DT maize as an adaptive mechanism. Ding *et al.* (2009) also reported that farmers' experience with drought increases their likelihood of adopting risk-reducing agricultural systems such as conservation tillage. Our results, however, have specifically shown how early and late dry spells affect adoption and adoption intensity, a component not addressed by either Holden and Fisher (2015) or Holden and Quiggin (2017a).

Access to seed subsidy is positive and significant in adoption and area models (consistent with Holden and Fisher, 2015) but negative in the area share model. On the other hand, fertiliser subsidy is negative on adoption and area but positive though insignificant on area share under DT maize varieties. The negative impact of seed subsidy on area share could be related to the small quantities of subsidised maize seed (2-kg bag of hybrid seed or 4-kg bag of OPV seed (Ricker-Gilbert and Jones, 2015)). Such quantities are too small to allow a significant increase on area share under DT maize varieties.

5. Conclusion and Policy Implications

Weather extremes, especially recurrent droughts, threaten agricultural productivity and food security in many countries especially in sub-Saharan Africa whose population largely depends on agriculture and maize for food. Drought tolerant maize is one promising technology to minimize the impact of droughts. Several drought tolerant maize varieties have been developed by national research institutions in collaboration with international research institutions such as CIMMYT and have been distributed across the countries. Examining determinants of adoption and adoption intensity of this promising technology is becoming increasingly important. Following Holden and Fisher (2015), Fisher *et al.* (2015) and Holden and Quiggin (2017a), we use a Mundlak-Chamberlain device with a Control Function approach to understand adoption of DT maize varieties in Malawi under rainfall stress.

We combine data from farm households in six districts collected in 3-year intervals between 2006 and 2015 with experience of previous dry spells computed from daily rainfall data from 2003 to 2015. We include lagged early and late season drought variables in the panel data analysis to assess how adoption and adoption intensity is affected by drought exposure experience. We define adoption intensity in terms of maize area (ha) allocated to DT maize varieties and area share under DT maize. DT maize is known by scientists to perform better than other maize varieties under late drought conditions but not necessarily under early drought conditions, except that DT maize varieties are early maturing. We also extend the Holden and Quiggin (2017a) analysis by examining how recent droughts affect distribution of DT seed under FISP and how choice of DT seed is conditioned by access to seed subsidy.

Adoption has increased from 3% in 2006 to 43% in 2015, DT maize area per household has increased from 0.02 ha in 2006 to 0.17 ha in 2015, with an increase in area share under DT maize varieties from 2% in 2006 to 18% in 2015. We find positive impacts of the late season droughts on the probability of DT seed being used under the seed subsidy programme. Farmers previously exposed to late season dry spells are more likely to redeem DT maize seed varieties using the seed subsidy coupon. We also find positive correlations between the likelihood of adoption of DT maize seed and 2-year lagged longest early dry spells and also seed subsidy access. Areas under DT maize are positively influenced by 1-year and 2-year lag of early season longest dry spells, 2-year and 3-year lag of longest late season dry spells and seed subsidy, but there is an unexpected and unexplained negative effect of 1-year lag of late season droughts and fertiliser subsidy. We also find positive correlations between area share under DT maize and early season longest dry spell, 2-year and 3-year lag of late season dry spells, though, again unexpectedly, a negative correlation with seed subsidy access.

Our results suggest that farmers respond to occurrence of early dry spells in current and previous seasons and exposure to previous late dry spells by adopting technologies that can minimize drought-related yield losses. Early droughts may signal a short rainy season, hence farmers are more likely to adopt early maturing varieties of which some are drought tolerant. Farmers' response to late droughts suggest that they are aware of the negative effects of late droughts and one way of hedging against such risks is by adopting drought tolerant maize varieties. Finally, the positive impact of seed subsidy on likelihood of adoption and area under DT maize is consistent with previous studies (e.g. Holden and Fisher, 2015) that FISP is a strong driver of DT maize adoption in Malawi. However the negative impact of seed subsidy on area share may reflect the small quantities of seed eligible for subsidy, suggesting that increasing the quantities of maize seed eligible for subsidy could significantly increase the area share allocated to DT maize seed.

Our paper has generated new evidence that previous early droughts affect adoption of DT maize varieties by increasing farmers' adaptive expectations with respect to duration of the rainy season. Farmers previously affected by early droughts are more likely to adopt early maturing DT maize varieties. On the other hand, previous late droughts affect adoption through risk aversion as farmers adopt technologies that hedge against late drought risks. In a country facing persistent weather shocks, mainly droughts and floods coupled with missing or poor markets for weather insurance and credit, these findings are of great importance to enhance agricultural productivity. Farmers' adoption of drought tolerant maize, a drought risk-substituting technology is an indication that farmers in drought-prone regions in SSA countries are more willing to adopt a drought-resilient technology. As discussed in the conceptual framework, late drought risks increases adoption of risk-substituting technologies such as DT maize varieties at the expense of other hybrids and local maize.

The understanding that farmers respond to exposure to weather shocks is an important observation not only for Malawi but other countries in the SSA region for the promotion of climate risk-reducing technologies. Promotion of technologies that are perceived by farmers themselves as climate-smart based on their experience are more likely to receive high adoption rates and make an impact on general household livelihood conditions. As the Government of Malawi is promoting adoption of climate-smart agriculture (CSA) technologies (Government of Malawi, 2016), extension messages should emphasize drought tolerant maize seed as a key component in the CSA campaign, with extension and promotion messages on the significance of DT maize under drought. Ensuring availability and affordability of the DT seed should continue being the priority strategy for the Government of Malawi. The government should make deliberate efforts to distribute more DT maize seed varieties in areas previously and frequently exposed to drought shocks, and consider increasing seed subsidy quantities from the current 2–4 kg. However since adoption outside FISP is low and this may present a sustainability problem, the agricultural extension service should do more to enhance awareness of DT maize seed so that farmers can continue using it even after FISP.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Factors affecting access to seed and fertiliser subsidy coupons and use of DT seed conditional of seed subsidy access

Table S2. Factors affecting adoption and adoption intensity of DT maize varieties

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