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# Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics

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ABSTRACT

Why do many smallholder farmers fail to adopt what appear to be relatively simple agronomic or management practices which can help them cope with climate-induced stressors? Using household and plot level data collected in 2011, we implement a multivariate probit model to assess the determinants of farmer adaptation behavior to climatic risks and the relative contribution of information, credit and education on the probability of adopting specific practices in response to adverse changes in weather patterns. We find that plot characteristics, credit constraints and availability of climate-related information explain the adoption of several of these practices. In relative terms, we also find that even when financial limitations are binding, making climate-related information available can still motivate farmers to adapt. Policy implications are that the deepening of extension access with information on the appropriate adaptation strategies is crucial to help farmers make adaptation choices. The need to foster credit markets for easy accessibility and affordability by farmers or otherwise strengthening access to assets is also important.



## 1. Introduction

### *1.1. Overview*

In the face of climatic change, the ability of agrarian economies to adapt to these new challenges is crucial if such economies are to avoid long-term negative impacts and a diminished ability to develop (World Bank, 2013). For the most part, countries in SSA and some parts of Asia have the least capacity to cope with climate shocks and their negative environmental and human consequences. For example, India and Africa are projected to see reductions in agricultural output by 30% or more (Cline, 2007). The situation is worse in Africa where for a long time, agricultural production has performed unsatisfactorily especially when compared to Asia from 1961 to 2007 (Pretty et al., 2011).

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Agriculture, as a natural resource-based industry will be affected by climate change more than any other sector. Yet, much of the discourse on climate change has been on the mitigation of the causes of climate change like industrial $CO_2$ emissions (IPCC, 2007). With the current agreements on limiting carbon emissions not likely to stabilize concentrations of greenhouse gases in the atmosphere over the next few decades, it is projected that agricultural productivity may diminish further in some places (Di Falco and Veronesi, 2013; Mendelsohn et al., 1994). Taking adaptation measures at the farm level should thus be an integral part of the responses needed to deal with climate change and its consequences (Burton et al., 2002). Farmers need to change their practices to cope or adapt in the face of rapidly changing climatic conditions. Adapting to climate change entails taking appropriate measures to reduce its negative effects (UNFCCC, 2007). In the agricultural sector context, these measures include: changing crop or livestock enterprises, use of more or less of certain inputs, implementing new resource management practices, diversifying farming systems and sometimes diversifying into non-farm activities (Howden et al., 2007).

Assuming economic rationality, farmers will seek to balance the benefits and costs of these new actions demanded by changing climatic conditions (Antle, 2009). Before these economic benefits can be realized, farmers need to have the requisite information about these new methods. In addition, they must have access to resources with which to successfully implement them. Whether resource scarcity or information deficiencies are the more constraining factors remains an empirical issue. Finding the answer to that question has important policy implications. If resources, rather than information, is the issue, then the policy focus should be on credit availability and asset building programs. If information is the issue, then strengthening extension systems and information delivery to farmers should be prioritized.

In this study, we analyze the major factors that act as co-determinants of why farmers opted to use various practices in response to difficulties related to climate risks. This study specifically asked farmers to state which practices they had adopted in recent years to cope with recently-observed changes in weather patterns. Results showed that nearly 40% of the farmers had changed to planting drought-tolerant varieties and 27% had made it a practice to plant early. Further, 35% reported that they had now switched to pest- and disease-tolerant varieties due to increased disease and pest pressures, while 36% now planted more than one crop type. The simulated impacts from a multivariate probit model showed that while issues such as credit remain crucial, in relative terms, the availability of climate information had a large impact; as much as 45% on the probability of farmers implementing crop diversification as an adaptive measure. An extra year of primary schooling (raising the average years of schooling as observed in the sample by one year), increased the probability of using drought-tolerant varieties by about 30%. Without minimizing the role of resources in enabling adoption and adaptation, these results show that adaptation and coping with weather and climate changes among farmers is likely to be an information-intensive phenomenon. Extension and information delivery systems will be a crucial element to enable smallholder communities to adapt successfully.

### *1.2. Country background and agro-climatic situation*

Rain-fed smallholder agriculture continues to dominate most economies of SSA. In Malawi, where over 74% of the population lives on less than 1.24 dollars per day (OECD, 2009), agriculture contributes over 39% to the GDP and employs about 85% of the country's entire labor force (Chirwa et al., 2008). The significant role of agriculture in the economy belies the fact that this sector faces a number of challenges. Decades of continuous cultivation like the predominant ridging practice coupled with inadequate use of capital (fertilizers, soil conservation, and mechanization) has led to a fragile production environment and stagnation in productivity (Denning et al., 2009). Low investments in soil fertility improvement and increasing climate variabilities over the last five decades have further compounded the problem, leaving the sector increasingly vulnerable (Binswanger-Mkhize et al., 2011).

There is evidence in the literature which strongly suggests that in recent decades adverse and extreme weather events such as droughts, floods, and dry spells have increased in frequency, intensity and magnitude, exacerbating rural poverty and threatening the sustainability of rural livelihoods (Ibrahim and Alex, 2009; Nangoma, 2007). Against the backdrop of rapidly changing weather conditions and the severity of the impact on poor subsistence farmers, it is urgent that the different options available to farmers to cope are documented. A good understanding of how these can be widely adopted is critical. This understanding includes the adaptation options that farmers may have access to, their perception towards these and the determinants to adopting them. Therefore, this study contributes to the emerging literature on agricultural technology adoption and its connections to adaptation to climate variability.

### *1.3. Climate change adaptation*

Broadly, several climate change adaptation strategies are identified in the literature and include: 1) use of drought-tolerant crop varieties (hereinafter DT); 2) use of pest and disease tolerant (PDT) varieties; 3) a change in the timing of agricultural activities (early planting or EP); 4) diversification of crop enterprises (CD); and 4) investment in soil and water conservation technologies (SWC). Despite the documented benefits of these practices in reducing exposure to climate risks, their uptake has been slow in Malawi (Jain, 2007; Nhemachena and Hassan, 2007). It is still not clear why, faced with climatic risks, farmers are not implementing practices that appear to demand modest amounts of external capital. Other than SWC, which may require increased amounts of labor, the other practices (DT, PDT, EP and CD) do not require large adjustments. Taking into consideration the expected benefits, the costs of such adjustments may well be justified.

Granted, the assumption that these practices require minimal capital and labor outlays could also be an empirical issue rather than a universal factor as we hypothesize in this study that factors related to information, household capital endowments and farm characteristics can offer insights into the observed patterns of slow adoption of adaptation practices. While acknowledging that capital could be a barrier to the adoption of modern technologies such as fertilizers as the literature has shown, there are large gaps in the adoption literature as to why relatively simple and accessible agronomic and/or management practices are not adopted by many farmers to manage climate-related risks.

The list of literature related to adaptation to climate change is still growing (World Bank, 2013; Antle, 2009; Kurukulasuriya and Mendelsohn, 2008; Mendelsohn, 2000). Climate change adaptation studies specifically in the context of Southern Africa are extant, albeit nascent. Most of these use single practices in studying adaptation (e.g. Kurukulasuriya and Mendelsohn, 2008; Seo and Mendelsohn, 2008). A departure is Nhemachena and Hassan (2007) who use a multivariate probit method to investigate barriers to climate change adaptation in the context of South Africa, Zambia, and Zimbabwe. This latter approach is more realistic given that a farmer inevitably needs to implement multiple options in combinations in order to successfully manage the natural resource base and deal with biophysical risks. Using the same econometric approach, we add to the literature by incorporating both plot level and household level variables in analyzing climate change adaptation in the context of Malawi. To our knowledge, no study has been carried out to investigate the adoption of specific practices as a direct response to climatic risks and therefore as means of climate change adaptation in Malawi. Many previous studies have focused on adoption as a way to achieve higher productivity, ignoring the need to adapt to new production conditions as dictated by ongoing climatic changes.

We use a rich dataset comprising plot level data (5641 plots) and household level data (1786 households) to investigate the factors that determine the interdependent adoption or co-adoption of multiple adaptation strategies like DT, PDT, EP, CD, and SWC. This primary dataset was collected by the Department of Agricultural Research Services in Malawi (DARS) in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT) in 2011. These data were collected as part of the Sustainable intensification of Maize and Legume Systems in Eastern and Southern Africa. We particularly explore the relationships in the adoption of these strategies either as substitutes or compliments in combating a myriad of climate change related risks.

The contribution of our paper is twofold. First, using a multivariate probit framework, we are able to capture the complementarities and substitutabilities among the various practices that can be implemented on-farm for maximum benefit. Secondly, we use the results from the multivariate model to simulate the impact of key policy variables to compare the impact of information relative to that of resources in explaining adoption outcomes. The reviews conducted for this paper show that the relative importance of family labor, liquidity and information remains an empirical question and is largely a function of local circumstances including agro-ecological conditions and policy situations (Marra et al., 2003). Our simulations enable us to identify the relative impact of information and resources in a way that can help in priority setting.

## 2. Conceptual framework

Adaptation strategies are a form of protection measure that reduce the farmers' risk exposure by reducing the marginal effect of climate change on productivity (Fisher-Vanden and Wing, 2011). We adopt a utility maximization function in the presence of risk to conceptualize adaptation decisions. In our case, the utility to a farmer need not be defined by higher yields. In the context of adaptation, the utility derived from adopting a practice could be yield stability and the implied reduction in downside risk. A risk-averse farmer maximizes utility by choosing an adaptation strategy if the benefits of adaptation (risk reduction) minus the cost of adaptation are higher than the benefits realized without adaption. Following Hazell and Norton (1986), we define the utility function as follows:

$$U_y = E_y - \alpha\omega_y$$

where $U_y$ is the perceived utility from choosing adaptation strategy $y$, $E_y$ is the non-stochastic component and $\omega_y$ is the disturbance term indicating variation in yields. The coefficient ($\alpha$) captures risk aversion of individual farmers which would affect the degree of the variability in the yields $\omega_y$. Following Finger and Schmid (2007), we define this coefficient as:

$$\alpha = -(\partial U/\partial\omega_y)/(\partial U/\partial y)$$

where if $\alpha < 0$, the farmer is risk averse and thus more likely to adapt; $\alpha = 0$ indicates a risk-neutral farmer and $\alpha > 0$ indicates a risk loving one. The utility of implementing a strategy ($y(U_y)$ is given by the revenues generated by the strategy less the variable costs incurred in implementation.

Given an array of adaptation strategies, a risk-averse farmer will choose the strategy, say $X$, that yields higher expected utility than the alternatives, say $Y$, i.e.

$$E(U_x) - M_x > E(U_y) - M_y$$

where the first term is the expected utility of implementing strategy $X$ and the associated costs $M_x$, while the second term is the expected utility of implementing strategy $Y$ and associated cost $M_y$. Assumptions about the relationship of disturbance terms of the adaptation equations, i.e. whether correlated or not, determine the type of qualitative choice model to use in analysis.

## 3. Methodology

### 3.1. Multivariate probit model

Faced with adverse climatic changes, farmers may opt to adopt a mix of strategies as a way of mitigation rather than relying on a single strategy to exploit complementarities among alternatives. Thus, in addition to adopting SWC, a farmer may choose to practice CD, EP, DT or PDT. Adoption could be path dependent with earlier adopted strategies informing decisions on subsequent practices in the future. It is thus necessary to use a model which estimates the influence of exogenous factors on the adoption of the strategies simultaneously, while allowing for the error terms of each of these strategies to be freely correlated. Failure to correct for these interrelations can lead to biased estimates (Kassie et al., 2013; Lin et al., 2005). We thus employ a multivariate probit model in this study to investigate the interdependent strategy adoption decisions.

We follow Lin et al. (2005) in formulating the multivariate model which has five dependent variables, $y_1, \ldots, y_5$ such that:

$$y_i = 1 \quad if\ \beta_i x' + \varepsilon_i > 0$$

and

$$y_i = 0 \quad if\ \beta_i x' + \varepsilon_i \leqslant 0 \quad i = 1,\ 2,\ \ldots,\ 5$$

where $x$ is a vector of the explanatory variables; $\beta_1,\ \beta_2,\ \beta_3,\ \beta_4,\ and\ \beta_5$ are conformable parameter vectors and $\varepsilon_1,\ \varepsilon_2,\ \varepsilon_3,\ \varepsilon_4\ and\ \varepsilon_5$ are random errors distributed as a multivariate normal distribution with zero mean, unitary variance and an $n \times n$correlation matrix.

### 3.2. Dependent variables

We asked farmers about their perceptions on changes in climate over the previous ten years and the number of times they had encountered specific climate risks like drought, floods, crop pests, diseases, and hailstorms, among other livelihood shocks. Based on these experiences, farmers were asked to list strategies they had recently used to reduce risks associated with such shocks. Consistent with the literature on climate change adaptation, the most adopted practices specific to climate-related shocks were: use of drought-tolerant varieties, pest- and disease-tolerant varieties, early planting, crop diversification and soil and water conservation measures (descriptive statistics of these are presented in Section 3.3). These variables were adopted in this study as outcome variables in the multivariate probit analysis.

### 3.3. Independent variables and hypotheses

This study incorporated the explanatory variables based on the review of existing literature on adoption studies and climate change adaptation, conceptual framework and the availability of the variables in the dataset. These variables can be grouped into plot-level characteristics and household/farm-level characteristics.

#### 3.3.1. Plot-level characteristics

Variables in this category include: land tenure (1 = owned; 0 = not owned including borrowed, rented and communal land); soil fertility (1 = fertile; 0 = lower/medium fertile); and soil slope (1 = gently sloped; 0 = more sloped/medium slope). Long-term investments in land are positively correlated with ownership of the said land. Strategies like SWC which require considerable investments with benefit streams accruing in the long term are likely to be implemented by households who actually own the land and have security of tenure (Kassie et al., 2013; Amsalu and de Graaff, 2007).

Farmers with fertile plots can still realize good higher returns even without much investment in management. Such farmers may, therefore, be reluctant to invest in relatively costly inputs like drought- or disease-tolerant seeds or SWC like terracing, unless the productivity impacts are substantial. This, of course, can be detrimental in the long run if it creates complacency about the need for soil recapitalization, but many farmers' planning horizons may not extend into the distant future where the benefit of increased soil fertility manifests itself. This variable is thus generally expected to have a negative sign on most of the adaptation strategies. Likewise, gently sloped plots are less prone to soil degradation through erosion. Farmers who have such plots are generally expected to invest less in SWC and other soil fertility management strategies (Di Falco et al., 2011).

#### 3.3.2. Household characteristics

Important variables considered under household characteristics include those related to household capital and information access. Household capital can be categorized into physical, social, human and financial capital. Physical capital considered in the study was in the form of livestock and land ownership. Livestock is a form of saving and insurance for many rural households (Bosman et al., 1997; Doran et al., 2014). The number of tropical livestock units (TLU) owned by a household is an indicator of wealth status in rural areas. Households with a higher TLU value can afford to take risks and rely on the livestock in times of climate shocks (Jones and Thornton, 2009). Access to land on the other hand can dictate whether one has the capacity to undertake intensive practices like SWC. It may also be the case that those with large land areas can use the economies of scale for higher outputs, thereby using less adaptation in their farms. While the association between livestock (TLU) and adaptation is expected to be positive, that between land ownership and adaptation is indeterminate.

Social capital in our study is proxied by kinship ties and group membership. Through kinship ties, households are able to take advantage of human capital as well as asset stocks that come with new technologies (Parthasarathy and Chopde, 2001). Members of a certain group (including neighbors) are able to share information among themselves which accelerates the process of technology adoption and diffusion (Munasib and Jordan, 2011). Thus the expected sign of social capital and adaptation is positive.

Human capital considered includes health status of members, age, education, and skills. Adoption studies point to a positive relationship between education levels and technology adoption (Czaja et al., 2006) but are divided on the effect of age (Akudugu et al., 2012; D'Souza et al., 1993; Uaiene, 2008).We thus hypothesize a positive relationship between education level and adaptation but are indeterminate on age.

Previous studies have pointed out a systematic bias against women which lowers adoption rates in this group (Ndiritu et al., 2014; Ragasa et al., 2013; Uaiene, 2008) Other studies, for example, Arano et al. (2010), present women as risk averse and hence, more likely to adopt technologies which would lower their risk exposure. Thus the direction of the association between adaptation and gender of the household head is indeterminate.

The credit constraint variable is categorized farmers into those who needed credit and did not get it or got less than they needed (=1) and those who did not need credit (=0). Credit access relaxes liquidity constraints thus increasing technology adoption (Simtowe and Zeller, 2006). Thus, we expect a negative relationship between credit constraint and the probability of observing an adaptation practice.

Participation in non-farm income activities has been shown to increase technology adoption (Fernandez-Cornejo and Mishra, 2007), though other findings give different opinions. For example, Diiro (2009) established that farmers without off-farm activities use all the available labor more intensively on farm and hence adopt yield increasing technologies more. The expected sign of the relationship between income and adoption of climate adaptation strategies can be indeterminate.

Lack of and/or limitations in information (on seasonal and long-term climate changes and agricultural production) increases downside risks due to failure to adopt new technologies and adaptation measures (Kandli and Risbey, 2000). Better climate, and agricultural information helps farmers choose strategies that enable them to cope well with changes in climatic conditions (Baethgen et al., 2003). Accordingly and in line with technology adoption literature, the general sign expected with access to extension is positive (Amsalu and de Graaff, 2007).

### *3.4. Data sources and sampling*

The study was conducted in 16 districts across Malawi's three administrative regions (see Fig. 1). Six of the districts included in the sample form the study areas of a CIMMYT-led project on Sustainable Intensification of Maize and Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA). To broaden the scope and have a nationally representative sample, ten more districts were included in the study.

The study was based on a primary survey of 1786 households. Malawi's four agro-ecological zones (AEZ's) (the Lower Shire Valley (<200 m), low altitude (200–760 m), middle altitude (760–1300 m) and high altitude (>1300 m)) formed the strata for the sample frame where random proportionate sampling was employed to select 16 districts. Proportionate (to size) random sampling was used to select the Extension Planning Areas (EPAs) included in the sample frame from which the 1786 households were randomly and proportionately selected.

Over 95% of the interviewed farmers' responded positively to having been exposed to a climate risk in the past. Specifically, 98% had been exposed to drought, 92% to floods, and 97% to crop pests and diseases, while a further 90% had been exposed to hailstorms. To understand whether such risks took place over time, the survey instrument was designed with a ten-year recall where farmers were asked to indicate the number of times each risk had occurred within that time frame.

On the adaptation measures undertaken by farmers as a result of past climate risk exposure, 85% of these were yield-related while the remaining 15% were non-yield related. About 32% of the farmers who had an exposure to risks in the past did not implement any adaptation strategy. Very few of the farmers who reported being exposed to drought in the past had not implemented a mitigation strategy. A higher percentage of those affected by hailstorms did nothing to mitigate its effects in case of a future occurrence. Specifically, farmers who reported DT as an adaptation strategy were 39% while 27% reported to have practiced EP (Table 1). The least used strategy was SWC measures. About 35% and 36% used PDT and CD, respectively.

The data show that over 83% of the households were male-headed and the average age and years of education of the household head were 50 years and six years. On extension access, about 47% of the interviewed households had accessed this through contacts with government extension agents, 35% through neighbor farmers and 39% through the media (radio and/or TV). Cumulatively, about 59% of the total sample had access to one to three of the three sources of extension. Access to credit is a major constraint with about 65% of the sampled households being credit constrained. Disaggregation of the household level explanatory variables by adoption status reveals less differentiation in socio-economic variables. However, there are clear differences in terms of access to information, even without performing statistical tests of significance. For instance, while about 31% of the farmers who adopted at least one strategy had access to climate related information, only 18% of their counterparts did (Table 2).

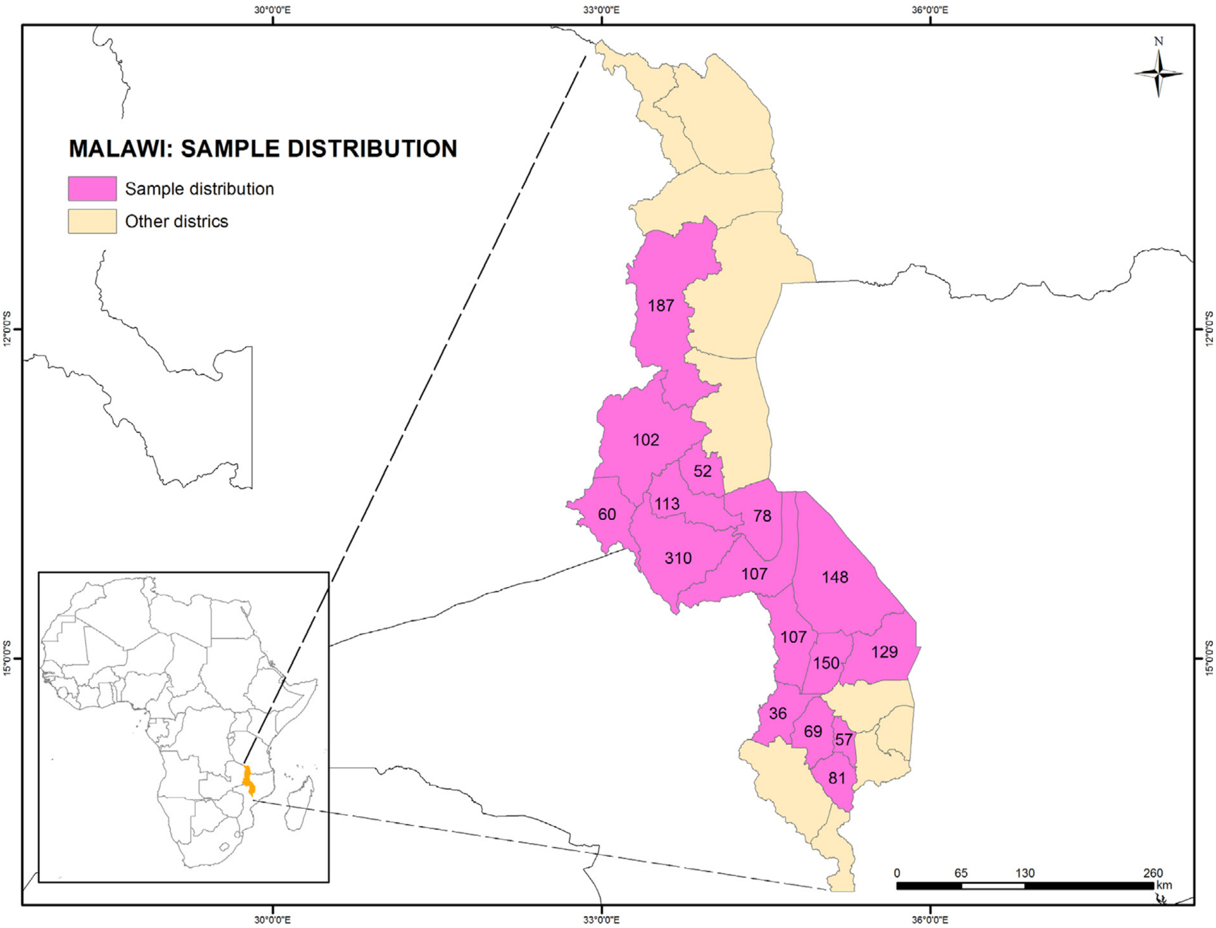


**Fig. 1.** Map showing the sample distribution.

## 4. Results and discussions

### 4.1. Pairwise correlations

This section discusses the results from the multivariate probit model. We present results from individual probit equations for comparative purposes. The likelihood ratio test ($chi^2(10) = 658.201$, $p < 0.000$) of the independence of the error terms of the different adaptation equations is highly rejected (Table 3). We thus adopt the alternative hypothesis of the mutual interdependence among the multiple adaptation strategies. The result thus supports the use of multivariate probit model (as explained in section 3 on empirical model).

Most of the pairwise coefficients are also revealed to be positively correlated indicating complementarity among these strategies. DT is positively correlated with EP, indicating that farmers who use these varieties couple it with planting the seed early. The same applies for PDT and DT, indicating that farmers use seeds with a combination of these characteristics. The association between SWC and CD is negative, perhaps since farmers diversifying into more resilient crops may find less use in intensive moisture conserving practices.

### 4.2. Parameter estimates: multivariate probit model

The results on parameter estimates from the multivariate probit and individual probit models are presented in Table 4. Variables related to *plot* and *household characteristics* as well as *information access* are significant in informing adaptation to climate change. In regard to *plot characteristics*, and consistent with Di Falco et al. (2011), we find that farmers with fertile plots are less likely to use DT, EP, and CD. These plots will more likely require lower levels of inputs to achieve the same level of yield, compared to older and poorer plots. Rather than invest in expensive inputs for these better-off plots, farmers may rationally save their resources for other uses or for investing in poorer plots. Total crop failure is less likely in fertile soils, thus farmers with such plots can afford to specialize in a few lucrative crops rather than diversify into many smaller crop

**Table 1**
Descriptive statistics (household level, $n = 1786$; plot level, $n = 5641$).

| Variable | Description | Mean | Std Dev. |
|---|---|---|---|
| *Dependent variables* | | | |
| Planting drought-tolerant varieties | Dummy = 1 if household adapted drought-tolerant varieties as an adaptation strategy, 0 otherwise | 0.3914 | 0. 4812 |
| Practicing early planting | Dummy = 1 if household adapted early planting as an adaptation strategy, 0 otherwise | 0.2725 | 0. 4478 |
| Planting disease/pest-tolerant varieties | Dummy = 1 if household adapted disease/pest-tolerant varieties as an adaptation strategy, 0 otherwise | 0.3501 | 0. 4795 |
| Crop diversification | Dummy = 1 if household adapted crop diversification as an adaptation strategy, 0 otherwise | 0.3618 | 0. 4904 |
| Practicing soil and water conservation measures | Dummy = 1 if household adapted practicing soil and water conservation measures as an adaptation strategy, 0 otherwise | 0.0854 | 0. 2768 |
| *Explanatory variables* | | | |
| *Farm characteristics* | | | |
| Land tenure | Dummy = 1 if plot is owned, 0 otherwise | 0.9463 | 0. 2254 |
| Fertile soil | Dummy = 1 if plot is highly fertile, 0 otherwise | 0.4724 | 0. 4992 |
| Medium fertile soil | Dummy = 1 if plot is of medium fertility, 0 otherwise | 0.3969 | 0. 4892 |
| Gentle slope | Dummy = 1 if plot is gently sloped, 0 otherwise | 0.6088 | 0. 4885 |
| Medium slope | Dummy = 1 if plot is of medium slope, 0 otherwise | 0.2775 | 0. 4474 |
| *Farmer and household characteristics* | | | |
| Sex | Gender of household head, 1 = male, 0 otherwise | 0.8319 | 0. 3536 |
| Age | Age of household head in years | 41.9035 | 13.9655 |
| Education | Years of education of the household head | 5.7632 | 3.7064 |
| Distance to main market | Distance to the main market in walking minutes | 83.2340 | 62.7409 |
| Distance to agricultural extension | Distance to the agricultural extension offices in walking minutes | 80.6675 | 63.2286 |
| Membership to farmer groups | Dummy = 1 if household head or spouse are members of a farmer group, 0 otherwise | 0.1036 | 0.3261 |
| Number of relatives in village | Number of relatives the household can rely on in the village | 3.2416 | 3.1988 |
| Reliance on government support | Dummy = 1 if household can rely on government support in times of need, 0 otherwise | 0.5944 | 0. 5641 |
| Labor (male person days) | Total labor committed to the plot in male person days | 51.5906 | 45.3722 |
| Off-farm income | Dummy = 1 if household has access to off-farm income, 0 otherwise | 0.7342 | 0. 4504 |
| Drought experience | Dummy = 1 if the household has ever experienced a drought, 0 otherwise | 0.8289 | 0. 3881 |
| Credit constrained | Dummy = 1 if household is credit constrained, 0 otherwise | 0.6501 | 0. 4730 |
| *Assets* | | | |
| TLU[a] | Total Livestock Units | 0.6822 | 1.8917 |
| Land owned (ha) | Total land owned by the household in hactares | 1.4811 | 1.3906 |
| *Information access* | | | |
| Access to government extension | Dummy = 1 if household had access to government extension, 0 otherwise | 0.4660 | 0. 4999 |
| Neighborhood extension | Dummy = 1 if household had access to neighbor extension, 0 otherwise | 0.3529 | 0. 4840 |
| Radio/TV extension | Dummy = 1 if household had access to radio/TV extension, 0 otherwise | 0.3919 | 0. 4922 |
| Access to climate information | Dummy = 1 if household had access to any information on climate change, 0 otherwise | 0.2670 | 0. 4564 |

enterprises. Consistent with Barungi et al. (2013), the probability of adopting SWC and EP increases with medium to steep slopes.

Access to climate-related information significantly determines adaptation across most strategies. This underscores the important role of making climate-related information available to farmers. Adaptation requires that farmers first notice that the climate has changed, and then identify useful adaptation strategies and implement them (Maddison, 2006). Specifically, access to government extension increases the probability of adaptation through EP and CD. Informal sources like neighbor-spread information increase the likelihood of adaptation through most strategies except DT. Likewise, media (TV and/or radio) are important in enhancing the likelihood of adaptation across all the strategies.

We find that access to credit was a major determinant of the decisions to adapt to climate change. With resource limitations, farmers may fail to meet the costs of adaptation and at times cannot make beneficial use of available information (Kandli and Risbey, 2000). Credit-constrained households were less likely to adapt through any of the five strategies. Adaptation strategies can be expensive with some requiring the purchase of new adaptive seeds while others are resource intensive (e.g. SWC). All these entails committing substantial and scarce resources considering that the majority of the Malawian population lives on less than $1.24 per day. Thus in the absence of micro-credit, farmers may still find it difficult to adapt even when provided with information on climate change because they are unable to purchase the requisite inputs.

In line with Velandia et al. (2009) but contrary to (Fernandez-Cornejo and Mishra, 2007), we find that households that have access to off-farm income are less likely to adapt through DT, EP, and CD. Depending on the proportion of total household income emanating from non-farm income, and the prevailing non-farm wages and therefore the opportunity costs of farm labor, farmers with access to non-farm incomes may be less exposed to production risks because their reliance on agricultural income and their own food production is lower than that of the median rural household. We find that farmers who trust the government for support in case of crop failure are more likely to adapt through DT, PDT, and CD. Those with less trust in government support are however more likely to use EP which would cushion them against total crop failure. We

**Table 2**
Household level descriptive statistics by adopters and non adopters.

| Variable | Adopters (any adaptation strategy) (n = 1295) | | Non adopters (n = 496) | |
|---|---|---|---|---|
| | Mean | Std Dev | Mean | Std Dev |
| *Farmer and household characteristics* | | | | |
| Sex | 0.8394 | 0.3673 | 0. 8165 | 0.3874 |
| Age | 41.71 | 14.43 | 42.12 | 14.23 |
| Education | 5.87 | 3.74 | 5.54 | 3.72 |
| Distance to main market | 82.53 | 62.24 | 85.79 | 62.95 |
| Distance to agricultural extension | 80.78 | 63.38 | 79.39 | 62.99 |
| Membership to farmer groups | 0.1027 | 0.3037 | 0.1008 | 0.3014 |
| Number of relatives in village | 3.31 | 3.27 | 3.01 | 2.92 |
| Reliance on government support | 0.6471 | 0.5274 | 0.4545 | 0.5913 |
| Labor (male person days) | 52.87 | 43.60 | 56.99 | 46.29 |
| Off-farm income | 0. 7282 | 0.4451 | 0.7399 | 0.4391 |
| Drought experience | 0.8811 | 0.3238 | 0.7056 | 0.4562 |
| Credit constrained | 0.6239 | 0.4846 | 0.7157 | 0.4515 |
| *Assets* | | | | |
| TLU[a] | 0.6950 | 1.7505 | 0.6523 | 1.7206 |
| Land owned (ha) | 1.28 | 1.15 | 1.22 | 1.02 |
| *Information access* | | | | |
| Access to government extension | 0.4988 | 0.5002 | 0.4012 | 0.4906 |
| Neighborhood extension | 0.3714 | 0.4834 | 0.3145 | 0.4648 |
| Radio/TV extension | 0.4239 | 0.4944 | 0.3206 | 0.4672 |
| Access to climate information | 0.3073 | 0.4616 | 0.1754 | 0.3807 |

[a] Total Livestock Units as defined in Storck et al. (1991).

**Table 3**
Correlation coefficients of the climate change adaptation strategies (from the multivariate probit estimation).

| Climate change adaptation strategy | Correlation coefficient | Standard Error |
|---|---|---|
| Drought tolerant varieties and Early planting | 0.2262*** | 0.0236 |
| Disease/pest tolerant varieties and drought tolerant varieties | 0.3444*** | 0.0218 |
| Crop diversification and drought tolerant varieties | 0.2615*** | 0.0224 |
| Soil & water conservation measures and drought tolerant varieties | 0.0098 | 0.0324 |
| Disease/pest tolerant varieties and early planting | 0.1781*** | 0.0227 |
| Crop diversification and early planting | 0.1287*** | 0.0222 |
| Soil & water conservation measures and early planting | 0.0453 | 0.0323 |
| Crop diversification and disease/pest tolerant varieties | 0.3122*** | 0.0206 |
| Soil & water conservation measures and disease/pest tolerant varieties | −0.1187*** | 0.0310 |
| Soil & water conservation measures and crop diversification | −0.1571*** | 0.0310 |

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0.
chi2 (10) = 658.201 Prob > chi2 = 0.0000.
*** $p < 0.01$.

converted the total farm labor count to male labor-equivalent (Rada and Valdes, 2012). The amount of male labor available to the households positively affects the decision to adapt by CD and SWC. These strategies may require more labor allocation and thus would be adopted more by labor-rich households. The same also inhibits the likelihood of adaptation through EP and PDT.

Diverging from others' findings (Kassie et al., 2013; Amsalu and de Graaff, 2007), we find that village kinship ties have a positive impact on adaptation strategies, especially in DT and CD. More kinship ties may act as a form of group dynamics facilitating the flow of information from one relative to another, hence leading to the easier and faster uptake of technologies. Further, sharing of seeds in the form of gifts among families may also contribute to a greater spread of improved seed use in these families. Consistent with others on the effect of education on technology adoption (Asafu-Adjaye, 2008; Velandia et al., 2009), we find that household heads with more years of schooling are more likely to adapt through DT and PDT. Risk mitigation through new improved technologies is a risky gamble with the possibility of negative payoffs in the worst case scenario (e.g. drought). Educated people tend to be less risk averse (Brick and Visser, 2015; Cole et al., 2013), thus a higher adoption rate among this group for these specific technologies.

Gender of the household head significantly affects adaptation through EP and SWC, which may be due to more labor availability and asset endowment characteristic of male-headed households (Ragasa et al., 2013). Similar to others (Kassie et al., 2009; Amsalu and de Graaff, 2007), we find that the adoption of DT, CD and SWC is limited by livestock ownership. Livestock may act as a coping strategy after risk occurrence with these either being sold or used for food. Farmers with higher

**Table 4**
Parameter estimates from multivariate probit and individual probit for estimating determinants of adaptation to climate change.

| Variable | Multivariate probit estimates | | | | | Individual probit estimates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Drought-tolerant varieties *DT* | Early planting *EP* | Disease/pest-tolerant varieties *DPT* | Crop diversification *CD* | Soil and water conservation measures *SWC* | Drought-tolerant varieties *DT* | Early planting *EP* | Disease/pest-tolerant varieties *DPT* | Crop diversification *CD* | Soil and water conservation measures *SWC* |
| *Farm characteristics* | | | | | | | | | | |
| Land tenure | 0.012 | −0.125 | −0.129 | −0.176** | −0.158 | 0.084 | −0.068 | −0.069 | −0.122 | −0.163 |
| | (0.092) | (0.085) | (0.081) | (0.082) | (0.109) | (0.090) | (0.083) | (0.080) | (0.081) | (0.108) |
| Highly fertile soil | −0.164*** | −0.154** | 0.121* | −0.300*** | 0.153* | −0.135** | −0.096 | 0.175*** | −0.250*** | 0.161** |
| | (0.063) | (0.060) | (0.060) | (0.058) | (0.080) | (0.062) | (0.059) | (0.060) | (0.057) | (0.080) |
| Mid-fertile soil | 0.016 | −0.050 | 0.354*** | −0.194*** | −0.189** | 0.052 | −0.003 | 0.404*** | −0.145** | −0.180** |
| | (0.063) | (0.061) | (0.060) | (0.059) | (0.086) | (0.062) | (0.060) | (0.060) | (0.058) | (0.086) |
| Gentle slope | 0.460*** | −0.225*** | 0.237*** | 0.396*** | −0.220*** | 0.544*** | −0.154** | 0.301*** | 0.454*** | −0.244*** |
| | (0.069) | (0.061) | (0.061) | (0.060) | (0.080) | (0.069) | (0.060) | (0.061) | (0.060) | (0.079) |
| Medium sloped | 0.376*** | −0.298*** | 0.128* | 0.205*** | −0.211** | 0.440*** | −0.249*** | 0.189*** | 0.243*** | −0.231*** |
| | (0.074) | (0.067) | (0.067) | (0.066) | (0.087) | (0.074) | (0.066) | (0.066) | (0.065) | (0.087) |
| *Household characteristics* | | | | | | | | | | |
| Sex | −0.001 | 0.159*** | 0.039 | −0.041 | 0.144* | −0.012 | 0.132** | 0.047 | −0.032 | −0.129* |
| | (0.056) | (0.057) | (0.053) | (0.052) | (0.077) | (0.055) | (0.057) | (0.053) | (0.052) | (0.076) |
| Age | 0.002 | 0.001 | −0.001 | 0.002 | 0.001 | 0.001 | −0.001 | −0.001 | 0.001 | 0.001 |
| | (0.002) | (0.001) | (0.001) | (0.001) | (0.002) | (0.002) | (0.001) | (0.001) | (0.001) | (0.002) |
| Education | 0.022*** | −0. 002 | 0.010* | 0.007 | 0.007 | 0.024*** | −0.001 | 0.010* | 0.00* | −0.005 |
| | (0.006) | (0.006) | (0.005) | (0.005) | (0.008) | (0.006) | (0.006) | (0.005) | (0.005) | (0.008) |
| Distance to main market | 0.001 | −0.001*** | −0.001*** | 0.001 | −0.001** | −0.001 | −0.001** | −0.001** | 0.001** | −0.001 |
| | (0.001) | (0.001) | (0.000) | (0.000) | (0.001) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Distance to agricultural extension | −0.001 | 0.001 | 0.001*** | 0.001 | −0.001 | −0.001 | −0.001 | 0.001** | 0.001 | −0.001 |
| | (0.001) | (0.001) | (0.000) | (0.000) | (0.000) | (0.000) | (0.001) | (0.000) | (0.001) | (0.000) |
| Membership to farmer groups | −0.248*** | 0.028 | 0.092 | 0.007 | −0.098 | −0.234*** | 0.035 | 0.098* | 0.026 | −0.050 |
| | (0.062) | (0.059) | (0.057) | (0.057) | (0.085) | (0.061) | (0.059) | (0.056) | (0.057) | (0.083) |
| Number of relatives in village | 0.021*** | 0.001 | −0.003 | 0.050*** | 0.001 | 0.026*** | 0.007 | −0.001 | 0.050*** | −0.000 |
| | (0.006) | (0.006) | (0.006) | (0.006) | (0.009) | (0.006) | (0.006) | (0.006) | (0.006) | (0.009) |
| Reliance on government support | 0.307*** | −0.305*** | 0.317*** | 0.223*** | 0.008 | 0.001 | −0.012** | 0.010* | 0.013** | 0.020 |
| | (0.034) | (0.033) | (0.033) | (0.033) | (0.048) | (0.005) | (0.005) | (0.005) | (0.007) | (0.028) |
| Labor (male person days) | 0.001 | −0.002*** | −0.003*** | 0.002*** | 0.003*** | 0.001 | −0.002*** | −0.003*** | 0.002*** | 0.004*** |
| | (0.001) | (0.001) | (0.005) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Off-farm income | −0.125*** | −0.133*** | 0.067 | −0.123*** | −0.058 | −0.149*** | −0.141*** | 0.043 | −0.125** | −0.062 |
| | (0.046) | (0.044) | (0. 042) | (0.042) | (0.060) | (0.045) | (0.043) | (0.042) | (0.042) | (0.060) |
| Drought experience | 2.393*** | 0.576*** | −0.039 | 0.621*** | 0.240*** | 2.437*** | 0.577*** | 0.056 | 0.651*** | 0.258*** |
| | (0.126) | (0.056) | (0.049) | (0.052) | (0.075) | (0.126) | (0.054) | (0.048) | (0.051) | (0.075) |
| Credit constrained | −0.514*** | −0.043 | −0.195*** | 0.043 | −0.098* | −0.534*** | −0.054* | −0.218*** | 0.034 | −0.118** |
| | (0.042) | (0.041) | (0.039) | (0.039) | (0.055) | (0.041) | (0.040) | (0.038) | (0.038) | (0.054) |
| *Assets* | | | | | | | | | | |
| TLU | −0.029** | −0.008 | 0. 007 | −0.020* | −0.065*** | −0.031*** | 0.007 | 0.009 | −0.020* | −0.070*** |
| | (0.011) | (0.010) | (0.010) | (0.011) | (0.024) | (0.011) | (0.010) | (0.010) | (0.010) | (0.024) |
| Land size | 0.007 | −0.019 | −0.032* | 0.035* | −0.029 | 0.011 | −0.032 | −0.052 | 0.019 | −0.025 |
| | (0.020) | (0.020) | (0.019) | (0.018) | (0.027) | (0.020) | (0.020) | (0.020) | (0.019) | (0.027) |

(*continued on next page*)

**Table 4** (*continued*)

| Variable | Multivariate probit estimates | | | | | Individual probit estimates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Drought-tolerant varieties *DT* | Early planting *EP* | Disease/pest-tolerant varieties *DPT* | Crop diversification *CD* | Soil and water conservation measures *SWC* | Drought-tolerant varieties *DT* | Early planting *EP* | Disease/pest-tolerant varieties *DPT* | Crop diversification *CD* | Soil and water conservation measures *SWC* |
| *Information access* | | | | | | | | | | |
| Access to government extension | 0.038 (0.051) | 0.304$^{***}$ (0.050) | −0.046 (0.048) | 0.101$^{**}$ (0.047) | 0.051 (0.070) | 0.073 (0.050) | 0.334$^{***}$ (0.049) | −0.021 (0.047) | 0.112$^{**}$ (0.047) | 0.029 (0.070) |
| Neighborhood extension | −0.018 (0.047) | −0.357$^{***}$ (0.045) | −0.071$^{**}$ (0.043) | 0.134$^{***}$ (0.044) | −0.189$^{**}$ (0.069) | −0.037 (0.046) | −0.401$^{***}$ (0.044) | −0.111$^{***}$ (0.043) | 0.106$^{**}$ (0.043) | −0.184$^{**}$ (0.068) |
| Radio/TV extension | 0.424$^{***}$ (0.053) | 0.161$^{***}$ (0.051) | 0.361$^{***}$ (0.049) | −0.110$^{**}$ (0.050) | −0.160$^{**}$ (0.075) | 0.346$^{***}$ (0.052) | 0.111$^{**}$ (0.050) | 0.304$^{***}$ (0.048) | −0.164$^{***}$ (0.049) | −0.148 (0.075) |
| Access to climate information | 0.252$^{***}$ (0.055) | 0.267$^{***}$ (0.053) | 0.308$^{***}$ (0.050) | 0.708$^{***}$ (0.051) | −0.316$^{***}$ (0.082) | 0.226$^{***}$ (0.053) | 0.250$^{***}$ (0.052) | 0.301$^{***}$ (0.049) | 0.707$^{***}$ (0.050) | −0.323$^{***}$ (0.082) |
| *Location* | | | | | | | | | | |
| North region | 0.134 (0.071) | 0.535$^{***}$ (0.068) | 0.408$^{***}$ (0.064) | 0.207$^{***}$ (0.064) | −0.154 (0.105) | 0.091 (0.071) | 0.484$^{***}$ (0.066) | 0.371$^{***}$ (0.063) | 0.203$^{***}$ (0.064) | −0.130 (0.104) |
| Central region | 0.061 (0.044) | 0.464$^{***}$ (0.045) | 0.267$^{***}$ (0.042) | −0.082$^{**}$ (0.042) | 0.115$^{*}$ (0.058) | 0.034 (0.043) | 0.439$^{***}$ (0.044) | 0.260$^{***}$ (0.042) | −0.088$^{**}$ (0.041) | 0.123$^{**}$ (0.058) |
| Constant | −3.151$^{***}$ (0.208) | −1.115$^{***}$ (0.164) | −0.969$^{***}$ (0.158) | −1.461$^{***}$ (0.157) | −1.132$^{***}$ (0. 211) | −3.069$^{***}$ (0.205) | −1.000$^{***}$ (0.161) | −0.893$^{***}$ (0.156) | −1.396$^{***}$ (0.155) | −1.137$^{***}$ (0.210) |

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: Chi2 (10) = 658.201 Prob > chi2 = 0.0000.
Figures in parentheses are robust standard errors.
$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$ $^{**}p < 0.05$.

TLU are thus less risk averse and act less to mitigate climate risks. On the other hand, land ownership does not seem to explain adaptation much, only increasing the likelihood of adapting through CD while diminishing the likelihood of adapting through DPT. Having a large land area gives farmers the room to try out different crops as a hedge against adverse outcomes.

Discussed above are the parameter estimates from the multivariate probit model. For comparison, we report on the parameter estimates from the individual probit model. The results from the two estimation procedures are fairly similar with regard to the significant variables and the direction of the effect. However, the multivariate probit model is superior in that we are able to compute the probability of adoption of one strategy conditional on the others, as explained hereafter.

We simulated the impacts of a selected set of variables to show their impact on the marginal probability of success (MPS) defined as the probability of observing the adoption of one practice conditional on the other practices (Table 5). The simulated impacts of access to credit, education level of the household head, availability of extension and access to climate information showed that the variable with the biggest impact on MPS was access to climate information. The impact of making climate information universally available was as much as 45% on MPS in the case of CD. It was also the single variable with the highest MPS percentage across all five strategies. Access to credit was important where the removal of the credit constraint greatly increased the MPS across all strategies, second only to universal availability of climate-related information. The reverse was true in a scenario of a total lack of climate information which had the least MPS across all the strategies, followed by the scenario of universally credit-constrained farmers in this respect. The effect of completing primary schooling (raising the average years of schooling as observed in the sample by one year), was about 30% for DT. The next highest impact of primary school completion was 1.3% and the lowest impact was at 0.3% in the case of MPS for EP. In the case of extension, the highest impact on MPS was 19% for EP and the lowest, 3.2% for DTV.

Overall, these simulated effects show that information and liquidity offer a clear entry point for strengthening the adaptive capacities of farmers with respect to climate change. To further assess the relative importance of these two variables in influencing adaptation, we ran a multivariate probit on a sub-sample of credit constrained households (Di Falco et al., 2011). Results show that information access variables are still highly significant, further asserting the importance of communicating climate information relative to credit provision. The importance of information access is crucial because even when farmers can access the capital needed to implement these beneficial practices, they can still fail to do so if they erroneously view them as unprofitable or lack the information and skills to implement them. Extension programs that are designed as educational platforms to impart correct information and knowledge can help resolve these contradictions in farmer technology adoption behavior.

## 5. Conclusions

This paper analyzed the determinants of climate change adaptation strategies, using detailed plot-level observations and the multivariate probit model. The null hypothesis of the independence of the different adaptation strategies was rejected. We thus adopt the alternative hypothesis of inter-dependence among the different adaptation strategies which justifies the use of the multivariate probit for this analysis. This result is important in informing extension policies on which strategies can be implemented together and which can be substituted, for greater effect.

One of the key findings from the study is that access to climate information can be a major driver of the decisions to adopt the adaptation practices. Various sources of extension information significantly inform adoption decisions. Key among these is government extension and information accessed through the media. Awareness of climate change and measures to mitigate its effects is thus depicted as a key hurdle in the adaptation process. The study identifies credit constraint as a key impediment to adaptation. Resource availability enables farmers to implement adaptation decisions, the lack of which presents the household with a significant challenge of adopting the adaptation measures. It emerged from the study that credit-constrained households are still able to adopt these beneficial practices when provided with climate change related information. Our study, therefore, identifies lack of information as the most important deterrent to climate change adaptation by the farm household.

These results have important policy implications. The policy message from this is that strong investments by governments in information delivery and farmer education will have large payoffs in building awareness and helping change farmers' practices. There is a need for clearly designed policies to disseminate climate change information to farmers. The same should incorporate deepening of extension access with information on the appropriate adaptation strategies. The need for fostering credit markets for easy accessibility and affordability by farmers is important. These specific policies geared towards overcoming information and resource constraints would lead to high adoption of crop varieties adapted to changing growing conditions and the implementation of agricultural practices that stabilize yields, thus enabling farm households to successfully respond to climate change. The positive impact of kinship ties in predicting adoption of some adaptive practices suggests that policies that encourage social capital formation among rural communities should be considered. These can include encouraging formal and informal farmer and community groups through training and formalization. These can be important vehicles for information dissemination and mutual support to help farmers acquire information and resources needed for implementing practices that enhance adaptation. The importance of credit in adoption model also suggests the need for policies that support microfinance to make credit available to farmers to finance the many improvements in practices needed to make them adapt successfully. The fact that off-farm income was associated with less adoption suggests that the opportunity costs of labor are higher for those with access to labor markets. The policy message being that it would

**Table 5**
Simulated impacts of some variables on probability of adoption.

| | Drought-tolerant crops ***DT*** | % Change in marginal probability of success | Early planting ***EP*** | % Change in marginal probability of success | Pest and disease tolerance ***PDT*** | % Change in marginal probability of success | Crop diversification ***CD*** | % Change in marginal probability of success | Soil and water conservation ***SWC*** | % Change in Marginal Probability of Success |
|---|---|---|---|---|---|---|---|---|---|---|
| All variables at observed values | 36.5 | | 27.8 | | 36.09 | | 40.7 | | 8.4 | |
| Education at sample 7 years (c.f. 6 years) | 47.4 | 29.9 | 27.9 | 0.3 | 36.6 | 1.3 | 41.0 | 0.8 | 8.4 | 0.43 |
| Education set at 9 years (mid-secondary) c.f. 6 years | 40.6 | 11.1 | 28.4 | 2.0 | 38.5 | 6.7 | 42.5 | 4.5 | 8.6 | 1.88 |
| No extension information on crops (c.f. 50%) | 35.5 | −2.9 | 22.6 | −18.6 | 35.4 | −2.0 | 39.0 | −4.2 | 8.2 | −2.23 |
| Extension information on crops available to 100% (c.f 50%) | 37.7 | 3.2 | 33.1 | 18.9 | 36.8 | 2.0 | 42.4 | 4.1 | 8.7 | 3.51 |
| 100% households credit constrained (c.f. | 31.2 | −14.5 | 27.1 | −2.6 | 33.5 | −7.1 | 40.0 | −1.8 | 7.9 | −6.22 |
| 0% credit constrained (c.f.) | 47.5 | 30.0 | 29.1 | 4.7 | 41.1 | 13.8 | 41.0 | 0.8 | 9.4 | 12.01 |
| Climate information not available | 34.4 | −5.8 | 25.2 | −9.2 | 32.8 | −9.1 | 33.0 | −18.8 | 5.3 | −37.30 |
| Climate information 100% available | 41.7 | 14.3 | 33.4 | 20.3 | 43.6 | 20.9 | 59.0 | 45.0 | 9.4 | 11.56 |

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be important for agricultural policy to encourage on-farm diversification through encouraging market access and information to lower the opportunity costs of on-farm labor and resource allocation. This will help lock in the labor needed for on-farm improvements and adaptation. Finally, the complementarities observed among the different adaption practices suggests that extension messaging and farmer education should be tailored to encourage farmers to think holistically in terms of adopting optimal combinations of practices and not just single farming techniques.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.crm.2017.01.002.

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