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# Climate variability and post-harvest food loss abatement technologies: evidence from rural Tanzania

This paper focuses on improved storage and preservation technologies as an adaptation strategy in response to climate change. We also study the trade-off between improved cereal storage technologies and the preservation techniques among rural households in Tanzania. We find that climate variables significantly influence farmers' choice of improved storage technologies and preserving decisions. Using a bivariate probit model, we find that modern storage technologies and preservation measures are substitutes. Farmers can significantly reduce annual costs associated with preservation by adopting (usually long lasting) modern storage facilities.

**Keywords:** Climate change adaptation, storage technologies, preservation methods, post-harvest loss abatement, bivariate probit model, Tanzania

**JEL classifications:** C35, O33, Q54

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## Introduction

Poor post-harvest management of cereals is one of the major challenges to food security in Sub-Saharan Africa (SSA), accounting to 15-30% annual grain losses (Affognon *et al.*, 2015; Bradford *et al.*, 2018; Kumar and Kalita 2017; Sheahan and Barrent, 2017; World Bank 2011). Assuming the minimum losses, World Bank (2011) estimates a monetary value of more than $4 billion a year out of an estimated annual value of grain production of $27 billion. This loss is estimated to exceed the total value of food aid ($6.1 billion) SSA received over one (1998-2008) decade. In addition, the loss is equivalent to the annual caloric requirement of at least 48 million people (at 2500 kcal per person per day) (World Bank, 2011). Therefore, there is potential for great gains in food security and significantly reducing food aid dependence by improving post-harvest cereals management.

Cereals production in SSA has been very low, compared to the rest of the world (World Bank, 2008; Abbas *et al.*, 2014). Low agricultural production has been blamed for food problems in SSA, an argument that has motivated hundreds of studies on the adoption of improved and production enhancing technologies in the region (Feder *et al.*, 1985; Sunding and Zilberman, 2001; Foster and Rosenzweig, 2010). Consequently, a significant amount of financial aid and support has been extended to these countries to address production related issues. However, can we continue to emphasise only production problems when 20-30% of the yields of the cereals harvested never reaches the consumers? Post-harvest losses continue to worsen food insecurity by contributing to high food prices, and by removing part of food supply from the market (Tefera, 2012). Although adoption of sustainable intensification practices is a promising step in making SSA food secure, existing post-harvest losses can reduce the benefits to be gained from such improved technologies. Reducing food losses arising from storage can be more environmentally sustainable than a corresponding increase in production.

Some studies have literally argued that some modern storage technologies are good enough to the extent that if they are adopted, one does not necessarily need to introduce any additional preservation technique for the safety of the crops (see, for example, the metal silos discussion in Gitonga *et al.* 2013, 2015 and Tefera, 2012). Nonetheless, experience has shown that some farmers still adopt both improved storage techniques and some additional preservation methods. If the former is scientifically proven to be an effective substitute for the latter, yet both are currently adopted together by farmers, then it is important to understand why that is the case, as this might help farmers reduce their storage costs significantly by choosing only one of the options.

In this paper we study the factors influencing the choice of improved cereals storage technologies and the preservation techniques among farming households in rural Tanzania, and assess how such technologies could act as adaptive strategies in response to climate change. First, we use farm level climate data to investigate the role of climate variables (rainfall, temperature and altitude) on the adoption decision of storage and preservation measures across households. Second, by using a bivariate probit model, we study the trade-off farmers make when choosing storage and preservation technologies during post-harvest food storage. Through this we can shed some light on complementary/substitutability nature of the technologies.

The current study contributes to the literature in two ways. First, to the best of our knowledge, this is the first study to exploit farm level climate data (temperature and rainfall) to estimate the effect of these variables on the adoption of storage technology and preservation methods. Second, we analyse the trade-offs farmers make in the choice of storage technologies and preservation measures. Unlike Adegbola and Gardebroek (2007), we study the trade-off farmers make when choosing improved cereals storage technologies and the preservation techniques. We relax the assumption of Adegbola and Gardebroek (2007) that the two adoption decisions are made separately. We do this because modern storage technologies (e.g. metal silos) do not need preservatives as they work hermetically (Tefera, 2012), and thus the decision to adopt modern storage is likely to affect the decision on whether to use preservation measures. Surprisingly, there is a limited number

 

of empirical studies in the peer-reviewed journals (from which Tanzania can learn) that assess the adoption of agricultural storage technologies in developing countries, and to the best of our knowledge, none of them investigates the role of climate variables and on the joint adoption decision.

In order to enable this, we exploit a very rich data set, the living standard measurement survey (LSMS) for Tanzania, collected in 2010/2011. The main findings of the study contribute to a new tweak in the climate change literature that climate variables (mainly rainfall and temperature) do influence the choice of improved storage technologies and preserving methods. In addition, we find that access to extension services significantly influences in increasing the adoption of improved storage technologies. Also, consistent with our expectation, we find that adoption of the modern storage technologies indeed negatively affects the adoption of preservation technology (i.e. substitution effect).

The rest of the paper is organized as follows: section 2 reviews the literature, while section 3 discusses methodology. Section 4 presents the data and descriptive statistics. Section 5 presents the results, while section 6 presents discussions and concludes the study.

## Literature review

Post-harvest cereal loss is the loss of grains between harvest and consumption (Proctor, 1994; USAID, 2011a). A recent definition by Bellemare *et al.* (2017) state that food waste is the difference between the amount of food produced and the sum of all food employed in any kind of productive use, whether food or nonfood. The majority of post harvest cereal losses are due to rodents, grain borers, grain weevils and microorganisms (molds, bacteria), resulting from poor post-harvest storage management (Abbas *et al.*, 2014; Kumar and Kalita, 2017; Mendoza *et al.*, 2017; World Bank, 2011). Adoption of improved post-harvest storage facilities (e.g. open drums, Metal Silo, airtight (hermetic) bags/drums, etc.) or one of various preservation methods are major approaches towards loss reduction (Abass *et al.*, 2018; Affognon *et al.*, 2015; Kumar and Kalita, 2017; Manandhar *et al.*, 2018). For a long time, cereal storage in SSA has relied on traditional methods (e.g. traditional granaries, etc.) of grain storage. But these traditional storage methods do not effectively protect the grain from climate change, pest and diseases, resulting in huge losses and threatening food security. This has resulted to introduction of several improved post-harvest technologies and/or other preservative techniques to minimise such huge loss. However, empirical information on the determinants of adoption of such technologies is scanty (Tefera *et al.*, 2011), with a good fraction of SSA farmers remaining to their traditional methods.

On the other hand, climate change and variability have continued to aggravate food security problems in Africa and world at large[1]. In response, research has focused on how farmers respond to such challenges on the production side (e.g. Di Falco et al, 2011; Mendelsohn et al, 1994; Deressa and Hassan, 2009). However, the post-harvest responses to such climatic shocks have largely been overlooked. Climate variables such as temperature, moisture content and relative humidity are asserted as principal physical factors that affect grain in storage as they influence insect and mold development, which causes deterioration and loss of grain in storage (USAID, 2011a; Tefera, 2012; Abass *et al.*, 2014). Higher (or very low) temperatures and low humidity level are less likely to support the growth and development of most of the pests and insects. Bendito and Twomlow (2015) have recently started the debate on strategies to save the existing and future post-harvest facilities from impacts related to floods, droughts, high temperatures and other weather-related disasters due to climate change and from earthquakes. There is also a need to understand how farmers residing to different climatic conditions respond in terms of storage and preservation technologies is important. If indeed different technologies work best under certain climatic conditions, then with current climate change and variability (where the less humid areas become more humid and the previously humid areas are now changing to semi-arid), such technologies could be promoted as ideal adaptations strategies in those areas.

Like many other countries in SSA, Tanzania is not immune to the post-harvest loss of cereal crops, neither to the negative shocks of climate change. It is estimated that up to 40 percent of the harvested cereals does not reach the final consumer due to the poor post-harvest management (Maunya, 2002 as cited in Rugumamu, 2003; USAID, 2011b). World Bank (2011) estimates that lack of or poor storage facilities account up to 38% of the post-harvest loses in the country. This type of loss generally refers to either qualitative or quantitative measurable decrease of the foodstuff mainly caused by insects, molds, bacteria, rodents, birds, sprouting and rancidity (USAID, 2011a). With low levels of agricultural productivity by many poor subsistence farmers in the country, such huge losses can have adverse effects on the food security of the farmers and of the country at large.

## Methodology

After harvesting the crops, cereal farmers must decide on how much of the harvest to store for either future household food consumption, seeds or later selling at higher market prices[2]. Then at this point, a farmer has to simultaneously decide on the use of storage and preservation technique that will maximise the value of stored cereals, at least for this period storage. The household faces a storage technology choice set to choose from, which contains traditional methods, improved traditional and modern methods, where the latter is assumed to be the most effective (i.e. with highest efficacy rate) storage method and this feature is common knowledge.

Storage handbook by USAID (2011a, p33) classify farm level storage facilities as traditional or modern based on some physical characteristics of the structures. Informed by

[1] When it comes to Tanzania, there is already strong evidence suggesting that climate change is an issue in the country as indicated by the drastic change in the annual mean rainfall of 1067 mm for the 1960-1990 period to 767 mm in the 2001-2009 period. A study by Rowhani *et al.* (2011) predicts that the temperature increase of $2^0$C by 2050 will reduce average maize, sorghum and rice yields in the country by 13%, 9% and 8%, respectively.

[2] This study only focuses on the decisions farmers make once they have decided to store a certain amount of their harvest.

this report, in this paper, we classify these facilities into three groups, traditional, improved and modern storage technologies. While traditional technologies include locally made traditional structures, improved locally made structures, unprotected piles and ceiling, while improved technologies include sacks/open drums, modern stores and airtight drums, while modern technologies only include airtight drums and modern stores (i.e. excludes sacks/open drums).

Following the discussions above, the econometric specification of this paper consists of two parts: in the first part, we test if the adoption of improved/modern technologies and preservation methods are interdependent by estimating a bivariate probit model; in the second part, we analyse the determinants of the three possible groups of storage technologies (i.e. traditional, improved traditional and modern technologies) by estimating an ordered probit model.

### Bivariate probit model

The choice of the storage technology is likely not to be independent of the decision to adopt preservation measures. To estimate the bivariate model, first, we consider the broad category of improved technologies (i.e. improved traditional and modern), where the base is traditional technologies. In the second bivariate estimation, we consider only the modern technologies, where the base is traditional and improved traditional. Following Greene (1998; 2008) we model simultaneously the choice of the storage technology and the preservation measures. Thus, we adopt the following bivariate probit model:

$$y_1^* = X_1'\beta_1 + \varepsilon_1, S = 1, if \quad y_1^* > 0; S = 0, otherwise \tag{1}$$

$$y_2^* = X_2'\beta_2 + \varepsilon_2, P = 1, if \quad y_1^* > 0; P = 0, otherwise \tag{2}$$

where S=1 for the choices of improved/modern storage technologies, zero otherwise and P is the decision to preserve. $\varepsilon_1$, $\varepsilon_1$, $\rho$ are assumed to be bivariate normal (BVN). $y_1^*$ and $y_2^*$ are the unobserved latent variables from which the two decisions are defined; $X_1$ and $X_2$ are the vectors of independent variables for both decisions; $\varepsilon_1$ and $\varepsilon_2$ are the error terms, which may be correlated (given by the correlation coefficient, ρ statistics), otherwise, univariate binary probit model is appropriate (Greene, 2008).

### Ordered probit model

Because the different technologies have different levels of efficacy, we group the technologies as low efficacy rate (traditional technologies), medium efficacy rate (improved traditional technologies) and high efficacy rate (modern technologies). Given the different efficacy rates, the storage technologies used have ordinal meaning: modern storage technologies are better than improved traditional, which are better than traditional storage technologies. In the literature, a standard way of modeling ordered response variables like our dependent variable is by means of ordered probit or ordered logit (for details of the models estimation see Greene, 2008). These two models are very similar; we opt for an ordered probit in this paper, because of its greater flexibility and it is relatively easy to estimate. The model assumes a normally distributed cumulative density function (cdf). For the model probabilities to be positive, we define two threshold parameters, $U_1$ and $U_2$, with $U_1 < U_2$. We do not observe the efficacy rate but we do observe choices made by respondents. Assuming $y_i$ = (1, 2, and 3) for traditional, improved traditional and modern storage, respectively, then the interval decision rule is:

$y_i = 1$ if $y_i^* \leq U_1$ (Traditional technologies)
$y_i = 2$ if $U_1 < y_i^* \leq U_2$ (Improved traditional technologies)
$y_i = 3$ if $y_i^* > U_2$ (Modern technologies)

Where $y_i^*$ is the latent index of efficacy rate. To estimate this model, we apply the usual maximum likelihood estimation to obtain both the threshold parameters and the model parameters.

The choice of control variables for both the bivariate probit model and the ordered probit model is mainly informed by existing post-harvest loss literature (e.g. Adegbola, 2010; Adegbola and Gardebroek, 2007; USAID, 2011a; World Bank, 2011; Tefera, 2012). The decisions made by farmers depend on a number of factors including the amount harvested, household size, short term climate variables (rainfall, temperature and altitude, with terms for rainfall and temperature squared in order to capture any nonlinearities), humidity (i.e. as measured by the interaction term between rainfall and temperature), amount of rainfall in the previous season, crops grown, marketing infrastructure and assets which is a proxy for wealth indicator.

## Data and descriptive statistics

We employ a very rich and nationally representative household survey data set from Tanzania, collected in year 2010-2011. The data was collected based on a stratified, multi-stage cluster sample design using the national master sampling frame constituting a list of all populated enumeration areas in the country (NBS, 2012). Information was collected from a total of 3846 households, 2121 (55 percent) of them from the rural areas. From this dataset, we select those rural cereal farming households who reported storing at least part of their crop, giving us a sample of 927 cereal storage (and or preservation) observations for 557 rural and cereal farming households[3]. From the final data set, 56% of households cultivate maize, 23% cultivate rice and the remaining 21% cultivate other cereals mainly millet, sorghum and beans.

[3] Households are likely to adopt different types of storage/preservation technique for different cereal crops. Following this, we use observations for cereal storages or/and preservation as our primary unit of analysis other than households. This also enables us to retain the highest number of observations in our dataset. However, for robustness checks, we shall also do the models estimation using household as unit of analysis.

**Table 1a:** Major types of storage facilities usage.

| | % of total population | Efficacy rate |
|---|---|---|
| **Tradition** | **24.10** | **LOW** |
| Locally made traditional structures | 16.85 | |
| Improved Locally made structures | 1.61 | |
| Unprotected pile | 1.79 | |
| Ceiling | 3.85 | |
| **Improved storage** | **68.01** | **MEDIUM** |
| Sacks/Open drums | 68.01 | |
| **Modern storage** | **6.36** | **HIGH** |
| Airtight drums | 5.91 | |
| Modern Stores | 0.45 | |
| Others | 1.52 | |

Source: Own composition

**Table 1b:** Proportion of households preserving, disaggregated by storage type.

| | Traditional storages | Improved storages | Modern storages | Whole population |
|---|---|---|---|---|
| Whether preserves (% of sample) | 29.0% | 31.6% | 18.3% | 30.7% |
| Distribution by category of preservation measure | | | | |
| Spraying | 18.6% | 29.2% | 16.9% | 26.3% |
| Smoking | 4.5% | 2.2% | 0.0% | 2.8% |
| Others | 5.6% | 0.2% | 1.4% | 1.5% |

Source: Own composition

**Table 2:** Descriptive statistics of key variables.

| Storage type | Tradition | | Improved | | Modern | | Whole sample |
|---|---|---|---|---|---|---|---|
| Variable | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | |
| Whether hhld adopts any preserving method | 29% | - | 32% | - | 18% | - | 31% |
| Mean annual temp | 22.56 | 2.295 | 22.81 | 2.797 | 20.81 | 2.446 | 22.8 |
| Mean annual rainfall (mm) | 778.7 | 177.840 | 745.3 | 221.802 | 571.0 | 228.816 | 754.4 |
| Households living in a humid region | 71% | - | 75% | - | 90% | - | 74% |
| Access to extension services | 14% | - | 15% | - | 21% | - | 15% |
| Number of years hhld lived in the village | 40.6 | 21.208 | 38.0 | 19.099 | 30.2 | 19.751 | 38.5 |
| Distance to the nearest major road (km) | 22.624 | 20.255 | 20.594 | 23.516 | 11.755 | 14.529 | 20.9 |
| Share of households sold any of the harvested crops | 47% | - | 39% | - | 58% | - | 41% |
| Maize farming hhld (dummy) | 58% | - | 52% | - | 83% | - | 54% |
| Proportion of heads without any formal education | 57% | - | 44% | - | 24% | - | 47% |
| Female headed houseolds | 15% | - | 18% | - | 23% | - | 17% |
| Age of the household head (Years) | 52 | 13.578 | 49 | 15.271 | 52 | 12.521 | 50 |
| Asset Index | -1.355 | 1.037 | -0.110 | 2.587 | 2.198 | 3.068 | -0.4 |
| Proportion of household encountered any storage losses | 6% | - | 8% | - | 3% | - | 8% |
| Household size | 9.1 | 9.129 | 6.2 | 3.313 | 6.4 | 2.992 | 6.9 |

Source: Own composition

Table 1a provides a detailed distribution of storage facilities. Major types of farm level storage facilities used in Tanzania mainly include: traditional storage (i.e. locally made traditional structures, improved locally made structures, unprotected pile and ceiling) adopted by 24% of our sampled households; improved storages (i.e. sacks/open drums) adopted by 68% and modern storages (i.e. airtight drums or modern store), adopted by 6%. Since modern storages are subset of improved storages, in the subsequent analyses we consider improved storages to constitute of both the only improved and the modern stores (i.e. sacks/open drums, airtight drums and modern store) but modern storage category does not include the only improved one (i.e. sacks/open drums).

We consider household to have adopted a preservation measure (preserve) if it reported to do something to protect the stored crops. In our sample (as presented in Table 1b), only 30.7% of the households reported to preserve their stored crops, with majority using spraying (26.3 %). We notice a small difference in the proportion of households who report to use preservative measures between those using improved and traditional storage methods (32% versus 29%, respectively). However, we notice that a much smaller share of households that adopt modern storage technology (i.e. 18.3 %) also preserve compared to that of 29% by those still using traditional storage methods.

In Table 2, we provide descriptive statistics of other major variables by type of storage technologies adopted. Adopters of modern storages live is areas with less temperatures and rainfall, have more access to extension services, are relatively more educated and wealthier when compared to those adopting traditional storages. However, when we investigate share of households living in humid regions (good environment for pests, insects and other microorganisms), we find that relatively larger share of modern storage adopters (90%) compared to 71% of the traditional storage adopters live in these regions. The mean annual temperature for the whole sample is 22.8 degrees Celsius but varying from 15.4$^{o}$C in some areas to 27.8$^{o}$C in others, and average rainfall is 754mm (varying from 359mm to 1652mm).

Regarding gender, only 17% of households in our sample are headed by females. However, 23% of households that have adopted modern storage technologies are female headed, as opposed to only 15% of the traditional storages adopters. In addition, larger share of maize farmers adopts modern technologies (constituting 83% of adopters) compared to those cultivating other cereals. This is not very surprising as maize storage dominates the food storage activity in Tanzania, with over 70% of the functional stores having it or its products as the main product (USAID, 2011b, p14). Adopters live much closer to major roads than their counter-

**Table 3:** Bivariate probit: Improved storage and preservation methods.

| Variables | Improved | Preserve |
|---|---|---|
| Mean annual temperature (long-term) | -0.680** | 0.817*** |
| | (0.274) | (0.253) |
| Mean annual temperature_SQR | 0.016*** | -0.017*** |
| | (0.006) | (0.006) |
| Mean annual rainfall (long-term) | 0.003 | 0.007*** |
| | (0.003) | (0.002) |
| Mean annual rainfall _SQR | 4.26e-07 | -2.14e-06** |
| | (1.09e-06) | (9.25e-07) |
| Annual rainfall in previous year (2008/2009) | -0.001 | 0.001** |
| | (0.001) | (0.001) |
| Interaction of rain and temperature | -0.001 | -0.001** |
| | (0.001) | (8.92e-05) |
| Elevation/Altitude in metres | -0.001*** | -0.001 |
| | (0.001) | (0.001) |
| Access to extension services | 0.295* | 0.441*** |
| | (0.154) | (0.131) |
| Number of years lived in village | -0.006* | 0.016*** |
| | (0.003) | (0.003) |
| Distance from the nearest major road (in logs) | -0.010 | -0.229*** |
| | (0.041) | (0.036) |
| Selling households | -0.064 | -0.223** |
| | (0.106) | (0.101) |
| Maize producing households | -0.189 | 0.489*** |
| | (0.123) | (0.118) |
| No schooling | -0.014 | -0.114 |
| | (0.115) | (0.116) |
| Female headed households | 0.181 | -0.168 |
| | (0.152) | (0.142) |
| Age of household head | -0.001 | -0.011** |
| | (0.005) | (0.004) |
| Asset Index | 0.160*** | 0.032 |
| | (0.037) | (0.023) |
| Whether any crop was lost from storage | 0.104 | -0.615*** |
| | (0.209) | (0.225) |
| Amout of crop harvested (in logs) | 0.018 | 0.209*** |
| | (0.052) | (0.048) |
| Household size | -0.073*** | -0.038*** |
| | (0.012) | (0.011) |
| Semiarid regions | -0.108 | -0.528*** |
| | (0.155) | (0.156) |
| Coast regions | -1.313*** | -0.164 |
| | (0.186) | (0.155) |
| Constant | 9.740*** | -13.420*** |
| | (3.645) | (3.305) |
| rho | | 0.070 |
| | | (0.066) |
| Observations | 993 | |

Note: Wald test of rho = 0; chi2(1) = 1.125; Prob > chi2 = 0.289; Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Own composition

parts and a relatively larger fraction (i.e. 21% versus 14%) of this group received some extension services.

## Results

First, we estimate the bivariate model of improved storage technologies and preservation methods. Estimation results (Table 3) suggest that there exists no statistically significant relationship between the adoption of improved storage methods and preserving, with the rho value of 0.07, but a p-value of 0.289. The statistical insignificancy of the results implies that the adoption of each of the two technologies (i.e. improved storage and preservation) can be modeled separately using an independent regression function. Following this, we estimate the binary probit model for each of the technologies.

The marginal effects from regression results of the improved storage and preservation probit models are presented in Table 4. As expected, climatic conditions influence (non-linearly) the households' decision to preserve the stored crops. We find significant positive and negative marginal effects for temperature and temperature squared variables respectively. This suggests that, at lower levels, the probability of preserving increases with temperature but the relationship reverses at higher levels of temperature (turning point is 20 degree Celsius, meaning that majority of the sampled households are in the regions where the use of preservatives declines with higher temperature). In addition,

we find that mean annual rainfall increases the probability of preserving and that households who experienced very high rainfall in previous years are more likely to adopt preserving measures in the current year. These findings are in line with Stathers *et al.* (2013), arguing that postharvest systems will be affected by changes in temperature, rainfall, humidity, extreme events and the natural and human responses to climate change and variability

Furthermore, higher cost of acquiring the preservatives (as proxied by household distance from the nearest major roads) reduces the probability of preservation usages. Households living far from the nearest major road are 7.6 percentage points less likely to adopt preservation measures. We also find that amount of crops harvested increases the probability of preserving. A 10% increase in the amount of crops harvested increases the likelihood of preserving by 7 percentage points.

With regard to storage, we find that households living in higher temperatures have a lower probability of adopting the improved storage, but this effect gradually falls and later changes its sign (turning point is 23.5 degree Celsius, meaning around 40% of the sampled households are in the regions where the adoption of improved storage increases with higher temperature). However, results suggest that neither rainfall nor humidity matter on the adoption of improved storage. Although, controlling for regional fixed effects shows those households living in semi-arid regions (i.e. long run climate average of both dry and hot) have lower probability to adopt preservation measures but no effect on improved storage adoption. Households living in semi-arid regions are 15 percentage points less likely to adopt preservation. In addition, households living in higher altitude areas are less likely to adopt improved storage methods.

Moreover, we find that extension services matter significantly for both improved storage and preserving. Households with access to these services are 7 and 16 percentage points more likely to adopt improved storage and preserve, respectively, compared to their counterparts. Other factors strongly related to the probability of adoption of improved storage are household wealth or income (as proxied by asset index) and household size. These results are in line with finding by Gitonga *et al.* (2015) that household size and land size (wealth) increased the likelihood of adopting the metal silo technology.

Table 5 reports bivariate probit model results for modern storage and preservation methods. Contrary to improved storage, here we find that modern storage and preservation methods are substitutes, with a rho value of -0.25 and P-value of 0.022 which allows us to reject the null hypothesis of independence.

Our data does not provide the price information for the adopted storage methods but coefficient of assets is statistically significant, indicating that wealthier households are more likely to choose modern storage. Given the adoption relation between modern storage and preserving, we jointly estimate their adoption decisions and we find that indeed transaction costs (as proxied by distance from the nearest major road) and household wealth (as proxied by asset index) are respectively negatively and positively correlated with the adoption of the modern storage. These results support findings that household characteristics and climate-related factors influences farm households' agricultural intensification technology adoption (Teklewold *et al.*, 2013; Ndiritu *et al.*, 2014; Beyene *et al.*, 2017).

**Table 4:** Marginal Effects results for the binary probit model for adoption of improved storages and preserving.

| VARIABLES | improved storage | preserve |
|---|---|---|
| Mean annual temperature (long-term) | -0.182** | 0.272*** |
| | (0.073) | (0.084) |
| Mean annual temperature_SQR | 0.004*** | -0.006*** |
| | (0.002) | (0.002) |
| Mean annual rainfall (long-term) | 0.001 | 0.003*** |
| | (0.001) | (0.001) |
| Mean annual rainfall _SQR | 1.31e-07 | -7.14e-07** |
| | (2.77e-07) | (3.08e-07) |
| Annual rainfall in previous year (2008/2009) | -0.001 | 0.001** |
| | (0.001) | (0.001) |
| Interaction of rain and temperature | -3.45e-05 | -7.20e-05** |
| | (2.87e-05) | (2.98e-05) |
| Elevation/Altitude in metres | -0.001*** | -3.86e-05 |
| | (7.67e-05) | (9.26e-05) |
| Access to extension services | 0.070** | 0.159*** |
| | (0.033) | (0.049) |
| Number of years lived in village | -0.002* | 0.005*** |
| | (0.001) | (0.001) |
| Distance from the nearest major road (in logs) | -0.002 | -0.076*** |
| | (0.011) | (0.012) |
| Selling households | -0.016 | -0.073** |
| | (0.028) | (0.033) |
| Maize producing households | -0.049 | 0.159*** |
| | (0.032) | (0.038) |
| No schooling | -0.004 | -0.037 |
| | (0.030) | (0.038) |
| Female headed households | 0.046 | -0.055 |
| | (0.035) | (0.044) |
| Age of household head | -2.14e-05 | -0.004** |
| | (0.002) | (0.002) |
| Asset Index | 0.042*** | 0.011 |
| | (0.009) | (0.008) |
| Whether any crop was lost from storage | 0.030 | -0.167*** |
| | (0.050) | (0.047) |
| Amout of crop harvested (in logs) | 0.004 | 0.069*** |
| | (0.014) | (0.016) |
| Household size | -0.019*** | -0.013*** |
| | (0.003) | (0.004) |
| Semiarid regions | -0.029 | -0.154*** |
| | (0.043) | (0.039) |
| Coast regions | -0.440*** | -0.053 |
| | (0.066) | (0.048) |
| Observations | 993 | 993 |

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Own composition

Table 6 reports ordered probit results. Consistent to the bivariate probit and probit models estimated above, households are less likely to adopt modern storage and improved storage technologies as temperature increases but the sign changes at very high temperatures (turning point is 26.6 degrees Celsius, with most of the farmers being on the downward sloping portion of the curve). Similar signs are observed for the rainfall and altitude variables. It is difficult to explain these results but one could suspect that possibly initial fixed costs of obtaining modern storage are so high to the farmers such that even those living in the riskiest envi-

**Table 5:** Estimation results: bivariate Probit for modern storage and preserve.

| VARIABLES | Modern storage | preserve | marginal effects (see note+) |
|---|---|---|---|
| Mean annual temperature (long-term) | 0.112 | 0.825*** | 0.004 |
| | (0.411) | (0.252) | (0.003) |
| Mean annual temperature_SQR | -0.015 | -0.017*** | -0.001* |
| | (0.011) | (0.006) | (9.53e-05) |
| Mean annual rainfall (long-term) | -0.011*** | 0.008*** | -3.76e-05 |
| | (0.004) | (0.002) | (3.02e-05) |
| Mean annual rainfall _SQR | 4.98e-07 | -2.17e-06** | -5.44e-09 |
| | (1.48e-06) | (9.34e-07) | (1.07e-08) |
| Annual rainfall in previous year (2008/2009) | 0.002 | 0.001** | 1.15e-05 |
| | (0.001) | (0.001) | (8.45e-06) |
| Interaction of rain and temperature | 0.001* | -0.001** | 1.18e-06 |
| | (0.001) | (8.95e-05) | (1.23e-06) |
| Elevation/Altitude in metres | -0.001* | -0.001 | -6.38e-06 |
| | (0.001) | (0.001) | (4.28e-06) |
| Access to extension services | 0.061 | 0.444*** | 0.003 |
| | (0.198) | (0.131) | (0.003) |
| Number of years lived in village | -0.017*** | 0.016*** | -4.42e-05 |
| | (0.005) | (0.003) | (4.40e-05) |
| Distance from the nearest major road (in logs) | -0.087 | -0.230*** | -0.002* |
| | (0.058) | (0.036) | (0.001) |
| Selling households | 0.113 | -0.219** | -0.001 |
| | (0.170) | (0.101) | (0.001) |
| Maize producing households | 0.241 | 0.485*** | 0.003 |
| | (0.196) | (0.118) | (0.002) |
| No schooling | -0.153 | -0.109 | -0.001 |
| | (0.247) | (0.116) | (0.002) |
| Female headed households | 0.132 | -0.173 | 0.001 |
| | (0.217) | (0.142) | (0.001) |
| Age of household head | 0.021** | -0.011** | 8.80e-05 |
| | (0.009) | (0.004) | (7.83e-05) |
| Asset Index | 0.125*** | 0.033 | 0.001* |
| | (0.042) | (0.023) | (0.001) |
| Whether any crop was lost from storage | -1.244* | -0.600*** | -0.003* |
| | (0.692) | (0.225) | (0.002) |
| Amout of crop harvested (in logs) | 0.058 | 0.209*** | 0.001 |
| | (0.081) | (0.048) | (0.001) |
| Household size | -0.037* | -0.038*** | -0.001 |
| | (0.022) | (0.011) | (0.001) |
| Semiarid regions | -0.708** | -0.527*** | -0.003* |
| | (0.344) | (0.156) | (0.002) |
| Coast regions | 0.233 | -0.164 | 0.001 |
| | (0.262) | (0.155) | (0.002) |
| Constant | 4.704 | -13.570*** | |
| | (5.202) | (3.309) | |
| Athrho | | -0.259** | |
| | | (0.113) | |
| rho | -0.254** | | |
| | (0.106) | | |
| Observations | 993 | | |

Wald test of rho = 0: chi2(1) = 5.238 Prob > chi2 = 0.022
+Marginal effects after biprobit y = Pr(improved2 = 1, preserve = 1) (predict) = .002
Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Own composition

ronment cannot afford buying them. However, consistent with the adoption of preservation technologies, we uncover that households living in semi-arid regions have lower probability to adopt improved and modern storage technologies, but more likely to adopt traditional storage methods.

The empirical results also suggest that extension services and household wealth as key determinants to the adoption of improved and modern storage technologies. A household that received extension services is 4 percentage points and 2 percentage points more likely to adopt improved and modern storage technologies, respectively. Wealthy households are 3 percentage points more likely to adopt improved storage technologies but 4 percentage points less likely to adopt traditional storage. Our results support Bokusheva *et al.* (2012) finding that access to training and advisory services for grain production and household wealth (proxy by land holding) influence adoption of metal silo and relevance of the content of the extension services and wealth in driving adoption of modern storage technologies. Earlier findings by Adegbola and Gardebroek (2007) also underscored the role of extension services in influencing adoption of improved storage technologies.

**Table 6:** Ordered Probit: Coefficients estimates and marginal effects estimation results.

| VARIABLES | Coefficient | Tradition | Improved | Modern |
|---|---|---|---|---|
| Mean annual temperature (long-term) | -0.626*** | 0.175*** | -0.128** | -0.047** |
| | (0.242) | (0.067) | (0.051) | (0.019) |
| Mean annual temperature_SQR | 0.010** | -0.003** | 0.002* | 0.001** |
| | (0.005) | (0.002) | (0.001) | (0.001) |
| Mean annual rainfall (long-term) | -0.005** | 0.001** | -0.001** | -0.001** |
| | (0.002) | (0.001) | (0.001) | (0.001) |
| Mean annual rainfall _SQR | 0.000* | -3.51e-07* | 2.56e-07* | 9.46e-08* |
| | (0.000) | (1.84e-07) | (1.36e-07) | (5.04e-08) |
| Annual rainfall in previous year (2008/2009) | -0.000 | 3.82e-05 | -2.79e-05 | -1.03e-05 |
| | (0.000) | (0.001) | (8.82e-05) | (3.25e-05) |
| Interaction of rain and temperature | 0.000 | -2.59e-05 | 1.89e-05 | 6.99e-06 |
| | (0.000) | (2.29e-05) | (1.67e-05) | (6.38e-06) |
| Elevation/Altitude in metres | -0.001*** | 0.001*** | -0.001*** | -4.62e-05** |
| | (0.000) | (6.46e-05) | (4.79e-05) | (1.85e-05) |
| Access to extension services | 0.248** | -0.064** | 0.042** | 0.022* |
| | (0.120) | (0.029) | (0.017) | (0.012) |
| Number of years lived in village | -0.012*** | 0.003*** | -0.002*** | -0.001*** |
| | (0.003) | (0.001) | (0.001) | (0.001) |
| Distance from the nearest major road (in logs) | -0.044 | 0.012 | -0.009 | -0.003 |
| | (0.032) | (0.008) | (0.007) | (0.002) |
| Selling households | -0.012 | 0.003 | -0.002 | -0.001 |
| | (0.096) | (0.027) | (0.020) | (0.007) |
| Maize producing households | -0.049 | 0.014 | -0.010 | -0.004 |
| | (0.107) | (0.029) | (0.022) | (0.008) |
| No schooling | -0.064 | 0.018 | -0.013 | -0.005 |
| | (0.107) | (0.030) | (0.022) | (0.008) |
| Female headed households | 0.207* | -0.055* | 0.037* | 0.018 |
| | (0.125) | (0.031) | (0.019) | (0.012) |
| Age of household head | 0.009** | -0.003** | 0.002** | 0.007** |
| | (0.004) | (0.001) | (0.001) | (0.001) |
| Asset Index | 0.131*** | -0.037*** | 0.027*** | 0.010*** |
| | (0.023) | (0.006) | (0.005) | (0.002) |
| Whether any crop was lost from storage | -0.290* | 0.089* | -0.072* | -0.018** |
| | (0.149) | (0.049) | (0.043) | (0.007) |
| Amout of crop harvested (in logs) | 0.016 | -0.005 | 0.003 | 0.001 |
| | (0.049) | (0.014) | (0.010) | (0.004) |
| Household size | -0.070*** | 0.020*** | -0.014*** | -0.005*** |
| | (0.010) | (0.003) | (0.002) | (0.001) |
| Semiarid regions | -0.284** | 0.0857* | -0.068* | -0.018** |
| | (0.140) | (0.045) | (0.038) | (0.008) |
| Coast regions | -0.884*** | 0.295*** | -0.253*** | -0.042*** |
| | (0.150) | (0.056) | (0.054) | (0.007) |
| cut1 | -11.967*** | | | |
| | (3.214) | | | |
| cut2 | -9.302*** | | | |
| | (3.195) | | | |
| Observations | 993 | | | |
| Model chi-square | 227.9 | | | |
| Pseudo R2 | 0.180 | | | |

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Own composition

Female headed households are less likely to adopt traditional storage but more likely to adopt improved storage technologies. Female farmers are 4 percentage points more likely to adopt improved storage technologies and 5.5 percentage points less likely to adopt traditional storage. Each year of age decreases chance of reporting traditional storage by 0.3 percentage points and increases chances to adopt improved technologies by 0.2 percentage points. This result collaborates with Bokusheva et al. (2012) finding that the probability of adoption declined with the age of the household head. Our analysis further reveals that household size reduces the changes to adopt improved and modern storage technologies but increases the likelihood to adopt traditional storage by 2 percentage points.

## Discussion

Climate change is indeed an issue in Tanzania as we have already observed a significant decrease in the mean annual rainfall in the country, with several regions affected differently, suggesting that more households are at risk of losing their crops as a result of poor storage. We find that farmers in risky climatic environment do respond by adopting

preservative measures against storage pests. Putting this to a policy perspective, we argue that preservation and modern storage methods could be useful adaptation measures to climate change. The finding that households' adoption of preservation methods, improved and modern storage technologies reduces with increase in temperature is consistent with scientific explanations that very hot environments are not conducive for the reproduction and growth of pests, insects and other micro-biological organisms like fungus, and hence households have less incentive to adopt preservation measures. Given the high poverty levels in semi-arid regions, there is increased adoption of traditional technologies as opposed to other regions with better-off farmers.

Farmers residing in humid and relatively warm areas (i.e. pests conducing environment) are more likely to adopt both improved storage technologies and preservation methods. This suggests therefore that with the climate change problem when the least humid and cold areas turn to humid and warm, modern storage and preservation technologies could be promoted as ideal adaptive measure. These would eventually shield the poor farmers from potential post-harvest loss attributable to the change. A growing body of literature has proven that African farmers' adaptation to climate change is an important action for improved food security and farmers' overall well-being (Di Falco *et al.*, 2011; Deressa and Hassan, 2009 and Rowhani et al, 2011). At this point, proper storage and preservation methods could become useful adaptation measures by farmers.

This study uncovers that resources matter on the adoption of both improved and modern storage technologies, while large households reduce the likelihood of adopting both improved and modern storage. Similar results are found in the agricultural technology adoption literature (see Foster and Rosenzweig (2010) for a review). Often improved and modern storage facilities are relatively costlier than the traditional methods, and larger rural families have higher dependency rate and are relatively poorer; all of which implying that wealthier and smaller households are better positioned on the adoption of both improved and modern storage technologies. These results thus corroborate those that have reported relatively low usage of modern granaries (e.g. Admire and Tinashe (2014) in Zimbabwe, and Midega *et al.*, 2016 in Kenya) with traditional granaries being more commonly used to store maize in most of rural Africa since modern granaries are perceived to be expensive and unaffordable for most of smallholder farmers.

In addition, our results also point to the role of extension services, age of the household head, female headed households and transaction cost, on adoption of preservation methods, improved and modern storage technologies. These results resonate with previous findings that extension services influences the dispersion of improved storage technologies information (Adegbola and Gardebroek 2007). Increasing farmers' technical know-how on adaptation of the farming systems to climate variability, and training on post-harvest management could reduce food losses (Abass *et al.*, 2014). Following our findings and previous findings in the literature, this study recommend that extension services should include comprehensive post-harvest loss abatement components. In countries like Tanzania, where majority of its farmers have a maximum of primary education, extension services are a major source of such information.

On the other hand, the joint estimation of improved storage and improved methods and modern technologies and preservation methods results suggests that while a slightly improved storage facility is unlikely to affect the preservation decision, adoption of modern storage is a substitute to adopting any preserving measures. These results also give an empirical support to the discussion in Tefera *et al.* (2011) and Gitonga *et al.* (2013), suggesting that adoption of modern technologies such as metal silos is sufficient to prevent grains from damage by pests. Therefore, the multi-million projects in Africa to promote modern storage technologies (e.g. metal silos and super grain bags) as post-harvest abatement technologies are worthwhile because they reduce the need for preservation.

Generally, there are a number of policy messages to be drawn from this study. First, modern storage and preservation techniques are potential adaptation strategy to climate change and that policy environment should be designed to foster their adoption and usage in climate prone areas. Second, a policy action to promote adoption of modern storage facility does not only abate post-harvest loss but also does that at significantly lower cost as farmers will not need to complement storage with any preservation measures. Third, for all these to happen, there is a strong need to stimulate the drivers for such adoption including increased extension education on post harvest management practices, reduced cost of the technologies through for example subsidy and distribution, etc.

Notably, the cost aspect of the modern technology however raises another yet important policy and research question; are the increased costs of these facilities justified by their net benefits? In other words, could the reduced loss by these technologies crowd out the incurred costs of their adoption? To provide some light to this question, an attempt to estimate the net impact of these technologies on farmers (income based) welfare is needed. This is the main limitation of our study considering the coverage of our data set. Future research should therefore collect comprehensive data on costs and benefits of the combination of the different technologies to strengthen the debate on the cost effectiveness of adopting modern storage technologies.

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