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The Impact of Climate Change and Adaptation on Food Production in Low-Income Countries

Evidence from the Nile Basin, Ethiopia

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ABSTRACT

This paper presents an empirical analysis of the impact of climate change on food production in a typical low-income developing country. Furthermore, it provides an estimation of the determinants of adaptation to climate change and the implications of these strategies on farm productivity. The analysis relies on primary data from 1,000 farms producing cereal crops in the Nile Basin of Ethiopia. Based on monthly collected meteorological station data, the thin plate spline method of spatial interpolation was used to interpolate the specific rainfall and temperature values of each household. The rainfall data were disaggregated at the seasonal level. We found that climate change and climate change adaptations have significant impact on farm productivity. Extension services (both formal and farmer to farmer), as well as access to credit and information on future climate changes, affect adaptation positively and significantly. Farm households with larger access to social capital are more likely to adopt yield-related adaptation strategies.

Keywords: adaptation, climate change, farm level productivity, rainfall, Ethiopia

JEL classification: Q18, Q54

1. INTRODUCTION

There is a growing consensus in the scientific literature that over the coming decades, higher temperatures and changing precipitation levels caused by climate change will depress crop yields in many countries. This is particularly true in low-income countries, where adaptive capacities are perceived to be low. Many African countries, which have economies largely based on weather-sensitive agricultural productions systems, are particularly vulnerable to climate change. This vulnerability has been demonstrated by the devastating effects of recent flooding and the various prolonged droughts of the twentieth century. Thus, for many poor countries that are highly vulnerable to effects of climate change, understanding farmers' responses to climatic variation is crucial in designing appropriate coping strategies to climate change. There has been a good deal of literature on agricultural innovations in developing countries. Most of that literature has looked into the determinants of farm technology adoption decisions (particularly, soil and water conservation, fertilizer, improved seed varieties, and biodiversity) and their impacts on farm productivity. A host of demand- and supply-side factors, including tenure insecurity, household endowments of physical and human capital, agricultural extension, credit and market access, limited profitability, households' limited ex-post consumption-coping capacity, and short time preferences, have been identified to explain the limited adoption of agricultural innovations in low-income countries. None of these studies, however, has looked into the role of climatic variables and information on future climate change in governing some of the decisions of these farm households in the presence of imminent and devastating effects of climate change.

Some attempts have been made to estimate the impact of climate change on food production at the country, regional, or global scale (Pearce et al. 1996; McCarthy et al. 2001; Parry et al. 2004; Stern 2007). Insights from these studies are crucial to appreciating the extent of the problem and to designing appropriate mitigation strategies at the global or regional level. However, these attempts fail to provide critical insights in terms of effective adaptation strategies at the micro or household level. Studies on the impact of climatic change (in particular rainfall and temperature) and climate-related adaptation measures on crop yield are very scanty. To the best of our knowledge, Deressa (2007) is the only economic study that attempts to measure the impact of climate change on farm profits in Ethiopia. This study applies the Ricardian approach, wherein the cost of climate change is imputed from farm net revenue as a proxy for capitalized land value. However, while this study was conducted using subregional (agro-ecology) agricultural data as well as household-level it did not identify the determinants of each of the adaptation methods used.

This study tries to fill the gap in the literature by examining the impact of key climatic variables on food production in a typical developing country, using household-specific survey data. Lack of enough variation (spatial variation) on key climatic variables (precipitation and temperature) in cross-sectional data is one bottleneck to conducting a micro level study on climate change. This is particularly true in developing countries, where one meteorological station is set to cover a wide geographic area. To partially fill this gap, this study employs the thin plate spline method of spatial interpolation and imputes the household-specific rainfall and temperature values using latitude, longitude, and elevation information for each household. To bring more insights into adaptation strategies that are crucial to coping with climatic variability and change, this study also investigates key factors that govern farmers' decisions to use climate change adaptations and the impact of this action on food production.

It should be noted that in addressing the issue of productivity gain from adaptation to climate change, care must be taken to disentangle productivity gain through adaptation to climate change from changes due to other unobserved heterogeneity, including differences in farmers' abilities. In the absence of appropriate econometric tools, the impact of climate change and adaptations on food production would be biased and the subsequent policy conclusions misguided. In this study, we address these problems by using a careful application of appropriate econometric tools. We employ both pseudo-fixed effect and two-stage least-square econometric approaches to control for unobserved heterogeneity and endogeneity and to ensure robustness of our results and conclusions.

In Section 2, we provide a background to climate change and agricultural production in Ethiopia. Section 3 details the survey design and the data employed in the empirical analysis. Section 4 provides some descriptive statistics on climate change and adaptations in the study site. The econometric estimation methodology, along with some considerations in the estimation procedure, is provided in Section 5. Section 6 presents the empirical findings, while Section 7 concludes the paper.

2. CLIMATIC CHANGE AND AGRICULTURAL PRODUCTION IN ETHIOPIA

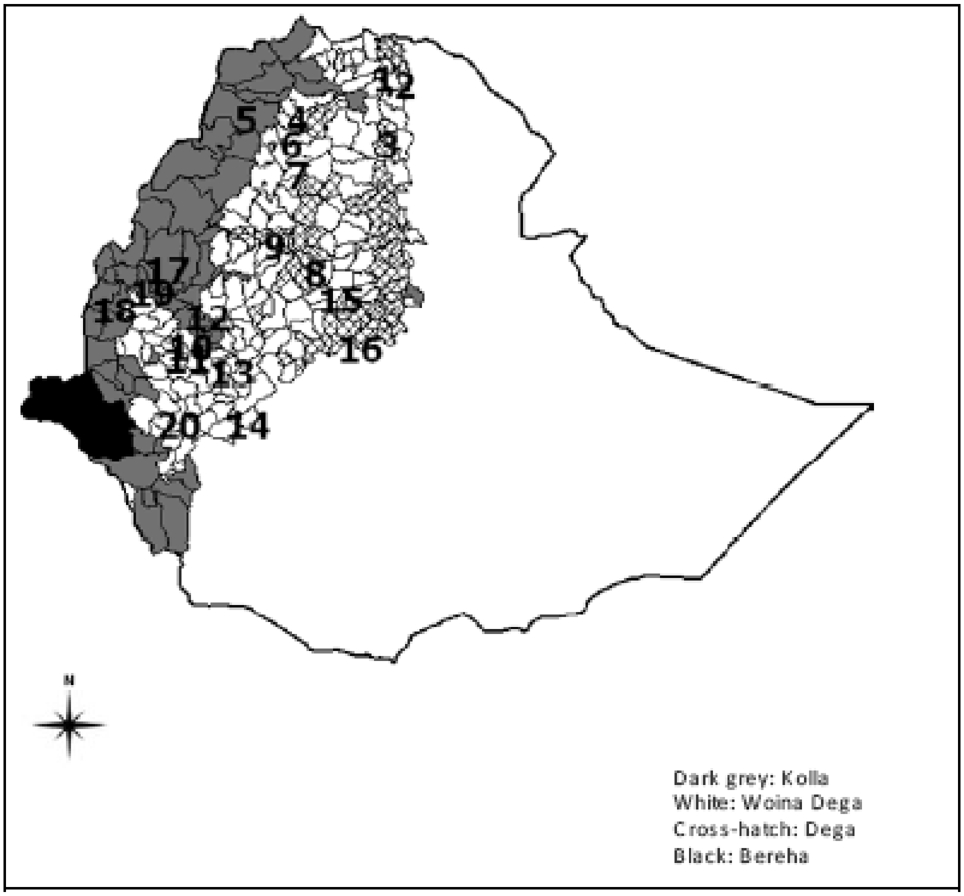
Ethiopia is one of the least developed countries in the world, with a gross domestic product (GDP) of slightly more than US$10 billion and a population of more than 70 million. Agriculture is the source of livelihood to an overwhelming majority of the Ethiopian population and is the basis of the national economy, where small-scale and subsistence farming are predominant. This sector employs more than 80 percent of the labor force and accounts for 45 percent of the GDP and 85 percent of the export revenue (Ethiopian Ministry of Finance and Economic Development [MoFED], 2006). Ethiopian agriculture is heavily dependent on rainfall, with irrigated agriculture accounting for less than 1 percent of the country's total cultivated land. Thus, the amount and temporal distribution of rainfall and other climatic factors during the growing season are important influences of crop yields and can induce food shortages and famine.

A recent mapping on vulnerability and poverty in Africa (Orindi et al. 2006; Stige et al. 2006) put Ethiopia as one of the countries most vulnerable to climate change with the least capacity to respond. Ethiopia has already suffered from extremes of climate, manifested in the form of frequent drought (1965, 1974, 1983, 1984, 1987, 1990, 1991, 1999, 2000, and 2002) and recent flooding (1997 and 2006). Rainfall variability and associated drought have been major causes of food shortage and famine in Ethiopia. At the national scale, the link between drought and crop production is widely known. However, little evidence is available on how climate change affects crop yield and farmers' adaptation strategies at the household level. Furthermore, not many studies have been conducted to understand the factors governing farmers' decisions to adapt climate change measures and the impact of these decisions on yield. This is particularly important for designing effective adaptation strategies to cope with the potential impacts of climate change.

3. DESCRIPTION OF THE STUDY SITES AND SURVEY INSTRUMENTS

The study was based on rural household survey conducted on 1,000 households located within the Nile Basin of Ethiopia. The sampling frame considered the traditional typology of the country's agro-ecological zones (namely, *Dega*, *WeynaDega*, *Kolla*, and *Bereha*)[1], percentage of cultivated land, degree of irrigation activity, average annual rainfall, rainfall variability, and vulnerability (number of food aid–dependent population). The sampling frame selected the *weredas*[2] in such a way that each class in the sample matched the proportions for each class in the entire Nile Basin. The procedure resulted in the inclusion of 20 villages. Random sampling was then used to select 50 households from each village. The study sites are depicted in Figure 1

Figure 1. The study sites



As in many parts of Ethiopia, the farming system in our survey sites is still very much traditional, with plough and yolk (animal draught power) and labor as the major means of production during land preparation, planting, and postharvest processing. Rain-fed agriculture is a common practice for many farm households, with only a few (0.6 percent) using irrigation water to grow their crops.

Production input and output data were collected for two cropping seasons—*Mehere* (the long rainy season) and *Belg* (the short rainy season)—at plot level. However, quite a few plots get a biannual

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[1] Generally Dega, WeynaDega, Kolla and Bereha represent highlands, midlands lowlands, and deserts, respectively. For more specific categorization of each agro-ecology, please refer to the Ethiopian Ministry of Agriculture (MoA), 2000.

[2] *Wereda* is the second lowest administrative unit (next to *kebele*) in Ethiopia

cropping pattern (they grow during both the *Mehere* and the *Belg* seasons). Thus, we estimated a production function only for the *Mehere* cropping season.

Detailed cost of the production data was collected at different production stages: land preparation, planting, weeding, harvesting, and postharvest processing. Labor inputs were disaggregated as adult male, adult female, and children. We believe that this approach of collecting data (both inputs and outputs) at different stages of production and at different levels of disaggregation reduces cognitive burden on the side of the respondents, while increasing the likelihood of retrieving better retrospective data. In our production function, the three forms of labor were aggregated as one labor input using adult equivalents.[3]

Monthly rainfall and temperature data were collected from all the metrological stations in the entire country. We then used the thin plate spline method of spatial interpolation to impute the household-specific rainfall and temperature values using each household's latitude, longitude, and elevation information. 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, thus ensuring that the generated rainfall and temperature data at the weather stations are exactly the same as the data at the weather station sites used for the interpolation. So, in our case, the rainfall and temperature data at the weather stations will be reproduced by the interpolation for those stations, which ensures the credibility of the method (see Wahba [1990] for details).[4]

Finally, although a total of 48 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. Our estimation of production function is limited to these crops. The scale of analysis is at plot level, and the basic descriptive statistics are presented in Table 1.

Table 1. Basic descriptive statistics of sampled farm households

Variables	Mean	Std. Dev.	Minimum	Maximum
Household/head characteristics				
Gender of household head (1 = male)	0.9253	0.2629	0	1
Age of household head (years)	45.09	13.84	16	92
Marital status of head (1 = married)	0.9046	0.2939	0	1
Literate household head (1 = yes)	0.4914	0.5000	0	1
Household size	6.6055	2.1874	1	15
Access to formal and informal institutional support				
Access to formal extension (1 = yes)	0.6054	0.4889	0	1
Farmer-to-farmer extension (1 = yes)	0.5103	0.5000	0	1
Access to formal credit (1=yes)	0.2568	0.4370	0	1
Number of relatives in a village	16.6148	43.2622	0	170
Climatic factors and adaptations				
Belg (short rain season) rainfall (mm)	312.5174	131.6499	84.3826	641.1218
Mehere (long rain season) rainfall (mm)	1,119.9250	340.5315	301.4326	1,777.7930
Average temperature (^{o}C)	17.7002	2.0321	13.0025	24.2330
Information received climate change through extension (1 = yes)	0.4260	0.4946	0	1

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[3] We employed the standard conversion factor in the literature in developing countries, where an adult female and children labor are converted into the adult male labor equivalent at 0.8 and 0.3 rates, respectively.

[4] We acknowledge Tingju Zhu of IFPRI for his support on interpolating the climatic data.

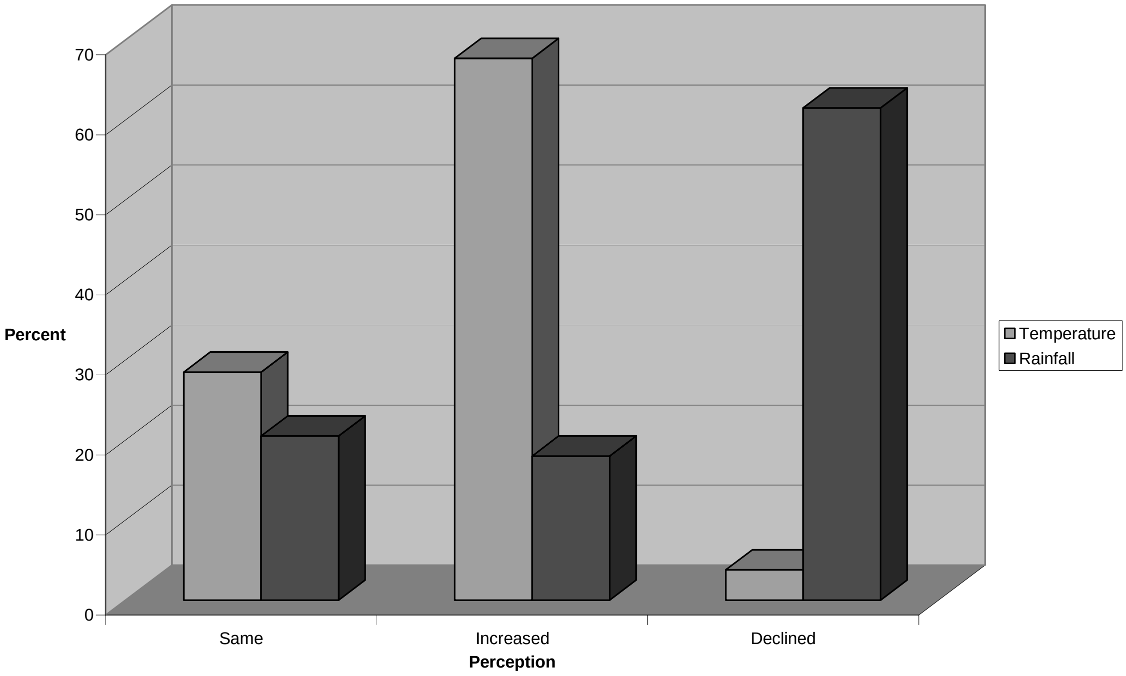
Table 1. Continued

Variables	Mean	Std. Dev.	Minimum	Maximum
Adaptation to climate change (1 = yes)	0.6338	0.4819	0	1
Agro-ecology				
Lowlands (Kolla)	0.2075	0.4056	0	1
Midlands (WeynaDega)	0.4841	0.4998	0	1
Highlands (Dega)	0.3084	0.4619	0	1
Production inputs and outputs				
Output per hectare (kg)	1,026.4990	1,194.6920	0	2,000
Seed use per hectare (kg)	114.2959	147.5515	10	260
Fertilizer use per hectare (kg)	59.6509	175.2201	0	410
Manure use per hectare (kg)	205.9626	888.2821	0	1,742.6
Labor use per hectare (adult days)	102.6744	172.4593	2.18	2,128

4. CLIMATE CHANGE AND ADAPTATION IN THE STUDY SITES[5]

One of the survey instruments was designed to capture farmers' perceptions and understanding of climate change, as well as their approaches to adaptations. Questions asked include whether the farmers have noticed changes in mean temperature and rainfall over the past two decades and their reasons for these observed changes. About 68 percent perceived mean temperature as increasing over the past 20 years; 4 percent, as decreasing; and 28 percent, as remaining the same. Similarly, 18 percent perceived mean annual rainfall as increasing over the past 20 years; 62 percent, as declining; and 20 percent, as remaining the same. Figure 2 depicts farmers' perceptions of climate change in our study sites. Overall, increased temperature and declining precipitation are the predominant perceptions in our study sites.

Figure 2. Households' perceptions on climate change over the past 20 years



In response to long-term perceived changes, farm households in our study sites have undertaken a number of adaptation measures, including changing crop varieties, adopting soil and water conservation measures, water harvesting, tree planting, and changing planting and harvesting periods. These adaptation measures 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 percentage of adaptation measures (fewer than 5 percent) were non–yield related and include migration and a shift in farming practices from crop production to livestock herding or other sectors. On the other hand, about 58 percent did not take adaptation measures in response to long term shifts in temperature and 42 percent did not take adaptation measures in response to long-term shifts precipitation. More than 90 percent of the respondents who took no adaptation measures indicated lack of information and shortages of labor, land,

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[5] This section draws heavily on Deressa, T., R. Hassen, T. Alemu, M. Yesuf, and C. Ringler. 2008. Analyzing the determinants of farmers' choice of adaptation measures and perceptions of climate change in the Nile Basin of Ethiopia. International Food Policy Research Institute (IFPRI) Discussion Paper No. 00798. Washington, DC: IFPRI.

and money as major reasons for not doing so. In fact, lack of information was cited as the predominant reason by 40 to 50 percent of the households. These results are summarized in Tables 2 and 3.

Table 2. Adjustments made to long-term shifts in climate change

	Temperature	Rainfall
Nothing	56.8	42.0
Implement soil conservation schemes	2.9	31.1
Changed crop variety	20.0	11.1
Planted trees	13.3	2.9
Harvested water	0.3	4.1
Sought off-farm activities	0.9	0.8
Planted late	0.4	0.4
Planted early	2.0	4.1
Migrated to urban area	0.2	1.1
Used irrigation	1.4	2.3
Sold livestock	1.4	0.1
Changed farming type (from crop to livestock)	0.2	0.3
Adopted new technologies	0.2	0.4

Table 3. Constraints to farm-level adaptations (in percentage)

Reason for not doing the following	Lack of Information	Lack of Money/Credit	Labor Shortage	Land Shortage	Water Shortage	Don’t See the Need	Other Reasons
Changing crop varieties	52	36	3	4	0.2	1	3.8
Water harvesting	41	27	18	3	1	2	8
Soil conservation	47	11	26	2	1	13	0
Planting trees	42	9	17	18	2	9	3
Irrigating	24	27	16	10	15	2	6

5. THE ECONOMETRICS APPROACH

We framed our analysis using the standard theory of technology adoption, wherein the problem facing a representative risk-averse farm household is to choose a mix of climate change adaptation strategies that will maximize the expected utility from final wealth at the end of the production period, given the production function and land, labor, and other resource constraints, as well as perceptions on long-term changes in climate. Assuming that the utility function is state independent, solving this problem would give an optimal mix of adaptation measures undertaken by the representative farm household, as given by

$$A_{ht} = A(x_{ht}^{h}, x_{ht}^{l}, x_{ht}^{c}; \beta) + \varepsilon_{ht} \tag{1}$$

where A is household h adaptation strategy at time t; x_{ht}^{h}, x_{ht}^{l}, x_{ht}^{c} are household characteristics, land and other farm characteristics, and climatic variables, respectively; β is the vector of parameters; and ε_{ht} is the household-specific random error term. Households will choose adaptation strategy 1 over adaptation strategy 2 if and only if the expected utility from adaptation strategy 1 is greater than that from adaptation strategy 2—that is, $E[U(A_1)] > E[U(A_2)]$.

This study employed a dummy variable to measure whether farm households had adopted any measure in any of their plots in response to perceived climate changes. In our study sites, we found that the adaptation decision is plot invariant; instead, it is a household-level decision. That is, if a farmer is facing changing weather conditions and decides to take action, he or she will do so for every piece of land at hand. It was also very uncommon to observe a household that chose a single adaptation strategy. Instead, each household usually chose a mix of adaptation strategies for its farm plots. Thus, assigning a specific adaptation measure to each household would be a crude measure of the optimal mix of adaptation strategies that each household chose. Thus, the dummy variable was a preferred and plausible alternative for measuring whether a particular household had adopted an adaptation strategy to avert or minimize the adverse effects of perceived climate change.

A probit regression fit our data to estimate determinants of adaptation as specified by equation (1). This study's central focus is to investigate whether climate change and adaptation have any impact on food production, with adaptation measured by a dummy variable entered into a standard household production function, y_{ht}:

$$y_{ht} = f(x_{ht}^{s}, x_{ht}^{c}, A_{ht}, \gamma) + \xi_{ht} \tag{2}$$

where x_{ht}^{s}, x_{ht}^{c}, r_{ht} are conventional inputs, climatic factors, and climate change adaptation measure, respectively; γ is a vector of parameters; and ξ_{ht} is a household-specific random error term.

To estimate the food production model in equation (2), we employed a pseudo-fixed-effect model. Use of a standard fixed-effect model would have an obvious advantage over random effect and other linear models (e.g., Tobit or truncated regressions), because it would enable us to produce consistent parameter estimates by controlling unobserved heterogeneity that might be correlated with observed explanatory variables. However, standard fixed-effect models rely on data transformation, which removes the individual effect. Thus, it can be important to instead model the individual effect. This was particularly true in our case, in which the variable of interest (adaptation) was measured at the household level. One way to address this issue is to run a random effect model while at the same time controlling for unobserved heterogeneity using pseudo-fixed effect model (Mundlak 1978; Wooldridge 2002).

The right side of our pseudo-fixed-effect regression equation includes the mean value of the time (plot)–varying explanatory variables, following Mundlak's (1978) approach. Mundlak's approach relies on the assumption that unobserved effects are linearly correlated with explanatory variables, as specified by

$$\psi_h = \bar{x}\alpha + \eta_h, \; \eta_h \sim \mathrm{iid}(0, \sigma_\eta^2) \tag{3}$$

where $\bar{x}$ is the mean of the time (plot)–varying explanatory variables within each household (cluster mean), α is the corresponding vector coefficient, and η is a random error unrelated to $\bar{x}$'s. The vector α will be equal to 0 if the observed explanatory variables are uncorrelated with the random effects. We conducted an F-test against the null hypothesis that the vector α are jointly equal to zero and the test results rejected the null hypothesis and justified the relevance of fixed effects.

Selection and endogenity biases are the two common sources of bias of non-fixed effect models. This is particularly true in this study since our variable of interest, the adaptation variable, is included in the right hand side of equation (2). The use of fixed-effects techniques and Mundlak's approach in our study helped address the problem of selection and endogeneity bias where the selection and endogeneity biases are due to time (plot)–invariant unobserved factors, such as household heterogeneity (Wooldridge 2002). If we had failed to control for these factors, we would not have obtained the true effect of adaptation.

To further address the issue of endogeneity bias, we considered the situation in which the correlation between the error term and climate adaptation would not happen via the individual fixed effect. In this situation, only controlling for the time (plot)–invariant unobservable characteristics may not have been enough. The estimated coefficients could still have been unreliable. We used some of the explanatory variables in equation (1) as instruments. The appropriate implementation of the estimator requires that the set of explanatory variables used as instruments should not be correlated with the error term in equation (2) but instead be correlated with the endogenous variables. Thus, to scrutinize our choice of instruments, we tested for their relevance by using an F test of the joint significance of the excluded instruments. We rejected the null hypothesis, indicating that the instruments are relevant. We also tested the over-identification restrictions using a Sargan/Hansen test of over-identifying restrictions and we found an over-identified equation in which the number of instruments exceeded the number of covariates. Overall, we failed to reject the null hypothesis that the excluded instruments are valid. The instruments are uncorrelated with error term and correctly excluded from the estimated equation. In addition, because the predicted values, and not the true values, of adaptation were used, the standard errors are bootstrapped.

6. RESULTS AND DISCUSSION

Tables 4, 5, and 6 report the estimates of the empirical analysis. Table 4 presents the probit results of the adaptation regression. The decision to employ adaptation measures is assumed to be a function of household characteristics (i.e., gender, age, marital status, literacy, and household size), formal and informal institutional support (formal extension, farmer-to-farmer extension, access to credit, social capital), climatic factors (i.e., *Belg* and *Mehere* rainfall levels, temperature level, information about future climatic conditions), and the farm household's agro-ecological setting. The results suggest that information about future climate change and access to formal and informal institutions tend to strongly govern each household's adaptation decisions. These results are consistent with a similar study by Deressa et al. (2008), which used a multinomial logit model in the Nile Basin. Households with good access to formal agricultural extension, farmer-to-farmer extension, credit, and information about future climate change tend to apply adaptation measures on their farms in comparison with those households that do not have this access. Likewise, households that experienced higher rainfall than average in the *Belg* season also seemed to adopt some climate change adaptation strategies in comparison with those that did not receive such rainfall. However, these households were less likely to employ any adaptation measures when the *Mehere* season was more than average, though this effect is not statistically significant.

Table 4. The determinants of on climate adaptation: Probit estimates

Variables	Coeffs.	Std. Errors	P Value
Household/head characteristics			
Male head	0.0509	0.1630	0.755
Age	0.0082	0.0026	0.001
Married	–0.1551	0.1473	0.292
Literate	0.2846	0.0646	0.000
Household size	0.0242	0.0142	0.088
Access to formal and informal institutional support			
Formal extension	0.4219	0.0758	0.000
Farmer-to-farmer extension	0.5061	0.0788	0.000
Access to formal credit	0.1389	0.0706	0.049
Relatives in a village	0.0095	0.0021	0.000
Climatic factors and adaptations			
Belg rainfall	0.0015	0.0002	0.000
Mehere rainfall	–0.0001	0.0001	0.457
Average temperature	–0.2683	0.0190	0.000
Climatic info extension	0.3639	0.0767	0.000
Agro-ecology			
Lowlands (Kolla)			
Midlands (WeynaDega)	–0.6269	0.0983	0.000
Highlands (Dega)	–0.4384	0.1088	0.000
Constant	3.8945	0.4418	0.000
LR chi2(15) = 1109.94; Prob > chi2 = 0.0000; Pseudo R2 = 0.3134			

Table 5. Food production model: Pseudo-fixed-effect results

Variables	Coeffs.	Std. Errors	P Value
Climatic factors and adaptations			
Climate adaptation	95.6948	48.0426	0.046
Belg rainfall	1.6169	0.8628	0.061
Mehere rainfall	0.7888	0.3740	0.035
$(\text{Belg})^2$	–0.0026	0.0013	0.046
$(\text{Mehere})^2$	–0.0003	0.0002	0.066
Average temperature	80.6761	117.7563	0.493
Standard production inputs			
Seeds	2.7685	0.1845	0.000
Fertilizers	0.8066	0.1489	0.000
Manure	0.1261	0.0304	0.000
Labor	0.7971	0.1455	0.000
Agro-ecology			
Lowlands (Kolla)	Reference agro-ecology		
Midlands (WeynaDega)	–502.4261	66.8271	0.000
Highlands (Dega)	96.4692	73.5773	0.190
Mean value of plot varying variables			
Average fertilizer use	–0.6403	0.2294	0.005
Average labor use	–0.1703	0.2526	0.500
Average manure use	–0.0829	0.0492	0.092
Average seed use	0.5848	0.3077	0.057
Average soil fertility	–120.6559	39.2812	0.002
Constant	1222.147	1043.758	0.242
Sigma_u	174.3161		
Sigma_e	953.0537		
Rho	0.032		
Wald chi2(18) = 1025.41; Prob > chi2 = 0.0000; Overall R2 = 0.2733; N=2859			

Table 6. Food production model: two-stage least-square (2SLS) results

Variables	Coeffs.	Std. Errors (bootstrapped)	P Value
Climatic factors and adaptations			
Climate adaptation	300.2321	136.5869	0.028
Belg rainfall	1.3351	0.8805	0.130
Mehere rainfall	1.1038	0.4011	0.006
$(\text{Belg})^2$	–0.0022	0.0013	0.097
$(\text{Mehere})^2$	–0.0005	0.0002	0.015
Average temperature	–12.5768	19.3283	0.515
Standard production inputs			
Seeds	3.0107	0.1512	0.000
Fertilizers	0.4772	0.1153	0.000
Manure	0.0874	0.0259	0.001
Labor	0.7313	0.1223	0.000
Agro-ecology			
Lowlands (Kolla)	Reference agro-ecology		
Midlands (WeynaDega)	–430.2581	68.7719	0.000
Highlands (Dega)	212.5593	74.1471	0.004
Constant	1541.912	426.2497	0.000
Partial R-squared of excluded instruments: 0.0422 Test of excluded instruments: F(12, 2679) = 81.35; Prob > F = 0.0000; Adjusted R2 = 0.2591; N=2679			
Hansen J statistic (over-identification test of all instruments): 3.847 Chi-sq(5) P-val = 0.27843			

We also observed significant differences in the likelihood of households' employing climate change adaptation strategies across agro-ecologies. Households in highlands (*Dega*) and midlands (*WeynaDega*) were less likely to take climate change adaptation measures than were households in the lowlands (*Kolla*). There was also a significant difference across age and literacy levels of the heads of households, as well as across the size of households. Old and literate household heads were more likely to adopt climate change adaptation measures than were younger or less-literate ones. Similarly, larger households were more likely to adopt than were smaller households, highlighting the role of household labor on the adoption decision.

Tables 5 and 6 report the estimated production function results with the pseudo-fixed-effect model and the two-stage least-square (2SLS) results, respectively. In the 2SLS model, we explored alternative functional forms and found the quadratic specification to be more robust. The production function estimates tell consistent stories in both model specifications. First, results show that the estimated coefficient for adaptation is positive and statistically significant. Farmers who adopted climate change adaptation strategies had higher food production than those who did not. Based on marginal effect estimates of our results, households with climate change adaptation measures tended to produce about 95 kg to 300 kg more food per hectare than did those who did not take such measures. This accounts for 10 to 29 percent of change in output in our study sites. In other words, the effect of climate change will be reduced by such a magnitude if households take adaptation measures.

Second, farm-level climatic variables are quite significant in explaining variations of food production across farm households. In both specifications, temperature level did not seem to explain variations in yield levels in our study sites. Precipitation levels, however, were significant in both specifications (except for *Belg* rainfall in the 2SLS specification, which is insignificant). However, precipitation tends to affect production in nonlinear ways. Controlling for agro-ecology and other major factors of production, an increase in both *Belg* and *Mehere* rainfall seemed to increase food production. However, too much or too little of both the *Belg* and *Mehere* rainfall seemed to affect food production negatively in our study sites.

Third, all the conventional inputs exhibit signs consistent with predictions of economic theory, and all are statistically significant. As expected, more use of seeds, fertilizers, manure, and labor tended to increase food production. There is also a significant difference across agro-ecologies once the standard production inputs, climatic variables, and climate adaptation variables were controlled for. More food per hectare was being produced in highlands (*Dega*), followed by lowlands (*Kolla*), than in midlands (*WeynaDega*).

Finally, the parameter estimates meant that values of plot-varying variables—α in equation (3)—are significant. This fact justifies the robustness of our pseudo-fixed-effect model over a standard random effect, Ordinary Least Square (OLS), or Tobit estimate, as well as the need to address unobserved heterogeneities in such food production models, which otherwise would result in biased and inconsistent results and wrong policy conclusions.

7. CONCLUDING REMARKS

This paper investigates factors affecting adoption of climate change adaptation strategies and the impact of climate change adaptation on food production using plot-level data from 1,000 farm households within the Nile Basin of Ethiopia. Mundlak's (1978) pseudo-fixed-effect and two-stage least-square models were employed to control for unobserved heterogeneities and endogeneity that would potentially bias the estimates. Our results indicate that apart from household characteristics, adoption of yield-enhancing adaptation strategies in our study sites was affected by informal and formal institutional support, provision of information on future climate change, and current levels of climatic variables. This result underlines the need to provide appropriate and timely information on future climate changes to farmers to alert them to take appropriate averting actions. The fact that access to credit markets, social ties and networks, and government and farmer-to-farmer extension is significant in the probit model indicates the role of both formal and informal institutions in addressing the issues of climate change adaptations in poor communities, like the ones in our sites. Finally, the fact that the adaptation variable is positive and significant in our estimates of production function indicates that adoption of yield related adaptation strategies have a win-win outcome. It helps in coping the adverse effects and risk of climate change while increasing agricultural productivities in poor farm households. Averting the effects of climate change and achieving food security are the two top development agendas of policymakers and development agencies. Future research should focus on specific adaptation measures in different agro-ecologies.

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