Environment for Development

Discussion Paper Series October 2011 ■ EfD DP 11-09

Climate Change and the Ethiopian Economy

A Computable General Equilibrium Analysis

Zenebe Gebreegziabher, Jesper Stage, Alemu Mekonnen, and Atlaw Alemu

EfD
Environment for Development

RESOURCES
FOR THE FUTURE

Environment for Development

The **Environment for Development** (EfD) initiative is an environmental economics program focused on international research collaboration, policy advice, and academic training. It supports centers in Central America, China, Ethiopia, Kenya, South Africa, and Tanzania, in partnership with the Environmental Economics Unit at the University of Gothenburg in Sweden and Resources for the Future in Washington, DC. Financial support for the program is provided by the Swedish International Development Cooperation Agency (Sida). Read more about the program at www.efdinitiative.org or contact info@efdinitiative.org.

Central America
Environment for Development Program for Central America
Centro Agronómico Tropical de Investigacíon y Ensenanza (CATIE)
Email: centralamerica@efdinitiative.org

China
Environmental Economics Program in China (EEPC)
Peking University
Email: EEPC@pku.edu.cn

Ethiopia
Environmental Economics Policy Forum for Ethiopia (EEPFE)
Ethiopian Development Research Institute (EDRI/AAU)
Email: ethiopia@efdinitiative.org

Kenya
Environment for Development Kenya
Kenya Institute for Public Policy Research and Analysis (KIPPRA)
Nairobi University
Email: kenya@efdinitiative.org

South Africa
Environmental Policy Research Unit (EPRU)
University of Cape Town
Email: southafrica@efdinitiative.org

Tanzania
Environment for Development Tanzania
University of Dar es Salaam
Email: tanzania@efdinitiative.org

Climate Change and the Ethiopian Economy:
A Computable General Equilibrium Analysis

Zenebe Gebreegziabher, Jesper Stage, Alemu Mekonnen, and Atlaw Alemu

Abstract

This paper analyses the economic impacts of climate change on Ethiopia's agriculture using a countrywide computable general equilibrium model. The impacts on agriculture are based on results from a Ricardian model where current (and future) agricultural production is analyzed as a function of temperature and precipitation. We project that the effect of overall climate change will be relatively benign until approximately 2030 and then worsen considerably. Our simulation results indicate that, over a 50-year period, the projected reduction in agricultural productivity may lead to 30 percent less average income, compared with the possible outcome in the absence of climate change. Autonomous adaptations that the farmers make and government policies in response will be crucial for Ethiopia's future development.

Key Words: climate change, computable general equilibrium, agriculture, Ethiopia

JEL Classification: Q54, Q56

Contents

Climate Change and the Ethiopian Economy: A Computable General Equilibrium Analysis

Zenebe Gebreegziabher, Jester Stage, Alemu Mekonnen, and Atlaw Alemu*

Introduction

In this paper, we examine the general equilibrium implications of climate change for the low-income country of Ethiopia and the potentially devastating effects it may have on Ethiopian agriculture, which contributes 42–45 percent to gross domestic product (GDP) and employs more than 80 percent of the population. We used a countrywide computable general equilibrium (CGE) model to look at the economic impacts of climate change-induced adjustments.

Understanding the potential economy-wide impacts of climate change for a given country is critical for designing national adaptation strategies, as well as formulating effective global climate-policy agreements. Developing countries particularly need to tailor adaptation policies to offset the specific impacts they anticipate. Quantifying the impact of climate change on the overall economy can be crucial in guiding appropriate policy.

Rain-fed agriculture will, in all likelihood, be substantially affected by climate change (Antle 2010; Sachs et al. 1999), especially in countries with large agricultural sectors in the tropics and subtropics, where agricultural production is weather sensitive and adaptive capacities are low. These areas will bear the brunt of any adverse economic impacts of climate change. Numerous partial equilibrium studies have assessed the micro-level impacts of climate change on agricultural performance in developing countries. (See, e.g., Deressa 2007; Deressa and Hassan 2009; Kates 2000; Kurukulasuriya and Mendelsohn 2006; Reilly et al. 1996; Reilly and Schimmelpfennig 1999; Rosenzweig and Parry 1994; Seo et al. 2009; Seo and Mendelsohn 2008.)

---

* Zenebe Gebreegziabher, Environmental Economics Policy Forum for Ethiopia (EEPFE), Ethiopian Development Research Institute (EDRI), and Department of Economics, Mekelle University, Addis Ababa, Ethiopia, (email) zenebeg2002@yahoo.com; Jesper Stage (corresponding author), Department of Social Science, Mid Sweden University, Holmgatan 10, 851 70 Sundsvall, Sweden, (email) jesper.stage@miun.se, (tel) + 46 60 14 84 46, (fax) + 46 60 14 87 83; Alemu Mekonnen, School of Economics, Addis Ababa University, Ethiopia, (email) alemu_m2004@yahoo.com; and Atlaw Alemu, School of Economics, Addis Ababa University, Ethiopia, (email) atlawalemu@yahoo.com.

The authors would like to thank the Environment for Development Initiative, Formas, Elforsk, and the International Institute for Environment and Development for financial support for this work.

Given the importance of agriculture to employment and livelihoods in many developing countries, loss of agricultural productivity due to climate change will affect their entire economies. Many other economic sectors—beyond agricultural value chains—will likely experience indirect effects on income and consumption. In sum, interactions between different sectors need to be studied to assess the whole impact of climate change on agriculture, and CGE models are well suited to this.

How countries cope with the climate impact on agriculture will depend on the magnitude of the initial shock. Previous experience indicates that economies subjected to significant external shocks respond differently. For example, Balassa's (1985) study of the impact of the oil crisis in the 1970s on developing countries found significant differences among countries in terms of the effect on economic growth. These differences may be due to the explicit adjustment policies applied, but also to different trade policies and trade patterns, the rate of growth of the labor force, investment rates, and (of course) the initial level of economic activity. It seems obvious that climate change will affect countries differently, due to a wide range of factors and not just their individual adjustments and adaptation policies.

The objective of this paper is to make a general equilibrium analysis of the potential impacts of climate change. We simulated the future development of the Ethiopian economy over 50 years, using results from a Ricardian model (discussed in more detail below) and two different scenarios for total factor productivity growth: 1) no growth at all during the projection period (present to 50 years out), and 2) average growth in this same period based on the political and economic reforms from 1992 to the present. We incorporated climate change into the model by letting land and livestock productivity decline over time, and compared the outcomes for a 50-year period.

Ethiopia has recently established a national climate-change forum and a civil society network on climate change, and has submitted both a national adaptation program of action (NAPA) and a nationally appropriate mitigation action (NAMA) plan to the United Nations Framework Convention on Climate Change. Impacts of current climate variability, identified in the NAPA document, include food insecurity due to drought and flood events; outbreak of diseases, such as malaria and water-borne and respiratory diseases; and land degradation from heavy rainfall.

Although some empirical studies on climate-change impacts in Ethiopia already exist (Deressa 2007; Deressa, Hassen, and Ringler 2008, Deressa et al. 2008; Deressa and Hassan 2009; Yesuf et al. 2008), they have significant limitations. First, most of them emphasize crop production and disregard the impact of climate change on livestock farming and its interlinks with crop production. This omission may underestimate the impacts of climate change on agriculture. Second, most of the studies are at a micro level and do not use agroecology-based analyses that might provide additional insight. Third, none of the Ethiopian studies have looked at climate change in relation to economic growth and poverty, which is what we attempt to address in this paper.

The rest of the paper is organized as follows. In section 1, we review climate change and CGE models. Section 2 outlines climate characteristics and the Ethiopian economy, as well as the potential impacts of climate change on agriculture. Section 3 describes the CGE model used in our analysis and shows how we include climate change in it. Section 4 discusses the study results, and section 5 concludes.

1. Literature Review of Climate Change and Computable General Equilibrium Models

There has been an explosive growth in analyses of developing countries' vulnerability to climate change, including its economy-wide impacts. Reid et al. (2008), for example, used a CGE model to estimate the effects of changed agricultural productivity and health of fisheries on the Namibian economy. Their static analysis assumed little or no adaptation or economic changes.

Another study by Thurlow et al. (2009) assessed the impact of climate variability and change on economic growth and poverty in Zambia, with a combined hydro-crop and dynamic CGE model. Their findings revealed that climate variability has cost the country US$ 4.3 billion over a 10-year period and might reach as high as $7.1 billion in a worst-case rainfall scenario. Most of the negative impacts of climate variability are concentrated in the southern and central regions of Namibia, where food insecurity is most vulnerable to climate shocks. On the whole, they found that by 2016 climate variability would keep 300,000 Namibians below the national poverty line.

A study by Arndt et al. (2010) focused on the potential impacts of climate change on Mozambique. They employed a framework of integrated modeling that translates outcomes of general circulation models to atmospheric changes that are, in turn, projected into biophysical outcomes with the aid of hydrological, crop, hydropower, and infrastructure models. The sector simulations compare a historical baseline with four different climate-change scenarios to estimate economy-wide impacts in terms of damage costs and national welfare losses with a dynamic CGE model. The study identifies adaptation measures, such as improved road design, agricultural sector investments, cooperative river basin management, and regional coordination of adaptation strategies.

Bezabih et al. (2011) analyzed the economic impacts of climate change-induced adjustments on the performance of the Tanzanian economy, using a countrywide CGE model. In this study, the projected effect of overall climate change on agricultural productivity is relatively limited to begin with, but becomes progressively worse. However, the long time periods involved and the low starting point of the economy leave ample time for factor substitutability, which allows adaptation measures to replace reduced land productivity with increased use of capital and labor. Therefore, the authors found that the overall impact on the Tanzanian economy may be quite limited in the long term.

Zhai et al. (2009) examined the potential long-term impacts of global climate change on agricultural production and trade in the People's Republic of China, using an economy-wide, global CGE model, as well as simulation scenarios of how global agricultural productivity may be affected by climate change up to 2080. This study suggested that, with a declining share of agriculture in GDP, the impact of climate change on the overall macro economy may be moderate. Food processing sectors carry the burden of some crop sectors (wheat, in particular) that are likely to expand due to increased demand.

The Development Prospects Group (2008) examined the economic impacts of climate change on Ethiopia. They used the 2005/2006 social accounting matrix for Ethiopia, constructed by the Ethiopian Development Research Institute and the Institute of Development Studies at the University of Sussex. They estimated impacts of climate change—seen as changes in mean temperatures and rainfall—on agricultural productivity with a Ricardian model. The study reported the outcomes of five simulation runs of the model, in addition to a baseline with no climate-related shocks. The first simulation reproduced Ethiopia's historical stochastic experience. A key finding of the study is that, in the worst-case scenario, real GDP in the final year (in a period of 25 years) would be 46 percent lower than in the baseline. The burden of adjustment appears to fall more on consumers, since aggregate consumption (which is dependent on agriculture) exhibits more variation. The variation of aggregate absorption is lower than that of GDP, indicating that international trade serves to dampen the impact of climate change.

Non-economic impacts (such as health impacts), following responses made to climate change, have also served as subjects of CGE analyses. For example, Pattanayak et al. (2009) examined the general equilibrium outcomes of a Brazilian policy to expand forests by 50 million hectares. Their results indicate a small decline in GDP, some decline in the welfare of urban households, and fewer opportunities for subsistence agriculture for rural households, although net welfare would improve due to the health benefits derived from the conservation of nearby forests.

We drew several conclusions from the Ethiopian studies reviewed. First, few studies looked into the impacts of climate change in Ethiopia in general or its economy-wide impact in particular. Second, most of the studies focused on the microeconomics of climate change. However, climate change may have area-specific effects above the household, or micro level. For example, agroecology-based analyses may provide better (or at least additional) insight into the impact of climate change.

Third, even though mixed crop and livestock farming dominate Ethiopian agriculture, climate-change studies (cf. Deressa 2007; Deressa, Hassen, and Ringler 2008; Deressa et al. 2008; Deressa and Hassan 2009; Yesuf et al. 2008) have all focused on crop agriculture, disregarding the role of livestock. Intuitively, however, we expect climate change will also affect livestock production and reduce farm incomes further. Hence, not including livestock production may underestimate the impact of climate change. There appear to be significant interlinks (and trade-offs) between the crop and livestock subsystems of farm households, particularly in times of stress. This is another dimension of interest in climate-change studies, which behooves us to look at the economy-wide impact of climate change in a way that includes livestock production.

Fourth, to our knowledge, previous studies on Ethiopia have not tried to link the climate-change issue to the broader context of economic growth and poverty reduction.

2. Ethiopia’s Climate Characteristics and Economy

Agriculture in Ethiopia is heavily dependent on rain. Its geographical location and topography, plus a low adaptive capacity, make the country highly vulnerable to the adverse impacts of climate change. Poverty in Ethiopia is a chronic problem and about two-thirds of its 72 million people live on less than $2 a day (World Bank 2008). It is one of the most food-insecure countries in the world, a situation compounded by droughts and famine that cycle in and out. Over 80 percent of the population of the country derives its livelihood from agriculture. Of the 4.3 million hectares of potentially irrigable agricultural land, less than 10 percent is currently farmed. Smallholder farmers dominate the sector, generating about 90 percent of agricultural output (Adenew 2006).

Economic performance was dismal during most of the second half of the twentieth century. A useful indicator is total factor productivity (TFP) growth, which measures economic growth that cannot be explained by increases in factors of production, such as labor, capital, or land. It gauges production increases that are caused by more efficient application of technology or more efficient use of existing inputs, rather than increased use of inputs. Between 1950 and 1990, Ethiopian TFP actually declined by over 1 percent per year. In the post-1992 reform period, on the other hand, its economic growth was among the highest in Africa, with TFP growth registering over 2.5 percent per year. Important constraints remain, however, in the forms of insecure property rights to land and a poorly developed private sector (Easterly 2006).

Geographically, Ethiopia can be subdivided into five agroecological zones, based on moisture and land use: 1) drought-prone highlands with insufficient rainfall; 2) rainfall-sufficient highlands dominated by enset-based farming; 3) rainfall-sufficient highland areas mainly planted with cereal-based crops; 4) generally dry, pastoral lowland areas (bordering on Eritrea); and 5) humid lowland areas further inland that primarily support crop farming. We expect that climate change will lead to adaptive shifts in cultivation patterns in all five regions. Whether input and output markets can change sufficiently in time, so that farmers can cope with these shifts, will be an important challenge for future adaptation policies.

Ethiopia has experienced at least five major national droughts since 1980, along with a large number of localized droughts (World Bank 2008). These cycles of drought create poverty traps for many households, constantly consuming their efforts to build up assets and increase income. About half of all rural households in the country experienced at least one major drought from 1999 to 2004 (Dercon 2009). With agriculture highly dependent on rainfall variability and amount, weather in general rules the lives and well-being of many rural Ethiopians. The weather determines whether they will have enough to eat, be able to provide basic necessities, and be able to earn a living. Indeed, farmers' dependence on rainfall and its erratic patterns have largely contributed to the food shortages and crises with which they constantly battle.

In Ethiopia, as well as many other African countries, a range of factors may undermine communities' ability to adapt to climate change (Boko et al. 2007). The country has a complex climate system, in addition to socioeconomic challenges, such as endemic poverty, limited access to capital and global markets, ecosystem degradation, complex disasters, and conflicts.

Accordingly, the effect of climate change on Ethiopia's economy will likely be a function of both the macroeconomy and sector-specific vulnerability. This means that the government's adaptation policies will be crucial. However, such policies are likely to be costly and, without a realistic baseline scenario, there is a risk that government programs will be evaluated against an inappropriate status quo (no cost, no climate change), rather than against the outcomes that will prevail if no government adaptation is carried out (Stage 2010). It is important, then, to assess the impacts climate change is likely to have, if private agents are left to adapt on their own. Such a baseline impact assessment can be used to assess the effects of activist adaptation policies.

3. Modeling Impacts on the Ethiopian Economy with a Computable General Equilibrium Model

CGE models have long been popular in policy analysis, particularly to evaluate economy-wide and distributional welfare effects of economic changes in both developed and developing countries. More recently, CGE models have been applied to analyze the impacts of climate change.

CGE models consist of numerical models of all supply-and-demand relationships in an economy. A baseline is then calibrated using current economic data, usually from a social accounting matrix (SAM), and the model can then be used to simulate the effects of external shocks, changes in economic policy, or changes in economic structure. CGE analysis is appropriate here because the impacts of climate change are generally economy-wide and produce strong general equilibrium feedback. Moreover, production-related shocks emanating from climate change may mean that different social groups or households will experience different effects or welfare consequences.

In our study, we simulated the impacts of climate change-induced variations in land productivity in the Ethiopian economy in the 2010–2060 period. We used a dynamic CGE model with a SAM that depicts production by sector in detail, including agriculture and manufacturing. The basic CGE framework closely follows the generic International Food Policy Research Institute (IFPRI) model. (See Lofgren et al. 2002 for a detailed discussion.)

IFPRI’s standard CGE model explains all the payments recorded in the SAM. It essentially follows the SAM disaggregation of factors, activities, commodities, and institutions. It is specified as a set of simultaneous equations, most of which are non-linear and there is no objective function. The equations define the behavior of the different actors. For production and consumption decisions, behavior is captured by non-linear, first-order optimality conditions. That is, production and consumption decisions are driven by the maximization of profits and utility, respectively. The equations also include a set of constraints, such as markets (for factors and commodities) and macroeconomic aggregates (balances for savings investment, the government, and the current account of the rest of the world), that have to be satisfied by the system as a whole, but are not necessarily considered by any individual actor.

Each producer (represented by an activity) is assumed to maximize *profits*, defined as the difference between revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to a production technology. The technology is specified by a constant elasticity of substitution function of the quantities of value added and a Leontief function of aggregate intermediate input. Each activity produces one or more commodities according to fixed-yield coefficients. In addition, a commodity may be produced by more than one activity.

The *revenue* of an activity is defined by the level of the activity, yields, and commodity prices at the producer level. As part of its profit-maximizing decision, each activity uses a set of factors up to the point where the marginal revenue product of each factor is equal to its wage (also called factor price or rent). Factor market closures equilibrate supplies and demands in each factor market, where the quantity supplied of each factor is fixed at the observed level. An economy-wide wage variable is free to vary to ensure that the sum of labor demands from all activities equals the quantity of labor supplied. Each activity pays an activity-specific wage, which is a product of the economy-wide wage and an activity-specific wage distortion term that is also fixed.

In the CGE model, institutions are represented by households, enterprises, government, and the rest of the world. Households—disaggregated as in the SAM—receive income (directly or indirectly from enterprises) via the factors of production, as well as transfers from other institutions. Transfers from the rest of the world to households are fixed in foreign currency. The same holds true for all transfers between the rest of the world and domestic institutions (households and enterprises) and factors.

Households use their income to pay direct taxes, save, consume, and make transfers to other institutions. The direct taxes and transfers to other domestic institutions (enterprises, government, and other households) are regarded as fixed shares of household income, whereas the savings share is flexible for selected households. Household consumption covers marketed commodities, purchased at market prices that include commodity taxes and transaction costs, and home commodities, which are valued at activity-specific producer prices. Household consumption is allocated across different commodities (both market and home commodities) according to linear-expenditure-system demand functions, derived from the maximization of a Stone-Geary utility function.

Enterprises may also receive transfers from other institutions. Enterprise incomes are allocated to direct taxes, savings, and transfers to other institutions. Enterprises do not consume.

The government collects taxes at fixed ad valorem rates and receives transfers from other institutions. The government uses this income to purchase commodities for its consumption and for transfers to other institutions. Government consumption is fixed in real (quantity) terms, whereas government transfers to domestic institutions (households and enterprises) are indexed to the consumer price index. Government savings—in other words, the difference between government income and spending—is a flexible residual.

The final institution is the rest of the world. Transfer payments between the rest of the world and domestic institutions and factors are all fixed in foreign currency. Foreign savings, or the current account deficit, is the difference between foreign currency spending and receipts.

In our formulation, the static CGE model is expanded into a dynamic CGE model for 2010–2060, using a recursive framework. This means that the model is solved for an individual year, savings and investment rates are used to update the capital stocks in various sectors, and the new values for the capital stocks are used in the solution for the subsequent year. In addition to this, numerous other values, such as the size of the population and the labor force, are updated from one year to the next.

3.1 Scenario Considerations

In the scenario development, we employed one of the current approaches to incorporating the impact of climate change in a CGE, namely the Ricardian model. We drew on the Ricardian results from Gebreegziabher et al. (2011) to model the impacts of the changes in temperature and precipitation indicated by the climate projections from the Intergovernmental Panel on Climate Change's A1B scenario.

The impact of climate change was modeled as declining productivity in land and livestock assets, rather than as declining agricultural yields. This provided scope for agents to adjust to the changes in productivity by applying more labor and/or capital, in order to limit yield losses. As a fictitious no-climate-change baseline, we also ran the same simulations for 2010–2060, under the assumption that none of these climate change-induced productivity changes took place. Two different scenarios were used for overall TFP growth: constant TFP throughout the simulation period 2100–2060; and 2.58 percent annual growth, the rate at which TFP has increased in the post-1992 period.

Apart from the changes in agricultural productivity and TFP, population, labor force, and capital stocks were also updated each year in the dynamic CGE model, in order to capture the effects of other long-term changes in the economy. Our projections for the population and the labor force followed the “medium” United Nations projections for 2010–2050 (UN 2009), after which both population and labor force are estimated to continue growing by 1.12 percent annually (the population growth rate at the end of the UN projection period). We assumed labor force participation rates stay constant throughout the period.

Notably, we assumed no changes in the distribution of education levels. If education levels improve in comparison with their current status, economic growth is likely to be higher than in our projections. We also assumed that investment, government spending, and the government budget deficit remained constant as shares of GDP. We also hypothesized that previously invested capital was immobile and remained in the sector where it had been invested, and that new investment was allocated to sectors with the highest returns.

3.2 Data Sources for the Computable General Equilibrium Model

The core data set capturing the structure of the Ethiopian economy comes from the 2005–2006 SAM developed by the Ethiopian Development Research Institute (EDRI). Constructed by EDRI and the Institute of Development Studies (University of Sussex) with support from IFPRI (Tebekew et al. 2009), the Ethiopian SAM captures all real income and expenditure flows in the economy for the year 2005–2006 and includes:

- 47 activities: 14 agricultural, 24 manufacturing, and 9 service;
- 86 commodities: agriculture (40), industry (30), and services (16);
- 3 factors: labor, land, and capital, with labor further categorized into professional, administrative, semi-skilled, and unskilled; and
- 6 types of households: rural poor, rural non-poor, small urban poor, small urban non-poor, big urban poor, and big urban non-poor. (Poor is defined as the poorest 40 percent of rural and urban households, according to the 2004–2005 survey data on household income, consumption, and per capita expenditure.)

The regionally disaggregated SAM includes five agroecological zones and captures the diversity of rainfall, land use, etc. The agroecological zones in the regional SAM are the drought-prone highlands, pastoralist lowlands, humid lowlands, moisture-sufficient highlands with cereal-based farming, and moisture-sufficient highlands with enset-based farming mentioned earlier. Such level of disaggregation of the SAM also allowed us to carry out analysis of agroecology-specific climate change, in addition to analyzing the effects on Ethiopian agriculture as a whole.

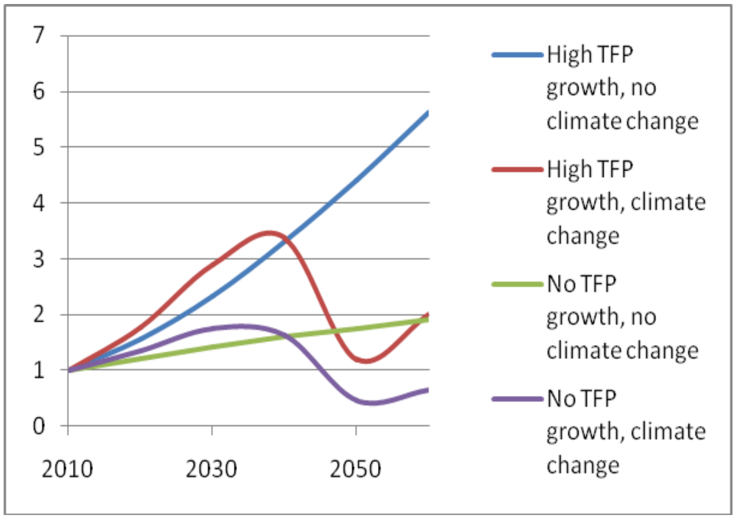
4. Climate Change Impacts on Ethiopian Agriculture, Growth, and Poverty

The impact of climate change was assessed in terms of its effect on crop and livestock farming and how these effects extend throughout Ethiopia, in terms of economic growth and poverty reduction. Looking at the two zones that dominate Ethiopia's agricultural production today—the moisture-sufficient highlands areas with cereal-based agriculture and the drought-prone highlands—their projected outcomes are somewhat different, but climate change is expected to have a huge impact on both.

In the moisture-sufficient highlands where cereals dominate, which currently accounts for the largest share of agricultural production, overall productivity is projected to increase until approximately 2030 as a result of climate change, but decline sharply thereafter. This is clearly visible in the projected overall production outcomes for crops (figure 1), as well as for livestock (figure 2). Both crop and livestock production increase faster in the climate-change scenarios than in the corresponding no-climate-change scenarios, until land productivity begins to decline around 2030. In the high TFP growth scenario, the increased overall productivity can compensate for the loss in land productivity until about 2040, but is unable to keep pace with the loss in land productivity after that. In the low TFP growth scenario, as a result of climate change, overall production of both crops and livestock is lower at the end of the projection period than at the beginning.

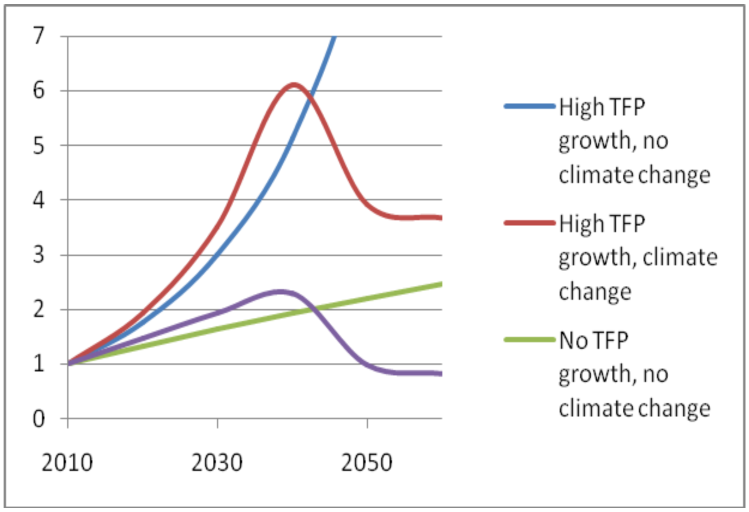
In the drought-prone highlands, the situation is somewhat different. Land productivity and crop yield is expected to decline as a result of climate change more or less continuously throughout the period studied, but much of the decline occurs relatively soon. After that, deterioration slows down temporarily between 2030 and 2050. This agroecological zone does not have the "grace period," until 2030 that the moisture-sufficient highlands do, and crop and livestock production both decline compared with the corresponding no-climate-change scenarios. However, the sharp fall in crop production also seen in other parts of the country after 2030 means that the value of crop production increases after 2030 and actually rises, albeit temporarily, above that in the no-climate-change baseline (figure 3). For livestock production, unlike crops, the long-term decline in land productivity does not slow down after 2030; therefore, there is no corresponding recovery period (figure 4). Instead, production is projected to decline throughout the projection period in both the climate-change and no-climate-change scenarios.

Figure 1. Value Added in Crop Production in Moisture-Sufficient Cereals-Based Highlands



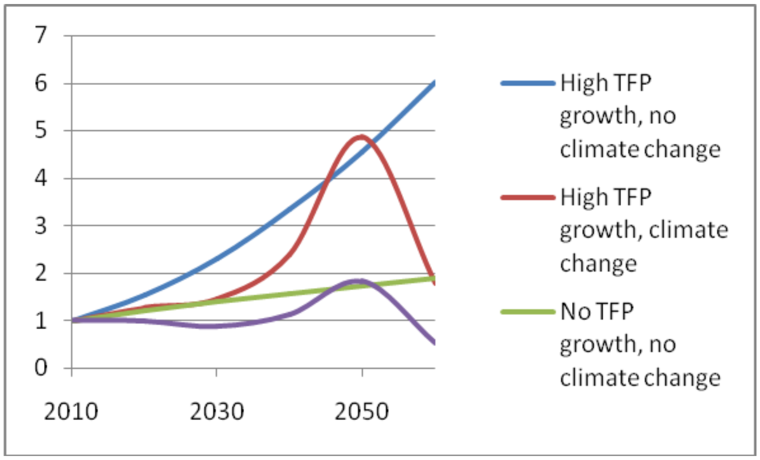
Index 2010 = 1; TFP = total factor productivity.

Figure 2. Value Added in Livestock Production in Moisture-Sufficient Cereals-Based Highlands



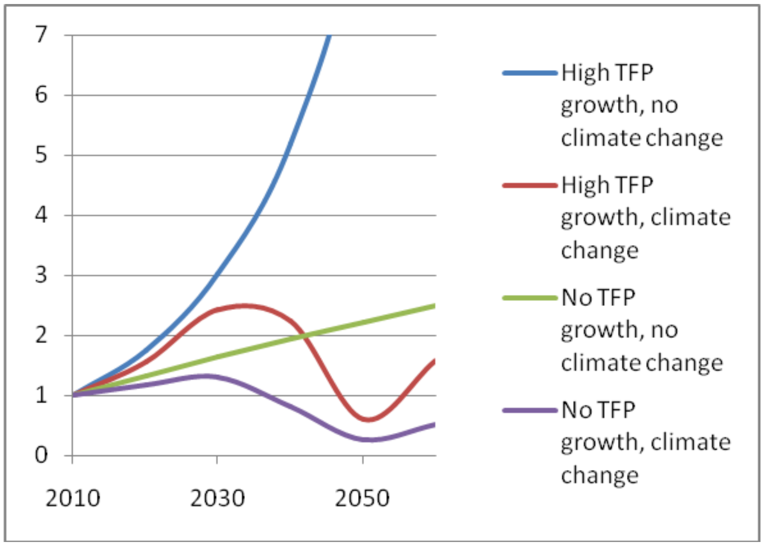
Index 2010 = 1; TFP = total factor productivity.

Figure 3. Value Added in Crop Production in Drought-Prone Highlands



Index 2010 = 1; TFP = total factor productivity.

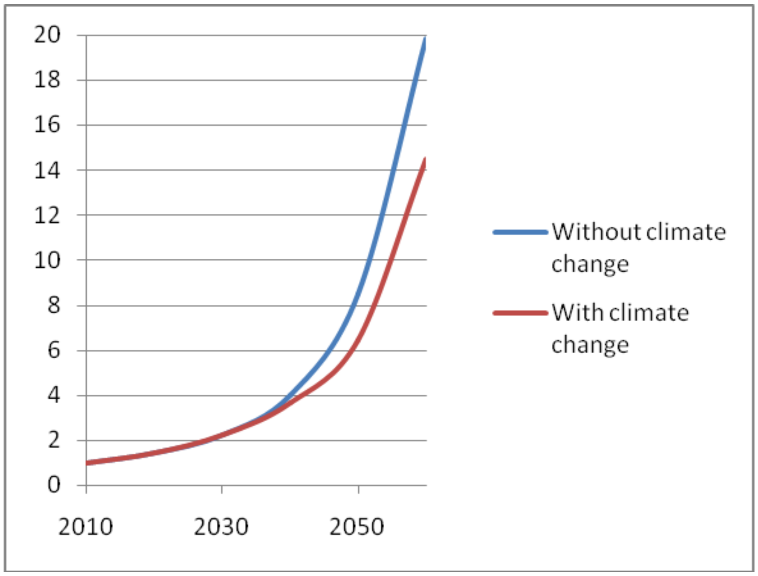
Figure 4. Value Added in Livestock Production in Drought-Prone Highlands



Index 2010 = 1; TFP = total factor productivity.

Looking at the implications for Ethiopia's economy as a whole, TFP growth matters more than climate change for the outcomes during the entire study period. Nonetheless, climate change has a sizeable impact. Even in the high TFP growth scenario, due to the sharp decline in agriculture after 2030, climate change is projected to have a sizeable impact on the economy (figure 5). Income is projected to increase dramatically in the high-TFP-growth scenario, but at the end of the simulation period, it is nonetheless some 30 percent lower than it would have been without climate change.

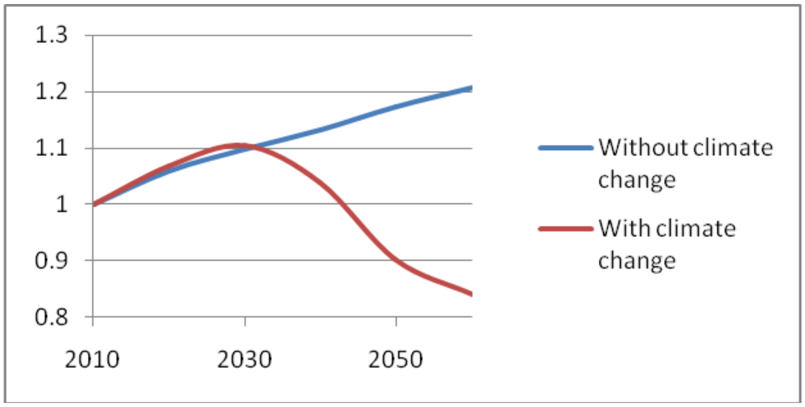
Figure 5. GDP per Capita with High TFP Growth Scenarios



Index 2010 = 1; TFP = total factor productivity.

In the no-TFP-growth scenarios, the outcome is considerably bleaker (figure 6). Since the effects of climate change on agriculture are benign in the main moisture-sufficient regions to begin with, income increases faster with climate change than without it. However, as the effects of climate change on agriculture become negative, incomes drop off considerably. At the end of the projection period, because of climate change, average incomes are lower than at the beginning of the period, despite the capital accumulation which takes place in the meantime. In the no-TFP-growth scenario, climate change also leads to a loss of some 30 percent of income, compared with the no-climate-change baseline.

Figure 6. GDP per Capita with No TFP Growth Scenarios



Index 2010 = 1; TFP = total factor productivity.

As noted, GDP per capita growth is vastly different in the four different projections. All four income categories studied are hurt considerably by climate change, regardless of the assumption made about TFP growth (table 1). The rural poor lose over 10 percent of their current per capita income due to climate change in the no-TFP-growth scenario. In the high-TFP-growth scenario, their per capita income is considerably greater at the end of the projection period than it is now, but over one-third of the income increase seen in the baseline scenario is lost as a result of climate change.

Table 1. Income Levels per Capita by Income Group

	2020	**2030**	**2040**	**2050**	**2060**
Rural poor					
High TFP, no climate change	1,431	2,170	3,819	8,170	19,342
High TFP, climate change	1,449	2,202	3,807	8,526	13,800
Zero TFP, no climate change	1,063	1,093	1,118	1,148	1,172
Zero TFP, climate change	1,076	1,110	1,105	1,171	0,837
Rural non-poor					
High TFP, no climate change	1,466	2,339	4,292	9,295	21,969
High TFP, climate change	1,474	2,358	4,018	7,881	15,852
Zero TFP, no climate change	1,077	1,127	1,173	1,223	1,263
Zero TFP, climate change	1,083	1,139	1,112	1,071	0,868
Urban poor					
High TFP, no climate change	1,314	1,922	3,226	6,282	13,344
High TFP, climate change	1,324	1,908	2,504	1,788	10,162
Zero TFP, no climate change	1,015	1,025	1,039	1,061	1,079
Zero TFP, climate change	1,023	1,018	0,823	0,344	0,754
Urban non-poor					
High TFP, no climate change	1,328	1,998	3,496	7,147	16,012
High TFP, climate change	1,338	1,981	2,699	1,994	12,269
Zero TFP, no climate change	1,024	1,040	1,062	1,093	1,118
Zero TFP, climate change	1,032	1,032	0,838	0,349	0,787

Index 2010 = 1; TFP = total factor productivity.

5. Discussion

Needless to say, modeling the development of the Ethiopian economy over a 50-year period is a formidable task: the country has experienced dramatic swings in economic policy over the past 50 years, and any projections of current trends into the future must be treated with caution. However, a few points from our projection results deserve comment.

TFP growth matters more than climate change for the overall outcome. If current growth trends continue, income levels will rise dramatically over the coming 50 years—despite climate change. If the country returns to the low (or even negative) growth trends experienced in the pre-1992 period, income levels may remain extremely low, even with no climate change to worry about. This is not surprising, in and of itself, and is analogous to the results from earlier studies.

That being said, climate change does have a dramatic impact even in the high-growth scenarios. Agriculture dominates Ethiopia’s economy completely and any climate-change impacts on agriculture will be considerable in the coming decades. Thus, even with optimistic assumptions about future growth trends, which would ease the transition of both labor and capital to new agricultural activities and to new activities outside agriculture, there is no way to avoid huge impacts on overall income levels, compared with what might prevail without climate change. Abandoning almost all the current economic activities in favor of new ones over the next few decades represents a major transition that farmers and private agents will have difficulty undertaking on their own, even in a favorable macroeconomic environment. This huge transition will have to be eased by active adaptation policies on the part of the government and will surely need outside support.

References

Adenew, B. 2006. Effective Aid for Small Farmers in Sub-Saharan Africa: Southern Civil Society Perspectives. Addis Ababa, Ethiopia: Canadian Food Security Policy Group.

Antle, J. 2010. Adaptation of Agriculture and the Food System to Climate Change: Policy Issues. Issue Brief 10-03. Washington, DC: Resources for the Future.

Arndt, C., K. Strzepeck, F. Tarp, J. Thurlow, C. Fant, and L. Wright. 2010. Adapting to Climate Change: An Integrated Biophysical and Economic Assessment for Mozambique. Working Paper, no. 2010/101. Helsinki, Finland: UNU-WIDER (United Nations University-World Institute of Development Economics Research).

Balassa, B. 1985. Exports, Policy Choices, and Economic Growth in Developing Countries after the 1973 Oil Shock. *Journal of Development Economics* 18(1): 23–35.

Bezabih, M., M. Chambwera, and J. Stage. 2011, forthcoming. Climate Change and Total Factor Productivity in the Tanzanian Economy. *Climate Policy*.

Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo, and P. Yanda. 2007. Climate Change: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II. In *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and E.E. Hanson, 433–67. Cambridge: Cambridge University Press.

Dercon, S. 2009. Risk, Poverty, and Insurance. Focus 17, Brief 3. In *Innovations in Insuring the Poor*. IFPRI 2020 Vision. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/sites/default/files/publications/focus17_03.pdf. Accessed September 2010.

Deressa, T.T. 2007. Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian Approach. Policy Research Working Paper, no. WPS 4342. Washington, DC: World Bank.

Deressa, T.T., and R.M. Hassan. 2009. Economic Impact of Climate Change on Crop Production in Ethiopia: Evidence from Cross-Section Measures. *Journal of African Economies* 18(4): 529–54.

Deressa, T.T., R.M. Hassen, C. Ringler. 2008. Measuring Ethiopian Farmers' Vulnerability to Climate Change across Regional States. IFPRI Discussion Paper 00806. Washington, DC: International Food Policy Research Institute.

Deressa, T.T., R.M. Hassen, T. Alemu, M. Yesuf, and C. Ringler. 2008. Analyzing the Determinants of Farmers' Choice of Adaptation Methods and Perceptions of Climate Change in the Nile Basin of Ethiopia. IFPRI Discussion Paper 00798. Washington, DC: International Food Policy Research Institute.

Development Prospects Group. 2008. A Country Study on the Economic Impacts of Climate Change. Ethiopia Report, no. 46946-ET. Washington DC: World Bank.

Easterly, W. 2006. Growth in Ethiopia: Retrospect and Prospect. New York: New York University, Center for Global Development.

Gebreegziabher, Z., A. Mekonnen, and M.M. Kassahun. 2011. Crop–Livestock Interlinkages and Climate Change Implications on Ethiopia's Agriculture: A Ricardian Approach. Photocopy. Unpublished research, Environmental Economics Policy Forum for Ethiopia, Addis Ababa.

Kates, R.W. 2000. Cautionary Tales: Adaptation and the Global Poor. *Climatic Change* 45: 5–17.

Kurukulasuriya, P., and R. Mendelsohn. 2006. Crop Selection: Adapting to Climate Change in Africa. CEEPA Discussion Paper, no. 26. Pretoria, South Africa: University of Pretoria, Centre for Environmental Economics and Policy in Africa.

Lofgren, H., R.L. Harris, S. Robinson, M. Thomas, and M. El-Said. 2002. A Standard Computable General Equilibrium (CGE) Model in GAMS. Washington, DC: International Food Policy Research Institute.

NZIER (New Zealand Institute for Economic Research) and Infometrics. 2009. Economic Modeling of New Zealand Climate Change Policy. Report to the Ministry for the Environment. Wellington: NZIER and Infometrics. http://www.climatechange.govt.nz/emissions-trading-scheme/building/reports/economic-modelling/economic-modelling-of-new-zealand-climate-change-policy.pdf. Accessed September 2011.

Pattanayak, S.K., M.T. Ross, B.M. Depro, S.C. Bauch, K.J. Wendland, and K. Alger. 2009. Climate Change and Conservation in Brazil: CGE Evaluation of Health and Wealth Impacts. *BE Journal of Economic Analysis and Policy* 9(2): 1–42.

Reid, H., I. Sahlén, J. Stage, and J. MacGregor. 2008. Climate Change Impacts on Namibia's Natural Resources and Economy. *Climate Policy* 8(5): 452–66.

Reilly, J., W. Baethgen, F.E. Chege, S.C. van de Geijn, L. Erda, A. Iglesias, G. Kenny, D. Patterson, J. Rogasik, R. Rotter, C. Rosenzweig, W. Sombroek, and J. Westbrook. 1996. Agriculture in a Changing Climate: Impacts and Adaptation. In *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change—Scientific-Technical Analyses*, Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, edited by R.T. Watson, M.C. Zinyowera, R.H. Moss, and D.J. Dokken, 427–68. Cambridge: Cambridge University Press.

Reilly, J.M., and D. Schimmelpfennig. 1999. Agricultural Impact Assessment, Vulnerability, and the Scope for Adaptation. *Climatic Change* 43: 745–88.

Rosenzweig, C., and M.L. Parry. 1994. Potential Impact of Climate Change on World Food Supply. *Nature* 367: 133–38.

Sachs, J., T. Panatayou, and A. Peterson. 1999. Developing Countries and the Control of Climate Change: A Theoretical Perspective and Policy Implications. Consulting Assistance for Economic Reform II Discussion Paper, no. 44. Cambridge, MA, USA: Harvard Institute for International Development.

Seo, S.N., and R. Mendelsohn. 2008. Measuring Impacts and Adaptations to Climate Change: A Structural Ricardian Model of African Livestock Management. *Agricultural Economics* 38: 1–15.

Seo, S.N., R. Mendelsohn, A. Dinar, R. Hassan, and P. Kurukulasuriya. 2009. A Ricardian Analysis of the Distribution of Climate Change Impacts on Agriculture across Agro-Ecological Zones in Africa. *Environmental and Resource Economics* 43: 313–32.

Stage, J. 2010. Economic Valuation of Climate Change Adaptation in Developing Countries. *Annals of the New York Academy of Sciences* 1185: 150–63.

Tebekew, T., A. Amoge, B. Teferra, Z. Seyoum, M. Amha, H. Beyene, E. Fisseha, E. Tsehaye, H.A. Ahmed, S. Robinson, D. Willenbockel, P. Dorosh, and S. McDonald. 2009. Ethiopia Input Output Table and Social Accounting Matrix 2005/06. Addis Ababa: Ethiopian Development Research Institute and Institute of Development Studies, University of Sussex.

Thurlow, J., T. Zhu, and X. Diao. 2009. The Impact of Climate Variability and Change on Economic Growth and Poverty in Zambia. IFPRI Discussion Paper 00890. Washington DC: International Food Policy Research Institute, Development Strategy and Governance Division, and Environment and Production Technology Division.

UN (United Nations). 2009. World Population Prospects: The 2008 Revision. New York: United Nations, Population Division, Department of Economic and Social Affairs.

World Bank. 2008. Ethiopia: A Country Study on the Economic Impacts of Climate Change. Environment and Natural Resource Management Report, no. 46946-ET. Washington, DC: World Bank, Sustainable Development Department, Africa Region.

Yesuf, M., S. Di Falco, C. Ringler, and G. Köhlin. 2008. Impact of Climate Change and Adaptation to Climate Change on Food Production in Low-Income Countries: Household Survey Data Evidence from the Nile Basin of Ethiopia. IFPRI Discussion Paper 00828. Washington, DC: International Food Policy Research Institute.

Zhai, F., T. Lin, and E. Byambdorj. 2009. A General Equilibrium Analysis of the Impact of Climate Change on Agriculture in the People's Republic of China. *Asian Development Review* 26(1): 206−225.