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# Adaptation to Climate Change and Variability and Its Implications for Household Nutrition in Kenya

**Jane Kabubo-Mariara, Richard M. Mulwa, and Salvatore Di Falco**

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## Abstract

Climate change and variability are affecting weather patterns and causing seasonal shifts with serious repercussions for households and communities in Kenya. The livelihoods of the majority of Kenyans are therefore threatened due to the potential adverse impacts of climate change, such as declining production and productivity, which could lead to food insecurity. To mitigate the negative impacts of climate change and variability, farmers need to adopt different strategies, such as new crop varieties, crop and livestock diversification, and water-harvesting technologies. These climate change adaptation strategies are expected to influence the level of food production (hence food security) in the country, and therefore their linkages with food security in Kenya need to be studied. It is against this background that this study was undertaken to assess factors influencing climate change adaptation and the implications of adaptation for nutrition, measured in kilocalories (Kcal) produced. To accomplish this task, an endogenous switching regression model is applied to household survey data of 708 households from 38 counties in Kenya. The results demonstrate that mean temperature does not influence Kcal production but increased precipitation can negatively or positively influence Kcal production, depending on whether it rains during harvest, land preparation or crop growing periods. Households living in areas with different soil types are likely to produce varying quantities of Kcal depending on the soil type. This requires intervention in improving soil fertility, alongside adopting crop enterprises suitable for these areas. In addition, older and more experienced farmers will produce more nutrition compared to younger farmers with little farming experience. Finally, it is shown that farmers who adapted to climate change produced 1,305,414 Kcal against 564,789 Kcal for households that did not adapt. The treatment effects results show that farm households that actually adapted would have produced about 996,224 Kcal less (that is, about 23.7% less) if they had not adapted. By contrast, if farmers who did not adapt had adapted, they would have produced about 773,879 Kcal more (that is, about 27.01% more). Thus, adaptation to climate change significantly increases production of nutrition.

**Key Words:** climate change, food security, Kcal/ha, adaptation, endogenous switching regression

**JEL Codes:** Q18, Q54

## Contents

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## 1. Introduction

According to UNDP (2008), the impacts of climate change, which include droughts, heat waves, floods and rainfall variation, will add 600 million people to the number facing malnutrition, and will increase the number of people facing water scarcity by 1.8 billion by the year 2080. At present, about a billion people worldwide live in chronic hunger, and humanity’s inability to offer them sustained livelihood improvements has been one of its most obdurate shortcomings (Lobell and Burke, 2010). Climate change affects agriculture and thus has a direct impact on food production.

The Intergovernmental Panel on Climate Change (IPCC, 2001) contends that climate change will lead to an expected reduction in agricultural productivity in already fragile areas, especially in sub-Saharan Africa (SSA). Most developing countries, especially in Africa, are already grappling with scarce food reserves due to high levels of poverty, low levels of human and physical capital, and inadequate infrastructure. Climate change and variability is expected to exacerbate the effect of food insecurity in these countries due to their high vulnerability to climate variability and heavy dependence on rain-fed agriculture (Nelson et al., 2009). IPCC predicts that, by 2050, crop yields in sub-Saharan Africa will have declined by 14% (rice), 22% (wheat) and 5% (maize), pushing the vast number of already poor people, who depend on agriculture for their livelihoods, deeper into poverty and vulnerability. It also predicts decreased food availability by 500 calories per person (a 21% decline) in 2050 and a further increase in the number of malnourished children by over 10 million, to a total of 52 million in 2050 in sub-Saharan Africa alone. Africa is at the tip of the spear of climate change impacts, mainly due to the interactions of multiple stressors, including extreme poverty, over-dependence on rain-fed agriculture, HIV/AIDS prevalence, insufficient public spending on rural infrastructure, poor data availability and quality, and knowledge gaps (IPCC, 2007).

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These stressors contribute to a weak overall adaptive capacity, and thus may compound poverty for vulnerable groups.

Adaptation to climate change is widely acknowledged as a vital component of any policy response.[1] Studies show that low-input farming systems, such as subsistence agriculture in marginal areas, are not only unsustainably depleting the natural resource base but also demonstrably ineffective at alleviating rural poverty (IPPC, 2007; Milder et al., 2011). Therefore, given the low-input farming systems coupled with low adaptation among most poor rural farmers, climate change will compound farmers' problems and push them onto a razor's edge of survival; with adaptation, however, vulnerability can be substantially reduced (Adams et al., 1998; FAO, 2008).

Adaptation to climate change involves a two-stage process: first, perceiving change and, then, deciding whether or not to adapt (Maddison, 2006). Perception, is therefore, a precondition for adaptation. Agricultural adaptations embrace a wide range of options that include micro-level options, such as crop diversification and altering the timing of operations; market responses, such as income diversification and credit schemes; adaptive capacity and institutional strengthening, such as developing meteorological forecasting capability, improvement in agricultural markets and information provision; and technological developments, such as development and promotion of new crop varieties and integrated water management (Smit and Olga, 2001; SEI, 2009). Most of these choices represent possible adaptation measures rather than actual farm-level adaptation strategies. Indeed, there is limited evidence that the possible adaptation options are feasible, realistic, or even likely to occur (Burton et al., 2002).

Most studies on the impact of climate change in Africa have concentrated on the impact of climate change on crop and livestock productivity, while others have assessed adaptation to climate change.[2] Most of the studies also have evaluated the extent to which farm-level strategies – such as early planting, use of irrigation or water harvesting techniques, diversification of crop and livestock varieties, use of drought-resistant crops,

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[1] Adaptation to climate change in this paper refers to any deliberate action to alter household actions in order to lessen the possible impact of climate change.

[2] See, for instance, Kabara and Kabubo-Mariara (2011); Herrero et al. (2010); Roncoli et al. (2010); Kabubo-Mariara (2008; 2009); Deressa et al. (2009); Dinar et al. (2008); Hassan and Nhemachena (2008); Kabubo-Mariara and Karanja (2007); Deressa et al. (2005); Gbetibouo and Hassan (2005); Turpie et al. (2002).

adjustment of planting dates, and terracing, among others – can lessen the expected impact of climate change. This study contributes to the literature by quantifying how adaptation to climate change and variability influences food security at the farm level.

The point of departure that differs from related studies is that most micro-level studies use one or a few crops to study the impact of adaptation to climate change on food security. This has been occasioned by aggregation problems across different quantities of various farm crops. To overcome this hurdle, this study used aggregated kilocalories for all crops. To achieve this, we converted the crops produced by the sampled farmers into Kcal by multiplying the produced quantities with edible Kcal of the different crops. Therefore, the dependent variable used in this analysis was Kcal/ha. This study covered most food crops produced on Kenyan farms, which gives a more balanced picture of the farm, compared to approaches that have adopted partial analysis using one or a few crops. The main shortcoming of our approach is that the value of crops is not determined by the edible kilocalories (as these are not sold in the market), but by the quantities harvested and sold. A related assumption is that households produce for consumption and no output is destined for the markets. This argument can be sustained in a smallholder production setup, as they mainly produce for subsistence.

## 2. Review of Literature

Climate change and variability affects four dimensions of food security: food production and availability; stability of food supplies; access to food; and food utilization (FAO, 2008; Schmidhuber and Tubiello, 2007; Ludi, 2009; Parry et al., 2009).

A number of studies have linked climate change and food security. For instance, Di Falco et al. (2011), in a study on the impact of adaptation to climate change on food security in Ethiopia, found significant differences in food productivity between households that adapted and those that did not adapt to climate change. Schmidhuber and Tubiello (2007), in a review of the potential impacts of climate change on food security, provide quantitative evidence that climate change will adversely affect food security. They argue, however, that the overall impact of climate change on food security depends on the overall socio-economic status that a country has achieved when the effects of climate change set in. The findings are corroborated by Ludi (2009) in a review of the link between climate change, water and food security. Arndt et al. (2011), in a study of Tanzania, found that food security is likely to deteriorate due to increases in temperature and changes in rainfall patterns, but that the impact of climate change is likely to vary by climate scenario, sector and region.

In a global study, Parry et al. (2004) found that climate change is not only likely to lead to declining crop yields, but is also likely to increase the disparities in cereal yields between developed and developing countries. Gregory et al. (2005) demonstrate that the impact of climate change on food security varies both between regions and between different societal groups within a region, a finding supported by Parry et al. (2005), who found that the impact of climate change on the risk of hunger is greatly influenced by pathways of development, and that Africa is at the greatest risk from climate change. Rosenzweig and Parry (1994) had also established that climate change is likely to increase disparities in food supply between developed and developing countries. They advanced that, while cereal production in developed countries could benefit from climate change, production in developing countries is likely to be adversely affected, even in the face of high-level farm adaptation measures.

The bulk of studies on climate change use the Ricardian model following Mendelsohn et al. 1994 (see also Mendelsohn et al., 2003). Modified approaches that take into account limitations of the Ricardian approach include Deschenes and Greenstone (2007; 2011), who advocated for a panel data fixed effects estimator and further innovated by accounting for time and individual-specific heterogeneities (Deschenes and Greenstone, 2007). The authors, however, cautioned that short-run variation in weather may lead to temporary changes in prices that obscure the true long-run impact of climate change, while farmers cannot undertake the full range of adaptations in response to a single year’s weather realization. These concerns were also raised by Massetti and Mendelsohn (2011). While these studies used agricultural profits as the dependent variable, it has been argued that farm profits could underestimate or overestimate farm returns. Roberts and Schlenker (2009; 2013) advocate the use of the sum of edible calories derived from the farmed crops as the dependent variable. This, they argue, presents a simple yet broad-scale analysis of the actual food situation in the household and can be used as an estimate of the household calorific food security.

Studies that have employed the Ricardian model in Africa include Molua (2002), who, in an analysis of the impact of climate on agriculture in Cameroon, found that increased precipitation is beneficial for crop production and that farm-level adaptations are associated with increased farm returns. Deressa et al. (2005), in a study on South African sugarcane production, show that climate change has significant non-linear impacts on net revenue, with higher sensitivity to future increases in temperature than to precipitation. Contrary to findings by Deressa et al. (2005), Gbetibouo and Hassan (2005) argue that irrigation would be an effective adaptation measure for limiting the harmful effects of climate change, and that the impact of climate change is agro-ecological zone specific.

In a study of the effects of climate change on food security in Kenya, Kabubo-Mariara and Kabara (2015) found that climate variability and change will increase food insecurity. They further found that food security responds positively to favourable agro-ecological zones, soil drainage and depth, and high population density. The results support Kabara and Kabubo-Mariara (2011), who found that global warming leads to decline in output. The results also find support in Molua's 2008 study of Cameroon. Kabubo-Mariara (2009) found that, in the long term, climate change is likely to lead to increased poverty, vulnerability and loss of livelihoods in Kenya. Kabubo-Mariara and Karanja (2007) found that climate affects crop productivity, but show that the temperature component of global warming is much more important than precipitation.

Other studies have used the production function approach. These include Turpie et al. (2002) in South Africa; Mohamed et al. (2002) in Niger; Downing (1992) in Zimbabwe and Kenya; and Schulze et al. (1993) in South Africa, Lesotho and Swaziland. The studies show that climate change has significant implications for food production in Africa.

This study, though related to other studies on climate change and food security, will build on existing literature in this area, but will innovate over other studies in both methods and choice of indicators of food security.

## 3. Data and Descriptive Statistics

### *3.1. Data Types and Sources*

The household data for this study were collected from six out of eight provinces in Kenya in 2004/5, covering 38 out of 47 counties. Two provinces were excluded from the sample: Nairobi because of urbanization, and North Eastern Kenya because of aridity, as well as inaccessibility of households and other field logistics. The sampled counties captured variability in a wide range of agro-climatic conditions (rainfall, temperatures and soils), market characteristics (market accessibility, infrastructure, etc.) and agricultural diversity, among other factors. Each county was divided into agro-ecological zones. Samples of three different farm types/sizes – large (>8 hectares), medium (2-8 hectares) and small (0-2 hectares) – were chosen from each ecological zone. Detailed information from the Ministry of Agriculture and from the Farm Management Handbook

(Jaetzold and Schmidt, 1982) was used to help identify agro-ecological zones and farm types. The sampling procedure was purposely designed to target at least four households from each agro-ecological zone, comprising at least one household from each farm type. The agro-ecological zones are illustrated in Table 1 below.

**Table 1. Agro-Ecological Zones in Kenya**

| Agro-Ecological zone Number | Ratio of rainfall to potential evaporation | Agro-Ecological zone | Possible crops and cropping systems |
|---|---|---|---|
| 0 | >1.20 | Per humid | Forest area |
| I | 0.80-1.20 | Humid | Tea, dairy |
| II | 0.65-0.79 | Sub-humid | Wheat, Maize, Beans, Irish Potatoes |
| III | 0.50-0.64 | Semi-humid | Beans and other pulses, Maize, Wheat, Cotton, Cassava |
| IV | 0.40-0.49 | Transitional | Barley, Cotton, Maize, Groundnut, Sorghum |
| V | 0.25-0.39 | Semi-arid | Livestock, Beans, Pigeon peas, Sweet potatoes, Sorghum, Millet |
| VI | 0.10-0.24 | Arid | Ranching and cropping only under irrigation |
| VII | <0.10 | Per arid | Rangeland |

Source: Jaetzold and Schmidt, 1982.

The data sets for climate variables were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis-Interim (ERA-Interim) Model, which archives the data in daily, twice daily, ten-day and monthly formats. The resolution of the data is 1.5 degrees by 1.5 degrees (approximately 150 km).[3] ECMWF is the most comprehensive model in terms of archiving most of the common and uncommon weather parameters. Precipitation data are measured in millimeters, while temperature data are measured in degrees Celsius.

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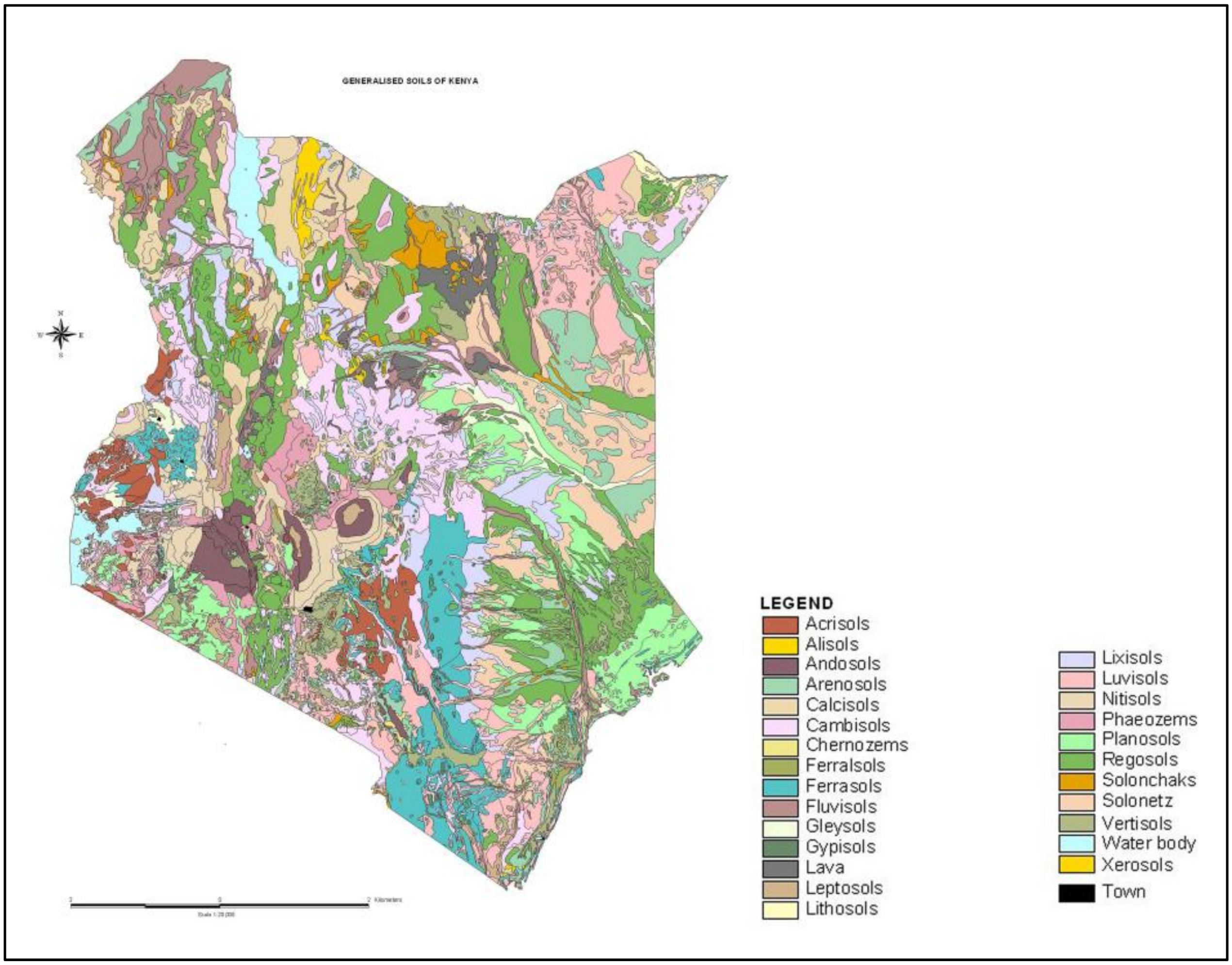
[3] Data with finer resolutions were available, but the problem was the time span. For instance, daily precipitation satellite data was retrieved from the Climate Prediction Centre (CPC) of the U.S. National Oceanic and Atmospheric Administration (NOAA) with a resolution of 0.1 degree by 0.1 degree (about 10km), while precipitation was obtained from the UK Met Office with a resolution of 50km by 50km. A collection of daily parameters from the ECMWF model can be found at http://data-portal.ecmwf.int/data/d/interim_daily/.

Soil data was obtained from the Food and Agricultural Organization (FAO, 2003). Kenya has at least 28 different types of soil but we focused only on the key types in the six sampled provinces, which can be divided into seven main groups: cambisols, ferrasols, lithosols, nitisols, andosols, vertisols and planosols. About 40% of Kenya is covered by nitisols and ferrasols. Ferrasols are very old, highly weathered and leached soils, and therefore have poor fertility, which is restricted to the topsoil, as the subsoil has a low cation exchange capacity. Phosphorous (P) and Nitrogen (N) are always deficient in ferrasols. Nitisols occur in highlands and on volcanic steep slopes. They developed from volcanic rocks and have better chemical and physical properties than other tropical soils, including good moisture-storage capacity and aeration. Nitisols often have a high clay content and are the best agricultural soils found in the East African region. They are intensely used for plantation crops and food production (Gachene and Kimaru, 2003). All other soils cover relatively small proportions.

**Figure 1. Generalized Soil Map of Kenya**



Source: Kenya Soil Survey.

### *3.2. Descriptive Statistics*

In the survey, production data for different crops were collected on a per-kilogramme basis, which presented challenges in aggregation across the quantities of different crops. For this reason, the quantities of crops produced were converted into their kilocalories (Kcal) equivalent per ha. This made summation across the crops feasible. Using the figures in Table 2, the respective quantities (in kgs) for different crops produced by different farmers were multiplied by the Kcal/kg parameters as shown, and then converted on a per-hectare basis. On average, the production of edible Kcal was 668,293 Kcal/ha per year for adapters and 417,794 Kcal/ha for non-adapters. For purposes of regression, we then took the natural logarithms of the Kcal for the different households.

### Table 2. Kcal/kg Conversion Table

| Crop | Kcal/kg | Crop | Kcal/kg | Crop | Kcal/kg |
|---|---|---|---|---|---|
| Apples | 520 | Mango | 650 | Sesame | 5,730 |
| Banana | 890 | Maize | 3,620 | Sorghum | 3,390 |
| Barley | 3,320 | Millet | 3,280 | Soybean | 4,150 |
| Beans | 3,330 | Palm seed | 2,030 | Spinach | 220 |
| Cassava | 1,600 | Onion | 400 | Sugarcane | 260 |
| Citrus | 470 | Pigeon pea | 3,430 | Sunflower | 5,880 |
| Chickpea | 1,640 | Pineapple | 480 | Tomato | 210 |
| Cowpeas | 3,360 | Plantain | 750 | Wheat | 3,390 |
| Grapes | 550 | Potato | 580 | Yam | 970 |
| Peanuts/Groundnuts | 5,670 | Rice | 3,580 | | |

*Source*: FAO Food Balance Sheets: A Handbook (2001); Lukmanji et al. (2008).

The variables presented in Table 3.1 are expected to influence farmers’ adaptation to climate change. The criteria for selecting such variables are based on related studies, such as Kabara and Kabubo-Mariara (2011), Herrero et al. (2010), Kabubo-Mariara (2008; 2009), Deressa et al. (2009), and Hassan and Nhemachena (2008), among others. For instance, household characteristics such as gender, age and education are unique to an individual and may be critical in adapting to climate change and variability. Other variables are external to the person but are within the household realm and are likely to influence a farmer’s adaptation decisions. For example, if a certain adaptation strategy requires a lot of capital and the household is poorly endowed with resources, then this may deter the household from adapting. Also important are farm production inputs such as labour, seed, fertilizer, etc. which directly influence the amount of Kcal produced on the farm.

Household assets such as machinery, buildings and livestock are measures of wealth which might influence adaptation, or might be sources of capital or other inputs required for adaptation, and hence are expected to influence adaptation. The mean values for these assets for adapters and non-adapters are shown in Table 3.1.

The type of soil in a certain locality is critical because it determines the fertility of the area, which might in turn be crucial to the success of a certain climate change adaptation strategy. For instance, it may not be prudent to diversify from livestock farming to crop farming in an area with poor soils. Table 3.2 shows the different soils considered in this study. These range from cambisols to planosols. Statistics indicate that most farmers are in areas with ferrasols and nitisols.

## Table 3.1. Descriptive Statistics – Household Level Variables

| Variable Name | All Farmers | | Adapters | | Non-Adapters | |
|---|---|---|---|---|---|---|
| Dependent variables | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Adapt (Yes/No) | 0.4039 | 0.4910 | 1.00 | 1.00 | 0.00 | 0.00 |
| Kcal/ha | 585,370.35 | 42,576.09 | 667,970.97 | 9,001.07 | 538,207.79 | 39,933.79 |
| Household Characteristics | | | | | | |
| Gender (1=male) | 0.88 | 0.32 | 0.91 | 0.28 | 0.86 | 0.34 |
| Age (years) | 51.71 | 12.26 | 51.73 | 12.85 | 51.69 | 11.85 |
| Education (years) | 10.19 | 3.74 | 10.05 | 3.55 | 10.28 | 3.87 |
| Household size | 6.54 | 2.43 | 6.62 | 2.30 | 6.49 | 2.51 |
| Hired labour wage (Ksh/day) | 93.90 | 33.44 | 91.26 | 34.93 | 95.91 | 32.16 |
| Farmer does farm work | 0.8121 | 0.3909 | 0.8462 | 0.3614 | 0.7891 | 0.4084 |
| Farmer does non-farm work | 0.4958 | 0.5003 | 0.4545 | 0.4988 | 0.5237 | 0.5000 |
| Farm experience (Years) | 21.81 | 12.32 | 23.10 | 12.30 | 20.94 | 12.27 |
| Farm Assets | | | | | | |
| Livestock value (Ksh) | 51,772 | 88,445 | 38,911 | 48,287 | 61,675 | 108,889 |
| Buildings value (Ksh) | 172,438 | 401,070 | 156,277 | 426,850 | 183,036 | 383,447 |
| Machine value (Ksh) | 9,579 | 46,478 | 8,359 | 45,256 | 10,412 | 47,330 |
| Cost of farm inputs | | | | | | |
| Total Family Labour/Ha | 72.57 | 101.48 | 73.56 | 100.49 | 71.91 | 102.26 |
| Total Hired Labour/Ha | 36.30 | 51.98 | 36.66 | 45.51 | 36.04 | 56.30 |
| Total Seed Value/Ha | 2716.07 | 3191.27 | 2679.86 | 2868.50 | 2741.09 | 3399.65 |
| Total Fertilizer/Ha | 124.21 | 181.57 | 127.29 | 197.95 | 122.10 | 169.72 |
| Tot Pesticide Value/Ha | 2732.42 | 4849.20 | 2329.39 | 4456.63 | 3033.42 | 5111.35 |
| Institutional variables | | | | | | |
| Climate extension | 0.2994 | 0.4583 | 0.3182 | 0.4666 | 0.2867 | 0.4528 |
| Agriculture extension | 0.6963 | 0.4602 | 0.7762 | 0.4175 | 0.6422 | 0.4799 |
| Number of extension visits/year | 9.13 | 12.85 | 9.680 | 13.392 | 8.68 | 12.39 |
| Credit Access | 0.1088 | 0.3116 | 0.12 | 0.33 | 0.0995 | 0.2997 |

*Note*: 1 Ksh. (Kenyan shilling) is approximately equal to USD .01.

### Table 3.2. Descriptive Statistics – Soil and Climate Variability

| Variable Name | All Farmers | | Adapters | | Non-Adapters | |
|---|---|---|---|---|---|---|
| Soil Information | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Cambisols | 0.2139 | 0.1139 | 0.2056 | 0.1118 | 0.2206 | 0.1155 |
| Ferrasols | 0.4211 | 0.2683 | 0.4101 | 0.2668 | 0.4290 | 0.2698 |
| Lithosols | 0.2180 | 0.1759 | 0.2189 | 0.1842 | 0.2174 | 0.1706 |
| Nitosols | 0.4104 | 0.2509 | 0.4137 | 0.2579 | 0.4083 | 0.2468 |
| Andsols | 0.2196 | 0.0914 | 0.2299 | 0.0739 | 0.2137 | 0.0999 |
| Vertisols | 0.1897 | 0.0990 | 0.1674 | 0.0715 | 0.2027 | 0.1105 |
| Planosols | 0.2380 | 0.1676 | 0.3231 | 0.1904 | 0.1889 | 0.1318 |
| Climate variability variables | | | | | | |
| Temp. Dec.-Feb. | 19.33 | 2.60 | 19.37 | 2.67 | 19.30 | 2.56 |
| Temp. March –May | 19.13 | 2.65 | 19.22 | 2.79 | 19.07 | 2.55 |
| Temp. June –August | 18.59 | 2.36 | 18.69 | 2.55 | 18.53 | 2.22 |
| Temp. Sept.- Nov. | 19.05 | 2.57 | 19.09 | 2.70 | 19.02 | 2.49 |
| Precip. Dec.-Feb. | 87.88 | 54.08 | 88.64 | 54.74 | 87.36 | 53.68 |
| Precip. March –May | 109.80 | 27.79 | 111.81 | 28.07 | 108.43 | 27.55 |
| Precip. June –August | 68.55 | 42.31 | 71.62 | 43.82 | 66.46 | 41.19 |
| Precip. Sept.- Nov. | 73.25 | 22.95 | 74.49 | 23.57 | 72.41 | 22.51 |

*Note*: The mean in each soil category represents the mean proportion of land under the particular soil type.

Kenya depends on rain-fed agriculture, and therefore climatic factors such as rainfall (moisture) and temperature are critical to the success of agriculture. Rainfall and favourable temperatures directly determine the quantity of Kcal produced. These variables are likely to influence adaptation strategies such as crop diversification, early planting, adoption of resistant crops, etc. In Table 3.2, we cluster temperatures and precipitation into four quarters of December to February (spring), March to May (summer), June to August (winter) and September to November (autumn).

The last set of variables – institutional variables – are expected to have some influence on the decision of a household to adapt a certain strategy and, hence, on Kcal produced on the farm. For instance, access to general agricultural extension information or climate-specific information is expected to change a farmer’s perception of climate change, and possibly influence his/her adaptation. The institutional environment is part of so-called planned adaptation.[4] However, the institutions promoting planned adaptation (such as extension offices, local governmental agencies, and NGOs) are relatively few in number and accessibility. Therefore, farmers generally make autonomous or individual adaptation decisions.

## 4. Methodology

The relationship between climate change and food security can be modeled in the setting of a two-stage framework (Di Falco et al., 2011). In the first stage, a selection model for climate change adaptation is specified, where a representative risk-averse[5] farm household chooses to implement climate change adaptation strategies if the strategies are expected to generate net benefits. The second stage involves modeling the effect of climate change adaptation on food productivity, represented here by the Kcal/ha produced by each household. The adaptation decision may be based on individual self-selection, such that adapting farmers may have different but unobservable characteristics from the farmers who did not adapt. Failure to account for such unobservables could lead to inconsistent estimates of the effect of adaptation on food security. Following Lokshin and Sajaia (2004) and Di Falco et al. (2011), we account for the endogeneity of the adaptation decision by estimating a simultaneous equation model of climate change adaptation and food productivity with endogenous switching regressions with full information maximum likelihood (Maddala and Nelson, 1975; Lee and Trost, 1978; Bourguignon et al., 2007). This model is used to compare the expected Kcal/ha produced by the farm households that adapted to those that did not adapt, and to investigate the expected Kcal/ha produced in the counterfactual case that the adapting households had not adapted and the non-adapting household had adapted (Loshkin and Sajaia, 2004; Di Falco et al., 2011).

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[4] Autonomous adaptation refers to adaptation that does not constitute a conscious response to climatic stimuli, but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Planned adaptation refers to adaptation which results from a deliberative policy decision, based on awareness that conditions have changed or are about to change and that action is required to return to, to maintain, or to achieve a desired state (IPCC, 2001).

[5] A risk-averse farmer does not like risk, and therefore will stay away from adding high-risk climate change adaptation strategies or taking up new technologies.

To motivate the model, consider a representative risk-averse farm household which chooses to implement climate change adaptation strategies if the strategies are expected to generate net benefits. Let $A^*$ be the latent variable that captures the expected benefits from the adaptation choice:

$$A_i^* = \boldsymbol{Z_i \alpha} + \eta_i \text{ with } A_i = \begin{cases} 1 \; if \; A_i^* > 0 \\ 0 \; otherwise \end{cases} \quad (1)$$

A farm household $i$ will choose to adapt ($A_i = 1$), through the implementation of some strategies in response to long-term changes in mean temperature and rainfall, if $A^* > 0$ , but will not adapt if $A^* < 0$.

Vector $\boldsymbol{Z}$ represents variables that affect the expected benefits of adaptation.

- Farm level: e.g., soil types
- Current climatic factors (e.g., rainfall, temperature) as well as the experience of previous extreme events such as droughts and floods (in the past few years)
- Institutional: e.g., access to credit, extension
- Household characteristics: age, gender, education, marital status, off-farm job, household size
- Assets: Machinery, animals

Climate change and variability adaptation strategies are endogenously determined; the decision to adapt or not is voluntary and may be based on individual self-selection. Farmers who adapted may have systematically different characteristics from the farmers who did not adapt. To account for possible selection bias, we adopt an endogenous switching regression model of food productivity where farmers face two regimes: (1) to adapt and (2) not to adapt, defined as follows.

$$Regime\ 1: y_{1i} = \boldsymbol{\alpha_1} + \boldsymbol{X_{1i}\beta_1} + \varepsilon_{1i} \; if \; A_1 = 1 \; (2a)$$

$$Regime\ 2: y_{0i} = \boldsymbol{\alpha_0} + \boldsymbol{X_{0i}\beta_0} + \varepsilon_{0i} \; if \; A_1 = 0 \; (2b)$$

where $y_1$ is the quantity of edible kilocalories per hectare (Kcal/ha)[6] produced in regimes 1 and 2; $\boldsymbol{X_i}$ represents a vector of inputs (e.g., seeds, fertilizers, manure, labour); and $\boldsymbol{Z}$ represents characteristics of the household head and household, soil characteristics, assets, and climatic factors. We observe $y_1$ when $A_i = 1$, in which case $y_0$ is unobserved, latent, or missing. Similarly, we observe $y_0$ when $A_i = 0$, in which case $y_1$ is unobserved, latent, or missing.

Note that error terms in Equations 2a and 2b are assumed to follow trivariate normal distribution with zero mean and covariance matrix $\boldsymbol{\psi}$, i.e. $(\eta, \varepsilon_1, \varepsilon_0)' \sim N(0, \boldsymbol{\psi})$; with

$$\boldsymbol{\psi} = \begin{pmatrix} \sigma_\eta^2 & \sigma_{\eta 1} & \sigma_{\eta 0} \\ \sigma_{\eta 1} & \sigma_1^2 & . \\ \sigma_{\eta 0} & . & \sigma_0^2 \end{pmatrix} \quad (3)$$

Also, note that $Cov\ (\varepsilon_1, \varepsilon_0) = 0$ because a farmer can't be observed in both regimes (adaptation and non-adaptation). The sign and magnitude of $Cov\ (\eta, \varepsilon_1)$ and $Cov\ (\eta, \varepsilon_0)$ give the magnitude and direction of the selection bias and $\alpha_1 - \alpha_0$ gives the treatment effect. Because the error term of the selection Equation (1) ($\eta_i$) is correlated with the error terms of the regime functions (2a) and (2b) ($\varepsilon_{1i}, \varepsilon_{0i}$), the expected values of $\varepsilon_{1i}$ and $\varepsilon_{0i}$ conditional on the sample selection are nonzero (Di Falco et al., 2011) and can be expressed as

$$E(\varepsilon_{1i} | A_i = 1) = \sigma_{1\eta} \frac{\phi \boldsymbol{Z_i \alpha}}{\Phi \boldsymbol{Z_i \alpha}} \equiv \sigma_{1\eta} \lambda_{1i} \ (4a)$$

$$E(\varepsilon_{0i} | A_i = 0) = -\sigma_{0\eta} \frac{\phi \boldsymbol{Z_i \alpha}}{1 - \Phi \boldsymbol{Z_i \alpha}} \equiv \ \sigma_{0\eta} \lambda_{0i} \ (4b)$$

For the model to be identified, it is important to use as selection instruments variables that directly affect the selection variable but not the outcome variable. In our study, for selection instruments in the adaptation equation, we use variables related to the information sources (e.g., different sources of extension, access to credit and, if received, information on climate). If a variable is a valid selection instrument, it will affect the

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[6] Most studies on the impacts of climate change use quantity, yield or revenue per hectare as the dependent variable. This paper innovates over previous studies by using calories produced, *a la* Roberts and Schlenker (2009; 2013).

adaptation decision but will not affect the quantity produced per hectare among farm households that did not adapt.

The endogenous switching regression model is used to:

- compare the expected food productivity (in Kcal/ha) of the farm households that adapted with respect to the farm households that did not adapt
- investigate the expected food productivity (in Kcal/ha) in the counterfactual hypothetical cases that the adapting farm households did not adapt and the non-adapting farm households did adapt, as shown in the following equation array.

$$E(y_{1i}|A_i = 1) = \boldsymbol{X_{1i}\beta_1} + \sigma_{1\eta}\lambda_{1i}\ (5a)$$

$$E(y_{0i}|A_i = 0) = \boldsymbol{X_{0i}\beta_0} + \sigma_{0\eta}\lambda_{0i}\ (5b)$$

$$E(y_{0i}|A_i = 1) = \boldsymbol{X_{1i}\beta_0} + \sigma_{0\eta}\lambda_{1i}\ (5c)$$

$$E(y_{1i}|A_i = 0) = \boldsymbol{X_{0i}\beta_1} + \sigma_{1\eta}\lambda_{0i}\ (5d)$$

where Equations (5a) and (5b) represent the actual expectations observed in the sample, while Equations (5c) and (5d) represent the counterfactual expected outcomes. These can, according to Loshkin and Sajaia (2004) and Di Falco et al. (2011), be presented in a table format as shown below.

**Table 4. Conditional Expectations, Treatment and Heterogeneity Effects**

| Sub-samples | Decision | | Treatment Effects |
|---|---|---|---|
| | Adapt | Not Adapt | |
| Adaptors | $E(y_{1i}\|A_i = 1)$ *(5a)* | $E(y_{0i}\|A_i = 1)$ *(5c)* | $TT$ |
| Non-Adaptors | $E(y_{1i}\|A_i = 0)$ *(5d)* | $E(y_{0i}\|A_i = 0)$ *(5b)* | $TU$ |
| Heterogeneity Effects | $HE_1$ | $HE_0$ | $TT - TU$ |

To account for the potential endogeneity of the adaptation decision, the first step is to select suitable instruments to identify the adaptation/Kcal production relationship. To do so, let's assume a basic model given by:

$$y = \boldsymbol{\alpha_0} + \boldsymbol{x}'\boldsymbol{\beta} + u\ (6a)$$

where $y$ is the amount of Kcal produced by the adapting household; $\boldsymbol{x}$ is a vector of exogenous variables which determine the output; $\boldsymbol{\beta}$ is a vector of parameters to be estimated; and $u$ is the error term. The decision to adapt ($A = 1$) or not ($A = 0$) is expected to influence the amount of Kcal produced, and therefore the model can be represented as

$$y = \boldsymbol{\alpha_0} + \boldsymbol{x}'\boldsymbol{\beta} + A + u \ (6b)$$

If there is endogeneity, then $cov(A, u) \neq 0$. Therefore, in our estimation, we need an instrumental variable or a vector of instrumental variables $\boldsymbol{z}$ that is/are correlated with the endogenous variable ($cov(A, \boldsymbol{z}) \neq 0$), but uncorrelated with the error term ($cov(A, \boldsymbol{z}) = 0$) and does not affect the outcome of interest (Kcal produced = $y$), conditional on the included regressors ($\boldsymbol{x}$). Using this reasoning, we predict that institutional variables, e.g., access to climate extension, access to general extension services, number of extension visits, and access to credit do influence the decision to adapt, i.e., they are correlated with the adaptation decision but do not directly influence the amount of Kcal produced. We test this assumption by regressing each of these variables on adaptation and other regressors.

$$\boldsymbol{z} = \boldsymbol{\alpha_0} + A + \ \boldsymbol{x}'\boldsymbol{\beta} + u \ (6c)$$

It is expected that $\boldsymbol{z}$ will have a statistically significant relationship with $A$ to qualify as a good instrument.

## 5. Results

### 5.1. Selection of Instrumental Variables

Institutional variables are used as instrumental variables for identification of the model. From the analysis, there is a statistically significant relationship between adaptation and the number of extension visits ($0.698, p = 0.001$). The same is true for the relationship between adaptation and access to general extension[7] services ($0.116, p = 0.000$). However, the relationship between adaptation and access to credit ($0.273, p = 0.33$) is not statistically significant. Neither is the relationship between adaptation and access to climate extension[8] ($0.057, p = 0.31$). Therefore, the number of extension visits and access to general extension services are strong instruments, while access to credit and

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[7] General extension refers to the advice given to farmers on general farm agronomic practices without any specific emphasis on climate change.

[8] Climate extension refers to the advice given to farmers specifically on climate change adaptation.

access to climate extension can at best be considered as weak instruments to adaptation. The four variables were used as instruments in the switching regression analysis as discussed below.

### 5.2. OLS and Switching Regression Models Results

Table 5 below presents the estimates from OLS regression and switching regression models. The first column presents results of the OLS regression where the decision to adapt is a dummy variable (dependent variable is Kcal produced on the farm). Columns 2, 3 and 4 present the estimated coefficients of selection Equation (1) on adapting or not to climate change, and of the food productivity functions (2a) and (2b) for farmers who adapted or did not adapt to climate change, respectively.

From the OLS equation, adaptation to climate change has a positive and significant impact on the amount of Kcal produced by farmers, as shown by the positive and significant coefficient. Other variables that positively influence the amount of Kcal produced include farm production inputs of seed and fertilizer. Precipitation in the March-May quarter is likely to negatively influence Kcal produced on the farm, while that in the September-November quarter is likely to increase Kcal produced. This is in line with farmers' expectations that the September-November quarter precipitation normally gives more yields of good quality than the March-May precipitation quarter. Households in areas dominated by lithosols are likely to produce fewer Kcal compared to other households. Older farmers and those with more farming experience are likely to produce more Kcal compared to others, while increase in the farm wage level increases the Kcal produced. Farmers who do non-farm work are likely to produce fewer Kcal. This could be explained by their divided attention between farm and non-farm work.

From the endogenous switching regression model, rho $(\rho_j)$ denotes the correlation coefficient between the error term $(\eta_j)$ in the selection equation (1) and the error term $(\varepsilon_{ji})$ of the outcome equations (2a) and (2b). The results of the estimated coefficients of the correlation terms $(\rho_j)$ for the two adaptation equations indicate that $\rho$ -1 (rho-1) is negative and insignificantly different from zero, meaning there is no correlation between the selection equation and adaptation equation. $Rh0 - 0$ is positive and also insignificantly different from zero, indicating lack of correlation between the selection equation and the non-adaptation equation. This implies that the hypothesis of absence of sample selectivity bias may not be rejected.

## Table 5. Estimates of Climate Change Adaptation and Food Security

| | | Endogenous Switching Regression | | |
|---|---|---|---|---|
| Model | OLS | Selection Equation | Adaptation=1 | Adaptation=0 |
| Dependent Variable | Ln Kcal | Adaptation (1/0) | Ln Kcal | Ln Kcal |
| Adapt | 0.2002* | | | |
| Farm production inputs | | | | |
| Total Family Labour | 0.0001 | | -0.001 | 0.001 |
| Total Hired Labour | 0.0021 | | 0.002 | 0.002 |
| Total Seed Value | 0.0000*** | | 0.000** | 0.000** |
| Total Fertilizer | 0.0012*** | | 0.002** | 0.001*** |
| Tot Pesticide Value | 0.0000 | | 0.000 | 0.001 |
| Climatic Factors | | | | |
| Temp. Dec.-Feb. | 0.3940 | -0.6992 | 0.381 | 0.566 |
| Temp. March -May | -0.6738 | 0.6880 | -0.393 | -0.936 |
| Temp. June -August | 0.4210 | 0.1467 | 0.231 | 0.378 |
| Temp. Sept.- Nov. | -0.2382 | 0.0369 | -0.432 | -0.013 |
| Precip. Dec.-Feb. | -0.0007 | 0.0008 | -0.005 | 0.006 |
| Precip. March -May | -0.0496* | -0.0114 | -0.016 | -0.088*** |
| Precip. June -August | -0.0049 | 0.0028 | -0.010 | -0.001 |
| Precip. Sept.- Nov. | 0.0578* | 0.0273 | 0.020 | 0.105*** |
| Soil information | | | | |
| Cambisols | -1.0430 | 1.0377 | -0.047 | -1.450 |
| Ferrasols | -0.8445 | 0.1701 | -1.700** | -0.041 |
| Lithosols | -1.3619* | 0.8407* | -1.023 | -1.708*** |
| Nitosols | -1.0062 | 0.4937 | -1.391* | -0.768 |
| Andosols | -1.3167 | -0.2071 | -2.418* | -0.059 |
| Vertisols | -1.2143 | -0.4332 | -3.124* | -0.222 |
| Planosols | -1.3832 | 1.1924 | -1.974 | -0.139 |
| Farm Assets | | | | |
| Livestock value | 0.0000 | 0.0000* | 0.000 | 0.000 |
| Buildings value | 0.0000 | 0.0000 | 0.000 | 0.000 |
| Machine value | 0.0000 | 0.0000 | 0.000* | 0.000 |
| Household Characteristics | | | | |
| Gender | -0.1091 | 0.3138* | -0.274 | -0.081 |
| Ln Age | 0.2851** | -0.2778** | 0.341 | 0.342** |
| Ln Education | 0.1294 | 0.0429 | 0.141 | 0.130 |
| Ln Household size | 0.0984 | 0.1707 | 0.224 | 0.055 |
| Ln Hired labour wage (Ksh/day) | 0.0900** | 0.0619** | 0.027 | 0.122*** |
| Farm experience (Years) | 0.2370** | 0.0911 | 0.155 | 0.225** |

| | | | | |
|---|---|---|---|---|
| Farmer does Farm work | -0.0120 | 0.14837 | -0.043 | -0.058 |
| Farmer does non-farm work | -0.4645*** | -0.18456* | -0.508* | -0.403** |
| Institutional Factors | | | | |
| Climate extension | | -0.0814 | | |
| General Agriculture extension | | 0.4522*** | | |
| Number of extension visits | | 0.0019 | | |
| Credit Access | | 0.1539 | | |
| Model Parameters | | | | |
| Constant | 14.7070*** | | 17.39** | 12.9381*** |
| $F$ | 51.27*** | | | |
| Wald Chi-Square | | | 300.67*** | |
| $\sigma_i$ | | | 1.218*** | 1.234*** |
| $\rho_j$ | | | -0.159 | 0.011 |

* ** *** Significance at 10%; 5% and 1% levels, respectively.

The other differences in the adaptation and non-adaptation equations are in the coefficients of the different exogenous variables. Farm inputs are expected to increase the quantities of Kcal produced by farmers. This is true for increased fertilizer use and seed use – both for adapters and non-adapters – but fertilizer use has a higher influence among the adapters and lower for the non-adapters. Farm labour (hired and family) does not influence Kcal produced for either adopters or non-adopters. This is also true for pesticide use, which may be classified as a damage control input rather than a conventional production input.

Climatic factors are also critical in production of nutrition. Increased precipitation in the March-May quarter negatively influences Kcal produced by non-adapters. This is the "long rains" period in the country and increased precipitation in this period has a negative effect on non-adapters' production of nutrition levels. Increased precipitation in the September-November quarter ("short rains" season) positively influences Kcal production for non-adapters. Temperatures do not seem to influence production of Kcal for the two groups, and neither does precipitation influence Kcal production for adapters. This could be attributed to the fact that the climatic factors (temperature and precipitation) were analysed on a quarterly basis (hence the non-influence), since the effect of climate variables is best realized over longer periods of time. It can be argued therefore that adaptation reduces reliance on temperature and precipitation, and therefore production of nutrition for adapters is not influenced by the two factors.

Production of Kcal among adapters is highly influenced by the type of soil. Adapting households in areas with ferrasols, nitosols, andosols and vertisols are likely to produce significantly fewer Kcal. For non-adapters, farmers in areas with lithosols are likely to produce significantly fewer Kcal. Increased farm assets have a correlation with Kcal produced in adapting households. For instance, adapters with farm machines are more likely to have higher Kcal production. This is not the case with non-adapters, where farm machinery and other farm assets have no influence on Kcal production.

Household characteristics also influence the level of Kcal production. For instance, among the non-adapters, older farmers and those with more farming experience are likely to produce more Kcal compared to their counterparts with less experience. Due to their age and experience, older, experienced farmers have in the course of time tried various technologies and have proven those most suitable for their agro-ecological zones. For non-adapters, increase in the farm wage level increases the Kcal produced. For both adapting and non-adapting households, farmers who do not do farm work but rely on other persons to manage their farms produce fewer Kcal than those who choose to be directly involved in day-to-day work on their farms.

Table 6 illustrates the expected quantities of Kcal produced on the farm under actual and counterfactual conditions. Cells (i) and (ii) are the expected quantities of Kcal produced per hectare, as observed in the sample. Households that adapted produced 1,305,414 Kcal, against 564,789 Kcal for households that did not adapt. The difference between the two is 740,645 Kcal, indicating that farmers who adapted produced 56.74% more than the farmers who did not adapt. This result supports findings by Di Falco et al. (2011), who found heterogeneity between adapters and non-adapters and that food productivity of households that adapted to climate change significantly differed from that of households that did not adapt.

**Table 6. Average Expected Kcal/ha, Treatment and Heterogeneity Effects**

| Sub-samples | Decision | | Treatment Effects |
|---|---|---|---|
| | Adapt | Not Adapt | |
| Adaptors | 1,305,414 (i) | 996,224 (iii) | 309,190 |
| Non-Adaptors | 773,879 (iv) | 564,789 (ii) | 209,090 |
| Heterogeneity Effects | 531,535 | 431,436 | 100,100 |

From the treatment effects of the adaptation column, in the counterfactual case (iii), farm households that actually adapted would have produced about 996,224 Kcal less (that is, about 23.7% less) if they did not adapt. In the counterfactual case (iv), if farmers who did not adapt had adapted, they would have produced about 773,879 Kcal more (that is, about 27.01% more). Therefore, adaptation to climate change significantly increases production of nutrition. The transitional heterogeneity effect is positive, implying that the effect of adaptation is significantly larger for the farmers who actually did adapt relative to those who did not adapt.

## 6. Conclusion

This study set out to assess the influence of climate change and variability adaptation on food security in Kenya. Results from the OLS regression indicated that adaptation to climate change has a positive and significant impact on the amount of Kcal produced for farmers who adapt. However, we could not rely on this model to draw conclusions because it's beset by problems of endogeneity. For this reason, we chose the endogenous switching regression model. From these results, farmers who choose not to adapt to climate change get significantly lower Kcal production than a random farmer from the sample would have gotten. Other results indicate that increased seed and fertilizer use – both for adopters and non-adopters – would improve Kcal production. This calls for planned adaptation strategies to promote use of improved seeds and fertilizer use among farmers. It has also been demonstrated that mean temperature does not influence Kcal production but increased precipitation can negatively or positively influence Kcal production, depending on whether it rains during harvest, land preparation or crop growing periods. Households living in areas with different soil types are likely to produce varying quantities of Kcal depending on the soil type. This requires intervention in improving soil fertility in these areas, alongside adopting crop enterprises suitable for these areas.

The results further show that older farmers and those with more farming experience are likely to produce more Kcal compared to their respective counterparts. Due to age and experience, such farmers have in the course of time tried many technologies and have identified and proven those most suitable for their agro-ecological zones. This calls for targeted interventions aimed at sensitizing younger and less experienced farmers to climate change and its impacts, and also possible adaptation strategies. In addition, increase in the farm wage level increases the Kcal produced. Farming households also need to occasionally increase wages of hired labour so as to increase labour productivity. Finally, the results show that farmers who adapted to climate change produced 1,305,414 Kcal, against 564,789 Kcal for farmers who did not adapt. From the treatment effects of adaptation, the results show that, in the counterfactual case, farm households who actually adapted would have produced about

23.7% Kcal/ha less if they had not adapted. In the counterfactual, farmers who did not adapt would have produced about 27.01% more Kcal/ha if they had adapted. Therefore, adaptation to climate change significantly increases Kcal production. This is evidence that adaptation to climate change significantly increases nutrition and thus food security. The transitional heterogeneity effect results are positive, implying that the effect of adaptation is significantly larger for the farmers who actually did adapt, relative to those that did not adapt. Therefore, to weather the adverse impacts of climate change and improve food production, farmers in Kenya should be encouraged to adapt to climate change.

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# Appendix

## Table A1. Variable Definitions and Measurement

| Variable | Definition/measurement |
|---|---|
| *Household Characteristics* | |
| Gender | 1=male |
| Age | Years |
| Education | Number of years of schooling |
| Household size | Number of members |
| Hired labour wage | Kenya shillings per day |
| Farmer does farm work | 1= yes |
| Farmer does non-farm work | 1= yes |
| Farm experience | Number of years |
| *Value of farm assets* | |
| Livestock | Kenya shillings |
| Buildings | Kenya shillings |
| Machinery | Kenya shillings |
| *Value of farm inputs* | |
| Family Labour | Kenya shillings per hectare |
| Hired Labour | Kenya shillings per hectare |
| Seeds | Kenya shillings per hectare |
| Fertilizers | Kenya shillings per hectare |
| Pesticides | Kenya shillings per hectare |
| *Institutional variables* | |
| Climate extension | Household received climate change extension information |
| Agriculture extension | Household received agricultural extension information |
| Number of extension visits | Number of extension visits received by a household |
| Credit Access | Household received farm credit |
| *Climate variables* | |
| Temperature | Degrees Celsius |
| Precipitation | Millimeters |
| *Soils* | |
| 7 different types of soils | Percentage of county covered by a particular soil type |