Journal of African Economies, Volume 18, Number 4, pp. 529–554
doi:10.1093/jae/ejp002 online date 15 March 2009

# Economic Impact of Climate Change on Crop Production in Ethiopia: Evidence from Cross-section Measures

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*This study used the Ricardian approach that captures farmer adaptations to varying environmental factors to analyze the impact of climate change on crop farming in Ethiopia. By collecting data from farm households in different agro-ecological zones of the county, net crop revenue per hectare was regressed on climate, household and soil variables. The results show that these variables have a significant impact on the net crop revenue per hectare of farmers under Ethiopian conditions. The seasonal marginal impact analysis indicates that marginally increasing temperature during summer and winter would significantly reduce crop net revenue per hectare whereas marginally increasing precipitation during spring would significantly increase net crop revenue per hectare. Moreover, the net crop revenue impact of predicted climate scenarios from three models (CGM2, HaDCM3 and PCM) for the years 2050 and 2100 indicated that there would be a reduction in crop net revenue per hectare by the years 2050 and 2100. Moreover, the reduction in net revenue per hectare by the year 2100 would be more than the reduction by the year 2050 indicating the damage that climate change would pose increases with time unless this negative impact is abated through adaptation. Additionally, results indicate that the net revenue impact of climate change is not uniformly distributed across the different agro-ecological zones of Ethiopia.*

**JEL classification:** *C53*, *Q25*, *Q54*

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## 1. Introduction

It is generally recognised that climate change has an impact on agriculture (IPCC, 1990). Many efforts have been made to estimate its economic impact (Adams, 1989; Rosenzweig, 1989; Mendelsohn *et al.*, 1994; Kaiser *et al.*, 1993). However, most of these studies have focused on the USA and other developed countries.

As climate change is global, concerns about its impact on agriculture in developing countries have been increasing (IPCC, 1996) and some attempts have been made to estimate this impact (Winter *et al.*, 1996; Dinar *et al.*, 1998; Kumar and Parikh, 1998; Mendelsohn and Tiwari, 2000). Though this effort is growing, not much research has been done in Ethiopia. Climate change could be particularly damaging to countries in Africa, and Ethiopia, being dependent on rain-fed agriculture and under heavy pressure from food insecurity and often famine caused by natural disasters such as drought, is likely to be affected (Mendelsohn and Tiwari, 2000).

So far there has not been any study to address the economic impact of climate change on Ethiopian agriculture and farm-level adaptations that farmers make to mitigate the potential impact of climate change. Accordingly, little is known about how climate change may affect the country's agriculture. This seriously limits policy formulation and decision-making in terms of adaptation and mitigation strategies.

The objective of this study is to assess the economic impact of climate change on Ethiopian farmers, using the Ricardian approach, and to inform policy-makers on proper adaptation options to counteract the harmful effects of such change.

This study is structured in the following way: Section 2 is an overview of Ethiopian agriculture. Section 3 presents approaches to measuring the economic impacts of climate change. Section 4 describes methodology and data. Section 5 discusses the results and Section 6 concludes and suggests policy options.

## 2. Overview of Ethiopian Agriculture

Agriculture remains by far the most important sector in the Ethiopian economy for the following reasons: (i) it directly supports about 85% of the population in terms of employment and livelihood; (ii) it contributes about 50% of the country's gross domestic product (GDP); (iii) it generates about 88% of the export earnings; and (iv) it supplies around 73% of the raw material requirement of agro-based domestic industries (MEDaC, 1999). It is also the major source of food for the population and hence the prime contributing sector to food security. In addition, agriculture is expected to play a key role in generating surplus capital to speed up the country's overall socio-economic development (MEDaC, 1999).

Ethiopia has a total land area of about 112.3 million hectares. Of this, about 16.4 million hectares are suitable for producing annual and perennial crops. Of the estimated arable land, about 8 million hectares are used annually for rain-fed crops. The country has a population of about 70 million (National Bank of Ethiopia, 1999) with a growth rate of about 3.3%. At the present growth rate, the population is expected to increase to about 129.1 million by the year 2030.

Small-scale farmers who are dependent on low-input and low-output rain-fed mixed farming with traditional technologies dominate the agricultural sector. The present government of Ethiopia has given top priority to this sector and has taken steps to increase its productivity. However, various problems are holding this back. Some causes of poor crop production are declining farm size; subsistence farming because of population growth; land degradation due to inappropriate use of land, such as cultivation of steep slopes; over cultivation and overgrazing; and inappropriate polices. Other causes are tenure insecurity; weak agricultural research and extension services; lack of agricultural marketing; an inadequate transport network; low use of fertilizers, improved seeds and pesticides; and the use of traditional farm implements. However, the major causes of underproduction are drought, which often causes famine, and floods. These climate-related disasters make the nation dependent on food aid.

The trends of the contribution of agriculture to total GDP of the country clearly explain the relationship between the performance of agriculture, climate and the total economy. As can be seen in Figure 1, years of drought and famine (1984/1985, 1994/1995, 2000/2001) are associated with very low contributions, whereas years of good climate (1982/83, 1990/91) are associated with better contributions.

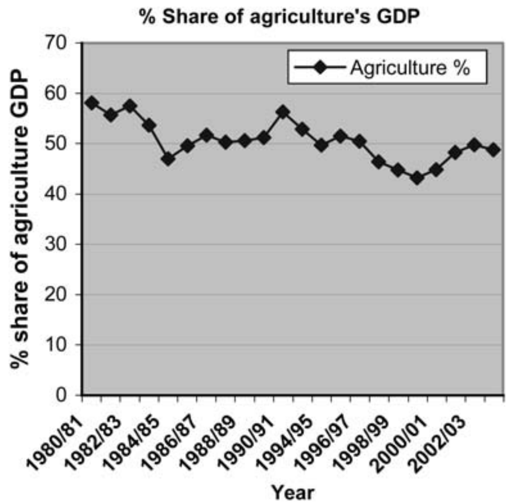


Figure 1: *Trend of Per cent Share of Agriculture's GDP*

## 3. Approaches to Measuring the Economic Impacts of Climate Change

There are two main types of economic impact assessment models in the literature, namely the economy-wide (general equilibrium) and partial equilibrium models. Economy-wide models are analytical models, which look at the economy as a complete system of interdependent components (industries, factors of production, institutions and the rest of the world). Partial equilibrium models, on the other hand, are based on the analysis of part of the overall economy such as a single market (single commodity) or subsets of markets or sectors (Sadoulet and De Janvry, 1995).

Computable general equilibrium (CGE) model is an economy-wide model, which is suitable for environmental issues as it is capable of capturing complex economy-wide effects of exogenous changes while at the same time providing insights into micro-level impacts on producers, consumers and institutions (Oladosu *et al.*, 1999; Mabugu, 2002). As climate change directly or indirectly affects different sectors of the economy, economy-wide models, which incorporate the complex interactions among different sectors, are needed, and their use is growing in the areas of climate change impact assessment studies (Winters *et al.*, 1996).

Although CGE models can analyse the economy-wide impacts of climate change, there are some drawbacks in using them. Key limitations include difficulties with model selection, parameter specification and functional forms, data consistency or calibration problems, the absence of statistical tests for the model specification, the complexity of the CGE models and the high skills needed to develop and use them (Gillig and McCarl, 2002).

The partial equilibrium models available in the literature can be classified as crop suitability, production function and Ricardian approaches. The crop suitability approach is also referred to as the agro-ecological zoning (AEZ) approach, which is used to assess the suitability of various land and biophysical attributes for crop production. In this approach, crop characteristics, existing technology and soil and climate factors, as determinants of suitability for crop production, are included (FAO, 1996). By combining these variables, the model enabled the identification and distribution of potential crop-producing lands. As the model includes climate as one determinant of the suitability of agricultural land for crop production, it can be used to predict the impact of changing climatic variables on potential agricultural outputs and cropping patterns (Du Toit *et al.*, 2001; Xiao *et al.*, 2002).

Adaptation to changing climatic conditions can be addressed within this model by generating comparative static scenarios with changes in technological parameters (Mendelsohn and Tiwari, 2000). The disadvantage of the AEZ methodology is that it is not possible to predict final outcomes without explicitly modelling all the relevant components, and thus the omission of one major factor would substantially affect the model's predictions (Mendelsohn and Tiwari, 2000).

The production function approach is based on an empirical or experimental production function that measures the relationship between agricultural production and climate change (Mendelsohn *et al.*, 1994). In this approach, a production function, which includes environmental variables such as temperature, rainfall and carbon dioxide as inputs into production, is estimated. Based on this estimated production function, changes in yield induced by changes in environmental variables are measured and analysed at testing sites (Adams, 1989; Kaiser *et al.*, 1993; Lal *et al.*, 1999; Alexandrov and Hoogenboom, 2000; Olsen *et al.*, 2000; Southworth *et al.*, 2000). The estimated changes in yield caused by changes in environmental variables are aggregated to reflect the overall national impact (Olson *et al.*, 2000) or incorporated into an economic model to simulate the welfare impacts of yield changes under various climate change scenarios (Adams, 1989; Kumar and Parikh, 1998; Chang, 2002).

One advantage of this model is that it more dependably predicts the way climate affects yield because the impact of climate change on crop yields is determined through controlled experiments. However, one problem with this model is that its estimates do not control for adaptation (Mendelsohn *et al.*, 1994). In order to properly apply the production function approach, farmers' adaptations should be included in the model (Dinar *et al.*, 1998). Moreover, simulations should be run with a variety of farm methods such as varying planting dates and crop varieties, dates of harvesting and tilling and irrigation methods. This makes it possible to identify the activities that maximise profit under changing climatic conditions (Kaiser *et al.*, 1993). In addition to the failure to consider farmers' adaptations, each crop considered under this model in general required extensive experimentation (involving high costs). The use of this methodology has therefore been restricted to the most important crops and a few test locations and hence has limited value for generalising the results.

The Ricardian model analyses a cross section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and agro-climatic factors (Mendelsohn *et al.*, 1994; Sanghi *et al.*, 1998; Kumar and Parikh, 1998; Polsky and Esterling, 2001). The most important advantage of the Ricardian model is its ability to incorporate private adaptations. Farmers adapt to climate change to maximise profit by changing the crop mix, planting and harvesting dates, and following a host of agronomic practices. The farmers' response involves costs, causing economic damages that are reflected in net revenue. Thus, to fully account for the cost or benefit of adaptation, the relevant dependent variable should be net revenue or land value (capitalised net revenues), and not yield. Accordingly, the Ricardian approach takes adaptation into account by measuring economic damages as reductions in net revenue or land value induced by climatic factors. The other advantage of the model is that it is cost effective, since secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socio-economic factors.

The weaknesses of the Ricardian approach are: it is not based on controlled experiments across farms; and it does not include price effects and carbon fertilisation effects (Cline, 1996).

## 4. Methodology

The Ricardian method used in this study is an empirical approach developed by Mendelsohn *et al.* (1994) to measure the value of climate in US agriculture. The technique has been named the Ricardian method because it is based on the observation made by David Ricardo (1817) that land values would reflect land productivity at a site under perfect competition. This model makes it possible to account for the direct impact of climate on crop yields as well as the indirect substitution among different inputs including the introduction of various activities, and other potential adaptations to a variety of climates by directly measuring farm prices or revenues.

The value of land reflects the sum of discounted future profits, which may be derived from its use. Any factor that influences the productivity of land will be reflected in land values or net revenue. Therefore, the value of land or net revenue contains information about the value of climate as one attribute of land productivity. By regressing land values or net revenue on a set of environmental inputs, the Ricardian approach makes it possible to measure the marginal contribution of each input to farm income as capitalised in land value.

Following Mendelsohn *et al.* (1994, 1996), the Ricardian approach involves specifying a net revenue function of the form:

$$R = \sum P_i Q_i(X, F, G, Z) - \sum P_X X \tag{1}$$

where $R$ is net revenue per hectare, $P_i$ is the market price of crop $i$, $Q_i$ is output of crop $i$, $X$ is a vector of purchased inputs, $F$ is a vector of climate variables, $G$ is a set of economic variables such as livestock ownership, $Z$ is a set of soil variables and $P_X$ is a vector of input prices.

The Ricardian method assumes that each farmer will seek to maximise net farm revenues by choosing inputs ($X$) subject to climate, soils and economic factors. The standard Ricardian model relies on a quadratic formulation of climatic variables:

$$R = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 G + \beta_4 Z + u, \tag{2}$$

where $u$ is the error term. To capture the nonlinear relationship between the net revenues and climate variables, the estimation includes both the linear and quadratic terms for climate variables, $F$ (temperature and precipitation).

### *4.1 Data description*

The household data for this study were based on a sample of 1,000 farmers randomly selected from different agro-ecological settings of the country, who were believed to be representatives of the whole nation (Table 1). A total of 50 districts (20 farmers from every district) were purposely selected, starting from the extreme highlands of the south-eastern regions of the Oromia Regional State to the lowlands of the Afar Regional States. Yale University and the University of Pretoria provided the questionnaire for this study, which asks about a variety of household attributes. The interviews with the farmers took place during the 2003/2004 production seasons. Almost all were small-scale farmers with rain-fed farms, as more than 95% of Ethiopian farmers are of this type.

The temperature data for this study were derived from the satellite data provided by the US Department of Defense and the precipitation data from the African Rainfall and Temperature Evaluation System (ARTES). The soil data for this study were obtained from the Food and Agricultural Organization (FAO). The FAO provides information about the major and minor soils in each location, including the slope and texture. The hydrological data (flow and run-off) were obtained from the University of Colorado (IWMI/ University of Colorado, 2003). The hydrology team calculated flow and run-off for each district using the hydrological model for Africa.

## **5. Results and Discussion**

### *5.1 Regression results*

The Ricardian approach estimates the importance of climate and other variables on the capitalised value of farmland. Net revenues were regressed on climatic and other control variables. A nonlinear

Table 1: *Districts Surveyed in the Sample AEZs*

| Number | Agro-ecology | Districts |
|---|---|---|
| 1 | Hot to warm sub-moist lowlands | Metema, Kefta Humera, Mi Tsebri, Tanqua Aberegele, Adama; Lume, Mieso, Dangur, Wembera Sherkole |
| 2 | Tepid to cool sub-moist mid-highlands | Estie, Achefer, Bahirdar, Hawzen, Jijiga Zuria, Gursum |
| 3 | Tepid to cool pre-humid mid-highlands | Enarj Enawga, Gozemen, Sude, Chiro, Hagere Mariam, Dega, Kedida Gamela, Soddo Zuria, Beleso Sorie |
| 4 | Tepid to cool humid midlands | Ejere, Muka Turi |
| 5 | Hot to warm sub-humid lowlands | Galena Abeya, Oddo Shakiso, Pawe, Dibati, Bambesi, Assosa Zuria |
| 6 | Tepid to cool moist mid-highlands | Aleta Wendo, Chena, Robe, Sinana, Genesebo, Gera, Seka Chekorsa |
| 7 | Cold to very cold moist Afro-alpine | Adaba |
| 8 | Hot to warm humid lowlands | Konso, Sheko |
| 9 | Hot to warm arid lowland plains | Shinile, Gode, Gewane, Amibara, Dubti |
| 10 | Hot to warm pre-humid lowlands | Wenageo |
| 11 | Tepid to cool sub-moist highlands | Bako |

Table 2: *Temperature (°C) (Sample Mean) of AEZs*

| Agro-ecological zones | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| Tepid to cool humid midlands | 21.13 | 21.75 | 20.74 | 20.09 |
| Cold to very cold moist Afro-alpine | 17.17 | 17.92 | 14.93 | 14.75 |
| Tepid to cool pre-humid mid-highlands | 19.89 | 21.38 | 18.58 | 18.04 |
| Tepid to cool moist mid-highlands | 18.30 | 19.06 | 16.96 | 16.37 |
| Tepid to cool sub-moist mid-highlands | 17.25 | 18.65 | 15.42 | 15.16 |
| Tepid to cool sub-moist highlands | 20.69 | 22.53 | 19.86 | 19.43 |
| Hot to warm humid lowlands | 18.47 | 18.39 | 16.10 | 16.10 |
| Hot to warm sub-moist lowlands | 19.01 | 21.21 | 18.27 | 17.54 |
| Hot to warm pre-humid lowlands | 17.66 | 18.00 | 15.67 | 15.50 |
| Hot to warm arid lowland plains | 22.48 | 25.46 | 26.05 | 23.75 |
| Hot to warm sub-humid lowlands | 20.35 | 22.62 | 18.38 | 17.73 |
| Total | 19.3 | 20.63 | 18.27 | 18.00 |

(quadratic) model was chosen, as it is easy to interpret (Mendelsohn *et al.*, 1994).

In the initial runs, different net revenues calculated per hectare were tried, where five measures of net revenue have been calculated (gross revenue − total variable costs − cost of machinery − total cost of household labour on crop activities in US$) as the dependent variable that fitted the model best and was therefore chosen. The independent variables include the linear and quadratic temperature and precipitation terms for the four seasons: winter (the average for December, January and February), summer (the average for June, July and August), spring (the average for March, April and May) and the fall (the average for September, October and November). Tables 2–4 show the averages of temperature, rainfall and net revenue per hectare for the sample districts.

The independent variables also include household attributes and soil types. The household variables in the model include livestock ownership, level of education of the head of the household, distance to input markets and household size. The soil types include nitosols and lithosols.

In this regression, temperature, household size and distance to input markets were expected to have a negative impact on the net revenue per hectare. Precipitation, level of education of the head

Table 3: *Precipitation (mm) (Sample Mean) of AEZs*

| Agro-ecological zones | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| Tepid to cool humid midlands | 22.30 | 74.33 | 42.76 | 55.34 |
| Cold to very cold moist Afro-alpine | 32.26 | 100.24 | 156.43 | 97.25 |
| Tepid to cool pre-humid mid-highlands | 22.22 | 77.18 | 146.63 | 81.38 |
| Tepid to cool moist mid-highlands | 26.29 | 78.59 | 109.87 | 70.58 |
| Tepid to cool sub-moist mid-highlands | 24.94 | 73.70 | 141.26 | 71.58 |
| Tepid to cool sub-moist highlands | 12.66 | 54.66 | 137.45 | 69.27 |
| Hot to warm humid lowlands | 26.14 | 80.12 | 92.00 | 66.50 |
| Hot to warm sub-moist lowlands | 18.89 | 66.32 | 153.44 | 74.18 |
| Hot to warm pre-humid lowlands | 27.35 | 86.53 | 42.74 | 61.44 |
| Hot to warm arid lowland plains | 17.92 | 45.45 | 83.21 | 43.92 |
| Hot to warm sub-humid lowlands | 23.50 | 97.63 | 224.18 | 114.71 |
| Total | 23.13364 | 75.89 | 120.90 | 73.29 |

Table 4: *Average Net Revenue per Hectare (US$) of The Sample AEZs*

| Agro-ecological zones | Net revenue per hectare |
|---|---|
| Tepid to cool humid midlands | 1270.7 |
| Cold to very cold moist Afro-alpine | 896.92 |
| Tepid to cool pre-humid mid-highlands | 998.04 |
| Tepid to cool moist mid-highlands | 1832.97 |
| Tepid to cool sub-moist highlands | 927.75 |
| Tepid to cool sub-moist mid-highlands | 655.36 |
| Hot to warm humid lowlands | 522.6 |
| Hot to warm sub-moist lowlands | 963.17 |
| Hot to warm pre-humid lowlands | 192.55 |
| Hot to warm arid lowland plains | 2918.6 |
| Hot to warm sub-humid lowlands | 1168.92 |
| Total | 1213.56 |

of the household, livestock ownership and soil types were expected to have a positive impact on the net revenue per hectare.

The regression results indicate that most of the climatic, household and soil variables have significant impacts on the net revenue

Table 5: *Regression Coefficients of Climatic and Control Variable over Net Revenue per Hectare*

| Variable | Coefficient |
|---|---|
| Winter temperature | 384.48 |
| Winter temperature squared | −35.00 |
| Spring temperature | −1740.69* |
| Spring temperature squared | 49.40** |
| Summer temperature | −4495.21** |
| Summer temperature squared | 84.85* |
| Fall temperature | 6743.39*** |
| Fall temperature squared | −133.40** |
| Winter precipitation | −1148.63*** |
| Winter precipitation squared | 16.11*** |
| Spring precipitation | 656.62*** |
| Spring precipitation squared | −2.98*** |
| Summer precipitation | 112.30*** |
| Summer precipitation squared | −0.48*** |
| Fall precipitation | −525.18*** |
| Fall precipitation squared | 3.06*** |
| Livestock ownership | 139.30 |
| Level of education of household head | 4.32 |
| Distance of input markets | −1.15 |
| Size of household | −109.42*** |
| Nitosols | 659.04 |
| Lithosols | 7619.68* |
| Constant | −384.70 |
| $N$ | 550.00 |
| $R^2$ | 0.30 |
| $F$ | 10.38 |

*significant at 10%; **significant at 5%; ***significant at 1%.

per hectare (Table 5). The table shows that while the coefficients of the spring and summer temperature are both negative, those of winter and fall are positive. The coefficients of the winter and fall precipitation are negative, whereas for spring and summer they are positive. The interpretations of the signs and magnitudes of impacts are further explained under the marginal analysis.

As expected, the education level of the head of the household and the livestock ownership are positively related to the net revenue per hectare. The distance to input market place is negative, as farmers incur more cost in terms of money and time as the market place is located farther from their farm plots. The household size is negatively related to the net revenue per hectare because there are many dependent and unproductive people in rural Ethiopia (such as children and the elderly and sick).

### *5.2 Marginal impact analysis*

The marginal impact analysis was undertaken to observe the effect of an infinitesimal change in temperature and rainfall on Ethiopian farming. Following Kurukulasuriya *et al.* (2006), the marginal impact of climate variable ($f_i$) on the net revenue evaluated at the mean of that variable is given as:

$$E\left[\frac{dR}{df_i}\right] = \beta_{1,i} + 2 \times \beta_{2,i} \times E[f_i] \tag{3}$$

Table 6 shows the marginal impacts of temperature and precipitation. Increasing temperature during the winter and summer seasons significantly reduces the net revenue per hectare. Increase in the temperature marginally during the winter and summer seasons reduces the net revenue per hectare by US$997.85 and US$1277.6, respectively. Increase in the temperature marginally during the spring and fall seasons increases the net revenue per hectare by US$375.83 and US$1877.7, respectively. During spring, a slightly higher temperature with the available level of precipitation enhances germination, as this is the planting season. During the fall, a higher temperature is beneficial for harvesting.

Table 6: *Marginal Impacts of Climate on Net Revenue per Hectare (US$)*

| Seasons | Winter | Spring | Summer | Fall | Annual |
|---|---|---|---|---|---|
| Temperature | −997.85*** | 375.83 | −1277.28** | 1877.69*** | −21.61 |
| Precipitation | −464.76*** | 225.08*** | −18.88 | −64.19 | −322.75*** |

**significant at 5%; ***significant at 1%.

It is important that crops have finished their growth processes by fall, and a higher temperature quickly dries up the crops and facilitates harvesting. Marginally increasing annual temperature reduces the net revenue per hectare by US$ 21.61, although the level of reduction is not significant.

Increasing precipitation during the spring season increases net revenue per hectare by US$225.08. As explained earlier, with slightly higher temperature and available precipitation (soil moisture level), crop germination is enhanced. Increasing precipitation levels during the winter significantly reduces the net revenue per hectare by US$464.76. Winter is a dry season, so increasing precipitation slightly with the already dry season may encourage diseases and pests. Marginally, increasing precipitation during summer and the fall also reduces the net revenue per hectare, by US$18.88 and US$64.19, respectively, even though the level of reduction is not significant. The reduction in the net revenue per hectare during summer is due to the already high level of rainfall in the country during this season, as increasing precipitation any further results in flooding and damage to field crops. The reduction in the net revenue per hectare with increasing precipitation during the fall is due to the crops' reduced water requirement during the harvesting season. More precipitation damages crops and may re-initiate growth during this season. Increasing annual precipitation marginally reduces net revenue per hectare by US$322.75. The reduction in the net revenue per hectare with increasing annual precipitation is due to the fact that the reduction caused by increasing precipitation in some seasons outweighs the benefits gained in the other season. This reduction in the net revenue hectare due to marginal increment in annual precipitation shows that there is already high intensity of rainfall in some of the seasons in which further increment is destructive to crop growth. Rainfall intensity is already high in some seasons overshadowing the need of an optimal seasonal distribution that is required to coincide with crop growth.

Additionally, the marginal impact analysis has been undertaken to observe the distribution of impacts across the different zones. The marginal effects of change in temperature and rainfall for each zone are calculated by using the parameter estimates from the net revenue regression at mean values of temperature and rainfall of each zone (Seo *et al.*, 2008). As expected, the results indicate that marginal impacts are not uniformly distributed across each

Table 7: *Marginal Impacts of Temperature across AEZs*

| Agro-ecological zones | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| Tepid to cool humid midlands | −1094.93 | 408.4072 | −975.476 | 1383.373 |
| Cold to very cold moist Afro-alpine | −817.663 | 29.96512 | −1961.49 | 2808.088 |
| Tepid to cool pre-humid mid-highlands | −1008.11 | 371.8475 | −1342.05 | 1930.314 |
| Tepid to cool moist mid-highlands | −896.783 | 142.6085 | −1616.98 | 2375.871 |
| Tepid to cool sub-moist mid-highlands | −823.265 | 102.0964 | −1878.33 | 2698.7 |
| Tepid to cool sub-moist highlands | −1064.12 | 485.4789 | −1124.82 | 1559.461 |
| Hot to warm humid lowlands | −908.686 | 76.4058 | −1762.93 | 2447.907 |
| Hot to warm sub-moist lowlands | −946.495 | 355.0498 | −1394.66 | 2063.714 |
| Hot to warm pre-humid lowlands | −851.972 | 37.86992 | −1835.91 | 2607.988 |
| Hot to warm arid lowland plains | −1189.45 | 774.9921 | −74.3166 | 406.8828 |
| Hot to warm sub-humid lowlands | −1040.32 | 494.3718 | −1375.99 | 2013.022 |

AEZ. Increasing winter temperature damages the hot to warm arid low-land plains the most and the cold to very cold moist Afro-alpine zones the least. The hot to warm arid lowland plains are already hot and arid places with very high moisture stress and thus, increasing temperature marginally highly reduces the net revenue per hectare. The cold to very cold moist Afro-alpine zones have relatively cooler temperature and thus, the reduction in the net revenue per hectare induced by marginally increasing temperature during the winter season is the smallest. The benefits from increasing the fall temperature are also not equally distributed among the different zones. For instance, increasing the fall temperature benefits the cold to very cold moist Afro-alpine zone the most and the hot to warm arid lowland plains the least (Table 7). Increasing winter precipitation damages the tepid to cool sub-moist

Table 8: *Marginal Impact of Precipitation across AEZs*

| Agro-ecological zones | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| Tepid to cool humid midlands | −430.243 | 213.5219 | 71.14928 | −186.482 |
| Cold to very cold moist Afro-alpine | −109.395 | 59.07165 | −38.1864 | 70.00727 |
| Tepid to cool pre-humid mid-highlands | −432.82 | 196.533 | −28.7601 | −27.1173 |
| Tepid to cool moist mid-highlands | −301.711 | 188.1279 | 6.598253 | −93.2135 |
| Tepid to cool sub-moist mid-highlands | −345.199 | 217.2773 | −23.5948 | −87.0934 |
| Tepid to cool sub-moist highlands | −740.783 | 330.7753 | −19.9301 | −101.231 |
| Hot to warm humid lowlands | −306.543 | 179.0075 | 23.78685 | −118.183 |
| Hot to warm sub-moist lowlands | −540.092 | 261.2697 | −35.3104 | −71.1814 |
| Hot to warm pre-humid lowlands | −267.564 | 140.7973 | 71.16852 | −149.15 |
| Hot to warm arid lowland plains | −571.339 | 385.6764 | 32.24168 | −256.373 |
| Hot to warm sub-humid lowlands | −391.587 | 74.62994 | −103.353 | 176.8627 |

highlands the most and the cold to very cold moist Afro-alpine zone the least (Table 8). This difference could be associated with the difference in humid conditions, which make higher rainfall more harmful to some of the zones than the others (Seo *et al.*, 2008).

### *5.3 The impacts of forecasted climate scenarios*

The impact of climate change on the net revenue per hectare was analysed using the climate scenarios from the Special Report on Emission Scenarios (SRES). The SRES was a report prepared on future emission scenarios to be used for driving climate change models in developing climate change scenarios (IPCC, 2001). Future climate change scenarios from climate change models are commonly used to analyse the likely impact of climate change on economic or biophysical systems (Du Toit *et al.*, 2001; Xiao *et al.*, 2002; Kurukulasuriya *et al.*, 2006).

Predicted values of temperature and rainfall from three climate change models (CGM2, HaDCM3 and PCM) were applied to help understand the likely impact of climate change on Ethiopian agriculture. The predicted values for the scenario analysis were taken from the hydrological component of the project from Colorado University.

By using parameters from the fitted net revenue model, the impact of changing climatic variables on the net revenue per hectare is analysed as:

$$\Delta y = y' - y \tag{4}$$

$$\mathrm{NRh} = \sum_{1}^{n} \frac{\Delta y}{n}, \tag{5}$$

where $y'$ is the predicted net revenue per hectare from the estimated net revenue model under the new[1] (future) climate scenario, $y$ is the predicted value of the net revenue per hectare from the estimation model under the current climate scenario, $\Delta y$ is the difference between the predicted value of the net revenue per hectare under the new climate scenarios and the current climate scenario, NRh is the average of the change in the net revenue per hectare and n is the number of observations.

Table 9 shows the predicted values of temperature and precipitation from the three models for the years 2050 and 2100. As can be observed from this table, all the models forecasted increasing temperature levels for the years 2050 and 2100. With respect to precipitation, while the CGM2 predicted decreasing precipitation for the years 2050 and 2100, both HaDCM3 and PCM predicted increasing precipitation over these years.

The results of the predicted impacts from the SRES models are presented in Table 10. The table shows that all the predicted values used from every SRES model result in the reduction of the net revenue per hectare by both 2050 and 2100. For the CGM2 scenario, the reduction is 9.71% for the year 2050 and 130.04% for the year 2100. In the case of the HADCM3 scenario, the net revenue

[1] New climate scenario equals the current climate scenario plus the projected change in climatic variables (temperature or rainfall) from the three climate prediction models.

Table 9: *Climate Predictions of SRES Models for 2050 and 2100*

| Model | Temperature | | | Precipitation | | |
|---|---|---|---|---|---|---|
| | Current | 2050 | 2100 | Current | 2050 | 2100 |
| CGM2 | 21.25 | 24.51 | 29.26 | 76.77 | 64.75 | 50.27 |
| HADCM3 | 21.25 | 25.07 | 30.66 | 76.77 | 83.53 | 93.46 |
| PCM | 21.25 | 23.50 | 26.69 | 76.77 | 80.83 | 85.67 |

Table 10: *Forecasted Average Net Revenue per Hectare Impacts from SRES Climate Scenario (US$)*

| Impacts | CGM2 | | HADCM3 | | PCM | |
|---|---|---|---|---|---|---|
| | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 |
| Change in net revenue per hectare (US$) | −182.60 (9.71%) | −1830.61 (130.04%) | −728.80 (303.27%) | −3601.17 (418.01%) | 309.77 (15.40%) | −1323.91 (103.39%) |

reduction amounts to 303.27% for the year 2050 and 418.01% for the year 2100. The reduction in the net revenue per hectare in the case of the PCM scenario amounts to 15.40% for the year 2050 and 103.39% for the year 2100. As can be observed, although the net revenue reduction is common for all models and both years, it is greater in the year 2100 than in 2050. This indicates that the level of damage due to climate change continues to increase in the future unless adaptation is undertaken to reduce this negative impact of climate change. This result is also in line with the fact that future climate change is damaging to African agriculture (Hassan and Nhemachena, 2008; Kurukulasuriya and Mendelsohn, 2008).

Moreover, net revenue impacts from the predicted SRES models are estimated for each of the AEZs by using the parameters from the net revenue regression to compare the distribution of impacts.

Table 11: *Forecasted Average Net Revenue per Hectare Impacts from SRES Climate Scenario across Different Agro Ecological Settings (US$)*

| Agro ecological zones | CGM2 | | HADCM3 | | PCM | |
|---|---|---|---|---|---|---|
| | 2050 | 2100 | 2050 | 2100 | 2050 | 2100 |
| Hot to warm sub-moist lowlands | −85.97 (8.93%) | −1076.59 (111.78%) | −921.53 (95.68%) | −3471.59 (360.43%) | −600.39 (62.33%) | −1403.77 (145.74%) |
| Tepid to cool sub-moist mid-highlands | −910.65 (98.16%) | −2731.45 (294.42%) | −1898.49 (204.63%) | −5490.08 (591.76%) | −1286.35 (138.65%) | −2679.23 (288.79%) |
| Tepid to cool pre-humid mid-highlands | −546.28 (54.74%) | −2592.00 (259.71%) | −813.10 (81.47%) | −3746.72 (375.41%) | −371.27 (37.20%) | −1442.22 (144.51%) |
| Tepid to cool humid midlands | −1341.62 (105.58%) | −4368.45 (343.78%) | −1792.08 (141.03%) | −5959.84 (469.02%) | −1005.75 (79.15%) | −2774.48 (218.34%) |
| Hot to warm sub-humid lowlands | 178.22 (15.52%) | −747.09 (63.91%) | −706.18 (60.41%) | −3230.05 (276.33%) | −396.89 (33.95%) | −1174.20 (100.45%) |
| Tepid to cool moist mid-highlands | −118.91 (6.49%) | −2016.49 (110.01%) | 10.69 (0.58%) | −2286.69 (124.75%) | 282.19 (15.40%) | −454.97 (24.82%) |
| Cold to very cold moist Afro-alpine | 467.79 (52.15%) | −1322.78 (147.48%) | 931.49 (103.85%) | −848.37 (94.59%) | 1064.79 (118.72%) | 598.04 (66.68%) |
| Hot to warm humid lowlands | −1071.85 (205.10%) | −3334.71 (638.10%) | −1611.51 (308.36%) | −5117.40 (979.22%) | −1011.67 (193.58%) | −2395.80 (458.44%) |
| Hot to warm arid lowland plains | 1470.53 (50.38%) | −433.08 (14.84%) | 986.22 (33.79%) | −2106.85 (72.19%) | 1475.00 (50.54%) | 315.91 (10.82%) |
| Hot to warm per humid lowlands | −44.93 (23.34%) | −1866.29 (969.25%) | −443.63 (230.40%) | −3317.83 (1723.1%) | −19.91 (10.34%) | −1049.06 (544.82%) |
| Tepid to cool sub-moist highlands | −416.67 (63.58%) | −1455.82 (222.14%) | −900.99 (137.48%) | −3078.89 (469.80%) | −675.44 (103.06%) | −1296.21 (197.79%) |

*Source*: Central Statistics Authority (2005).

Following Seo *et al.* (2008), impact estimates for each AEZ are calculated at the mean of a climate variable at that AEZ. As expected, the results indicated that the different AEZs are not uniformly affected by future changes in climate (Table 11). This result is in line with the findings by Seo et al. (2008), which revealed that different AEZs in Africa are not equally affected by future climate change.

For the CGM2 scenario, the hot to warm sub-humid lowlands, cold to very cold moist Afro-alpine zone and hot to warm arid lowland plains will benefit from climate change, whereas the remaining zones will experience a reduction in net revenue by 2050. Under the HADCM3 scenario, the tepid to cool moist mid-highlands and hot to warm arid lowland plains will benefit by the year 2050, whereas the remaining zones will lose. By the year 2100, all of the zones will experience a reduction in the net revenue per hectare both for the CGM2 and HADCM3 scenarios. The tepid to cool moist mid-highlands, cold to very cold moist Afro-alpine zone and hot to warm arid lowland plains will benefit from climate change by 2050 under the PCM scenario, whereas the remaining zones will experience a reduction. By the year 2100, the cold to very cold moist Afro-alpine zone and the hot to warm arid lowland plains will benefit from climate change under the PCM scenario, whereas the others will lose. As these results indicate, although a few of the AEZs benefit from climate change under the different scenarios, the majority of the zones will lose both by the years 2050 and 2100 with higher levels of loss by the year 2100. Moreover, the estimated future losses are so high that agriculture has to adapt in order to avoid the likely failure of the sector.

## 6. Conclusions and Policy Implications

This study is based on the Ricardian approach that captures farmers' adaptations to varying environmental factors to analyse the impact of climate change on Ethiopian agriculture. A total of 1,000 households from 50 districts across the country were considered for this study.

Net revenues were regressed on climatic and other control variables. The independent variables include the linear and quadratic temperature and precipitation terms for the four seasons (winter, spring, summer and the fall), household variables and soil types collected from different sources. The regression results indicated that the climatic, household and soil variables have a significant impact on the net revenue per hectare for Ethiopian farmers.

The marginal impact analysis showed that increasing temperature marginally during winter and summer reduces the net revenue per hectare by US$997.85 and US$1277.28, respectively, whereas increasing temperature marginally during spring and the fall increases it by US$375.83 and US$1877.69, respectively. Increasing the annual temperature reduces the net revenue per hectare by US$ 21.61. Increasing precipitation during spring increases the net revenue per hectare by US$225.08, whereas increasing precipitation during winter significantly reduces the net revenue by US$464.76. Marginally increasing precipitation during summer and the fall also reduces the net revenue per hectare by US$18.88 and US$64.19, respectively, even though the level of reduction is not significant. Increasing the annual precipitation marginally reduces the net revenue per hectare. This is mainly due to the high intensity of precipitation in some of the seasons, which is more than that of crop requirement, damaging crop growth by overweighting the benefits from marginal increments in precipitation in some of the seasons. Moreover, the marginal impact analyses undertaken for each of the AEZs indicate that the impacts are not uniformly distributed across the different zones.

Forecasts from three different climate models (CGM2, HaDCM3 and PCM) were also considered in this study to see the effects of climate change on Ethiopian farmers' net revenue per hectare in the years 2050 and 2100. The results indicated that climate change reduces the net revenue per hectare both by 2050 and 2100 under all scenarios from the SRES models. The reduction in the net revenue per hectare is more in the year 2100 than 2050 under all scenarios. Furthermore, the net revenue impacts from the predicted SRES models are estimated for each AEZ to compare the distribution of the impacts. Results indicate that the different AEZs are not uniformly affected by future changes in climate. These indicate that the damages that climate change causes to the welfare of Ethiopian farmers continue to increase over years, affecting the different AEZs differently. Moreover, the calculated future damages are so severe that the survival of the Ethiopian agricultural sector itself will be at stake unless adaptation is practiced.

The above analysis shows the magnitude and direction of impact of climate change on Ethiopian agriculture. Most of the results show that climate change, especially increasing temperature, is damaging. The damage is also not uniformly distributed across different AEZs. This has a policy implication worth thinking about and planning before further damage occurs. The Ethiopian government must consider designing and implementing adaptation policies to counteract the harmful impacts of climate change. The adaptation policies should target different agro-ecologies based on the constraints and potentials of each agro-ecology instead of recommending uniform interventions. Adaptation options, which could be appropriate for different agro-ecologies, include investment in technologies such as irrigation, planting drought-tolerant and early-maturing crop varieties, strengthening institutional set-ups working in research, educating farmers and encouraging ownership of livestock, as owning livestock may buffer the effects of crop failure or low yields during harsh climatic conditions.

## Funding

The GEF and World Bank sponsored this study.

## Acknowledgements

This is part of an Africa-wide study on the economic impact of climate change on agriculture co-ordinated by the Center for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria and Yale University. The authors would like to thank Prof. Rashid Hassan, Dr James Benhin, Dr Pradeep Kurukulasuria, Prof. Robert Mendelson, Prof. Arial Dinar, Dr Kidane Georgis and Ato Abebe Tadege. The views expressed are the authors' alone.

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