How African Agriculture Can Adapt to Climate Change?

A Counterfactual Analysis from Ethiopia

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Abstract. We analyse and compare the impact of different adaptation strategies on crop net revenues in the Nile Basin of Ethiopia. To this end, we implement a counterfactual analysis, and estimate a multinomial endogenous switching regression model of climate change adaptation and crop net revenues. We combine data from 1,000 farm households with spatial climate data at the farm household level in Ethiopia. We find that adaptation to climate change based upon a combination of strategies -opposed to strategies adopted in isolation- increases farm net revenues. In particular, the combinations of changing crops with water or soil conservation strategies deliver the highest pay off.

Keywords: adaptation, climate change, endogenous switching, Ethiopia, net revenues, strategies.

JEL classification: Q54, Q56

1. Introduction

Effective adaptation of agriculture to climate change is crucial to achieve food security in Sub Saharan Africa (Lobell et al. 2011). This part of Africa is characterized by millions of small scale subsistence farmers that farm land and produce food in extremely challenging conditions. The production environment is characterized by a joint combination of low land productivity and harsh weather conditions (i.e., high average temperature, and scarce and erratic rainfall). These result in very low yields of food crops and food insecurity. Because of the low level of economic diversification and reliance on rain-fed agriculture, sub-Saharan Africa's development prospects have been closely associated with climate. Climate change is projected to further reduce food security (Rosenzweig and Parry 1994; Parry, Rosenzweig and Livermore 2005; Cline 2007; Lobell et al. 2008; Schlenker and Lobell 2010). For instance, the fourth Intergovernmental Panel on Climate Change (IPCC) suggests that at lower latitudes, in tropical dry areas, crop productivity is expected to decrease "for even small local temperature increases (1 – 2° C)" (IPCC 2007). In many African countries access to food will be severely affected, "yields from rain fed agriculture could be reduced by up to 50% by 2020" (IPCC 2007, p.10). Future warming seems unavoidable. Current agreements to limit emissions, even if implemented, will not stabilize atmospheric concentrations of greenhouse gases and climate change. Farmers will still face a warmer production environment.

The identification of climate change adaptation strategies is therefore vital in sub Saharan Africa.[1] These strategies can indeed buffer against the implications of climate change and play an important role in reducing the food insecurity of farm households. While the importance of adaptation is widely accepted, our understanding

[1] Countries at low latitudes are predicted to bear three-fourth times climate change damages (Mendelsohn et al. 2003). The effect of warming on agricultural systems in temperate countries is instead projected to be positive. This identifies losers and winners as results of global warming (Mendelsohn et al. 2006).

on how to adapt and its economic implications are still quite weak. Adaptation is a complex phenomenon comprising of different strategies that may play an important role in reducing the food insecurity of farm households. There are different measures, that in principle, farmers can adopt to address climate change. For instance: switching crops, adopting water harvesting technologies, or adopting conservation measures to retain soil moisture. Farmers can implement these measures in isolation or in combination.

In this study, we analyze and compare the role of these different strategies to answer the following research questions: What are the "best" strategies that can be implemented to deal with climatic change in the field? In particular, what are the economic implications of different strategies? To answer these questions is important to make the adaptation process explicit. The basic premise of this paper is that a possible way to understand the role of adaptation is to study farmers mitigating responses to impacts of changes to date. Adaptation to changing climatic conditions is not, in fact, a new process. Farmers have constantly implemented adjustments to cope with the vagaries of climatic conditions. Thus, understanding the impacts of past adaptation can help us gauging the importance of these strategies in the face of future climate change. In addition, a farm level perspective can be particularly useful to inform us of the barriers and drivers behind the different adaptation strategies.

We contribute to the existing literature on climate change in agriculture in three ways. First, we disentangle the economic implications of different climate change adaptation strategies within a Ricardian framework.[2] This is within the spirit of the so called "structural Ricardian analysis" (pioneered by Seo and Mendelsohn

[2] Di Falco, Veronesi and Yesuf (2011) follow a similar approach, however, they focus on the binary choice between adapting or not adapting to climate change without distinguishing the effect of different strategies.

(2008a), Seo and Mendelsohn (2008b), Seo (2010) and Kurukulasuruya et al.).[3] In addition we investigate whether implementing these strategies in combination is more effective than implementing them individually. Second, we identify the most successful strategies by implementing a counterfactual analysis. This provides information on what farm households would have earned if they had not adapted a particular strategy. Third, we add some empirical evidence from Ethiopia on farmers climate change adaptation strategies to a number of country specific studies (e.g., Seo and Mendelsohn 2008; Seo and Mendelsohn 2008d; Deressa et al. 2009; Kurukulasuriya et al. 2011).

We have access to a unique database on Ethiopian agriculture to answer our research questions. One of the survey instruments was specifically designed to analyze farmers' climate change perception and adaptation. Specifically, farmers were asked what adjustments they made in response to long-term shifts in temperature and/or rainfall. Farmers in the study sites have undertaken a number of adaptation measures, including changing crop varieties, adopting soil conservation measures, and water strategies such as water harvesting and water conservation. These adaptation measures account for more than 95 percent of the measures followed by the farm households that actually undertook an adaptation measure. These measures can be implemented individually or jointly.

Farmers' decision to adapt and what strategy to adopt is voluntary, and based on individual self-selection. Farm households that adopted a particular strategy are not a random sample of the original population, they may have systematically different characteristics from farm households that did not adapt or adopted a different strategy. Unobservable characteristics of farmers and their farm may affect both the adaptation

[3] Differently from these studies we do not look at types of farms (specialized vs. mixed), livestock switching, or a specific technology adoption such as irrigation. We instead map the full set of actual adaptation strategies implemented by individual farms.

strategy decision and net revenues, resulting in inconsistent estimates of the effect of adaptation on net revenues. For example, if only the most skilled or motivated farmers choose to adapt or choose the most profitable strategy then self-selection bias can affect the estimates. In addition, this simple approach assumes that the observable variables have the same marginal effects on net revenues independently of the type of strategy considered. This assumption imposes a model restriction, which may yield to biased estimates.

We address these issues by estimating a multinomial endogenous switching regression model of climate change adaptation and crop net revenues by a two stage procedure which allows producing selection-corrected net revenues. In the first stage, we use a selection model where a representative farm household chooses to implement a specific strategy, while in the second stage the information stemming from the first step is used in a Ricardian model (Mendelsohn et al., 1994), where farm net revenues are regressed against climatic variables and other control variables. Climatic variables at the household level were constructed via the *Thin Plate Spline* method of spatial interpolation. The inclusion of these variables is essential to estimate the Ricardian model, and to test whether the strategies were indeed implemented in response to climate change. We use as selection instruments in the net revenue functions the variables related to past information sources (e.g., government extension, farmer-to-farmer extension, information from radio, and if received information in particular on climate). We establish the admissibility of these instruments by performing a simple falsification test: if a variable is a valid selection instrument, it will affect the decision of choosing an adaptation strategy but it will not affect the net revenue per hectare among farm households that did not adapt (Di Falco et al. 2011).

We find that adaptation to climate change based upon a combination of strategies –opposed to strategies adopted in isolation- increases farm net revenues. In particular, the combination of water strategies and changing crop varieties delivers the highest pay off.

2. Background

Ethiopia’s GDP is closely associated with the performance of its rainfed agriculture (Deressa and Hassan 2010). For instance, about 40 percent of national GDP, 90 percent of exports, and 85 percent of employment stem from agricultural sector. The rainfed production environment is characterized by large extent of land degradation and very erratic and variable climate. Historically, rainfall variability and associated droughts have been major causes of food shortage and famine in Ethiopia. The success of the agricultural sector is crucially determined by the productivity of small holder farm households. They account for about 95 percent of the national agricultural output, of which about 75 percent is consumed at the household level (World Bank 2006). With low diversified economy and reliance on rain-fed agriculture, Ethiopia’s development prospects have been thus associated with climate. For instance, the World Bank (2006) reported that catastrophic hydrological events such as droughts and floods have reduced its economic growth by more than a third.

The frequency of droughts has increased over the past few decades, especially in the lowlands (Lautze et al. 2003; NMS 2007). A study undertaken by the national meteorological service (published in 2007) highlights that annual minimum temperature has been increasing by about 0.37 degrees Celsius every 10 years over the past 55 years. Rainfall have been more erratic with some areas becoming drier while other becoming relatively wetter. These findings point out that climatic variations have already happened in this part of the world.The prospect of further climate change can exacerbate this very difficult situation. Climate change is indeed projected to further reduce agricultural productivity (Rosenzweig and Parry 1994; Parry et al. 2005; Cline 2007). Most of climate models converge in forecasting scenarios of increased temperatures for most of Ethiopia (Dinar et al., 2008).

3. Survey and Data Description

This study relies on a survey conducted in 2005 on 1,000 farm households in the Nile Basin of Ethiopia, one of the countries most vulnerable to climate change with least capacity to respond (Orindi et al. 2006; Stige et al. 2006). This is a very large area covering roughly one third of the country. The sampling frame considered traditional typology of agro-ecological zones in the country (namely, *Dega*, *Woina Dega*, *Kolla* and *Berha*), percent of cultivated land, average annual rainfall, rainfall variability, and vulnerability (number of food aid dependent population). The sampling frame selected the *woredas* (an administrative division equivalent to a district) in such a way that each class in the sample matched to the proportions for each class in the entire Nile basin. The procedure resulted in the inclusion of twenty *woredas*. Random sampling was then used in selecting fifty households from each *woreda*.

Production input and output data were collected at the plot level for two cropping seasons, i.e., *Meher* (long rainy season) and *Belg* (the short rainy season). Although a total of forty-eight annual crops were grown in the basin, the first five major annual crops (teff, maize, wheat, barley, and beans) cover 65 percent of the plots. These are also the crops that are the cornerstone of the local diet. We limit the analysis to these primary crops. The final sample includes 941 farm households, and 2,802 plots. The scale of the analysis is at the plot level. The farming system in the survey sites is very traditional with plough and yolk (animals' draught power). Labor is the major input in the production process during land preparation, planting, and post harvest processing. Labor inputs were disaggregated as adult male's labor, adult female's labor, and children's labor. This approach of collecting data (both inputs and outputs) at different stages of production and at different levels of disaggregation should reduce cognitive burden on the side of the respondents, and increase the likelihood of retrieving a better retrospective data. The three forms of labor were aggregated as one labor input using adult equivalents. We employed the standard conversion factor in the literature on developing countries where an adult female and children labor are converted into adult male labor equivalent at 0.8 and 0.3 rates, respectively.

One of the survey instruments was specifically designed to analyze farmers' climate change perception and adaptation. Specific questions were included to investigate whether farmers have noticed changes in mean temperature and rainfall over the last two decades, and whether in response to these changes they made some adjustments in their farming by adopting some particular strategies. Farm households in the study sites have undertaken a number of adaptation measures, including changing crop varieties, adopting soil conservation measures, and water strategies such as water harvesting and water conservation (Table 1). These adaptation measures were implemented both in isolation and jointly. They are mainly yield related and account for more than 95 percent of the measures followed by the farm households that actually undertook an adaptation measure. The remaining adaptation strategies were much less adopted. For instance, migration or finding off-farm jobs were considered viable adaptation strategies in less than 7 percent of the sample. We identified eight main strategies: (1) changing crop varieties *only;* (2) implementing *only* water strategies such as water harvesting, irrigation or water conservation; (3) implementing *only* soil conservation; (4) implementing water strategies *and* changing crop varieties; (5) implementing soil conservation *and* changing crop varieties; (6)

implementing water strategies *and* soil conservation; (7) implementing water strategies, soil conservation*, and* changing crop varieties; and (8) implementing other strategies. We set "non-adapting" as the reference category. As Table 2 shows, (3) and (5), that is implementing *only* soil conservation, and soil conservation *and* changing crop varieties, are the most popular strategies.

Monthly rainfall and temperature data were collected from all the meteorological stations in the country. Then, the *Thin Plate Spline* method of spatial interpolation was used to impute the household specific rainfall and temperature values using latitude, longitude, and elevation information of each household.[4] This method is one of the most commonly used to create spatial climate data sets. Its strengths are that it is readily available, relatively easy to apply, and it accounts for spatially varying elevation relationships. However, it only simulates elevation relationship, and it has difficulty handling very sharp spatial gradients. This is typical of coastal areas. Given that our area of the study is characterized by significant terrain features, and no climatically important coastlines, the choice of the *Thin Spline method* is reasonable (for more details on the properties of this method in comparison to the other methods see Daly 2006). The basic descriptive statistics and variables definition are presented in tables A1 and A2 of the appendix.

4. Modelling Climate Change and Adaptation Strategies

In this section we specify a model of climate change adaptation and net revenues. Particular functional forms are chosen to remain within the spirit of previous work in this area (e.g, Deressa and Hassan 2010). We first assume that farm households face a

[4] By definition, *Thin Plate Spline* is a physically based two-dimensional interpolation scheme for arbitrarily spaced tabulated data. The Spline surface represents a thin metal sheet that is constrained not to move at the grid points, which ensures that the generated rainfall and temperature data at the weather stations are exactly the same as data at the weather station sites that were used for the interpolation. In our case, the rainfall and temperature data at the weather stations are reproduced by the interpolation for those stations, which ensures the credibility of the method (see Wahba 1990).

choice of *M* mutually exclusive strategies to long term changes in mean temperature and rainfall, which can be indexed *j = 1 … M*. We then outline an econometric model that is used to investigate the effects of different climate change adaptation strategies on net revenues.

Stage I – Selection Model of Climate Change Adaptation Strategies

In the first stage, let *A** be the latent variable that captures the expected net revenues from implementing strategy *j* (*j = 1 … M*) with respect to implementing any other strategy *k*. We specify the latent variable as

$$(1)\quad A_{ij}^{*} = \overline{V}_{ij} + \eta_{ij} = \mathbf{Z_i}\boldsymbol{\alpha}_\mathbf{j} + \eta_{ij}$$

$$\text{with } A_i = \begin{cases} 1 \quad iff \quad A_{i1}^{*} > \max\limits_{k \neq 1}(A_{ik}^{*}) \text{ or } \varepsilon_{i1} < 0 \\ \vdots \qquad\qquad \vdots \qquad\qquad\qquad \vdots \\ M \; iff \quad A_{iM}^{*} > \max\limits_{k \neq M}(A_{ik}^{*}) \text{ or } \varepsilon_{iM} < 0 \end{cases}$$

that is farm household *i* will choose strategy *j* in response to long term changes in mean temperature and rainfall if strategy *j* provides expected net revenues greater than any other strategy *k ≠ j*, that is if $\varepsilon_{ij} = \max\limits_{k \neq j}(A_{ik}^{*} - A_{ij}^{*}) < 0$. Equation (1) includes a deterministic component ($\overline{V}_{ij} = \mathbf{Z_i}\boldsymbol{\alpha}_\mathbf{j}$), and an idiosyncratic unobserved stochastic component η_{ij}, the latter captures all the variables that are relevant to the farm household's decision maker but are unknown to the researcher (e.g., farmers' skills, motivation), it can be interpreted as the unobserved individual propensity to adapt, and it is assumed that that the covariate vector $\mathbf{Z_i}$ is uncorrelated with η_{ij}, i.e., $E(\eta_{ij} | \mathbf{Z_i}) = 0$.

The deterministic component $\overline{V}_{ij}$ depends on factors $\mathbf{Z_i}$ that affect the likelihood of choosing strategy *j* such as farmer head's and farm household's characteristics (e.g., age, gender, education, marital status, if the farmer head has an off-farm job, and farm household size),), the presence of assets (e.g., machinery and animals), the characteristics of the operating farm (e.g., soil fertility and erosion), past climatic factors (e.g., 1970 – 2000 mean rainfall and temperature), the presence of assets (e.g., machinery and animals), tree planting, the experience of previous extreme weather events such as droughts and floods. Experience is approximated by age and education. Furthermore, farm households must have access to information about farming strategies before they can consider adopting them, and information about climate. Since extension services are one important source of information for farmers, we use access to government and farmer-to-farmer extensions as measures of access to information. We also control for tree planting. Trees besides providing agroecological benefits they provide a very important function in Ethiopia: they are a proxy for land tenure security (Mekonnen, 2009).

Under the assumption that η_{ij} are independent and identically Gumbel distributed, that is under the Independence of Irrelevant Alternatives (IIA) hypothesis, selection model (1) leads to a multinomial logit model (McFadden 1973) where the probability of choosing strategy j (P_{ij}) is

$$(2)\quad P_{ij} = P(\varepsilon_{ij} < 0 | \mathbf{Z_i}) = \frac{\exp(\mathbf{Z_i}\boldsymbol{\alpha}_\mathbf{j})}{\sum_{k=1}^{M}\exp(\mathbf{Z_i}\boldsymbol{\alpha}_\mathbf{k})}.$$

Table A2 of the Appendix presents parameters estimates of the multinomial logit model.

Stage II - Multinomial Endogenous Switching Regression Model

In the second stage, we estimate a multinomial endogenous switching regression model by applying Bourguignon et al. (2007) selection bias correction model. Our model implies that farm households face a total of M regimes (one regime per strategy, where $j=1$ is the reference category "non-adapting"), and that we have a net revenue equation for each possible regime j defined as:

$$(3a)\ \text{Regime 1:}\quad y_{i1} = \mathbf{X_i}\boldsymbol{\beta}_\mathbf{1} + u_{i1} \quad if \quad A_i = 1$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$(3m)\ \text{Regime M:}\ y_{iM} = \mathbf{X_i}\boldsymbol{\beta}_\mathbf{M} + u_{iM} \quad if \quad A_i = M$$

where y_{ji} is the net revenue per hectare of farm household i in regime j, ($j = 1 \dots M$), and $\mathbf{X_i}$ represents a vector of inputs (e.g., seeds, fertilizers, manure, and labour), farmer head's and farm household's characteristics, soil's characteristics, and the past climatic factors included in $\mathbf{Z}$; u_{ij} represents the unobserved stochastic component, which verifies $E(u_{ij} | \mathbf{X_i}, \mathbf{Z_i}) = 0$ and $V(u_{ij} | \mathbf{X_i}, \mathbf{Z_i}) = \sigma_j^2$. For each sample observation only one among the M dependent variables net revenues is observed. When estimating an OLS model, the net revenues equations (3*a*)-(3*m*) are run separately (Table A4 of the Appendix). However, if the error terms of the selection model (1) η_{ij} are correlated with the error terms u_{ij} of the net revenues functions (3*a*)-(3*m*), the expected values of u_{ij} conditional on the sample selection are nonzero, and the OLS estimates will be inconsistent. To correct for the potential inconsistency, we employ the model by Bourguignon et al. (2007), which takes into account the correlation between the error terms η_{ij} from the multinomial logit model estimated in the first stage and the error terms from each net revenue equation u_{ij}. We refer to this model as a "multinomial endogenous switching regression model" following the terminology of Maddala and Nelson (1975) extended to the multinomial case.

Bourguignon et al. (2007, p. 179) show that consistent estimates of $\boldsymbol{\beta}_\mathbf{j}$ in the outcome equations (3*a*)-(3*m*) can be obtained by estimating the following selection bias-corrected net revenues equations,

$$(4a)\ \text{Regime 1:}\quad y_{i1} = \mathbf{X_i}\boldsymbol{\beta}_\mathbf{1} + \sigma_1 \left[\rho_1 m(P_{i1}) + \sum_j \rho_j m(P_{ij}) \frac{P_{ij}}{(P_{ij}-1)} \right] + v_{i1}\ if\ A_i = 1$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$(4m)\ \text{Regime M:}\ y_{iM} = \mathbf{X_i}\boldsymbol{\beta}_\mathbf{M} + \sigma_M \left[\rho_M m(P_{iM}) + \sum_j \rho_j m(P_{ij}) \frac{P_{ij}}{(P_{ij}-1)} \right] + v_{iM}\ if\ A_i = M$$

where P_{ij} represents the probability that farm household i chooses strategy j as defined in (2), ρ_j is the correlation between u_{ij} and η_{ij}, and $m(P_{ij}) = \int J(\nu - \log P_j) g(\nu) d\nu$ with $J(.)$ being the inverse transformation for the normal distribution function, $g(.)$ the unconditional density for the Gumbel distribution, and $\nu_{ij} = \eta_{ij} + \log P_j$. This implies that the number of bias correction terms in each equation is equal to the number of multinomial logit choices M. Table A6 of the Appendix shows the parameter estimates of the multinomial endogenous switching regression model.

For the model to be identified it is important to use as exclusion restrictions, thus as selection instruments, not only those automatically generated by the nonlinearity of selection model (1) but also other variables that directly affect the selection variable but not the outcome variable. In our case study, we use as selection instruments in the net revenue functions the variables related to the information sources (e.g., government extension, farmer-to-farmer extension, information from radio, and if received information in particular on climate). We establish the admissibility of these instruments by performing a simple falsification test: if a variable is a valid selection instrument, it will affect the decision of choosing an adaptation strategy but it will not affect the net revenue per hectare among farm households that did not adapt. Table A7 of the Appendix shows that the information sources can be considered as valid selection instruments: they are jointly statistically significant drivers of the decision to adapt strategy j (Model 1, χ^2= 75.16; p-value = 0.00) but not of the net revenue per hectare by the farm households that did not adapt (Model 2, F-stat. = 1.22, p-value = 0.34). In addition, standard errors are bootstrapped to account for the heteroskedasticity arising from the two-stage estimation procedure.

A crucial assumption of the Bourguignon et al. (2007)'s model is that IIA holds. However, Bourguignon et al. (2007) show that "selection bias correction based on the multinomial logit model can provide fairly good correction for the outcome equation, even when the IIA hypothesis is violated" (p. 199). An alternative estimation method is provided by Dahl (2002), which corrects the outcome equation of endogenous selection semi-parametrically by adding a polynomial of choice probabilities to the covariate vector. However, Bourguignon et al. (2007) show that their method is more robust than the one proposed by Dahl (2002), which is more suitable when a large number of observations is available and the number of choices in the selection model is small otherwise "the identification of the covariance matrix between all model residuals becomes intractable" (p. 200) as it would be in our case.

In addition, we exploit plot level information to deal with the issue of farmers' unobservable characteristics such as their skills. Plot level information can be used to construct a panel data and control for farm specific effects (Udry 1996). Including standard fixed effects (where variables are transformed in deviations from their means) is, however, particularly complex in our multinomial switching regression approach. In addition, the alternative method of adding the inverse Mills ratio to the second step and using fixed effects does not lead to consistent estimates (Wooldridge 2002, p. 582-583). We follow Mundlak (1978) and Wooldridge (2002) to control for unobservable characteristics. We exploit the plot level information, and insert in the net revenues equations (4*a*)-(4*m*) the average of plot–variant variables, such as the inputs used (seeds, manure, fertilizer, and labor). This approach relies on the assumption that the unobservable characteristics are a linear function of the averages of the plot-variant explanatory variables across plots, that is $\nu_i = \bar{\mathbf{X}}_\mathbf{i}\boldsymbol{\pi} + \psi_i$ with $\psi_i \sim IIN(0, \sigma_\psi^2)$ and $E(\psi_i / \bar{\mathbf{X}}_\mathbf{i}) = 0$, where $\bar{\mathbf{X}}_\mathbf{i}$ includes the mean of plot-variant explanatory variables, $\boldsymbol{\pi}$ is the corresponding vector of coefficients, and ψ_i is a normal error term uncorrelated with the plot-variant explanatory variables $\bar{\mathbf{X}}_\mathbf{i}$. This approach also allows for the coexistence of both plot-variant and plot-invariant factors in the net revenues equations. This is crucial in a setting like this one where, for instance, climatic variables' and farmers' characteristics are plot-invariant. The Mundlak specification is therefore, a general way to address the role of climate in a Ricardian setting while controlling for unobservable characteristics without dropping variables that are at the individual/farm level.

5. Counterfactual Analysis and Treatment Effects

In this section, we show how to estimate the treatment effect (Heckman et al. 2001), that is the effect of the treatment "adoption of strategy *j*" on the net revenues of the treated farm households that adopted strategy *j*. In absence of a self-selection problem, it would be appropriate to assign to farm households that adapted a counterfactual net revenue had they not adapted equal to the average net revenue among non-adapters with the same observable characteristics. However, unobserved heterogeneity in the propensity to choose an adaptation strategy affecting also net revenues creates a selection bias in the net revenue equation that cannot be ignored. The multinomial endogenous switching regression model can be applied to produce selection-corrected predictions of counterfactual net revenues.

In particular, we follow Bourguignon et al. (2007, p. 179 and pp. 201-203), and we first derive the expected net revenues of farm households that adapted, that in our study means $j = 2 \dots M$ ($j = 1$ is the reference category "non-adapting"), as

$$(5a)\quad E(y_{i2} \mid A_i = 2) = \mathbf{X_i \beta_2} + \sigma_2 \left[\rho_2 m(P_{i2}) + \sum\nolimits_{k \neq 2}^{M} \rho_k m(P_{ik}) \frac{P_{ik}}{(P_{ik} - 1)} \right]$$

$$\vdots$$

$$(5m)\quad E(y_{iM} \mid A_i = M) = \mathbf{X_i \beta_M} + \sigma_M \left[\rho_M m(P_{iM}) + \sum_{k=1 \dots M-1} \rho_k m(P_{ik}) \frac{P_{ik}}{(P_{ik} - 1)} \right]$$

Then, we derive the expected net revenues of farm households that adopted strategy *j* in the counterfactual hypothetical case that did not adapt (*j=1*) as

$$(6a)\quad E(y_{i1} \mid A_i = 2) = \mathbf{X_i\beta_1} + \sigma_1 \left[\rho_1 m(P_{i2}) + \rho_2 m(P_{i1}) \frac{P_{i1}}{(P_{i1} - 1)} + \sum_{k=3...M} \rho_k m(P_{ik}) \frac{P_{ik}}{(P_{ik} - 1)} \right]$$

$$\vdots$$

$$(6m)\quad E(y_{i1} \mid A_i = M) = \mathbf{X_i\beta_1} + \sigma_1 \left[\rho_1 m(P_{iM}) + \sum_{k=2...M} \rho_k m(P_{i,k-1}) \frac{P_{i,k-1}}{(P_{i,k-1} - 1)} \right]$$

This allows us calculating the treatment effects (TT), as the difference between equations (5*a*) and (6*a*) or (5*m*) and (6*m*), for example.

6. Results

In this section, we investigate the implications of adopting a particular strategy on farm households' net revenues. Two simple and standard approaches could be applied to identify the "best" adaptation strategy. First, we could compare actual mean net revenues per hectare by farm household adaptation strategy (Table 2). This naïve comparison would drive the researcher to conclude that farm households that adopted water strategies *and* soil conservation measures are those that earned the most, in particular, about 1,550 Etb/ha more than farm households that did not adapt (difference significant at the 1% level, t-stat.= -4.30). A second possible approach consists in estimating a linear regression model of net revenues that includes binary variables equal to 1 if the farm household adapted a particular strategy (Table A4 of the Appendix). This approach would lead us to conclude that farm households implementing *only* water strategies would earn the most, about 1,700 Etb/ha more than farm households that did not adapt (significant at the 1% level).

However, both approaches can be misleading, and should be avoided in evaluating the impact of adaptation strategies on net revenues. They both assume that adaptation to climate change is exogenously determined while it is a potentially endogenous variable. The difference in net revenues may be caused by unobservable characteristics of the farm households such as their skills. For instance, the apparently most successful farm households could also be the most skilled ones, and so, those that would have done better than the others even without adapting. We address this issue by estimating counterfactual net revenues, that is what farm households would have earned if they had not adapted, by applying equations (6*a*-6*m*).

Table 2 presents net revenues per hectare under actual and counterfactual conditions. We compare expected net revenues under the actual case that the farm household adopted a particular strategy to adapt to climate change and the counterfactual case that did not, that is we compare columns (1) and (2) of Table 2. The last column of table 2 presents the impact of each adaptation strategy on net revenues, which is the treatment effect, calculated as the difference between columns (1) and (2).

Importantly, we find no statistical evidence of the impact of strategies that are implemented in isolation. Thus, changing crops, water conservation, and soil conservation if implemented individually do not seem to significantly impact revenues. We find that adaptation to climate change based upon a portfolio of strategies significantly increases farm households' net revenues, instead. The counterfactual analysis allows us to identify the portfolio of strategies that can deliver the highest pay off. As already identified by the existing literature, switching crops is one of the most remunerative strategies implemented by farmers (e.g., Kurukulasuriya and Mendelsohn 2007; Seo and Mendelsohn, 2008c; Hassan and Nhemachena, 2008; Deressa et al. 2009; Wang et al 2010). We find that changing crops, is highly significant (at the 1% statistical level) when is implemented along with water conservation or soil conservation. We find indeed that impact of the former is equal to about 4,221 Etb/ha while the impact of the latter is about 3,837 Etb/ha. The combination of water and soil conservation has also a positive and statistically significant impact (about 2,993 Etb/Ha). Interestingly, when all these three strategies are implemented as part of the same adaptation portfolio they deliver a lower pay off (1,552.9 Etb/Ha).

7. Conclusions

This study investigated what are the best strategies to adjust to long term changes in temperature and rainfall by estimating the impact of engaging in various agricultural practices on net revenues in the Nile Basin of Ethiopia. We implement a counterfactual analysis, and estimate a multinomial endogenous switching regression model of climate change adaptation and crop net revenues to account for the heterogeneity in the decision to adopt or not a particular strategy, and for unobservable characteristics of farmers and their farm.

We find that the choice of what adaptation strategy to adopt is crucial to support farm revenues. We find that strategies adopted in combination with other strategies rather than in isolation are more effective. Adaptation is, therefore, more effective when it is composed by a portfolio of actions rather than one single action. More specifically, we find that the positive impact of changing crop is higher when is coupled with water conservation strategies. The impact is a bit smaller when changing crop is implemented in conjunction with soil conservation measure. Interestingly, when all three strategies are implemented the farm household obtain the lowest pay off. This is a very intriguing and novel result. We speculate that it may indicate the existence of “decreasing” marginal return to adaptation. It may also simply reflect the higher cost of implementing a more complex strategy. Adaptation through three strategies has higher impact on the costs of adaptation, thus eroding net revenues.

These finding are crucial to design polices for effective adaptation strategies to cope with the potential impacts of climate change. Public policies can indeed play an important role in helping farm households to adapt. The identification of the “best” portfolio is also crucial. The dissemination of information on changing crops and implement conservation strategies are very important. Extension services are, for instance, very important in determining the implementation of adaptation strategies (see Table A3 of the Appendix), which could result in more food security for all farmers irrespective of their unobservable characteristics. The availability of information on climate change may raise farmers' awareness of the threats posed by the changing climatic conditions. Extension services provide an important source of information and education on choosing the best combination of strategies that can deliver the highest revenues. Both adaptation strategies and drivers of adaptation are traditional components of rural development programs. This stresses the importance of not treating climate change adaptation interventions separately from other rural development and poverty alleviation interventions. Raising the awareness of farmers regarding climate change and increasing their capacity to adapt to the challenges that climate change implies increase the opportunity of development.

In conclusion, some caveats are important. The results reported in this paper rely on cross sectional and plot level data. Admittedly, this is an important limitation. More and better data (e.g., panel data with time dimension) should be made available to provide more robust evidence on both the role of adaptation and its implications for agriculture. The dynamic of the problem should be also explicated. Some adaptation strategies can be effective in the short run while other may be delivering a pay off in the long run. Future research should be allocated to address these issues as well as the behavioural dimension of adaptation.

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Table 1. Climate change adaptation strategies

	Frequency	%
Soil conservation	1,397	72.27
Changing crop varieties	1,186	61.36
Water strategies		
Building water harvesting scheme	309	15.99
Water conservation	82	4.24
Irrigating more	279	14.43
Other strategies		
Early-late planting	176	9.11
Migrating to urban area	23	1.19
Finding off-farm job	132	6.83
Leasing the land	3	0.16
Changing from crop to livestock	71	3.67
Reduce number of livestock	121	6.26
Adoption of new technology	26	1.35

Note: sub-sample of farm households that adapted at the plot level (sample size: 1,933)

Table 2. Impact on Net Revenues by Adaptation Strategy

	Frequency	%	(1) Actual net revenues (Etb/Ha)	(2) Counterfactual net revenues if farm households did not adapt (Etb/Ha)	(3) Impact (treatment effect - Etb/Ha))
(1)Changing crop varieties only	230	11.90	3,963.939	3,441.88	522.0591
			(199.161)	(663.356)	(608.450)
(2)Water strategies only	57	2.95	4,752.995	3,725.251	1,027.744
			(611.048)	(1,140.373)	(1,184.190)
(3)Soil conservation only	411	21.26	4,349.334	4,753.916	-404.582
			(160.641)	(445.537)	(390.779)
(4)Water strategies and changing crop varieties	111	5.74	4,173.987	-37.431	4,211.419***
			(371.890)	(544.582)	(525.693)
(5)Soil conservation and changing crop varieties	556	28.76	4,598.201	760.755	3,837.446***
			(218.679)	(565.406)	(473.736)
(6)Water strategies and soil conservation	141	7.29	5,211.351	2,217.598	2,993.754***
			(450.832)	(858.745)	(874.497)
(7)Water strategies, soil conservation, and changing crop varieties	289	14.95	4,493.598	2,940.633	1,552.965***
			(206.240)	(648.144)	(587.526)
(8)Other strategies	138	7.14	3,682.941	1,017.593	2,665.348***
			(289.140)	(389.882)	(411.964)

Note*:* The final total sample includes 941 farm households and 2,802 plots. Percentages are calculated with respect to sub-sample of farm households that adapted at the plot level (sample size: 1,933). Values in columns (2) have been calculated following equations (6*a*)-(6*m*). Values in column (3) have been calculated as the difference between columns (1) and (2). Etb = Ethiopian birr, 1 Etb corresponds to $ 0.0592. *** Significant at the 1% statistical level.

Appendix

Table A1. Descriptive Statistics

Variable name	Total sample		Farm households that did not adapt		Farm households that adapted	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Dependent variables						
net revenues	4,167.203	4,901.327	3,661.458	3,295.894	4,394.567	5,457.213
Strategy j						
changing crop varieties only	0.082	0.275	-	-	0.119	0.324
water strategies only	0.020	0.141	-	-	0.029	0.169
soil conservation only	0.147	0.354	-	-	0.213	0.409
water strategies and changing crop varieties	0.040	0.195	-	-	0.057	0.233
soil conservation and changing crop varieties	0.198	0.399	-	-	0.288	0.453
water strategies and soil conservation	0.050	0.219	-	-	0.073	0.260
water strategies, soil conservation, and changing crop varieties	0.103	0.304	-	-	0.150	0.357
other strategies	0.049	0.216	-	-	0.071	0.258
Explanatory variables						
Climatic factors						
Belg rainfall	322.668	160.670	356.033	177.310	307.668	150.251
Meher rainfall	1,111.069	295.173	1,034.002	302.518	1145.715	285.180
average temperature	17.737	2.034	19.022	1.991	17.159	1.773
Soil characteristics						
highly fertile	0.280	0.449	0.333	0.471	0.257	0.437
Infertile	0.158	0.365	0.127	0.333	0.172	0.378
no erosion	0.484	0.500	0.510	0.500	0.472	0.499
severe erosion	0.104	0.306	0.082	0.274	0.114	0.318
Inputs and assets						
Labour	101.096	121.362	90.385	87.701	105.912	133.503
Seeds	115.151	148.714	91.315	103.513	125.867	163.948
Fertilizers	60.739	176.934	57.728	174.630	62.092	177.988
manure	198.572	832.187	73.009	438.860	254.955	952.355
animals	0.874	0.332	0.844	0.363	0.887	0.317
Farmer head and farm household characteristics						
literacy	0.489	0.500	0.413	0.493	0.524	0.500
male	0.926	0.262	0.914	0.281	0.932	0.252
married	0.928	0.259	0.922	0.269	0.931	0.254
Age	45.738	12.546	44.560	13.782	46.267	11.914
household size	6.602	2.189	6.242	2.260	6.765	2.136
Relatives	16.490	43.674	9.466	13.280	19.561	51.321
flood experience	0.172	0.378	0.207	0.405	0.217	0.412
drought experience	0.443	0.497	0.074	0.261	0.565	0.496
Information sources						
Government extension	0.608	0.488	0.269	0.444	0.761	0.427
farmer-to-farmer extension	0.516	0.500	0.197	0.398	0.659	0.474
radio information	0.307	0.461	0.139	0.346	0.382	0.486
climate information	0.422	0.494	0.111	0.314	0.563	0.496
Sample size	2,802		869		1,933	

Note: The sample size refers to the total number of plots. The final total sample includes 20 *woredas*, 941 farm households, and 2,802 plots.

Table A1 (cont.). Descriptive Statistics

	Changing crop varieties only		Water strategies only		Soil conservation only		Water strategies and changing crop varieties		Soil conservation and changing crop varieties		Water strategies and soil conservation		Water soil cons changing
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean
Dependent variable													
net revenues	3,950.616	3,959.401	4,752.995	5,651.228	4,272.669	5,997.582	4,271.221	4,454.657	4,566.582	6,099.243	5,211.351	6,797.752	4,483.133
Explanatory variables													
Climatic factors													
Belg rainfall	347.966	157.382	330.544	147.302	293.275	148.036	247.510	122.641	289.417	138.199	308.099	172.200	308.123
Meher rainfall	1,169.225	302.370	1,215.350	290.553	1,157.462	281.592	1,019.399	287.027	1,165.197	271.078	1,173.223	248.530	1,110.076
average temperature	16.968	1.696	17.459	1.241	16.869	2.586	17.275	0.788	16.903	1.387	17.776	1.879	17.292
Soil characteristics													
highly fertile	0.209	0.407	0.333	0.476	0.251	0.434	0.216	0.414	0.340	0.474	0.255	0.438	0.201
infertile	0.196	0.398	0.175	0.384	0.185	0.389	0.279	0.451	0.174	0.380	0.135	0.343	0.152
no erosion	0.448	0.498	0.684	0.469	0.397	0.490	0.495	0.502	0.487	0.500	0.539	0.500	0.488
severe erosion	0.117	0.323	0.123	0.331	0.151	0.358	0.180	0.386	0.131	0.338	0.064	0.245	0.045
Inputs and assets													
labour	113.545	131.221	106.727	135.718	101.945	125.071	94.372	114.142	112.802	159.835	127.478	144.102	89.241
seeds	130.334	194.910	120.336	91.044	128.453	140.717	104.597	105.903	128.836	195.086	170.367	171.318	115.776
fertilizers	73.159	171.875	62.933	111.958	52.951	127.914	38.986	64.249	75.932	266.837	49.169	86.172	42.779
manure	222.720	850.262	820.221	2,052.245	298.849	1,135.466	161.506	519.779	199.403	693.824	552.640	1,604.505	206.183
animals	0.935	0.247	0.754	0.434	0.893	0.310	0.838	0.370	0.890	0.313	0.887	0.318	0.865
Farmer head and farm household characteristics													
literacy	0.426	0.496	0.509	0.504	0.591	0.492	0.631	0.485	0.505	0.500	0.674	0.471	0.446
male	0.917	0.276	0.877	0.331	0.956	0.205	0.937	0.244	0.937	0.243	0.965	0.186	0.920
married	0.917	0.276	0.912	0.285	0.981	0.138	0.955	0.208	0.923	0.267	0.972	0.167	0.900
Age	48.074	10.484	49.684	14.404	45.998	11.652	45.856	14.984	46.209	11.913	47.199	11.630	45.239
household size	6.809	1.984	6.649	2.074	6.839	2.163	6.622	2.072	7.029	2.351	6.887	2.473	6.519
off-farm job	0.313	0.465	0.368	0.487	0.292	0.455	0.306	0.463	0.238	0.426	0.390	0.490	0.280

relatives	12.762	14.721	15.895	22.417	22.384	27.168	11.569	10.908	24.658	87.162	20.355	20.199	20.225
gold	0.461	0.500	0.439	0.501	0.467	0.500	0.324	0.470	0.578	0.494	0.418	0.495	0.322
flood experience	0.174	0.380	0.070	0.258	0.375	0.485	0.279	0.451	0.185	0.389	0.092	0.290	0.183
drought experience	0.426	0.496	0.667	0.476	0.655	0.476	0.541	0.501	0.637	0.481	0.638	0.482	0.536
Information sources													
government extension	0.752	0.433	0.649	0.481	0.701	0.458	0.820	0.386	0.833	0.374	0.723	0.449	0.875
farmer-to-farmer extension	0.630	0.484	0.474	0.504	0.623	0.485	0.811	0.393	0.674	0.469	0.709	0.456	0.817
radio information	0.222	0.416	0.351	0.481	0.258	0.438	0.486	0.502	0.464	0.499	0.624	0.486	0.474
neighborhood information	0.530	0.500	0.105	0.310	0.397	0.490	0.225	0.420	0.282	0.451	0.064	0.245	0.284
climate information	0.409	0.493	0.509	0.504	0.547	0.498	0.631	0.485	0.605	0.489	0.504	0.502	0.767
Sample size	230		57		411		111		556		141		

Note: The sample size refers to the total number of plots. The final total sample includes 20 *woredas*, 941 farm households, and 2,802 plots.

Table A2. Variables' Definition

Variable name	Definition
Dependent variables	
net revenues	net revenues per hectare in Ethiopian birr (Etb). 1 Etb= $0.0592.
Strategies	
changing crop varieties only	dummy = 1 if the farm household *only* changed crop varieties as adaptation strategy, 0 otherwise
water strategies only	dummy = 1 if the farm household adopted *only* water strategies (i.e., irrigation, water harvesting scheme, water conservation) as adaptation strategy, 0 otherwise
soil conservation only	dummy = 1 if the farm household adopted *only* soil conservation as adaptation strategy, 0 otherwise
water strategies and changing crop varieties	dummy = 1 if the farm household adopted water strategies *and* changed crop varieties as adaptation strategy, 0 otherwise
soil conservation and changing crop varieties	dummy = 1 if the farm household adopted soil conservation *and* changed crop varieties as adaptation strategy, 0 otherwise
water strategies and soil conservation	dummy = 1 if the farm household adopted water strategies *and* soil conservation as adaptation strategy, 0 otherwise
water strategies, soil conservation, and changing crop varieties	dummy = 1 if the farm household adopted water strategies, soil conservation *and* changed crop varieties as adaptation strategy, 0 otherwise
other strategies	dummy = 1 if the farm household did not change crop varieties *and* did not adopt water strategies *and* did not adopt soil conservation strategies but other strategies such as early-late planting, migrating, off-farm jobs etc. (see Table 1).
Explanatory variables	
Climatic factors	
Belg rainfall	rainfall rate in *Belg*, short rain season (mm) 1970 - 2000
Meher rainfall	rainfall rate in *Meher*, long rain season (mm) 1970 - 2000
average temperature	average temperature (^{o}C) 1970 - 2000
Soil characteristics	
high fertility	dummy =1 if the soil has a high level of fertility, 0 otherwise
infertile	dummy =1 if the soil is infertile, 0 otherwise
no erosion	dummy=1 if the soil has no erosion, 0 otherwise
severe erosion	dummy=1 if the soil has severe erosion, 0 otherwise
Assets	
animals	dummy=1 if farm animal power is used, 0 otherwise
Inputs	
labour	logarithm of labour used per hectare (adult days)
seeds	logarithm of seeds used per hectare (kg)
fertilizers	logarithm of fertilizers used per hectare (kg)
manure	logarithm of manure used per hectare (kg)
Farmer head and farm household characteristics	
literacy	dummy =1 if the household head is literate, 0 otherwise
male	dummy =1 if the household head is male, 0 otherwise
married	dummy =1 if the household head is married, 0 otherwise
age	age of the household head
household size	household size
relatives	number of relatives in the *woreda*
flood experience	dummy =1 if the farm household experienced a flood during the last 5 years

drought experience	dummy =1 if the farm household experienced a drought during the last 5 years
Information sources	
government extension	dummy =1 if the household head got information/advice from government extension workers, 0 otherwise
farmer-to-farmer extension	dummy =1 if the household head got information/advice from farmer-to-farmer extension, 0 otherwise
radio information	dummy =1 if the household head got information from radio, 0 otherwise
climate information	dummy =1 if extension officers provided information on expected rainfall and temperature, 0 otherwise

Table A3. Parameters Estimates of Climate Change Adaptation Strategies – Multinomial Logit Model

	(1) Changing crop varieties only	(2) Water strategies only	(3) Soil conservation only	(4) Water strategies and changing crop varieties	(5) Soil conservation and changing crop varieties	(6) Water strategies and soil conservation	(7) Water strategies, soil conservation, and changing crop varieties	(8) Other strategies
average temperature	0.125	4.622**	2.317***	5.423***	1.991***	0.115	5.215***	0.443
	(0.360)	(2.180)	(0.456)	(1.144)	(0.438)	(1.140)	(1.200)	(0.407)
squared average temperature	-0.008	-0.113**	-0.056***	-0.132***	-0.053***	-0.011	-0.138***	-0.014
	(0.009)	(0.052)	(0.011)	(0.026)	(0.011)	(0.026)	(0.029)	(0.010)
Belg rainfall	-0.019***	-0.029***	-0.008	0.002	-0.022***	-0.031***	-0.015***	0.009
	(0.004)	(0.008)	(0.006)	(0.008)	(0.004)	(0.009)	(0.005)	(0.007)
squared Belg rainfall/1000	0.015**	0.033***	-0.017	-0.017	0.023***	0.013	0.008	-0.018*
	(0.006)	(0.012)	(0.012)	(0.014)	(0.006)	(0.019)	(0.009)	(0.010)
Meher rainfall	-0.012***	-0.019***	0.000	-0.010***	-0.014***	-0.039***	-0.027***	-0.007*
	(0.003)	(0.006)	(0.004)	(0.004)	(0.003)	(0.005)	(0.004)	(0.004)
squared Meher rainfall/1000	0.006***	0.009**	-0.002	0.004**	0.007***	0.021***	0.014***	0.003
	(0.002)	(0.004)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
highly fertile	-0.621***	-0.250	-0.453**	-0.534	-0.091	-0.552*	-0.884***	-1.214***
	(0.222)	(0.387)	(0.195)	(0.329)	(0.189)	(0.305)	(0.250)	(0.317)
infertile	0.086	-0.086	-0.020	0.614*	0.087	-0.554	-0.199	-0.773**
	(0.247)	(0.401)	(0.231)	(0.316)	(0.225)	(0.358)	(0.259)	(0.353)
no erosion	0.024	0.658	-0.245	0.566**	-0.028	-0.248	-0.334	0.044
	(0.196)	(0.425)	(0.182)	(0.255)	(0.172)	(0.264)	(0.215)	(0.225)
severe erosion	-0.447	0.156	-0.436	0.287	-0.333	-0.902**	-1.298***	-0.300
	(0.311)	(0.557)	(0.265)	(0.354)	(0.273)	(0.450)	(0.367)	(0.410)
animals	0.854***	-1.001**	0.140	-0.343	-0.024	0.298	0.129	1.100***
	(0.315)	(0.457)	(0.247)	(0.323)	(0.254)	(0.353)	(0.289)	(0.380)
literacy	0.081	1.018***	0.719***	1.000***	0.239	1.371***	0.096	0.353
	(0.202)	(0.331)	(0.182)	(0.258)	(0.171)	(0.270)	(0.199)	(0.231)
male	0.730*	-0.092	0.642	-0.133	1.098***	0.786	0.664	0.387
	(0.440)	(0.700)	(0.468)	(0.766)	(0.416)	(0.741)	(0.479)	(0.485)
married	-0.957**	0.108	-0.046	0.186	-1.251***	0.387	-0.771	-1.105**
	(0.460)	(0.773)	(0.552)	(0.860)	(0.474)	(0.748)	(0.483)	(0.484)
Age	0.014**	0.022	0.009	0.020*	-0.006	0.015	-0.002	-0.002
	(0.007)	(0.014)	(0.007)	(0.011)	(0.007)	(0.011)	(0.008)	(0.009)
household size	0.105**	0.149**	0.040	0.048	0.185***	0.141**	0.095**	-0.014

	(0.042)	(0.075)	(0.040)	(0.060)	(0.040)	(0.058)	(0.046)	(0.047)
relatives	0.006	0.007	0.012**	-0.002	0.015***	0.006	0.015***	-0.015
	(0.006)	(0.009)	(0.005)	(0.009)	(0.005)	(0.006)	(0.005)	(0.013)
flood	-0.061	-1.031*	0.595***	0.646**	-0.255	-0.615	0.191	0.176
	(0.277)	(0.564)	(0.230)	(0.284)	(0.243)	(0.436)	(0.277)	(0.342)
drought	-0.141	0.567	0.074	0.034	0.530***	0.543*	-0.055	-0.435
	(0.213)	(0.369)	(0.218)	(0.279)	(0.201)	(0.303)	(0.239)	(0.300)
tree planting	24.439***	24.627	24.751***	24.907***	25.207***	25.460***	25.343***	25.248***
	(0.320)	(.)	(0.303)	(0.338)	(0.293)	(0.344)	(0.307)	(0.347)
government extension	1.077***	0.313	0.293	0.348	0.956***	0.199	0.434	0.205
	(0.209)	(0.422)	(0.203)	(0.319)	(0.196)	(0.316)	(0.271)	(0.266)
farmer-to-farmer extension	0.988***	0.255	0.621***	1.569***	0.496**	1.252***	1.125***	-0.597*
	(0.220)	(0.277)	(0.211)	(0.304)	(0.202)	(0.338)	(0.258)	(0.308)
radio information	-0.180	0.343	-0.456**	0.946***	0.745***	1.415***	0.975***	0.231
	(0.229)	(0.325)	(0.206)	(0.272)	(0.191)	(0.263)	(0.218)	(0.303)
climate information	0.236	0.406	0.653***	0.923***	0.659***	-0.063	1.683***	1.263***
	(0.239)	(0.384)	(0.217)	(0.282)	(0.206)	(0.298)	(0.255)	(0.308)
constant	5.155	-38.648	-23.263***	-55.005***	-11.668**	17.416	-37.547***	-3.257
	(4.472)	(24.607)	(5.670)	(12.628)	(5.438)	(13.876)	(13.067)	(5.378)
Wald test on information sources (χ^2)	86.47***	7.76*	50.50***	100.74***	102.25***	53.57***	171.95***	24.99***

Note: The baseline is farm households that did not adapt to climate change. Pseudo-R^2: 0.323. Sample size: 2,802 plots. Robust standard errors in parentheses.
* Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table A4. OLS Estimates of Net Revenue Equations on Pooled Sample

Dependent variable: net revenues per hectare	Coefficient (std. error)
changing crop varieties only	-83.375
	(319.038)
water strategy only	1,713.853**
	(795.089)
soil conservation only	348.467
	(316.649)
water strategy and changing crop varieties	1,155.491**
	(479.795)
soil conservation and changing crop varieties	461.594*
	(266.500)
water strategy and soil conservation	1,327.526**
	(546.687)
water strategy, soil conservation, and changing crop varieties	850.059***
	(318.232)
other strategies	195.551
	(317.781)
average temperature	-182.639
	(1144.367)
squared average temperature	-0.966
	(26.880)
Belg rainfall	-6.476
	(13.178)
squared Belg rainfall/1000	17.106
	(19.912)
Meher rainfall	5.023
	(6.591)
squared Meher rainfall/1000	-2.170
	(3.258)
highly fertile	75.869
	(184.043)
infertile	-450.923*
	(251.939)

no erosion	-23.181
	(158.833)
Severe erosion	402.406
	(381.347)
animals	513.027**
	(206.071)
labor	16.190***
	(3.076)
squared labor/100	-0.393
	(0.359)
seeds	0.931
	(2.143)
squared seeds/100	0.626***
	(0.243)
fertilizers	3.846***
	(1.439)
squared fertilizers/100	-0.079*
	(0.043)
manure	0.257
	(0.468)
squared manure/100	-0.002
	(0.007)
literacy	-358.384**
	(158.871)
male	675.798**
	(316.772)
married	113.884
	(339.133)
Age	-24.321***
	(6.613)
household size	-28.712
	(36.378)
relatives	-0.109
	(1.220)
Flood	-363.079
	(298.968)

drought	-34.767
	(250.479)
tree planting	-166.675
	(187.603)
Mundlak's fixed effects	
mean fertilizers	-0.938
	(0.809)
mean seeds	5.000**
	(1.977)
mean manure	-0.036
	(0.281)
mean labor	-8.430***
	(2.391)
constant	5,705.936
	(14,342.901)

Note: Robust standard errors in parenthesis. Fixed effects at the municipality level ("Kebele") are included. Adjusted R^2 = 0.333. Sample size: 2,802 plots. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table A5. OLS Estimates of Net Revenue Equations by Adaptation Strategy

Dependent variable	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Net revenues per hectare	No adaptation	Changing crop varieties only	Water strategies only	Soil conservation only	Water strategies and changing crop varieties	Soil conservation and changing crop varieties	Water strategies and soil conservation	Water strategies, soil conservation, and changing crop varieties	Other strategies
average temperature	-2835.491	114.713	0.000	8443.794**	306496.988	-2586.115	-15559.025	8319.800	824.779
	(2130.596)	(3157.802)	(0.000)	(3576.168)	(186386.121)	(2046.997)	(79153.142)	(5311.539)	(6132.171)
squared average temperature	56.761	-11.195	4.440	-201.289**	-8254.417*	53.549	304.597	-208.821	-20.640
	(53.241)	(65.588)	(17.873)	(86.311)	(4616.657)	(45.078)	(2135.495)	(150.011)	(140.139)
Belg rainfall	-8.619	-201.615	-29.265	-184.608	-288.147	26.094	-2808.206**	105.575	142.943
	(13.014)	(286.047)	(46.150)	(121.156)	(4875.819)	(35.622)	(1132.886)	(94.716)	(345.827)
squared Belg rainfall/1000	7.789	353.471	51.599	803.640*	-8623.109	-10.975	5157.550*	-317.328**	-158.699
	(15.363)	(406.811)	(77.762)	(444.015)	(11059.768)	(47.050)	(2915.586)	(155.730)	(462.598)
Meher rainfall	-42.327***	-31.460	-48.301	121.581**	-5773.989*	8.468	-464.493	-14.736	-12.701
	(10.924)	(56.342)	(31.771)	(60.804)	(3409.470)	(11.650)	(671.398)	(72.358)	(96.942)
squared Meher rainfall/1000	19.622***	22.011	24.766	-67.067**	2689.873*	-1.860	181.843	6.893	1.599
	(6.411)	(21.724)	(16.087)	(32.072)	(1531.606)	(5.372)	(376.211)	(27.940)	(39.248)
highly fertile	-20.207	688.600	-714.485	8.305	-1078.122	-574.008	55.846	867.069	-5.664
	(208.889)	(549.318)	(2703.098)	(605.215)	(1291.489)	(442.868)	(1311.687)	(671.487)	(924.159)
infertile	87.202	-288.087	-641.283	-627.625	-1398.610	-670.712	-1057.901	-284.160	-1532.864
	(363.822)	(837.670)	(7227.036)	(813.320)	(1015.163)	(460.090)	(1556.507)	(749.956)	(1208.809)
no erosion	97.655	-99.642	668.255	31.248	-818.527	-365.681	1136.420	227.275	126.693
	(226.463)	(484.656)	(3272.768)	(545.588)	(1298.368)	(373.891)	(1402.323)	(461.185)	(620.048)
severe erosion	-84.674	1846.074*	-191.928	890.289	1323.197	-26.545	-346.356	-284.356	127.316
	(516.608)	(1077.877)	(3369.322)	(1529.203)	(1146.896)	(550.706)	(1853.214)	(1056.844)	(979.480)
animals	899.833***	204.833	0.000	1045.705*	-384.365	1174.646**	204.076	714.074	1994.137**
	(251.353)	(1351.305)	(0.000)	(620.280)	(1605.854)	(487.660)	(1801.191)	(551.893)	(904.336)
labor	19.712***	19.494***	13.286	10.655*	57.110***	11.169**	10.220	14.482	6.005
	(4.971)	(7.334)	(20.148)	(6.153)	(20.691)	(4.691)	(13.467)	(9.795)	(7.310)
squared labor/100	-1.942***	-0.155	-1.190	-0.613**	-4.347**	-0.490	2.020	5.324	-3.728***
	(0.574)	(0.739)	(1.623)	(0.272)	(1.654)	(0.553)	(1.808)	(3.308)	(0.793)

seeds	-2.040	10.415***	61.721*	6.107	4.016	-3.193	11.640	2.769	20.730**
	(4.374)	(3.988)	(34.458)	(4.991)	(10.901)	(3.647)	(8.080)	(5.797)	(10.072)
squared seeds/100	1.321	-0.410	-9.753*	-0.414	0.006	1.158***	-0.091	0.039	-4.841**
	(1.028)	(0.262)	(5.643)	(0.907)	(1.653)	(0.343)	(0.621)	(0.272)	(2.318)
fertilizers	5.948***	-9.498	23.596	12.043***	11.042	3.893	24.860*	20.170***	-22.580**
	(1.978)	(6.013)	(45.351)	(4.202)	(12.751)	(2.854)	(14.197)	(7.744)	(8.654)
squared fertilizers/100	-0.146***	2.471*	-4.120	-1.108***	-3.395	-0.053	-5.797	-3.363**	10.355***
	(0.045)	(1.433)	(5.352)	(0.398)	(3.484)	(0.079)	(4.394)	(1.564)	(2.493)
manure	-1.133	-1.822*	-5.810*	0.693	-4.006	1.025	-0.472	1.211	-3.017
	(0.781)	(1.013)	(3.025)	(1.566)	(3.401)	(1.191)	(0.662)	(1.133)	(3.891)
squared manure/100	0.041***	0.015	0.099*	-0.000	0.109	-0.010	0.003	-0.022	0.473
	(0.014)	(0.010)	(0.048)	(0.018)	(0.107)	(0.017)	(0.006)	(0.023)	(0.286)
literacy	-624.189***	-1196.423*	-4387.658	-870.826*	963.818	191.224	891.879	-1018.431	-1399.127
	(226.432)	(655.373)	(3437.338)	(508.522)	(1533.468)	(446.003)	(1851.100)	(732.778)	(1235.427)
male	1393.858***	787.912	-4208.584	1100.784	-14739.719**	595.035	714.346	242.616	-615.180
	(531.797)	(1405.407)	(17825.178)	(1215.671)	(6900.371)	(777.111)	(3409.508)	(1108.514)	(1634.157)
married	-442.470	-988.641	-2298.368	1125.198	-3114.054	73.312	11515.979***	-54.064	1926.346
	(561.849)	(959.832)	(6240.689)	(1259.499)	(4933.004)	(849.644)	(3624.141)	(998.655)	(1679.446)
Age	-13.963*	-54.656**	-253.672**	-47.172	135.206*	-6.361	-99.123*	-35.725	-68.950
	(8.366)	(23.290)	(116.146)	(30.165)	(70.256)	(19.956)	(56.000)	(22.345)	(42.998)
household size	-59.647	94.269	1422.176**	-113.143	97.250	25.096	73.227	-152.056	-4.305
	(44.562)	(134.280)	(587.877)	(191.350)	(458.065)	(86.055)	(366.757)	(120.055)	(230.143)
relatives	4.383	132.821***	-132.919	-25.318*	94.592	0.392	-14.667	6.153	-21.450
	(13.877)	(25.680)	(107.588)	(13.119)	(60.273)	(1.450)	(18.418)	(7.509)	(85.483)
flood	-621.080	-1336.273	-2265.169	116.837	-3032.249	-240.185	-7452.597*	629.394	-3476.767*
	(496.909)	(918.251)	(7391.171)	(631.065)	(3657.435)	(501.512)	(4180.230)	(497.754)	(2058.406)
drought	706.319	635.653	9172.165*	-498.929	-3617.783*	-618.026	-4384.515**	-1177.865*	-2114.703
	(594.789)	(1098.059)	(4893.323)	(1139.888)	(2044.060)	(508.799)	(1719.792)	(710.390)	(1634.295)
tree planting	0.000	1123.375	0.000	613.980	-1013.924	-240.555	-2331.776	1710.398**	922.780
	(0.000)	(735.784)	(0.000)	(561.479)	(2273.935)	(318.534)	(1510.467)	(726.056)	(1191.233)
Mundlak's fixed effects									
mean fertilizers	-0.016	4.089	90.352***	-5.675	-90.211**	-1.284	13.054	-15.293	10.464
	(1.776)	(6.032)	(29.408)	(4.535)	(37.781)	(1.300)	(12.939)	(10.395)	(8.363)
mean seeds	5.092**	-15.002***	-52.086	17.349*	3.978	9.303**	-3.383	15.749	-16.446
	(2.318)	(4.212)	(39.599)	(9.572)	(20.873)	(4.407)	(8.236)	(12.843)	(16.044)
mean manure	0.520	2.092**	0.597	-0.671	3.586	-0.580	-0.591	0.065	-7.257
	(0.824)	(1.012)	(1.017)	(0.895)	(2.458)	(0.818)	(0.610)	(0.983)	(5.199)

mean labor	-6.405*	-3.477	-14.497	-4.577	2.132	-7.277*	-10.446	0.481	11.238
	(3.477)	(5.732)	(13.060)	(3.117)	(13.636)	(3.741)	(8.469)	(13.977)	(8.594)
constant	61778.939**	-62640.904	28770.509	-129422.952***	1643186.622	23527.175	594793.613	-83078.817**	-7248.479
	(24684.399)	(60006.483)	(39637.260)	(44559.044)	(2398012.659)	(20508.430)	(916364.091)	(41704.704)	(113219.909)
Sample size	868	230	57	411	111	556	141	289	138
Adjusted R^2	0.297	0.383	0.171	0.163	0.514	0.610	0.416	0.434	0.597

Note: Robust standard errors in parentheses. Fixed effects at the municipality level (“Kebele”) are included. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table A6. Estimates of Net Revenue Equations by Multinomial Endogenous Switching Regression Model

Dependent variable	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Net revenues per hectare	No adaptation	Changing crop varieties only	Water strategies only	Soil conservation only	Water strategies and changing crop varieties	Soil conservation and changing crop varieties	Water strategies and soil conservation	Water strategies, soil conservation, and changing crop varieties	Other strategies
average temperature	2,394.757	-368.078	.	6,593.958	-5147502.166	2,129.246	42,623.052	7,518.716	-3,741.996
	(1,595.020)	(5,953.280)	.	(5,994.810)	(4956196.427)	(2,736.005)	(104,965.688)	(11,135.146)	(9,092.927)
squared average temperature	-63.347	-40.981	-3,088.514	-148.086	113,707.684	-46.493	-1,181.387	-184.596	106.179
	(40.005)	(122.616)	(8,881.649)	(138.193)	(116,005.954)	(61.753)	(2,792.974)	(306.844)	(229.717)
Belg rainfall	53.175	-442.601	-17,277.342	-149.562	192,974.457	46.380	-1,826.369	48.940	179.772
	(66.428)	(406.206)	(41,410.283)	(190.478)	(156,463.535)	(41.291)	(1,660.224)	(109.403)	(427.318)
squared Belg rainfall/1000	-77.727	662.651	22,560.762	746.925	-411,129.636	-41.807	4,705.822	-194.781	-92.105
	(111.780)	(576.280)	(58,609.519)	(671.904)	(322,301.763)	(54.703)	(3,159.168)	(182.604)	(584.516)
Meher rainfall	-36.470	35.478	-12,467.327	170.477*	-45,407.700	32.624*	259.243	-10.891	-194.632
	(35.263)	(81.649)	(24,554.135)	(89.476)	(50,418.511)	(17.049)	(1,034.928)	(103.456)	(152.253)
squared Meher rainfall/1000	13.780	-11.630	7,694.931	-90.497*	18,666.702	-16.362*	-123.989	4.203	81.486
	(18.273)	(34.212)	(15,166.228)	(46.572)	(21,494.690)	(8.871)	(544.323)	(43.719)	(62.146)
highly fertile	15.069	2,352.806**	-48,339.768	155.491	-6,567.182	-405.333	-1,366.760	2,427.686	895.358
	(428.872)	(1,165.263)	(71,638.170)	(991.299)	(11,819.777)	(644.143)	(3,854.782)	(1,567.790)	(2,165.702)
infertile	-449.503	-237.336	383,068.379	-179.632	5,808.735	443.085	-721.926	9.789	692.484
	(488.508)	(886.445)	(752,801.259)	(1,016.217)	(9,105.595)	(658.693)	(3,450.781)	(1,208.118)	(2,272.726)
no erosion	-113.244	196.619	265,915.549	305.274	2,637.311	556.156	2,442.095	376.079	1,172.748
	(330.811)	(793.432)	(706,466.422)	(1,032.253)	(8,099.922)	(586.463)	(3,000.577)	(1,086.401)	(1,154.901)
severe erosion	-574.519	3,927.658***	98,764.748	1,806.775	2,876.750	1,525.161*	-535.279	-99.313	2,399.510
	(602.222)	(1,273.337)	(332,823.126)	(1,200.320)	(9,917.080)	(801.425)	(4,185.556)	(2,221.608)	(1,449.360)
animals	762.370	-2,951.395	-345,730.512	740.882	-21,846.465	676.569	-1,849.509	564.411	-3,403.175

	(575.508)	(2,295.642)	(892,453.784)	(1,659.628)	(24,971.318)	(942.575)	(6,018.817)	(1,648.565)	(3,950.457)
labor	28.853***	22.635***	-3.740	11.721**	58.584***	10.451***	7.559	9.392	12.555
	(4.247)	(6.882)	(60.418)	(5.828)	(13.430)	(3.288)	(10.405)	(12.907)	(8.480)
squared labor/100	-3.530***	-0.723	9.745	-0.668**	-4.422***	-0.477	2.321**	6.773	-4.851***
	(0.463)	(0.890)	(23.217)	(0.322)	(1.124)	(0.311)	(1.042)	(4.131)	(0.915)
seeds	-9.807***	9.953***	76.444*	6.435	-2.088	-3.607	12.475	2.825	13.537
	(3.487)	(3.078)	(45.953)	(6.070)	(12.880)	(2.524)	(9.080)	(5.101)	(9.907)
squared seeds/100	3.383***	-0.311	-12.407	-0.480	0.110	1.185***	-0.216	0.056	-3.106
	(0.572)	(0.221)	(9.010)	(0.880)	(1.807)	(0.185)	(0.818)	(0.273)	(2.391)
fertilizers	6.915**	-3.234	18.329	11.149*	21.605	3.919	26.253	19.570***	-32.930***
	(3.430)	(5.813)	(26.861)	(6.407)	(14.389)	(2.488)	(22.280)	(7.306)	(8.689)
squared fertilizers/100	-1.025***	1.170	-3.641	-1.022	-3.265	-0.049	-6.003	-3.807***	12.576***
	(0.438)	(1.220)	(3.677)	(0.745)	(5.505)	(0.057)	(5.263)	(1.796)	(2.338)
manure	-1.796***	-1.546*	-1.044	0.702	-4.003	1.258*	-0.686	1.032	-1.723
	(0.793)	(0.876)	(13.584)	(0.728)	(2.664)	(0.649)	(0.930)	(0.937)	(5.226)
squared manure/100	0.049***	0.009	-0.212	-0.000	0.152	-0.013	0.006	-0.020	0.201
	(0.015)	(0.012)	(0.658)	(0.008)	(0.098)	(0.011)	(0.010)	(0.019)	(0.443)
literacy	-576.106	-1,499.399	427,289.350	-1,393.723	298.048	347.067	333.251	-1,959.984*	-2,488.511
	(410.564)	(1,125.083)	(673,704.216)	(1,203.984)	(19,879.580)	(745.722)	(5,539.631)	(1,114.540)	(2,067.350)
male	497.399	1,984.044	379,888.228	-244.611	-566.867	-1,118.785	3,421.809	1,863.828	-1,138.620
	(796.033)	(2,632.031)	(459,630.536)	(2,182.744)	(93,580.349)	(1,161.355)	(6,782.478)	(1,952.259)	(2,340.324)
married	-568.843	-1,094.630	-288,058.879	1,864.029	88,398.707	1,215.680	15,430.013	-3,091.682*	4,043.526
	(990.893)	(1,992.804)	(703,304.222)	(3,291.358)	(78,134.157)	(1,321.962)	(14,837.192)	(1,801.463)	(2,494.442)
Age	-16.233	-82.658**	-5,373.234	-8.178	-1,029.780	10.591	-12.068	-78.194*	-37.924
	(12.781)	(39.298)	(5,510.549)	(42.527)	(1,362.441)	(22.170)	(120.065)	(46.719)	(67.601)
household size	-164.670**	252.136	40,803.843	-323.531	-9,458.889	-139.228	-538.792	83.632	-210.582
	(79.853)	(210.662)	(149,375.239)	(216.558)	(8,705.832)	(115.022)	(1,128.526)	(253.973)	(295.150)
relatives	-2.684	172.308***	6,963.111	-33.499	-777.878	-0.380	-11.777	15.905	98.790
	(13.835)	(34.788)	(17,545.995)	(21.150)	(801.377)	(10.411)	(75.925)	(17.012)	(120.000)
flood	-1,098.581	-2,526.461*	.	13.445	103,439.405	1,366.934	20,584.243	47.543	-8,125.467**
	(963.092)	(1,476.607)		(1,396.096)	(91,584.444)	(833.123)	(29,596.611)	(1,123.727)	(3,349.722)
drought	-244.338	1,662.272	.	-932.910	3,324.965	-1,233.812**	-3,047.451	-478.805	-3,459.196
	(640.811)	(1,622.514)		(1,202.361)	(16,528.244)	(622.088)	(3,637.769)	(1,106.513)	(3,817.199)
tree planting	0.000	8,062.134***	.	-1,244.804	-54,265.796	79.293	-4,283.938	1,872.509*	-2,790.993
	(0.000)	(2,164.034)		(1,711.469)	(47,343.247)	(636.002)	(4,246.436)	(1,085.809)	(4,540.291)

Mundlak's fixed effects									
mean fertilizers	-3.370	-10.428	-3,934.486	-3.742	-319.567	-2.263	11.585	-14.893	9.774
	(3.122)	(7.919)	(9,083.715)	(6.169)	(367.451)	(1.705)	(23.848)	(9.784)	(9.396)
mean seeds	7.597**	-17.504***	3,271.203	18.322***	-230.663	7.792**	-11.317	10.227	24.618
	(3.057)	(4.453)	(4,791.747)	(6.676)	(364.354)	(3.827)	(13.791)	(8.138)	(21.106)
mean manure	0.613	2.802***	31.090	-0.717	-1.418	-1.115	0.382	0.130	-0.389
	(0.753)	(0.727)	(35.376)	(0.663)	(26.216)	(0.701)	(1.257)	(0.904)	(6.710)
mean labor	-5.272	4.506	-824.645	-6.010	125.628	-3.888	-10.930	8.155	-2.889
	(4.058)	(5.668)	(2,273.083)	(6.183)	(169.974)	(4.151)	(13.609)	(13.712)	(10.351)
Selection Bias Correction Terms									
$m(P_{i1})$	-2,050.755	-36,915.649	-3489848.202	-2,577.516	22,181.468	-4,401.293	42,558.299	-1,370.377	179.664
	(5,648.023)	(13,643.304)	(6508623.572)	(7,618.684)	(69,777.916)	(4,131.968)	(49,838.578)	(6,697.330)	(13,305.302)
$m(P_{i2})$	-6,789.478	-7,851.515	0.000	1,675.693	92,586.935	-2,152.156	1,576.400	-1,734.696	-8,411.878
	(7,050.535)	(2,816.254)	(0.000)	(10,270.702)	(106,116.366)	(4,955.817)	(41,687.670)	(9,310.340)	(16,566.816)
$m(P_{i3})$	707.543	-10,579.171	266,341.446	521.378	-26,806.275	2,108.423	38,954.062	-1,359.101	50,132.722
	(24,508.492)	(18,989.287)	(1063127.862)	(15,191.766)	(57,676.779)	(7,890.782)	(27,181.820)	(10,400.908)	(46,114.196)
$m(P_{i4})$	1,812.799	-12,740.709	-1804661.217	-3,143.292	20,901.721	1,312.831	-2,059.810	-4,880.496	-13,560.239
	(6,933.841)	(14,188.687)	(4383286.834)	(2,760.687)	(71,364.265)	(5,058.591)	(25,350.341)	(7,299.565)	(14,438.574)
$m(P_{i5})$	-3,554.755	-19,353.318	2708375.006	2,011.467	23,371.942	15,616.575**	-230.803	-8,925.029	16,252.449
	(10,709.541)	(12,065.937)	(5619998.985)	(9,671.046)	(32,853.040)	(6,767.855)	(43,094.250)	(11,069.276)	(15,985.158)
$m(P_{i6})$	-9,543.155	-10,345.965	-1659379.556	-10,839.959*	15,216.501	-904.023	-9,858.987	7,887.987	472.557
	(6,246.380)	(14,434.548)	(3514338.890)	(6,334.270)	(84,649.469)	(1,849.382)	(23,675.938)	(8,394.503)	(11,895.690)
$m(P_{i7})$	4,815.101	-38,015.233	0.000	-9,767.997	5,639.044	-11,124.129**	2,107.279	-9,015.887	9,923.044
	(23,736.512)	(13,159.514)	(0.000)	(9,304.499)	(41,888.965)	(5,337.600)	(5,108.522)	(7,372.265)	(22,820.797)
$m(P_{i8})$	24,471.781	-35,566.784	0.000	-13,516.293	48,740.798	-6,603.170	24,842.028*	-930.505	-14,841.905
	(15,447.559)	(11,554.204)	(0.000)	(8,714.203)	(39,246.441)	(4,354.558)	(13,146.854)	(2,831.031)	(12,533.931)
$m(P_{i9})$	2,514.793	-16,260.606	-7147824.506	-3,836.875	-26,919.602	3,495.475	15,456.819	-134.916	-2,655.534
	(6,590.683)	(10,083.341)	(13702503.049)	(14,021.096)	(65,079.197)	(4,615.798)	(54,358.046)	(7,751.857)	(4,040.206)
Constant	-939.295	61,217.717	5059717.885**	-143,982.036	74691397.388	-43,714.064	-335,426.252	-50,303.794	83,844.737
	(31,513.575)	(103,498.002)	(10732436.879)	(68,678.912)	(59486620.856)	(31,675.949)	(1325332.053)	(98,106.835)	(168,839.822)

Note: $m(P_{ij})$ refers to the correction term described in equation (4a). Fixed effects at the municipality level ("Kebele") are included. Sample size: 2,802 plots. Bootstrapped standard errors in parentheses. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table A7. Parameter Estimates – Test on the Validity of the Selection Instruments

	Net revenues by farm households that did not adapt
Belg rainfall	-2449.611
	(1936.192)
squared Belg rainfall/1000	47.235
	(49.019)
Meher rainfall	-6.973
	(13.455)
squared Meher rainfall/1000	4.303
	(15.818)
average temperature	-42.885***
	(10.922)
squared average temperature	19.865***
	(6.373)
highly fertile	-43.578
	(211.589)
infertile	86.626
	(369.313)
no erosion	115.265
	(229.565)
severe erosion	-19.760
	(505.070)
animals	929.104***
	(286.719)
labor	20.070***
	(4.966)
squared labor/100	-1.997***
	(0.569)
seeds	-2.335
	(4.373)
squared seeds/100	1.376
	(1.026)
fertilizers	5.833***
	(1.967)
squared fertilizers/100	-0.142***
	(0.044)
manure	-1.120
	(0.791)
squared manure/100	0.041***
	(0.014)
literacy	-676.126***
	(228.230)
male	1370.344***
	(526.319)
married	-530.172
	(568.227)
age	-13.161
	(8.344)
household size	-62.406
	(46.209)
relatives	5.785
	(14.165)
flood	-645.937

	(509.819)
drought	736.152
	(606.384)
Information sources	
government extension	17.225
	(362.454)
farmer-to-farmer extension	193.561
	(520.855)
radio information	222.875
	(313.508)
climate information	537.764
	(548.335)
Mundlak's fixed effects	
mean fertilizers	-0.381
	(1.756)
mean seeds	5.012**
	(2.327)
mean manure	0.478
	(0.839)
mean labor	-6.450*
	(3.520)
constant	58125.581***
	(21995.727)
Wald test on information sources (F-stat.)	0.88
Sample size	868
Adjusted R^2	0.297

Note: Robust standard errors in parentheses. Fixed effects at the municipality level ("Kebele") are included. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.