Crop switching as an adaptation strategy to climate change: the case of Semien Shewa Zone of Ethiopia

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Abstract

Purpose – The geographical range of agricultural crops is shifting because of climate change. Reducing the potential negative impact of this shift requires efficient crop switching at farm level. Yet there are scant studies that examine how crop switching is currently taking place and what factors facilitate the process. Even these few existing studies often based their analysis on inadequately established causal link between climate change and switching decisions. This study aims to identify the specific switching decisions that are primarily motivated by climate change, and their determinants.

Design/methodology/approach – The study used a household survey on 190 households in Semien Shewa Zone in Ethiopia. Subjective rating of farmers was used to identify the relative importance of climate change in motivating the different types of switching decisions. A logit model is used to identify determinants of crop switching decisions primarily motivated by climate change.

Findings – Farmers in the study area are currently abandoning certain crops as a response to climate change. The adoption of new crops is, however, mainly attributed to price changes. Most farmers who abandoned at least one crop adopted mung bean mainly due to its price advantages. As expected, crop switching as an adaptation strategy is more prevalent particularly in drier and hotter agroecologies. The logit model showed that crop switching is strongly correlated with land size and agroecology.

Originality/value – This paper provides an in-depth examination of crop switching as an adaptation strategy to climate change. Crop switching is an adaptation strategy that is expected to substantially reduce the damage from climate change in agriculture. The findings are particularly relevant for adaptation planning in the context of smallholder agriculture.

Keywords Crop switching, Climate change, Adaptation, Determinant, Logit, Ethiopia

Paper type Research paper

1. Introduction

Major shift is projected in the suitable climate space of many crops across the globe due to climate change (Seo and Mendelsohn, 2008; Wang *et al.*, 2010; Rippke *et al.*, 2016). This phenomenon is similar to the range-shift of plant species pole wards, or upwards for elevation-induced climate zones. Many species have recently shifted their ranges toward higher elevations and latitudes at a median rate of 11.0 m and 16.9 km per decade, respectively (Chen *et al.*, 2011). Similarly, the geographical range of agricultural crops is

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expected to shift. In sub-Saharan Africa, the area suitable for maize and beans, two of the nine major crops in the region, is predicted to shrink by about 30 and 60 per cent, respectively, by the end of the twenty-first century (Rippke *et al.*, 2016). These shifts entail transformational adaptations such as substituting maize with more drought-resistant crops such as sorghum and millet (Rippke *et al.*, 2016).

To avoid or reduce the potential loss in profit due to shifts in suitable climate spaces, farmers need to make appropriate adjustments particularly crop switching. Global modeling studies suggest that two-thirds of the potential damage from climate change in the agricultural sector can be avoided by effective crop switching (Costinot *et al.*, 2016). We define crop switching here to consist of two types of adjustments:

(1) starting the adoption of a new crop for the first time; and

(2) abandonment of existing crops.

Therefore, the term switching is better understood at plot level rather than farm level, i.e. adopting a new crop does not necessarily mean abandoning existing ones, and vice versa.

Studies in the past have examined the process of crop switching as an adaptation response and the factors that facilitate it. Most of these studies focused on revealing whether farmers are adapting by switching crops and what type of socio-economic and environmental factors influence the process (Maddison, 2007; Deressa *et al.*, 2011; Gbetibouo, 2009; Bryan *et al.*, 2013). These studies often consider crop switching just as one type of adaptation response without attempting to disentangle the specific types of switching decisions that are primarily motivated by climate change. This can be considered a key gap in the literature because certain types of switching decisions could be caused by non-climatic drivers such as price (Seo and Mendelsohn, 2008). Moreover, earlier studies do not give appropriate focus to non-climatic variables (Below *et al.*, 2012; Fosu-Mensah *et al.*, 2010; Gbetibouo *et al.*, 2010). Crop switching, however, takes place in the context of different drivers such as markets dynamics, pest occurrence and land degradation. The consideration of such drivers is, therefore, vital to understand the relative importance of climate change in switching crops.

Few studies partially addressed the common methodological gaps in the literature. Alauddin and Sarker (2014) identified the determinants of a specific category of crop switching decision (adopting water-saving non-rice and horticultural crops) in a study area in Bangladesh. This is a major improvement from previous studies as it singles out narrowly defined types of switching decisions as adaptation strategies to climate change. The study, however, did not adequately clarify the basis for identifying the specific strategy as an adaptation response among others. Mertz *et al.* (2009) identified climate-induced crop adoptions in their study area in Senegal. An important contribution of the study is the fact that it categorizes adoption decisions at the level of individual crops, i.e. as adoption of millet, maize, etc. Unfortunately, the study relied on a small sample size and did not analyze the determinants of the short-listed crop switching decisions strongly induced by climate change.

The study builds on the works of Alauddin and Sarker (2014), and Mertz *et al.* (2009) to identify the specific types of crop switching decisions induced by climate change and their determinants. We first examine crop switching decisions specific to the level of individual crops with the aim of identifying the determinants of the specific crop switching decisions primarily motivated by climate change. The examination of crop switching in detail at the level of individual crops enables validating the results based on predictions from studies on crop distribution modeling and ecological change. This is a key addition to the literature on farm-level adaptations in general where the link between climate change and farm adjustments is still unclear. The identification of the socio-economic and environmental determinants of crop switching is also vital to suggest interventions that could keep adjustment costs as minimal as possible.

2. Method

2.1 Study area

The study area, Semien Shewa Zone, is one of the administrative zones of Amhara Regional State of Ethiopia. It is located in the central highlands of the country; covers 15,936 km^2 area of land; and hosts about 1.8 million people (CSA, 2007). Ankober Woreda (district), which is one of the 24 districts in the administrative zone, was purposively selected. Ankober District was selected as it encompasses the typical crop production systems and agroecological zones (AEZs) in Semien Shewa Zone (CSA, 2013; Ege, 2005; Hurni, 1998). The district is found on an escarpment that stretches across four common AEZs, according to the traditional climate typology in the country: Kolla (lowland, altitude 500-1,500 m a.s.l.), Weynadega (middle land, 1,500-2,300 m a.s.l.), Dega (highland, 2,300-3,200 m a.s.l.) and Wurich (frosty zone, above 3,200 m a.s.l.) (Hurni, 1998). Kolla is characterized by drier and hotter climate with annual rainfall often below 1,400 mm, where some places may receive annual rainfall below 900 mm. Weynadega is relatively cooler and wetter than Kolla with annual rainfall from below 900 mm up to over 1,400 mm. Dega and Wurch are wetter and colder than the remaining zones often with annual rainfall over 900 mm reaching to over 1,400 mm. Wurch is, however, a much colder yet relatively rare agro-ecology with higher frequency of frost. Three Kebeles (Laygorebela, Alyuamba Zuria and Hagereselam), the lowest administrative unit, were selected from the 18 Kebeles in the district, making sure that all the four AEZs were included (Figure 1). There are two growing seasons in the study area:

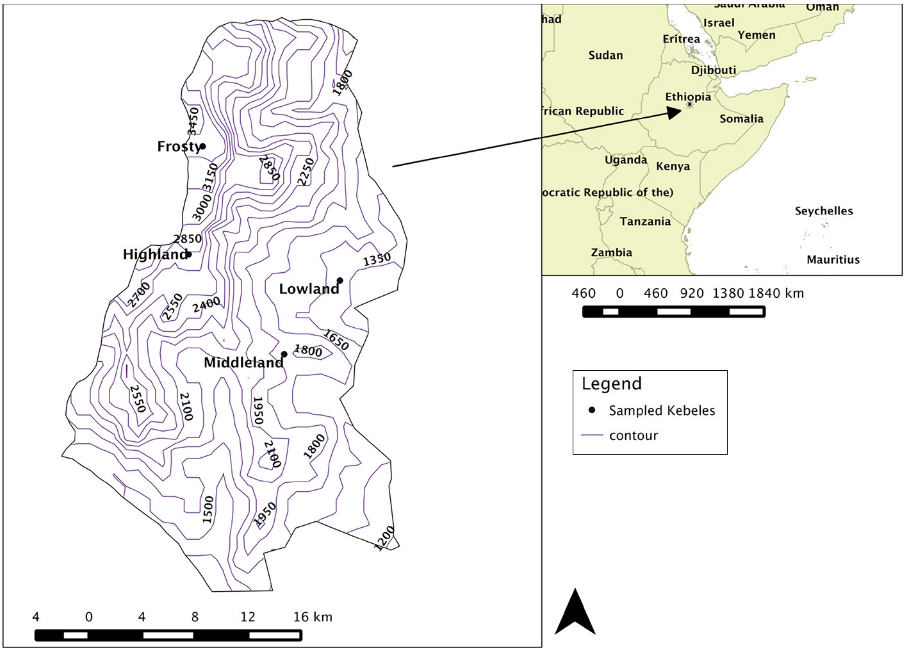
(1) Meher (depends on rainy season from June to September); and
(2) Belg (rainy season from March to April) (Tanto Hadado *et al.*, 2009).

Meher is the main growing season in the country (Tanto Hadado *et al.*, 2009).

2.2 Sampling and data collection

A total sample size of 190 households was proportionally allocated among the four AEZs based on their coverage in the study area, Semien Shewa Zone. For the Wurch, however, which is a rare AEZ in the study area (Hurni, 1998; Ege, 2005), a sample size of 30 is allotted based on the central limit theorem. Kolla and Dega each were allocated a sample size of 40, while Weynadega took 80. Systematic random sampling was used to sample households from the selected three Kebeles. For this purpose, records of households from Kebele administrative offices were used. The study also made use of data collected in an earlier survey (in 2014) on the same households.

The rural household survey was conducted in January and February of 2016, and the data collected are for the immediately preceding growing seasons. To collect the data, a semi-structured interview schedule was used. The interview schedule was translated to Amharic, the common language in the study area, and was administered by nine enumerators. The first key area of enquiry was the types of crops permanently adopted or abandoned by farmers over the past 20 years. For each of these crop switching decisions, respondents were asked to identify the first and second most important drivers from a list of six potential drivers: climate change, pest and disease, price change, soil erosion and changes in intra household characteristics. The interview schedule clearly defined climate



Notes: Central positions for the sampled Kebeles, the smallest administrative area, are indicated with dots labeled as frosty (Wurch), highland (Dega), Middleland (Weyandega) and Lowland (Kolla) following the traditional climate typology in Ethiopia

Figure 1. Map of the study area, Ankober District

change for respondents to differentiate it from short-term weather variability. The non-climatic drivers were selected based on their potential importance in Ethiopia (Eshte *et al.*, 2015; PPSE, 2008; Shimeles and Delelegn, 2013; World Bank, 2007). Respondents were also given the option to mention other drivers in case the list is not exhaustive enough for them.

2.3 Data analysis

Descriptive statistical methods of frequency and bar graphs are used to describe the crop switching process and its relation to climate change. A binary regression model (logit) is applied to analyze the relation between farmers' crop switching decision, those specifically linked to climate change, and the socio-economic and environmental context of farmers.

The logit model is defined below, where the log of the odds ratio for positive outcome of the dependent variable is represented as the function of the explanatory variables (Gujarati, 2004).

$$L - \ln\left(\frac{P}{(1-P)}\right) = \beta_0 + \beta_1 X_1 + \ldots + \beta_{10} X_{10}$$

Here, $P/(1-P)$ is the odds ratio for making an adaptive crop switching decision, where P stands for the probability of a positive outcome for the dependent variable, i.e. making an adaptive switching decision, whereas $(1-P)$ is the probability of not making the adaptive switching decision, L stands for the logs of the odds ratio for a positive outcome of the dependent variable and β_0 is the constant term, while β_1 to β_{10} are coefficients of the explanatory variables ($X_1 - X_{10}$) described in Table I. L is estimated for given X values.

For ease of interpretation, the marginal effect of L_i is calculated as follows:

$$\text{Marginal effect} = \frac{\partial P}{\partial X}$$

The logit model is evaluated using Likelihood ratio test, Wald statistic, classification test, area under ROC curve (AUC) and variable inflation factor (VIF).

2.4 Empirical specification of explanatory variables

The explanatory variables for the logit model were selected based on empirical evidence on their importance in influencing farm adaptation responses in particular, and farm decision-making in general. The hypothesized relationships of the explanatory variables with crop switching along with their descriptive statistics are given in Table I.

The age of a farmer is hypothesized to be positively associated with crop switching because older farmers are more experienced and have a better chance of perceiving and adapting to climate change (Maddison, 2007). As switching crops is expected to occur primarily through locally available inputs, it is expected that the role of farm experience is pronounced. Larger land and family sizes represent more land and labor resources at the disposal of a farmer; therefore, they are expected to relax the resource constraints thereby facilitating any adjustment (Alauddin and Sarker, 2014; Yong, 2014; Shikuku *et al.*, 2017; Croppenstedt *et al.*, 2003) and hence positively influence switching crops. Particularly, larger land size allows farm experimentation, which may particularly accelerate crop switching. Farmers living close to markets are expected to be in advantage in accessing information (Maddison, 2007), while enjoying a relatively wider switching option with better prospect for profitability (Foster and Rosenzweig, 2010). Therefore, it is hypothesized that distance from market is inversely related to

Explanatory variable	Description	Hypothesized signs
Age of the household head in years	Continuous	+
Land owned in ha	Continuous	+
Family size	Continuous	+
Walking distance from market in hours	Continuous	−
Level of education	Dummy, 0 if illiterate and 1 otherwise	+
Access to extension services	Dummy, 0 if without access, and 1 otherwise	+
Access to credit	Dummy, 0 if without access, and 1 otherwise	+
Access to irrigation	Dummy, 0 if without access, and 1 otherwise)	+
Number of relatives (an estimated number of blood relatives in the village)	Continuous	+
AEZs	Ordinal, 1 if Kolla (lowland), 2 if Weynadega (middle land), 3 Dega (highland), and 4 Wurch (Frosty)	No hypothesis

Table I. Descriptive explanatory variables and hypothesized relations switching of crops. Better schooling is hypothesized to positively influence switching crops as it may enhance access to information along with the complementary skills of processing it (Foster and Rosenzweig, 2010; Tan, 2014; Adesina and Baidu-Forson, 1995). Access to extension services is hypothesized to facilitate any adjustment including switching crops as it avails information including on climate change (Falco *et al.*, 2011; Maddison, 2007; Nhemachena and Hassan, 2007).

Improved access to credit has been shown to positively influence the adoption of agricultural technologies (CIMMYT, 1993; Feder and Umali, 1993). Even if switching crops is less likely to be capital intensive, it is expected that there is positive correlation between access to credit and switching crops. Access to irrigation can influence switching crops either directly by increasing the types of crops grown on a farm and potentially indirectly through its linkage with wealth. The number of relatives is used as a proxy for social capital that is expected to positively influence adjustment by switching crops. Social capital can be directly related with access to information, and facilitates learning new practices (Bandiera and Rasul, 2006). Finally, farmers in drier and hotter AEZs are more likely to take adaptation measures than those in humid climates (Deressa *et al.*, 2009). Therefore, more cases of crop switching are expected in AEZs at lower altitudes that are characterized with relatively drier and hotter climate than those in higher altitudes (Hurni, 1998).

To summarize, the main steps involved in the method are as follows:

- The study first identifies the types of crops permanently adopted or dropped in the study area over the past two decades.
- Crop switching decisions primarily driven by climate change are disentangled based on subjective rating of farmers.
- A logit model is used to identify the determinants of adaption by crop switching. The dependent variable is whether a farmer has permanently switched crops because of climate change, i.e. a dummy variable.

3. Results

3.1 Household characteristics and cropping pattern

The average age of the sampled household heads is 51. The majority of the respondents are male (84 per cent). An average household owns 0.95 ha of land (S.D = 0.47) and cultivates 0.98 ha (S.D = 0.5) in the Meher season, the main growing season. The total land cultivated by the sampled households in the Meher season is 185 ha, where 187 out of the 189 farmers grew at least one crop. For Belg season, only 17 ha is cultivated by 55 of the 189 farmers. The most commonly grown crop in Belg is barley followed by potato and onion, and Dega and Wurch are the main Belg producing AEZs.

The major crops grown in Meher season in Kolla and Weynadega, based on cultivated area, are teff (*Eragrotis tef)* and sorghum. Teff dominates in Weynadega, with about 60 per cent of cultivated area, whereas sorghum is slightly more commonly grown in Kolla, accounting about 42 per cent of the cultivated land. Other important crops grown in the two AEZs include mung bean and maize. The Weynadega zone also hosts crops such as wheat, barely, fava bean and chickpea. The Dega and Wurch zones' cultivation is highly dominated by barley, which covers about 57 and 78 per cent of the land cultivated, respectively. Almost all-remaining land (19 per cent) in Wurch zone is covered by potato production. Besides barley, the Dega zone is covered with potato, wheat, fava bean and pea.

3.2 The process of crop switching

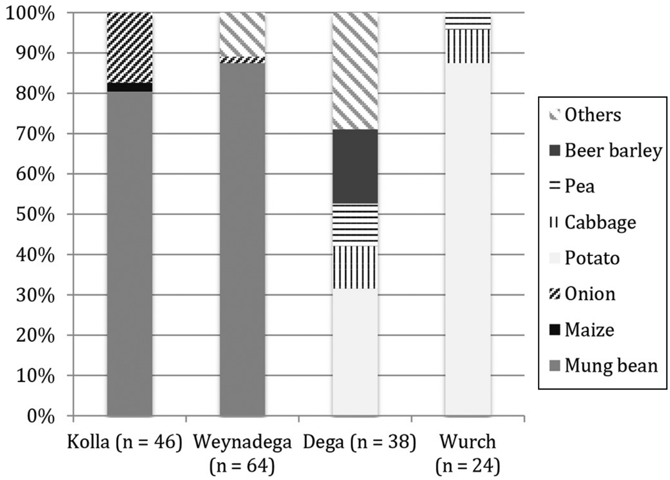
Most farmers in all AEZs in Ankober District have switched crops at least once. The highest frequency of crop switching is in Kolla, where 97.5 per cent of the respondents have made at least one type of crop switching. In the remaining AEZs, the percentage is around 80 per cent. Crop adoption took place on average 6.57 years (SD = 3.76) ago, and abandoning existing crops occurred about 7.24 years ago (SD = 4.04). Crop adoption occurs relatively recently in Kolla AEZ with average year of 3.22 (SD = 1.74), whereas it has been occurring since on average 10.87 years (SD = 2.05) in Dega. For crop abandonment, the notable inter AEZ difference is the fact that Weynadega areas are characterized with a little bit more recent adjustments, mean = 5.40 (SD = 3.03). Most farmers who adopted a new crop (67.57 per cent) did not abandon any existing crop, while the rest (32.43 per cent) had to drop at least one existing crop. On the other hand, the large majority of farmers (89.9 per cent) who dropped an old crop adopted at least one new crop.

3.2.1 Adopting new crops. The majority (95 per cent) of farmers in Kolla zone started growing at least one new crop in the past 20 years. The percentage in the rest of the AEZs is relatively lower than Kolla and ranges between 72 and 78 per cent. Few (13 per cent) farmers adopted more than one crop.

In Kolla and Weynadega, the majority (>80 per cent) of the adoptions involve mung bean (Figure 2). In Kolla, a good number (17 per cent) of farmers also started growing onion. The other crops seldom adopted in the two zones are maize, sorghum, teff and tomato.

In the Dega and Wurch zones, the most frequently adopted crop is potato, where it accounts 32 and 87.5 per cent of the new adoptions in the two zones, respectively. In Dega, the other crops adopted are beer-barley (18 per cent), cabbage (10.5 per cent) and pea (10.5 per cent). The other crops reported are apple, fava bean, wheat, onion and garlic. In Wurch zone, cabbage (8 per cent) and pea (4 per cent) are adopted by few famers.

3.2.2 Abandoning existing crops. Relatively high percentage of farmers in Kolla (65 per cent) and Weynadega (30 per cent) permanently abandoned growing existing crops at least



Notes: n stands for the number of switching decisions in each AEZ; it can be larger than sample size as some farmers switched crops more than once

Figure 2. Newly adopted crops by percentage of total number of adoptions in each AEZ

once in the past two decades. In Dega and Wurch, however, only 7 (three respondents) and 4 per cent (one respondent) of the respondents dropped old crops, respectively. In Dega, abandoning pea and wheat were reported, while in Wurch, only one case of dropping potato was observed. To avoid ambiguity, the cases in these two zones are excluded from Figure 3. Maize is the major (57 per cent of all cases) crop abandoned in Kolla, followed by teff (30 per cent) (Figure 3). In Weynadega, fava bean accounts for 36 per cent of all crop-abandoning decisions, followed by barley (21 per cent), wheat (18 per cent) and sorghum (11 per cent).

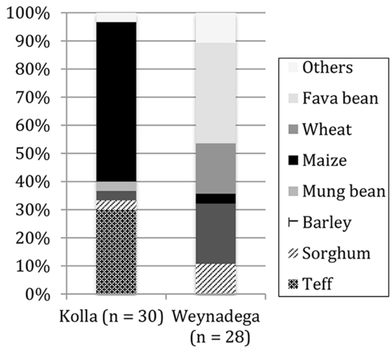
3.3 Drivers of crop switching decisions

3.3.1 Drivers of crop adoption. Price change is the most frequently (74-89 per cent) cited primary reason for crop adoptions across all AEZs (Figure 4). Climate change is mentioned as the main driver for crop adoption only occasionally (less than 20 per cent in all AEZs). Climate change is, however, rated as the second most important driver for the majority of adoption decisions (70 per cent). The examination of drivers for each of the newly adopted crops also reveals that in general the same set of drivers influence the adoption of the most commonly adopted crops, i.e. mung bean in Kolla and Weynadega; onion in Kolla; potato in Dega and Wurch; and beer-barley in Dega.

3.3.2 Drivers of abandoning crops. Climate change is by far the most important driver of abandoning crops in Kolla (90 per cent) and Weynadega (79 per cent) (Figure 5). Pest and disease, and price change are identified as the second most important drivers. Climate change is also the major driver for the commonly abandoned crops, i.e. maize and teff in Kolla and fava bean, barley and wheat in Weynadega. Crop abandonments are rare in Dega and Wurch zones; hence, the results for these two zones are neglected. Out of the total number of farmers (44) who dropped at least one crop due to climate change, 93 per cent of them adopted mung bean, where price is the main reason for the adjustment, followed by climate change.

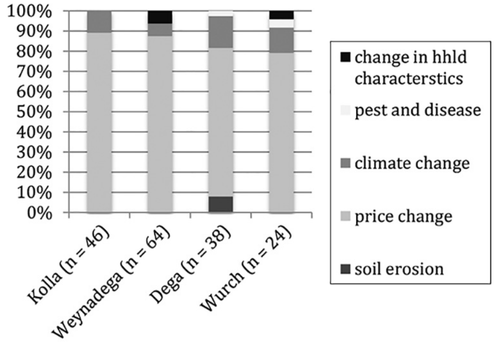
3.4 Determinants of crop switching

A logit model is fitted and marginal effects are estimated (Table II). The dependent variable is a dummy variable defined as 1 if a farmer stopped growing an existing crop primarily due



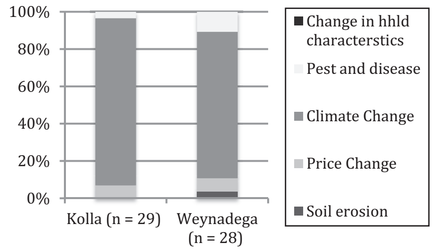
Notes: n stands for the number of switching decisions in each AEZ; it can be larger than sample size as some farmers switched crops more than once

Figure 3.
Abandoned crops by percentage of total number of similar cases in each AEZ



Notes: hhld = household; n stands for the number of switching decisions in each AEZ: it can be larger than sample size as some farmers switched crops more than once

Figure 4. Drivers of crop adoption decisions across AEZs



Notes: hhld = household; n stands for the number of switching decisions in each AEZ: it can be larger than sample size as some farmers switched crops more than once

Figure 5. Drivers of new crop abandonment decisions across AEZs

Table II. Marginal effects of the logit model

Determinants	Crop switching
Age of the household head in years	−0.001
Land owned in ha	0.094**
Family size	−0.001
Walking distance from market in hours	0.017
Level of education (dummy, 0 if illiterate and 1 otherwise)	−0.061
Access to extension services (dummy, 0 if without access, and 1 otherwise)	0.053
Access to credit (dummy, 0 if without access, and 1 otherwise)	0.034
Access to irrigation	−0.058
Number of relatives in village	0.001
AEZ (ordinal, 1 if Kolla, 2 if Weynadega, 3 Dega, and 4 Wurch)	−0.190***

Notes: ** and *** respectively indicate level of significance of 5% and 1%

to climate change, and 0 otherwise. As climate change is not strongly associated with adopting new crops, the analysis is confined to only crop abandonment. Out of the 189 households finally included in the analyses, 44 (23 per cent) dropped at least one crop primarily due to climate change.

The logit model has a very good overall model fit shown by Likelihood ratio test [LR chi2 (10) = 71.82, $p < 0.01$] (Table II). Wald statistic also confirmed the same [chi2 (10) = 31.51, $p < 0.01$]. Classification test showed that the model correctly specifies 82 per cent of the time for a cutoff point of 0.5. AUC is 0.88, indicating a high predictive accuracy of the model. VIF values range between 1.13 and 1.45, which indicated the absence of any important multicollinearity problem. Land size and AEZ are the only variables that are significantly related to crop switching. Land size is positively related to crop switching. A one-hectare change on average is expected to increase the likelihood of adaptation by crop switching by 9.4 per cent. The influence of AEZ is more pronounced where a shift to a higher altitude zone (i.e. from Kolla to Weynadega, for example) is associated with about 19 per cent decline in the likelihood of adaptation by crop switching.

4. Discussion

The study revealed that considering crop switching as an adaptation strategy without narrowly defining it could be misleading. For our case study, only crop abandoning is associated to climate change, while the adoption of new crops is primarily motivated by price changes. This is a new finding which challenges the results of most previous studies that considered crop switching at aggregate level or under a general heading of crop switching without separately considering the different types of switching decisions (Maddison, 2007; Bryan *et al.*, 2009; Gbetibouo, 2009; Deressa *et al.*, 2009). The particular relevance of abandoning crops to climate change also suggests that farmers initially take more risk-averting measures to adapt to climate change.

Empirical evidences from studies on crop-distribution modeling and ecological change further validate the findings. In Kolla (lowland) and Weynadega (middle land), of the study area, a significant number of farmers shifted away from crops (teff, maize, fava bean, barley and wheat) that are typically grown at higher altitudes, in relative terms to the particular AEZ considered (Hurni, 1998). This is what is expected as a warming climate shifts agroecologies toward drier classifications (Kala *et al.*, 2012), or in upward direction for elevational range-shifts (Mekasha *et al.*, 2013). Furthermore, the result on the abandonment of maize is in line with the results of crop-distribution modeling by Rippke *et al.* (2016). According to this study, the suitable climate space for maize in sub-Saharan Africa is shrinking, and 30 per cent of the currently cultivated area may become unviable by the end of this century. Ethiopia is one of the regions that is affected by this particular change (Rippke *et al.*, 2016). The decline of land allocated to barley production, one of the abandoned crops, in Ethiopia has also been reported (Rashid *et al.*, 2015). The fact that crop abandonment is rare in higher altitudes (Dega and Wurch) could be related to the fact that already hotter and drier climates are likely to strongly feel climate change than cooler and wetter areas (Deressa *et al.*, 2009). Furthermore, the finding may be attributed to the positive influence of non-climatic drivers that offset the effect of climate change. For example, abandoning barley in higher altitudes may be delayed due to price increase in relation to flourishing beer factories in the vicinity of the study area, which is actually the case in the study area. This issue, however, needs further empirical investigation.

The importance of market dynamics in the adoption of the commonly adopted new crops in the study area, i.e. mung bean and potato, is also well supported. Mung bean is a cash crop that is in recent times enjoying high increase in price due to rise in export demand (Seyoum, 2014).

Besides its market advantages, the crop possesses favorable characteristics of short growing period and suitability for semiarid climate (Beshah, 2015). Similarly, potato is one of the fastest expanding crops in the country owing to its nutritional advantage, increasing local demand and short growing season (Emana and Nigussie, 2011; Haverkort *et al.*, 2012).

To sum up, farmers in Kolla (lowland) and Weynadega (middleland) switched away from crops such as maize and fava bean primarily due to climate change, and a large majority of them have adopted mung bean for which price is the main driver followed by climate change. This demonstrates the importance of opportunities, in this case favorable price, in adapting to risks. The adoption of mung bean is an opportunity created due to export market linkage, yet its agronomic qualities makes it an ideal candidate to adapt in climate change. The fact that farmers rated climate change as the second important driver next to price supports this argument.

This study examined the determinants of adaptation by crop switching. Land size and AEZ are significantly correlated with adaptation by crop switching. Farmers with bigger land are found to be more likely to switch crops as a response to climate change. Larger land may allow experimentation with different crops that facilitates appropriate switching. The finding could also be associated with the general correlation of land size with wealth as it represents a major asset of a smallholder farmer. The importance of land size in farm-level adaptations has been shown by a number of studies in the past (Alauddin and Sarker, 2014; Nhemachena and Hassan, 2007). The inverse relationship of adaptation by crop switching to AEZ (ordered altitude wise) is also in line with the findings of previous studies. It has been shown that farmers in drier and hotter climate zones are more likely to take adaptive measures (Deressa *et al.*, 2009).

The interpretation of the results should, however, be made keeping some conditions in perspective. The first is the design of the sampling that selected a study area that shows variations in AEZs within a short distance. Such design is likely to include the borders of the climate spaces of various crops, which are the frontlines of shifts in crop mixes as the climate changes (Cho and McCarl, 2017). Hence, it is probable that this type of sampling design reveals more switching decisions than could have been otherwise. Moreover, the study area, Ankober District, located 40 km to the nearest asphalt road/major town, is by Ethiopia standard (Schmidt and Kedir, 2009) relatively close to a major urban center. The importance of market changes are, therefore, more likely to have a pronounced effect in the district. Finally, this study used a sample size of 190, which is big enough for the carried out analyses but can be considered small relative to several studies in the literature. The results should, therefore, be interpreted in light of this fact, and the research problem can highly benefit from future studies.

The major policy implication of the study is that adaptation through crop switching is better facilitated taking into account opportunities in the environment. The specific case of mung bean can serve as a classical example of how farmers can adapt to climate change through adjustments that are primarily motivated by opportunities. Moreover, the risk-averting behavior of smallholder farmers in low-income countries (Hamal and Anderson, 1982; Yesuf and Bluffstone, 2009) could confine their adaptation responses to crop abandonment, at least initially. This may call for appropriate mechanisms that facilitate other complementary adjustments. On the other hand, the findings revealed the strong correlation of the process of adaptation responses to agroecology and implied the need for spatially cautious adaptation planning. Especially in mountainous countries such as Ethiopia, where there is high agroecological diversity, a detailed spatial planning of adaptation could be vital.

5. Conclusions

The main objective of the study is to disentangle specific group of switching decisions that are primarily motivated by climate change and the socio-economic and environmental factors that influence them. The study shows that farmers in relatively drier and hotter AEZs are currently abandoning existing crops such as maize and fava bean as a response to climate change, and the adoption of new crops is primarily induced by price changes. The crop abandonment trend is in line with the predictions of ecological studies and crop-distribution modeling, which further validates the findings. The fact that abandonment rather than adoption is associated to climate change may also indicate the risk-averting behavior of smallholder farmers. Most farmers who abandoned existing crops because of climate change adopted a cash crop (mung bean) primarily due to price increases for the crop because of new linkage to export market. The adoption of the cash crop is secondarily motivated by climate change, as it is evident in its agronomic qualities, and farmers' subjective assessment. The most important determinants of crop switching are land size and agroecological factors.

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