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Measuring The Economic Impact of Climate Change on Ethiopian Agriculture:

Ricardian Approach

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Abstract

This study uses the Ricardian approach to analyze the impact of climate change on Ethiopian agriculture and to describe farmer adaptations to varying environmental factors. The study analyzes data from 11 of the country's 18 agro-ecological zones, representing more than 74 percent of the country, and survey of 1,000 farmers from 50 districts. Regressing of net revenue on climate, household, and soil variables show that these variables have a significant impact on the farmers' net revenue per hectare.

The study carries out a marginal impact analysis of increasing temperature and changing precipitation across the four seasons. In addition, it examines the impact of uniform climate scenarios on farmers' net revenue per hectare. Additionally, it analyzes the net revenue impact of predicted climate scenarios from three models for the years 2050 and 2100. In general, the results indicate that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture. Although the analysis did not incorporate the carbon fertilization effect, the role of technology, or the change in prices for the future, significant information for policy-making can be extracted.

This paper—a product of the Sustainable Rural and Urban Development Division, Development Economics Research Group Department—is part of a larger effort in the department to mainstream economic research on climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at ttderessa@yahoo.com.

MEASURING THE ECONOMIC IMPACT OF CLIMATE CHANGE ON ETHIOPIAN AGRICULTURE: RICARDIAN APPROACH[1]

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SUMMARY

This study used the Ricardian approach that captures farmer adaptations to varying environmental factors to analyze the impact of climate change on Ethiopian agriculture. Of the 18 agro-ecological zones, 11 agro-ecological zones, representing more than 74% of the country, were selected and total of 1000 farmers from 50 districts were interviewed. Net revenue was regressed on climate, household and soil variables. The results show that these variables have a significant impact on the net revenue per hectare of farmers under Ethiopian conditions.

A marginal impact analysis of increasing temperature and precipitation across the four seasons (winter, spring, summer and fall) was also undertaken. The results indicated that a unit increase in temperature during summer and winter would reduce net revenue per hectare by US$177.62 and 464.71 respectively, whereas the marginal impact of increasing precipitation during spring would increase net revenue per hectare by US$225.09.

In addition, the study examined the impact of uniform climate scenarios on the net revenue per hectare of Ethiopian farmers. These uniform scenarios include increasing temperature by 2.5^{o}C and 5^{o}C; and decreasing precipitation by 7% and 14%. These results indicate that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture. According to this analysis, decreasing precipitation appeared to be more damaging than increasing temperature. For instance, while increasing temperature by 5^{o}C reduced net revenue per hectare by US$0.00016, reducing precipitation by 14% reduced net revenue per hectare by US$0.39.

The study also examined the net revenue impact of predicted climate scenarios from three models (CGM2, HaDCM3 and PCM) for the years 2050 and 2100. All these models indicated that there would be a positive net revenue impact for the year 2050 but a negative one for the year 2100 even though the net impacts in all cases are very meager.

In general, the above analysis indicates that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture. Even though the analysis did not incorporate the carbon fertilization effect, or the role of technology and change in prices for the future, significant information for policy making can be extracted. By filling these gaps, more information for decision making can be generated.

1. Introduction

It is generally recognized 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 United States and other developed countries.

Because 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 & 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 rainfed agriculture and under heavy pressure from food insecurity and often famine caused by natural disasters such as drought, is likely to be affected (Mendelsohn & 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, as part of the Global Environment Facility/World Bank Project: *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*, 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 reviews the literature on the impact of climate change and the methodologies used to study this impact. Section 4 describes the agro-ecological features of the sample districts and Section 5 the methodologies and data types. Section 6 discusses the results and Section 7 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 eight million hectares is used annually for rainfed 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 rainfed 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; overcultivation 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.

2.1 Crop production

Rainfed crop production is the basis of all subsistence farming in most parts of Ethiopia and accounts for more than 95% of the land area cultivated annually. In general farming is mixed: both animal and crop production are important. A typical farming household in the semi-arid areas owns just a small portion of land (generally less than one hectare) on which crops are produced and which also partly supports variable numbers of cattle, goats, donkeys, and sheep.

The country's diverse agro-ecological conditions enable it to grow a large variety of crops. Most of these are cereals (teff, maize, sorghum, wheat, barley, millet, oats, etc.), pulses (horse beans, field peas, lentils, chickpeas, haricot beans, vetch, etc.), oil seeds (linseed, niger seed, fenugreek, rapeseed, sunflower, castor bean, groundnuts, safflower, etc.), and herbs and spices (pepper, garlic, ginger, mustard, etc). Stimulants (coffee, tea, chat, tobacco, etc.) are the major cash crops. Fruits (banana, orange, grape, papaya, lemon, mandarin, apple, pineapple, mango, avocado, etc.) sugar cane, fibers (cotton, sisal, etc.), vegetables (onion, tomato, carrot, cabbage, etc.), roots and tubers (potato, sweet potato, beets, yams, etc.) are the other crops grown.

A wide range of both biotic and abiotic stresses constrains field crop production. The main biotic constraints are weeds, insects and disease, and the main abiotic ones are drought, low soil fertility, waterlogging, and low level of technology.

The production of crops is dominated by small-scale subsistence farmers (about eight million peasant households). These small-scale farmers account on average for 95% of the total area under crops and for more than 90% of the total agricultural output. Most of the food crops (94%) and coffee (98%) are produced by small-scale farmers, while the remaining 6% of food crops and 2% of coffee is generated by commercial farms (state and private). Most farmers still use traditional farming methods, i.e. plowing the land with ox-drawn wooden ploughs with steel pikes, minimal application of fertilizer and pesticides, and low use of improved seeds.

The 1994 agricultural sample survey indicates that the average yield of all crops at the national level was about 1000kgs (10 quintals) per hectare, while the average yield of cereals, pulses and other crops was about ten, nine and three quintals per hectare respectively (CSA 1995). Crop production has been poor for the last three and half decades. Food grain per capita has registered a downward trend for several years. Once self-sufficient in food production and a net exporter of food grains, Ethiopia has since 1981/82 become a net grain importer (MEDaC 1999).

2.2 Livestock

Ethiopia has the largest livestock population in Africa and the tenth largest in the world. Livestock is an integral part of the farming systems in the country. It is the source of many social and economic values such as food, power, fuel, cash income, security and investment in both the highland and the lowland pastoral farming systems. The livestock sector contributes approximately 12 to 15% to total GDP and about 25 to 30% to the agricultural GDP (MEDaC 1999). It is also a major source of foreign exchange, second only to coffee.

In general the country's livestock resources are characterized by low productivity. Average yields per animal slaughtered or milked are estimated at 110kg of beef, 10kg of mutton and 213kg of cow's milk. At present the per capita consumption of milk and meat is estimated to be 16 kg and 10 kg per annum respectively. Compared with its neighbors, Ethiopia has the lowest consumption rates of these two products because of the low income level of the majority of its population (MEDaC 1999).

Inadequate food and nutrition, the low level of veterinary care, the high occurrence of diseases, poor genetic structure, inadequate budget allocation, limited infrastructure, limited research on livestock, insecure land tenure and recurrent drought are the main constraints in this subsector (Befekadu & Nega, 1999/2000).

3. Review of literature on climate change impact studies and methodologies employed

3.1 Climate prediction models

Human activities such as the burning of fossil fuels and deforestation increase the concentration of carbon dioxide (CO_2) and other trace gases in the atmosphere, which in turn alters the energy balance of the earth (Rosenzweig 1989). The gases do this by absorbing long wave radiation emitted by the earth to balance the incoming short wave solar radiation. In the long run, if the absorbed solar radiation is not balanced by outgoing thermal radiation, global warming will occur. The warming caused by the trapping of the long wave radiation is known as the 'greenhouse effect. and the trace gases responsible are known as 'green house gases' (Rosenzweig 1989).

The behavior of a climate system, its components and their interactions are studied and simulated using climate prediction models. These models are designed mainly for studying climate processes and natural climate variability, and for projecting the response of climate to human induced forces. The most complex climate prediction models developed and used are called the global climate models or general circulation models (GCMs). These are mathematical representations of the atmosphere, ocean, and land surface processes involving mass, momentum, energy and water and their interactions. They are based on physical laws describing the dynamics of atmosphere and ocean expressed in mathematical equations. These equations incorporate numerical representations of the physical processes of radiation, turbulent transfers at the ground-atmosphere boundary, cloud formations, condensation of rain and transport of heat by ocean currents (Barron 1995).

Through mathematical simulations, GCMs make it possible to predict what would happen to climate around the world in response to a wide variety of changes in the concentrations of greenhouse gases in the atmosphere (Barron 1995; IPCC 2001). Two different strategies are applied to make projections of future climate changes using GCMs: the equilibrium and the transient methods (IPCC 2001).

Equilibrium models (as the case in comparative statics) are not dynamic, i.e. do not trace changes over time but compare two points of equilibrium. In these models, first the base-line climate is simulated under present conditions (emission levels) to determine the current equilibrium. Then climate is simulated under a new scenario, such as the doubling of CO_2, which leads to a new equilibrium. The difference between the climate levels of the two simulations provides an estimate of the climate change corresponding to the doubling of CO_2. While this method is relatively cheap and easy to apply, it does not provide insight into the time dependence of climate change (IPCC 2001).

Transient models trace changes over time at various points of disequilibria or paths to new equilibrium. These models project climate change based on different emission levels, which are developed based on assumptions concerning future socio-economic and demographic changes such as the growth of world population, energy intensity and efficiency, and economic growth, which lead to different emissions scenarios. The difference between the simulated climate change under different emission scenarios and the original base-line simulation provides a time dependent projection of climate change. These methods are thus more realistic ways of projecting future climate than forcing the GCMs with an abruptly doubled concentration of atmospheric carbon dioxide as in the case of the equilibrium method (Rosenzweig et al. 1998).

Though crucial in climate research, the GCMs have limitations, the significant ones being poorly understood ocean circulation processes, lack of knowledge about cloud formation and feedbacks, crudely formulated hydrological processes, coarse spatial resolution, and inability to simulate current regional climate accurately (Rosenzweig 1989; Dinar & Beach 1998). In addition, Barron indicates that ‘predictions of future climate using climate models are imperfect as they are limited by significant uncertainties that stem from: 1) the natural variability of climate; 2) our inability to predict accurately future greenhouse gases and aerosol emissions; 3) the potential for unpredicted or unrecognized factors, such as volcanic eruptions or new unknown human influences, to perturb atmospheric conditions and 4) our as-yet incomplete understanding of the total climate system’ (1995).

3.2 *Economic impact assessment models*

There are two main types of economic impact assessment models in the literature: 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 & De Janvry 1995)

3.2.1 Economy-wide models of climate change

Computable general equilibrium (CGE) models are one kind of economy-wide policy impact assessment model. Currently, economic analysis of environmental issues and policies is a principal area of CGE model applications (Oladosu et al. 1999). This class of economic model is suitable for environmental issues because 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 (Mabugu 2002; Oladosu et al. 1999)

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. For instance, Winters et al. (1996) studied the impact of global climate change on the less developed countries using a CGE model for three economies representing the poor cereal importing countries of Africa, Asia and Latin America. The said study showed that all these countries would suffer damage and that their agricultural outputs would fall as a result of climate change, and that Africa would be the most severely affected. Yates and Strzepek (1998) also used a dynamic CGE model to assess the impact of climate change on the Egyptian economy, and concluded that the net effects of climate change on per capita GDP were not significant.

Nordhaus and Yang (1996) used a dynamic general equilibrium model to analyze various national strategies in climate change policies such as pure market solutions, efficient cooperative outcomes and non-cooperative equilibria. This study revealed that there are substantial differences in the levels of controls in both the cooperative and the non-cooperative policies among different countries and that the high-income countries may be the major losers from cooperation. In addition to these, Deke et al. (2001) used the CGE model approach in a regionally and sectorally disaggregated framework to analyze adaptation to climate change in various regions of the world. The study result showed that vulnerability to climate impact differs significantly across regions and that the overall adjustment of the economic system somewhat reduces the direct economic impacts.

Although CGE models can analyze 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 and the complexity of the CGE models and the high skills needed to develop and use them (Gillig & McCarl 2002).

3.2.2 Partial equilibrium models of climate change impacts

The partial equilibrium models available in the literature can be classified according to two ways of analyzing the sensitivity of agriculture to climate change. The first is based on crop growth simulation models and the second uses econometric procedures. These two approaches are compared and discussed in further detail in the following subsections.

3.2.2.1 Crop growth simulation models

The two approaches commonly used for analyzing the impact of climate change on agriculture in this group of models are a) the crop suitability approach and b) the production function approach.

a) Crop suitability approach

This 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 agricultural land suitability 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 2002).

The AEZ framework contains three basic elements (FAOSTAT 2002). The first is land utilization types (LUTs), which are selected agricultural production systems with defined input and management relationships, and crop specific environmental requirements and adaptability characteristics. The second is agro-referenced climate, soil and terrain data, which are combined into a land resource database. The third element is the procedure for calculating potential yields by matching crop/LUT environmental requirements with the environmental characteristics captured in the database. These models were developed to look at potential production capacity across various ecological zones by using a simulation of crop yields rather than measured crop yields (Mendelsohn & Tiwari 2000).

Xiao et al. (2002) used the AEZ approach to estimate the area and spatial distribution of global potential croplands under different climate change predictions. The Xiao et al. (2002) study indicated that the area of global potential croplands is about $(32.91)\text{x}10^6$ km^2 under contemporary climate, with a tendency to increase substantially over the period of 1977–2100 as a result of global warming. In this study, developed countries accounted for most of the increase in global potential croplands, while developing countries showed little change in area of cropland. A similar study by the Food and Agriculture Organization (FAOSTAT 2002) showed that a temperature increase of 3^{o}C, paired with a 10% increase in rainfall, would lead to about 4% more cultivable rainfed land. The cultivable land in developed countries would increase by 25% whereas it would decrease by 11% in developing countries, which clearly indicates the uneven distribution of climate benefits.

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

b) The production function approach

The production function approach to analyzing the impacts of climate change on agriculture 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 analyzed at testing sites (Adams 1989; Kaiser et al. 1993; Lal et al. 1999; Olsen 2000; Southworth et al. 2000; Alexandrov & Hoogenboom 2000). The estimated changes in yield caused by changes in environmental variables are aggregated to reflect the overall national impact (Olson, 2000) or incorporated into an economic model to simulate the welfare impacts of yield changes under various climate change scenarios (Adams 1989; Kumar & 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). Farmers are likely to respond to changing climate and other environmental factors by varying, among other things, the crop mix, planting and harvesting dates, irrigation scheduling and application of fertilizers and pesticides to mitigate the potential harmful effects of climate change. Moreover, this model does not consider the introduction of new crops, technological changes and changes in land use, and thus the main bias or weakness of the model is its failure to allow for economic substitution as conditions change (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 maximize profit under changing climatic conditions. A successful introduction of adaptation to the production function approach is found in Kaiser et al. (1993), who altered crop mix, crop varieties, sowing times, harvesting dates and water saving technologies (tillage) for farms in the United States and found that these adaptation activities reduce the damages from climate change. Although this model included adaptation, it was restricted to limited test sites, and general conclusions about climate change and agriculture at the national level could not be made.

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 few test locations and hence has limited value for generalizing the results.

3.2.2.2. Econometric approaches: The Ricardian model

The Ricardian model analyzes 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 & Parikh 1998; Polsky & Esterling. 2001). This model has been applied to value the contribution that environmental factors make to farm income by regressing land values on a set of environmental inputs and thereby measuring the marginal contribution that each input makes to farm income. Net revenue or price of land can be used to represent farm income. Mendelsohn et al. (1994) used both net revenue and land value, whereas Polsky and Esterling, (2001) used only land value as the dependent variable in their studies of the impact of climate change on the United State's agriculture. Additionally, Sanghi et al. (1998) used land value for Brazil, while Kumar and Parikh (1998) used net revenue as the dependent variable in analyzing the impact of climate change on Indian agriculture.

The most important advantage of the Ricardian model is its ability to incorporate private adaptations.. Farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates, and 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 (capitalized 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.

One of the weaknesses of the Ricardian approach is that it is not based on controlled experiments across farms. Farmers' responses vary across space not only because of climatic factors, but also because of many socio-economic conditions. Such non-climatic factors are seldom fully included in the model. Attempts have been made to include soil quality, market access and solar radiation to control for such effects (Mendelsohn et al. 1994; Kumar & Parikh 1998). In general, however, it is often not possible to get perfect measures of such variables and thus not all of them may be taken into account in the analysis using this method (Mendelsohn 2000)

The other weakness of the Ricardian model is that it does not include price effects (Cline 1996). If relative prices change because of the way climate change affects aggregate supply, the method underestimates or overestimates the impact depending on whether the supply of a commodity increases or decreases. This oversight leads to a bias in the calculations of producer and consumer surplus and hence to biased welfare calculations (Cline 1996).

Mendelsohn and Tiwari (2000) argue that for a number of reasons it is difficult to include price effects carefully using any method. First, for most crops prices are determined in global markets and the prediction of what would happen to each crop needs global crop models. But global crop models are poorly calibrated, so it is difficult to predict what will happen to the global supply of any single crop in a new world climate. Second, the few global analyses completed so far (Reilly et al. 1994) have predicted that the range of warming expected for the next century have only a small effect on aggregate supply. Third, if aggregate supply changes by only a moderate amount, the bias from assuming constant prices is relatively small. Thus, based on the above points, Mendelsohn and Tiwari (2000) argue that keeping prices constant is justified because it does not pose a serious problem in using the model.

The fact that the model does not take into account the fertilization effect of carbon dioxide concentrations (higher CO_2 concentration can enhance crop yield by increasing photosynthesis and allowing more efficient use of water) is another weakness of the model (Cline 1996; Mendelsohn & Tiwari, 2000). However, in spite of these weaknesses, it can be used to analyze the impact of climate change on agriculture by fully considering the adaptations farmers make to mitigate the harmful effects of the change.

Climate models such as the GCMs make it possible to predict climatic conditions based on the levels of various economic activities (such as CO_2 emission). Impact assessment models rely on predictions from GCMs and analyze the impacts of the predicted conditions on the economy.

4. Agro-ecological features of the sample area

Ethiopia has diverse agro-ecologies, which enable the production of a variety of crops and livestock. The agro-ecological zones in Ethiopia are defined on the basis of temperature and moisture regimes (MoA 1998). According to the Ministry of Agriculture (1998), Ethiopia has 18 main agro-ecological zones (Figure 2). Of the 18 zones, 11 zones representing more than 74% of the country were selected for this study. Table 1 shows the agro-ecological zones and the selected districts in each of the study zones. A brief description these is given below.

Hot to warm sub-moist lowlands

This zone covers the warm sub-moist plains in the north-west and Rift Valley lake regions of the country. The altitude here ranges from 400 to 1600m above sea level and the mean annual rainfall from 200 to 1000mm. Some parts are under rainfed annual crop production such as sesame, cotton, sorghum, coffee, papaya and banana. The dominant soil types are vertisols, cambisols, fluvisols, leptosols, orthic acrosols and eutric nitosols. The farming system includes both crop cultivation and livestock production. Bush and grasses cover the majority of the land that is not under farming. The major constraints in this zone are deforestation, malaria and poor infrastructure.

Tepid to cool sub-moist mid-highlands

This zone consists of the plains and mountains of the Tegray, Amhara and Somali Regional States. The altitude varies from 1400 to 2200m. The dominant soil types are eutric cambisols, vertic luvisols, vertisols and eutric fluvisols. The zone is intensively cultivated, the farming system being mixed cereal livestock production. Among the annual crops, the dominant ones are teff, wheat, sorghum and pulses. The livestock here are cattle, sheep, goats and donkeys. This zone has potential for rainfed agriculture on the plains and afforestation in the mountains area. The constraints here are erosion and deforestation.

Tepid to cool pre-humid mid-highlands

This zone is physio-geographically mountainous with an altitude range of 1000–3000m and it is found in different parts of the country. The climate is favorable for crop production and livestock grazing. The mean annual rainfall varies from 600 to 2200mm. Mixed crop livestock production is the faming system of this zone. The crops are both annual and perennial. The annual crops are maize, tubers, barley, wheat, sorghum and pulses, and the perennials are coffee, banana and chat. The major soil units are orthic acrisols and dystric and eutric cambisols that have high inherent fertility and adaptability to a variety of systems of land use, particularly to mixed farming. The main constraints are the shortage of fuelwood, and wind erosion in some places.

Tepid to cool humid midlands

This zone has a good climate and flat to gentle sloping terrain, which make it favorable for agriculture. The altitude ranges from 2000 to 2800m, and the mean annual rainfall from 900 to 2000mm. The dominant soil types in this zone are orthic acrisols, pellic vertisols, lithosols and vertic cambisols. The main cereal crops are maize, sorghum, wheat, barley and teff. The livestock here are cattle, sheep, goats, donkeys, mules and horses. Shallow soil depth and degraded topography and drainage are some of the major constraints of the zone.

Hot to warm sub-humid lowlands

This zone covers the warm sub-humid plains in the Gambella and Beneshangul Gumuz National Regional States. Its altitude ranges from 400 to 1000m. The major soil types are vertisols, fluvisols, regosols and leptosols. The natural vegetation cover is wooded grassland and cultivation is practiced mainly along major rivers such as the Baro and Akobo. Cotton, sorghum, maize and rice are the major annual crops and the perennials are mango and sugar cane. Tsetse fly, malaria and the workability of vertisols are the major constraints in this zone.

Tepid to cool moist mid-highlands

This zone covers the high potential areas of Oromia and Southern Nations, Nationalities. and People's Regional State (SNNPRS). Its climate is highly conducive to the growth and development of various plant and animal species. The general physio-geographiy is mountainous, with altitudes ranging from 1000 to 2800m The mean annual rainfall varies from 1100mm to 1500mm. The major soil types here are distric nitosols, orthic acrisols and chromic luvisols. The perennial crops are coffee, banana, papaya, mango and sugar cane, and the annuals are mainly maize and sorghum. This zone has a high potential for crops, livestock, forestry and wildlife production. Topography is the major constraint here, as it impedes the use of large-scale mechanized farming.

Cold to very cold moist Afro-alpine

This zone covers the southeastern parts of the Oromia Regional State. The altitude here ranges from 3000 to 4200m. The mean annual rainfall varies from 900 to 1800 mm. The main soil types are dystric nitosols, orthic acrisols, chromic luvisols and pellic vertisols. Barley, wheat and pulses are the major annual crops, and cattle, sheep, donkeys and horses are the major livestock. The potential for forestry and wildlife is high here. The main constraints are the rugged topography, shallow soil depth and wind erosion.

Hot to warm humid lowlands

This zone covers Oromia and the Southern Regional States. As it has favorable climatic conditions, many plant and animal species grow here. The topography is mainly mountains, with altitudes ranging from 800 to 2200m. The mean annual rainfall ranges from 1300 to 1700mm. The major soil types of the zone are dystric nitosols, cambic arenosols, lithosols and dystric cambisols. The major annual crops are sorghum, maize, wheat and barley and the major perennials are coffee, chat and sugar cane. The potential for forestry and wildlife is high here. The main constraints are the rugged topography and shallow soil depth.

Hot to warm arid lowland plains

This zone covers the arid valley and escarpment of the Afar Regional State. The altitude ranges from 0 to 1200m, and the annual precipitation from 100–600mm. The dominant soil types are leptosols, cambisols and fluvisols. The zone is sparsely cultivated (mostly irrigated) and covered by wooded grassland. Maize and sorghum are the major crops, and the livestock are goats, sheep, camels and cattle. This zone has a potential for livestock rearing and irrigated agriculture. Low rainfall, high temperature and lack of adequate infrastructure are the major constraints.

Hot to warm pre-humid lowlands

This zone is found in the SNNPRS. The climatic and soil conditions are conducive to the development of plant and animal species. The altitude ranges from 1400 to 2000m and the mean annual rainfall from 1000 to 1500mm. The major soil types are mollic andosols, eutric regosols, eutric fluvisols and lithosols. The major annual crops are maize, sorghum and teff, and the perennials are coffee, false banana, sugar cane, avocado and mango. This zone has a high potential for crop production. The main constraint to production is the shallow soil depth.

Tepid to cool sub-moist mid highlands

This zone is found in the Oromia National Regional State (ONRS) and the SNNPRS. The topography here is mountainous, with altitudes ranging from 1600 to 3200m. The mean annual rainfall ranges from 700 to 2200mm. The main soil types are dystric nitosols, orthic acrisols, lithosols, dystric cambisols and eutric nitosols. The major annual crops are maize, sorghum, teff and pulses, and the major perennials are coffee, chat, banana, papaya, mango and sugar cane. The livestock here are mainly cattle, sheep, goats, donkeys, horses and mules. Shallow soil depth and drainage are the constraints on agricultural production here.

5. 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 the United States 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 which 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 on a set of environmental inputs, the Ricardian approach makes it possible to measure the marginal contribution of each input to farm income as capitalized in land value.

5.1 The analytical model

The Ricardian model is based on a set of well-behaved (twice continuously differentiable, strictly quasi-concave, and positive marginal products) production functions of the form:

$$Q_i = Q_i(K_i, E) \qquad (1)$$

Where, Q_i is quantity produced of good i, K_{ij} is a vector of production inputs *j* used to produce Q*i* and *E* defines a vector of exogenous environmental factors such as temperature, precipitation, and soil, characterizing production sites.

Given a set of factor prices w_j , *E* and *Q*, cost minimization gives the cost function**:**

$$C_i = C_i(Q_i, W, E) \qquad (2)$$

Where C_i is the cost of production of good *i* and $W\ (w_1, w_2 ... w_n)$ is the vector of factor prices. Using the cost function C_i at given market prices, profit maximization by farmers on a given site can be specified as:

$$Max.\ \pi = \left[P_i Q_i - C_i(Q_i, W, E) - P_L L_i \right] \quad (3)$$

Where P_L is annual cost or rent of land at that site, such that under perfect competition all profits in excess of normal returns to all factors (rents) are driven to zero

$$P_i Q_i^* - C_i^*(Q_i^*, W, E) - P_L L_i^* = 0 \quad (4)$$

If the production of good *i* is the best use of the land given *E*, the observed market rent on the land will be equal to the annual net profits from the production of the good. Solving for P_L from the above equation gives land rent per hectare to be equal to net revenue per hectare:

$$P_L = (P_i Q_i^* - C_i(Q_i^*, W, E)) / L_i \quad (5)$$

The present value of the stream of current and future revenues gives the land value V_L:

$$V_L = \int_0^\infty P_L e^{-rt} dt = \int_0^\infty \left[(P_i Q^*_i - C_i(Q^*, W, E) / L_i \right] e^{-rt} dt \quad (6)$$

The issue to be analyzed is the impact of exogenous changes in environmental variables on net economic welfare (ΔW). The net economic welfare is the change in welfare induced or caused by changing environment from a given state to another. Consider an environmental change from the environmental state *A* to *B*, which causes environmental inputs to change from E_A to E_B. The change in annual welfare from this environmental change is given by:

$$\Delta W = W(E_B) - W(E_A) = \int_0^{Q_B} [(P_i Q_i - C_i(Q_i, W, E_B) / L_i] \, e^{-rt} dQ - \int_0^{Q_A} [(P_i Q_i - C_i(Q_i, W, E_A) / L_i] \, e^{-rt} dQ$$

If market prices do not change as a result of the change in E, then the above equation reduces to:

$$\Delta W = W(E_B) - W(E_A) = \left[PQ_B - \sum_{i=1}^{n} C_i(Q_i, W, E_B) \right] - \left[PQ_A - \sum_{i=1}^{n} C_i(Q_i, W, E_A) \right] \quad (7)$$

Substituting for $P_L L = P_i Q_i^* - C_i (Q_i^*, W, E)$ from (5)

$$\Delta W = W(E_B) - W(E_A) = \sum_{i=1}^{n} (P_{LB} L_{Bi} - p_{LA} L_{Ai}) \quad (8)$$

Where P_{LA} and L_A are at E_A and P_{LB} and L_B are at E_B

The present value of the welfare change is thus:

$$\int_0^{\infty} \Delta W e^{-rt} dt = \sum_{i=1}^{n} (V_{LB} L_{Bi} - V_{LA} L_{Ai}) \quad (9)$$

The Ricardian model takes either (8) or (9) depending on whether data are available on annual net revenues or capitalized net revenues (land values V_L). The model in (8) was employed for this research, as data on land prices for the selected samples were not available. This is the same approach followed by Sanghi et al. (1998) and Kumar & Parikh (1998) for India.

5.2 Data description

The household data for this study was based on a sample of 1000 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 southeastern 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 rainfed farms, as more than 95% of Ethiopian farmers are of this type.

The temperature data for this study was 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 was obtained from the Food and Agricultural Organization. The FAO provides information about the major and minor soils in each location, including the slope and texture. The hydrological data (flow and runoff) was obtained from the University of Colorado (IWMI/ University of Colorado 2003). The hydrology team calculated flow and runoff for each district using the hydrological model for Africa.

6. Results and discussion

6.1 Regression results

The Ricardian approach estimates the importance of climate and other variables on the capitalized value of farmland. Net revenues were regressed on climatic and other control variables. A non-linear (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 labor on crop activities in US$) as dependent variable 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 fall (the average for September, October and November). Tables 2, 3 and 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 net revenue per hectare. Precipitation, level of education of the head of the household, livestock ownership, and soil types were expected to have a positive impact on net revenue per hectare.

The regression results indicate that most of the climatic, household and soil variables have significant impacts on the net revenue per hectare (Table 6). This table shows that while the coefficients of spring and summer temperature are both negative, those of winter and fall are positive. The coefficients of 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 becomes further 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).

6.2 Marginal impact analysis

The marginal impact analysis was undertaken to observe the effect of an infinitesimal change in temperature and rainfall on Ethiopian farming. Table 7 shows the marginal impacts of temperature and precipitation. Increasing temperature during winter and summer seasons significantly reduces the net revenue per hectare. Increasing temperature marginally during the winter and summer seasons reduces the net revenue per hectare by US$997.7 and US$177.6 respectively. Increasing temperature marginally during the spring and fall seasons increases the net revenue per hectare by

US$337.8 and US$1879.7 respectively. During spring, a slightly higher temperature with the available level of precipitation enhances germination, as this is the planting season. During fall, a higher temperature is beneficial for harvesting. It is important that crops have finished their growth processes by fall, and a higher temperature quickly dries up the crops and facilitates harvesting.

Increasing precipitation during the spring season increases net revenue per hectare by US$225.1. 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$464.7. Winter is a dry season, so increasing precipitation slightly with the already dry season may encourage diseases and insect pests. Marginally increasing precipitation during the summer and fall also reduces net revenue per hectare, by US$18.9 and US$64.2 respectively, even though the level of reduction is not significant. The reduction in net revenue per hectare during the 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 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 reinitiate growth during this season.

6.3 The impacts of forecasted climate scenarios

6.3.1 Uniform scenarios

The impact of climate change on the net revenue per was analyzed using uniformly changed temperature and precipitation levels. These uniform scenarios assume that only one aspect of climate changes and that the change is uniform across the country. These scenarios increase temperature by 2.5^o C and 5^o C and reduce precipitation by 7% and 14%.

Using the estimated regression coefficients in Table 6, the impact of changing climatic variables on net revenue per hectare (NR) for a given district i. is given by.

$$\Delta NR_i = NR_{i,t\,t} - NR_{i\,,t-1} \qquad (10)$$

Where

$$NR_{i,t} \text{ is } NR_i\,(\,T_t,\,P_t) \qquad (11)$$

$$NR_{i,t-1} \text{ is } NR_i\,(\,T_{t-1},\,P_{t-1}) \qquad (12)$$

$$\text{And } T_t = T_{t-1} + \Delta T, \text{ and, } Pt = P_{t-1} + \Delta P \qquad (13)$$

ΔNR_i is the change in net revenue per hectare of a given district

NR_{it} is the forecasted value of net revenues per hectare under a new climate scenario

$NR_{i,\ t-1}$ is predicted value of net revenue per hectare of the base climate scenario

T_t , P_t is temperature and precipitation under the new climate scenario

T_{t-1}, P_{t-1} is temperature and precipitation for the base climate scenario

Δ T, ΔP is change in temperature and precipitation.

The average of ΔNR_i gives the impact of a given climate change scenario.

The results of this analysis are shown in Table 8. As can be observed from this table, increasing temperature by 2.5°C and 5°C affects net revenue per hectare marginally. Moreover, reducing precipitation by 7% and 14% also reduces net revenue per hectare, even though the level of damage is very small. These results are in line with the expectations that increasing temperature and reducing precipitation is damaging to agriculture in Africa, indicating a need for policy intervention targeting adaptation through technology such as irrigation, and the use of drought tolerant and early maturing crop varieties.

6.3.2 SRES climate scenarios

Predicted values of temperature and rainfall from three climate change models (CGM2, HaDCM3 and PCM) were also 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. 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. As can been seen from this table, using climate forecasts from all the models, this study revealed that by 2050 net revenue per hectare would increase, whereas by 2100 it would decrease. Even though the effects in both cases are marginal, this analysis further shows that climate change is damaging in the long run. The fact that all models show similar results in the long run indicates a need for policy intervention before damage is done.

7. Conclusions and policy implications

This study is based on the Ricardian approach that captures farmer adaptations to varying environmental factors to analyze the impact of climate change on Ethiopian agriculture. A total of 1000 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 fall), household variables and soil types collected from different various sources. The regression results indicated that climatic, household and soil variables have a significant impact on net revenue per hectare for Ethiopian farmers.

The marginal impact analysis showed that increasing temperature marginally during winter and summer reduces net revenue per hectare by US$997.7 and US$177.6 respectively, whereas increasing temperature marginally during spring and fall increases it by US$337.8 and US$1879.7 respectively. Increasing precipitation during spring increases net revenue per hectare by US$225.1, whereas increasing precipitation during winter significantly reduces it by US$464.7. Marginally increasing precipitation during summer and fall also reduces net revenue per hectare by US$18.9 and US$64.2 respectively, even though the level of reduction is not significant.

Uniform climate scenarios were also used to observe the likely impacts of climate change on Ethiopian agriculture. The uniform climate scenarios considered were increasing temperature by 2.5^{o}C and 5^{o}C while reducing precipitation by 7% and 14%. The results of these scenarios indicated that increasing temperature by 2.5^{o}C and 5^{o}C reduces net revenue per hectare by US$0.00016 and US$0.00036. Decreasing precipitation by 7% and 14% reduces net revenue per hectare by US$0.934 and US$0.933 respectively. These results are in line with the expectation that increasing temperature and decreasing precipitation is damaging to African agriculture.

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 is beneficial for 2050 but harmful in the year 2100 even though the effects are marginal in both cases. This result is also in line with the anticipation that future climate change is damaging to African framers.

The above analysis more or less shows the magnitude and direction of climate change impact on Ethiopian agriculture. Most of the results show that climate change, especially increasing temperature, is damaging. This has a policy implication worth thinking about and planning before damage occurs. The Ethiopian government must consider designing and implementing adaptation policies to counteract the harmful impacts of climate change. Adaptation options include investment in technologies such as irrigation, planting drought tolerant and early maturing crop varieties, strengthening institutional set-ups working in research, and educating farmers and encouraging ownership of livestock, as owning livestock may buffer the effects of crop failure or low yields during harsh climatic conditions.

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Table 1: Districts surveyed in the sample agro-ecological zones

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 per humid lowlands	Wenageo
11	Tepid to cool sub-moist mid-highlands	Bako

Table 2: Temperature (^oC) (sample mean) of agro-ecological zones

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 mid-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

Table 3: Precipitation (mm) (sample mean) of agro-ecological zones

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 mid-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 agro-ecological zones

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 mid-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

Table 5: Regression coefficients of climatic variables over net revenue per hectare

Variable	Coefficient
Winter temperature	737.49
Winter temperature squared	-35.25
Spring temperature	1216.78
Spring temperature squared	33.19*
Summer temperature	-5393.23***
Summer temperature squared	130.65***
Fall temperature	6752.78***
Fall temperature squared	-161.8735***
Winter precipitation	-621.04***
Winter precipitation squared	7.82*
Spring precipitation	392.60***
Spring precipitation squared	-1.97***
Summer precipitation	80.93***
Summer precipitation squared	-0.41***
Fall precipitation	-292.11***
Fall precipitation squared	2.13***
Constant	-3995.33
N	646
R2	0.24
F	12.02

* significant at 10% ** significant at 5% *** significant at 1%

Table 6: 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%

Table 7: Marginal impacts of climate on net revenue per hectare (US$)

Seasons	Winter	Spring	Summer	Fall
Temperature	-997.66***	337.84	-177.62**	1879.69***
Precipitation	-464.71***	225.09***	-18.88	-64.21

** significant at 5% *** significant at 1%

Table 8: Average net revenue per hectare impacts of uniform climate scenarios (US$)

Impacts	2.5 ^{0}C warming	5 ^{0}C warming	7 % decreased precipitation	14 % decreased precipitation
Change in ne revenue per hectare (US$)	-0.00016 (-1.31902E-05 %)	-0.0003646 (-3E-05 %)	-0.3941333 (-0.03249 %)	-0.393894 (-0.03247)

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$)	0.0000342	-0.0003328	0.0004001	-0.0005612	0.0001707	-0.0003668
	(2.81946E -06 %)	(-2.74361E-05 %)	(3.29843E -05 %)	(-4.62655E-05 %)	(1.40725E -05 %)	(-3.02391E-05%)

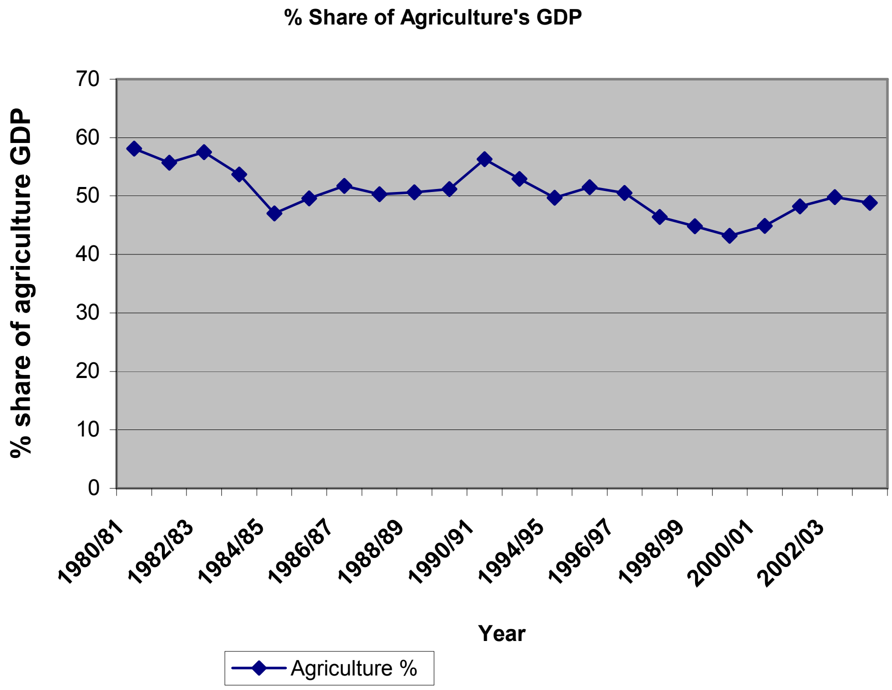

Figure 1: Trend of % share of agriculture's GDP

Source: Central Statistics Authority (2005)

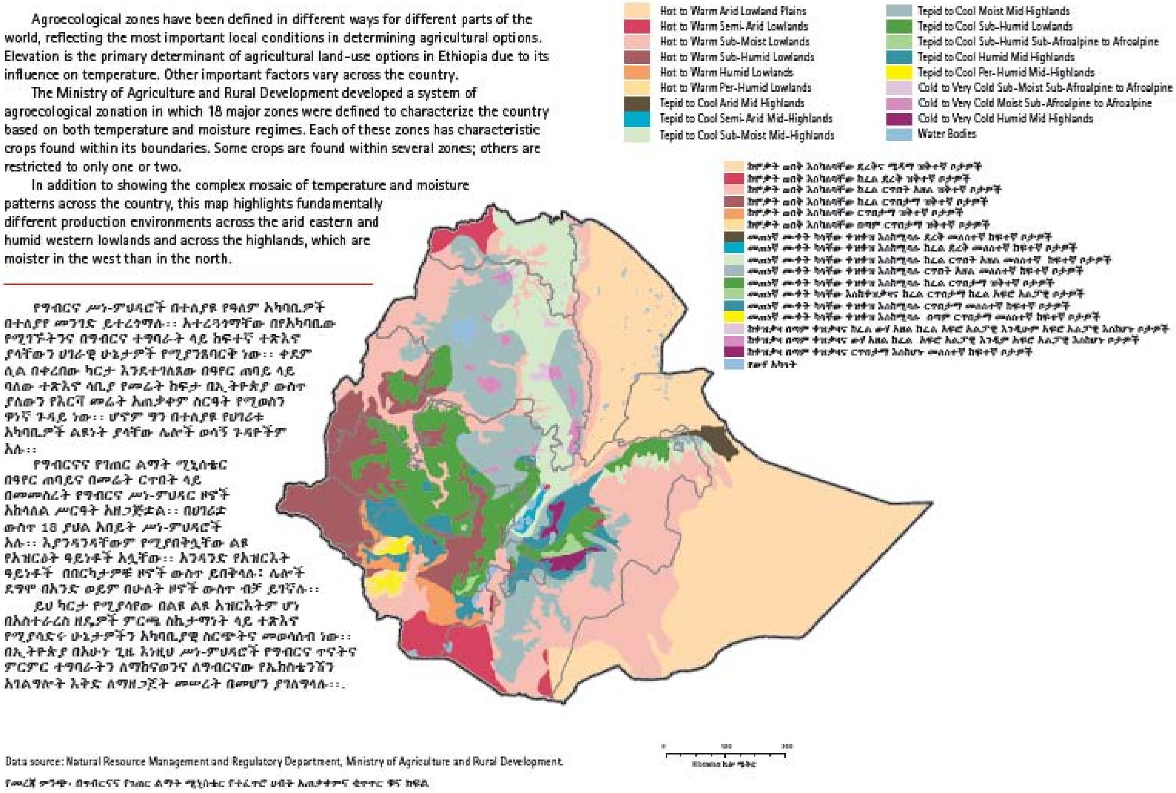

Figure 2: Agro-ecological zones of Ethiopia

Source: IFPRI and EDRI, 2006 (Permission for use was granted).