UNITED NATIONS UNIVERSITY

UNU-WIDER
World Institute for Development Economics Research

Working Paper No. 2011/89

# A Dynamic General Equilibrium Analysis of Adaptation to Climate Change in Ethiopia

Sherman Robinson,[1] Kenneth Strzepek,[2] and Dirk Willenbockel[3]

December 2011

**Abstract**

This study links a multi-sectoral regionalized dynamic computable general equilibrium model of Ethiopia with a system of country-specific hydrology, crop, road and hydropower engineering models to simulate the economic impacts of climate change towards 2050. In the absence of externally funded policy-driven adaptation investments Ethiopia's GDP in the 2040s will be up to 10 percent below the counterfactual no-climate change baseline. Suitably scaled adaptation measures could restore aggregate welfare to baseline levels at a cost that is substantially lower than the welfare losses due to climate change.

JEL classification: Q54, O55, D58, C68

Keywords:CGE analysis, global warming, growth, adaptation costs, development

[1]International Food Policy Research Institute; [2]Massachusetts Institute of Technology; [3]University of Sussex, Institute of Development Studies, email: d.willenbockel@ids.ac.uk.

This study has been prepared within the UNU-WIDER project on Development under Climate Change, directed by Channing Arndt.

UNU-WIDER gratefully acknowledges the financial contributions to the project by the Finnish Ministry for Foreign Affairs and the Swedish International Development Cooperation Agency—Sida, and the financial contributions to the research programme by the governments of Denmark (Ministry of Foreign Affairs), and the United Kingdom (Department for International Development).

*The World Institute for Development Economics Research (WIDER) was established by the United Nations University (UNU) as its first research and training centre and started work in Helsinki, Finland in 1985. The Institute undertakes applied research and policy analysis on structural changes affecting the developing and transitional economies, provides a forum for the advocacy of policies leading to robust, equitable and environmentally sustainable growth, and promotes capacity strengthening and training in the field of economic and social policy making. Work is carried out by staff researchers and visiting scholars in Helsinki and through networks of collaborating scholars and institutions around the world.*

*www.wider.unu.edu* *publications@wider.unu.edu*

UNU World Institute for Development Economics Research (UNU-WIDER)
Katajanokanlaituri 6 B, 00160 Helsinki, Finland

Typescript prepared by Lisa Winkler at UNU-WIDER

## 1 Introduction

Despite an impressive growth performance in recent years, Ethiopia's economyremains heavily dependent on rain-fed agriculture. The country is historically prone to extreme weather events. Regional projections of climate models do not only predict a substantial rise in mean temperatures over the 21st century but also an increase in rainfall variability with a rising frequency of both floods and droughts.[1]

To contribute to a scientifically grounded assessment of Ethiopia's economic development prospects in a changing climate, this paper employs a dynamic computable general equilibrium (CGE) model with a disaggregated representation of the country's main agro-ecological zones. The CGE framework is linked to an inter-related ensemble of specialist models that serve to translate regionalized climate projections from global circulation models into hydrological impacts, crop and livestock productivity effects, hydropower generation, and road infrastructure impacts in the absence and in the presence of policy-led adaptation investments.

The inter-disciplinary modeling approach adopted in this study aims to overcome some of the limitations of all two existing previous CGE-based climate change assessments for Ethiopia we are aware of. In contrast to the comparative static analysis of Mideska (2010)[2] and the dynamic analysis of Arndt et al. (2011), the present study moves beyond an exclusive focus on agricultural performance by considering additional impact channels and employs a new social accounting matrix that allows to take more detailed account of Ethiopia's diverse topography. It is the first study of its kind for Ethiopia that derives climate change impacts on agricultural productivity and changes in the frequency of extreme weather events by linking region-specific calibrated crop models and a hydrological model with high resolution climate projections across the range of existing global circulation models.

The paper is organized as follows: Section 2 provides a non-technical description of the analytical framework and highlights selected key features of the initial benchmark data set which reflects the structure of the Ethiopian economy at the start of the simulation horizon. Section 3 explains how climate shocks enter the CGE model and presents dynamic climate change impact simulation results. Section 4 contrasts these results with the simulated economic outcomes in the presence of policy-led adaptation investment measures and Section 5 concludes.

---

1 See Arndt, Robinson and Willenbockel (2011), World Bank (2010a), Ahmed, Arndt, Robinson and Willenbockel (2009).

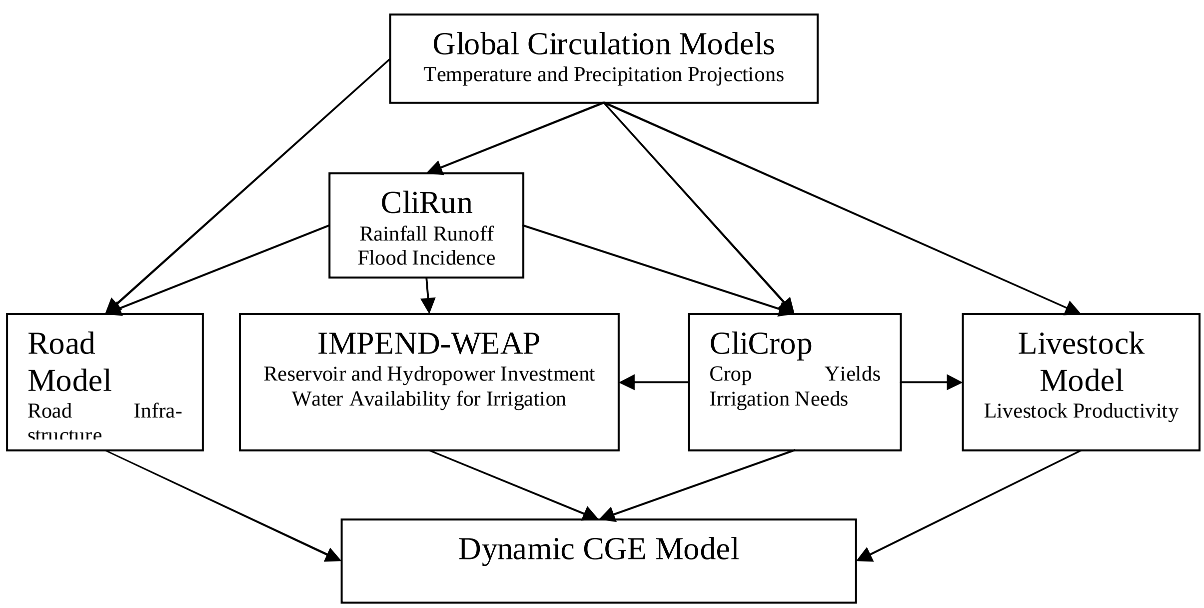
2 Which is by design unable to take account of the climate change impacts on economic growth emphasized by Fankhauser and Tol (2005) and captured in the present study.

## 2 The analytical framework

### 2.1 Outline of the modeling framework

The modeling approach adopted here has been developed in close collaboration with a parallel study for Mozambique (Arndt et al. 2010). Since global circulation model (GCM) projections of precipitation changes for East Africa differ substantially across climate models and International Panel on Climate Change (IPCC) greenhouse gas emission scenarios, a baseline scenario incorporating historically observed temperature and precipitation variability and four different climate change scenarios are included in the simulation analysis.They span the whole range of conceivable outcomes in terms of the climate moisture index (CMI), which is an annual measure of water availability (Table 1). The four scenarios include the wettest and driest projections on a global scale (global wet and global dry) out of the 22 GCMs available in the IPCC Fourth Assessment Report as well as the wettest and driest projections for Ethiopia (local wet and local dry).[3] Monthly baseline and GCM temperature and rainfall projections up to 2050 are passed on to the various linked model component as shown in Figure 1.

Figure 1: The Modelingframework




3 Since CMI is an annual measure, it does not account for seasonal changes and the potential for increased flooding due to changes in daily and monthly scale precipitation processes in the midst of annually drier climate. Indeed, all four GCM models suggest increases in precipitation intensity at the daily and weekly scale. This implies more flooding even in the 'dry' scenarios.

Table 1: Scenarios

| Scenario label | GCM - SRES | CMI (%) | Description |
|---|---|---|---|
| Base | Historical Climate | - | Historical climate shocks |
| Local wet | Ncar_ccsm3.0-sresa1b | 23 | Very wet CC shocks for Ethiopia |
| Global wet | Ncar_ccsm3.0-sresa2 | 10 | Global wet CC shocks |
| Global dry | Csiro_mk3.0-sresa2 | -5 | Global dry CC shocks |
| Local dry | Gfdl_cm2.1-sresa1b | -15 | Very dry CC shocks for Ethiopia |

Notes: GCM-SRES: Global Circulation Model and SRES (Special Report on Emission Scenarios, see IPCC-TGICA 2007) emission scenario combination. CMI: Crop moisture index change.

CliRun is a hydrological model calibrated to historical climate and rainfall runoff observations for Ethiopia. It uses GCM precipitation and temperature projections to estimate the availability of water at a sub-basin scale for 21 basins and the incidence of regional floods. The CliRun runoff projections are handed down to the hydropower planning model IMPEND (Block and Strzepek 2010).

IMPEND was developed to plan reservoirs and power generation facilities on the upper Blue Nile river in Ethiopia. Hydropower production is calculated for existing and planned dams based on an expected investment and construction schedule as detailed in Block and Strzepek (2011). The IMPEND output includes time series of energy generation and associated project costs for each climate scenario. To take account of potential interactions between growing municipal and industrial water use, irrigation, and hydropower demands under climate change, the IMPEND hydropower projections are modified using the water evaluation and planning toolWEAP (Sieber and Purkey 2007). The modified hydropower generation and investment time series as well as perturbations to irrigations yields generated in WEAP for each climate scenario are passed on to the CGE model.

CliCrop is a generic crop model used to calculate the effect of temperature, CO2 concentrations and variations in daily precipitation patterns caused by climate change on crop yields and irrigation water demand. The model was developed in response to the limitations of available crop models that use monthly average rainfall and temperature to produce crop outputs. These monthly models do not capture the effects of changes in precipitation patterns, which greatly impact crop production. CliCrop is able to produce predicted changes in crop yields due to climate change for both rain-fed and irrigated agriculture, as well as changes in irrigation demand. The weather inputs into CliCrop for future scenarios are extracted directly from the four GCMs. The daily distributions ofprecipitation and temperature are derived from the NASA POWER data set. Input data for the crop- and zone-specific calibration include a range of soil parameters from the FAO soils database, historic yield, and crop distribution data by province and irrigation distribution data. Corresponding to the crop types distinguished in the CGE model, separate CliCrop models have been calibrated for maize, barley, sorghum, and millet (mapped to teff and enset in the CGE model). The output of the CliCrop runs are modified to take account of eventual flood damages to crop harvests based on the

CliRunresults and enter the CGE model in the form of annualized time series of crop productivity variations by zone, crop, and GCM climate scenario.CliCrop results are also used in WEAP to determine changes in irrigation demand on reservoir water supply.

The CliCrop results for millet—a primary source of livestock feed in Ethiopia—are also passed on to a model for the determination of climate change impacts on livestock productivity. This model adopts a hybrid approach that has two components: a biophysical component that considers the effect of temperature on expected livestock incomes, and a component that incorporates the effect of changing availability of livestock feed. The biophysical component transfers the Ricardian model of African livestock developed by Seo and Mendelsohn (2008) to the Ethiopia-specific context.

Finally, the GCM and CliRun projections are fed into a stressor-response road network model that determines climatechange induced changes in maintenance costs for existing costs and costs to adapt roads by switching design standards at regular design life intervals. The model distinguishes primary, secondary, and tertiary roads. To incorporate flood damages to the road network, a custom damage function was used to generate loss estimates based on the return period of the floodingevents projected by CliRun.[4]

## 2.2 The CGE model

The economy-wide simulation analysis is based on a recursive-dynamic extension of a standard social accounting matrix (SAM)-based singlecountry CGE model presented in full technical detail in Robinson et al. (1999) which has been further modified to incorporate agricultural production in multiple agro-ecological zones as described in Robinson et al. (2010).

Producers in the model are price takers in output and input markets and maximize profits using constant returns to scale technologies.Primary factor demands are derived from constant elasticity of substitution value added functions, while intermediate input demand by commodity group is determined by a Leontief fixed-coefficient technology. The decision of producers between production for domestic and foreign markets is governed by constant elasticity of transformation functions that distinguish between exported and domestic goods in each traded commodity group. Under the smallcountry assumption, Ethiopia faces perfectly elastic world demand curves for its exports at fixed world prices. The profit-maximizing equilibrium ratio of exports to domestic goods in any traded commodity group is determined by the relative prices for these two commodity types.

On the demand side, imported and domestic goods are treated as imperfect substitutes in both final and intermediate demand.In line with the smallcountry assumption, Ethiopia faces an infinitely elastic world supply at fixed world prices. The equilibrium ratio of imports to domestic goods is determined by the utility- and profit-maximizing decisions

---

4 For a more detailed description of these model components see World Bank (2010a, 2010b) and its separate annexes downloadable at http://climatechange.worldbank.org/content/country-case-studies-economics-adaptation-climate-change .

of domestic agents based on the relative tax-inclusive prices of imports and domestic goods.

The model includes 14 household groups comprising poor and non-poor rural households residing in each of the five regional zones as well as poor and non-poor households distinguished by big and small urban settlements. Households receive factor income from the production sector plus net transfer income, pay direct taxes, and save according to their respectivesaving propensities. Household consumption expenditure is allocated across commodities according to a linear expenditure system specificationas derived from a Stone-Geary utility function. The government receives revenue from direct and indirect taxes and net transfers from the rest of the world, and pays transfers to households. Residual revenue after government consumption expenditure is saved (with budget deficits representing negative savings). All savings from households, government, and the rest of the world are collected in a savings pool from which investment is financed.

In order to establish macro-economic balance, it is necessaryto specify a set of 'macro-closure' rules. A 'balanced' macro-closure is assumed such that investment, government demand, and aggregate consumption are fixed shares of total domestic absorption. Savings rates are assumed to adjust to finance investment. The time path of the current account is exogenous in foreign currency terms and the real exchange rate adjusts to maintain external balance. Finally, the fiscal deficit is endogenous, with government demand a fixed share of absorption and all tax rates held constant, so that government income depends on the level of economic activity.

Labor is assumed to be mobile across sectors and fully employed. The assumption of full employment is consistent with widespread evidence that, while relatively few people have formal sector jobs, the large majority of workingage people engage in activities that contribute to GDP. Capital accumulation is modeled with annual resolution. The model adopts a puttyclay formulation, whereby new investment is allocated across sectors in response to rate of return differentials but installed equipment remains immobile.Long-run sectoral factor productivity growth is specified exogenously.Within the CGE model, the decisions of consumers, producers, and investors change in response to changes in economic conditions driven by different sets of climate outcomes, as do market outcomes. The model allows a degree of endogenous adaptation within periods, with changes in labor allocation across sectors and crops in response to shocks. In agriculture, land cannot be reallocated across crops within a period in response to climate shocks—cropping decisions are assumed to be made in the beginning of the period, before the realization of climate shocks are imposed. Between periods, land use can shift in response to return differentials arising from changes in the economic environment.

### 2.3 Empirical calibration and specification of the dynamic baseline path

The model is calibrated to SAMof Ethiopia for the year 2005/06 (EDRI 2010). SAM provides a detailed representation of the structure of production, demand, international trade, and income distribution. It contains a regional disaggregation of agricultural activities, household income, and household consumption. The five regions distinguished in this database are differentiated by their agro-ecological characteristics, as summarized in Table 1. The Ethiopia CGE model contains 22 commodity groups and 46 activities, including 35 regionally differentiated agricultural sectors. Fifteen primary factors of production are identified: four types of labor, agricultural land, and livestock capital in each of the five agro-ecological zones, and non-agricultural capital employed in industry and the service sector.

Table 2: Five agro-ecological zones

| SAM Region | Temperature and moisture regime |
|---|---|
| Zone 1 | Humid lowlands, moisture reliable |
| Zone 2 | Moisture-sufficient highlands, cereals-based |
| Zone 3 | Moisture-sufficient highlands, enset-based |
| Zone 4 | Drought-prone (highlands) |
| Zone 5 | Pastoralist (arid lowland plains) |

Agriculture and food processing (AgFood) account for 42 percent of gross production value and generate around 50 percent of Ethiopia's GDP at factor cost in 2005/06. AgFood imports account for only 8.4 percent of Ethiopia's total import bill, and the share of AgFood imports in domestic AgFood demand is also fairly low (5.3 percent). The only agricultural commodity with a large share of imports in domestic demand is wheat. Teff, maize, barley, sorghum, and enset are all virtually non-traded goods. On the other hand, agriculture makes a significant contribution to Ethiopia's total export revenue. Agricultural exports, which consist primarily of coffee and oilseeds, account for nearly 80 percent of total exports. Agriculture represents 63 percent of total household consumption, including non-marketed home production for own home consumption, with a far higher share for rural poor households. Regionally, zone 2 produces nearly 50 percent of Ethiopia's total agricultural output and has the largest production share in all agricultural commodities except enset, while zone 1's contribution is marginal. 96percent of zone 5's agricultural output value is livestock production, and livestock accounts for 31 percent of Ethiopia's total agricultural gross production value.

In order to use the model to estimate costs imposed on Ethiopia by global warming, we start by specifying a hypothetical dynamic baseline path to 2050 that reflects development trends, policies, and priorities in the absence of climate change but incorporatesthe observed historical pattern of climate shocks. The baseline is not a forecast, but instead provides a counter-factual—a reasonable trajectory for growth and structural change of the economy in the absence of climate change that is used as a basis for comparison with the various climate change scenarios.

In the baseline, underlying rates of labour force growth, trend productivity growth, world prices, foreign aid inflows, tax rates, and government investment policies are imposed exogenously. The labour force growth is based on UN medium population growth projections, while total factor productivity (TFP) trends are set in conformity with World Bank long-run GDP growth projections for Ethiopia in the absence of climate change (World Bank 2010a, 2010b). Policy documents as well as sectoral planning documents were used in establishing the baseline path of public road, irrigation, and power infrastructure investments. The average annual baseline growth rate of GDP over the period 2010 to 2050 is 6 percent, while per capita income grows at an average annual rate of 4.2 percent, which entails a roughly five-fold increase in baseline per capita income over this period. Since consumer preferences are non-homothetic with income elasticities of demand below unity for staple food products, the baseline share of agriculture in GDP gradually declines towards 2050. However, since Ethiopia's population is projected to rise from an estimated 85 million in 2010 to nearly 175 million in 2050, baseline agricultural production expands in absolute terms.

## 3 Economic impacts of climate change

### 3.1 Transmission of climate shocks to the CGE model

The following impact channels through which climate change affects economic growth and development in Ethiopia are incorporated in the CGE analysis (Figure 1):

(i) Productivity impacts in crop and livestock agriculture enter the model in the form of crop- and zone-specific annual temporary shocks to the TFP parameters of the sectoral agricultural production functions.

(ii) Fluctuations in hydropower generation as a function of river flow and dam infrastructure enter the model as temporary TFP shocks in the electricity sector and are endogenously transmitted to other production sectors through the input-output matrix of the model.

(iii) Rainfall or temperature realizations outside of the band of road design tolerances entail more frequent or more expensive road network maintenance expenses as determined by the road model. For a given baseline road infrastructure investment and maintenance budget, these increased maintenance requirements imply a less rapid expansion of the road network compared to the baseline path. In the CGE model, this effect is translated into a corresponding series of shock to the accumulation path of the capital stock of the transport sector along with a shift in the transport margin parameters.

(iv) The impact of a changing frequency of extreme weather events in the form of severe zone-specific flooding on crop harvests and road infrastructure enters the CGE model via damage functions which relate flood severity to losses of agricultural output and road stocks.[5]

---

5 Given the multi-dimensional nature of the various shocks (by sector, year, zone and climate scenario), Summary statistics for the various time series of shocks passed to the CGE model are provided in a separate Annex.

## 3.2 Simulation results

The climate shocks affect relative prices and household incomes and trigger endogenous autonomous adaptation responses by producers and consumers. The changes in real income influence aggregate savings, capital accumulation, and economic growth.

Table 3 shows the annual average percentage deviations of real GDP from the baseline path by decade from 2010 to 2050. From an economy-wide perspective, the adverse impacts are most pronounced in the local dry scenario across all decades and the losses increase in severity over time. By 2050 GDP is projected to be some 10 percent smaller than in the no-climate change baseline. The local wet scenario is especially damaging in the final decade due to a marked rise in the frequency of extreme floods in the 2040, with a GDP loss of nearly 8 percent compared to the base. The damages from the global wet and global dry scenarios are spread more evenly over the simulation period.

Table 3: Deviation of real GDP from baseline by decade and cumulated aggregate welfare loss

| | 2010s | 2020s | 2030s | 2040s | PV ∆Absorption |
|---|---|---|---|---|---|
| Local wet | -2.0 | -3.0 | -2.2 | -7.7 | -3.5 |
| Global wet | -2.8 | -3.0 | -2.4 | -1.5 | -2.3 |
| Global dry | -2.5 | -4.5 | -3.6 | -3.0 | -3.1 |
| Local dry | -6.2 | -9.5 | -10.3 | -10.6 | -8.7 |

Note: 10-year averages of annual real GDP deviations from Baseline. PV ∆Absorption: Present value (PV) of annual absorption deviations from Baseline as a percentage of PV Baseline GDP 2010–50.

As an aggregate measure of the cumulated welfare loss over the whole simulation period, the last column of Table 3 displays the present value of the annual deviations of real absorption (i.e. total private and public expenditure on final goods at constant prices) from the baseline, expressed in percent of the present value of real GDP over the same period.[6] The cumulated welfare loss is highest under the driest climate scenario, followed by the wettest scenario, which is the scenario with the strongest increase in the frequency of severe flooding events.

Table 4 shows decadal average deviations in annual agricultural value added at constant factor prices from the baseline. The crop models predict the strongest adverse yield impacts under the local dry climate and this translates into agricultural GDP losses compared to the baseline across all decades in this scenario. Under the local wet scenario, agricultural GDP benefits on average initially from a wetter climate, but from the 2030s onwards the impacts turn increasingly negative, as flood damages to crop harvests become more prevalent. With small to moderate average gains across all decades, the global wet climate appears to be most conducive to agricultural production.

However, it is important to note that the decadal averages mask a significant increase in the year-to-year variability in agricultural real income generation in all four climate

6 The present values are calculated with a 5 percent discount rate.

change scenarios, as shown in the last column of Table 4. Thus, even under the global wet scenario with its positive net effect on agricultural GDP on average, the simulation analysis suggests strong weather-induced declines in agricultural production in individual years and for individual crops and zones.

Table 4: Deviation of agricultural real GDP from baseline by decade and standard deviation of agricultural year-to-year growth rates

| | 2010s | 2020s | 2030s | 2040s | SD Growth p.a. 2010-50 |
|---|---|---|---|---|---|
| Local wet | 1.0 | 0.9 | -1.6 | -7.1 | 6.09 |
| Global wet | -2.3 | -1.9 | -1.3 | -0.3 | 5.08 |
| Global dry | 1.8 | 0.7 | 2.9 | 0.9 | 5.16 |
| Local dry | -3.8 | -4.6 | -1.3 | -3.2 | 4.47 |
| Baseline | - | - | - | - | 3.57 |

Note: 10-year averages of annual real agricultural value added deviations from Baseline. Last column: Standard deviation (SD) of annual growth rates of agricultural GDP 2010–50.

The impacts of climate change on agricultural production differ greatly across regions for different scenarios (Table 5). In zone 5, the pastoralist arid lowland plains, agriculture is almost exclusively based on livestock, and is particularly sensitive to water availability and temperature. However, in the observed initial equilibrium at the starting point of the simulation horizon, this region contributes only 7 percent to Ethiopia's total gross output and 22 percent of livestock output, while the moisture-sufficient highlands (zone 2) account for nearly 50 percent, and the drought-prone highlands (zone 4) for nearly 30 percent of agricultural gross output. Zone 1's agricultural GDP is projected to be badly hit under the local dry scenario in the 2040s, but contributes less than one percent to Ethiopia's agricultural output in the observed benchmark equilibrium.

The impacts of the shocks on electricity generation are significant. However, since the baseline incorporates Ethiopia'sambitious power generation development plan, the supply of electricity grows faster than domestic demand and there are significant exports within a few years. The CC shock scenarios lead to large variations in exports, but in no scenario is there a significant shortage or price rise in the domestic market.

Climate change impacts tend to hurt the poor more. Table 6 provides statistics on the year-to-year growth rates of household consumption for poor and non-poor households for the local dry and local wet scenarios. The percentage point deviations of the means from the baseline are very similar for both groups, but poor households, whose main income source is agricultural labor,have to adjust to more variability in income and hence aggregate consumption than non-poor households.

Table 5: Deviation of agricultural GDP from baseline by decade and zone

| | 2010s | 2020s | 2030s | 2040s |
|---|---|---|---|---|
| | Local Wet | | | |
| Zone 1 | -1.4 | -3.2 | -5.2 | -2.4 |
| Zone 2 | -3.8 | -3.7 | -4.9 | -15.5 |
| Zone 3 | 3.2 | 4.3 | -3.6 | 0.2 |
| Zone 4 | 5.0 | 3.4 | 3.1 | -3.7 |
| Zone 5 | 12.1 | 16.0 | 10.4 | 30.9 |
| | Local Dry | | | |
| Zone 1 | 1.8 | 0.4 | -2.2 | -15.1 |
| Zone 2 | -2.4 | -1.2 | -1.0 | 0.6 |
| Zone 3 | -2.3 | -3.9 | 5.6 | -4.9 |
| Zone 4 | -7.7 | -7.4 | -3.0 | -4.2 |
| Zone 5 | -0.4 | -20.1 | -19.1 | -29.1 |

Table 6: Statistics on year-to-year growth rates of household consumption

| Scenario | Household type | Mean | SD | Min. | Max. |
|---|---|---|---|---|---|
| Base | Poor | 5.29 | 1.82 | 2.01 | 8.97 |
| | Non-Poor | 5.57 | 1.78 | 0.61 | 9.25 |
| Local wet | Poor | 5.18 | 3.37 | -4.50 | 12.77 |
| | Non-Poor | 5.44 | 3.23 | -4.19 | 12.61 |
| Local dry | Poor | 5.09 | 2.50 | -0.65 | 11.65 |
| | Non-Poor | 5.34 | 2.43 | 0.65 | 11.03 |

Notes: Statistics on year-to-year growth rates over the entire period. Mean: simple mean of year-to-year growth rates; SD: standard deviation; Min.: minimum; Max.: maximum.

## 4 A stylized analysis of climate change adaptation investments

The presence of considerable initial uncertainty about the future climate trajectory calls for an adaptation strategy that favors no-regret and low-regret measures that promise net benefits under any climate scenario until uncertainty is gradually resolved with the passage of time. With respect to irreversible investments with expected gains under a drier climate and losses under a wet climate (or vice versa), the option value of delaying investments until further information becomes available should be taken into account in decisions about the timing of projects. Given the pre-existing readily observable adaptation deficits to historical weather variability in Ethiopia's agriculture, road network and hydropower infrastructure, investments aimed at increasing the resilience to climate change in these areas are obvious components of such a no-regret adaptation strategy.[7]

[7] See World Bank (2010a, 2010b) for further details.

Thus, the economy-wide effects of undertaking the following adaptation investments are simulated:

(i) Agricultural adaptation: the assumed agricultural adaptation investment plan combines investments in irrigation and drainage infrastructure with programs in research and development of new crop varieties and farm management practices aimedprimarily at raising yields in rain-fed areas. In all adaption scenarios, the baseline irrigationdevelopment plan of 3.7 million hectares by2050 is increased gradually to 4.1 million hectaresby 2050.The level of irrigation infrastructure ismatched to the magnitude of climatechange-inducedirrigation deficit under each of the four climate change scenarios. In particular, in the dry scenarios, water harvesting andstorage reservoir investments are required while the wet scenarios involve only stream diversion for supplemental irrigation. Changesin precipitation intensity and seasonality call forincreased installation of drainage systems, especiallyin the wet scenarios.The estimated incremental costs of these investments are reported in Table 7. The adaptation simulations take account of the tradeoff between water used for irrigation and for power generation. In the local dry scenario with adaptation, we assume that policy favors irrigation, with some loss of hydropower production and exports as a result. The CGE model tracks the changes in the share of irrigated land and adjusts the crop productivity parameters accordingly. The other adaptation measures are assumed to dampen adverse climate change impacts on crop productivity by 50 percent.

(ii) Road infrastructure adaptation: the adaptation scenarios assume the adoption of modified design standards for roads and bridges involving the useof enhancedmaterials and technologies that are better able to withstandthe increased climate stressors including floods. In the model, these incremental road infrastructure investments are reflected in reduced climate change damages to the transport sector capital stock compared to the no-adaptation scenarios.

(iii) Dam and hydropower adaptation:adaptation consists of altering the scale and timing of planned dam construction and hydropower projects, as well as constraining downstream flow and irrigation flow in order to restore total electricity generation to the dynamic baseline path. This requires additional costly hydropower capacity investments on top of baseline investments only in the dry scenarios from the 2030s onwards (Block and Strzepek 2011).

Table 7 shows the estimated average annual investment costs over the period 2010 to 2050 associated with these adaptation measures as well as the undiscounted cumulated total costs. The highest cost isassociated with the local dry scenario, which tends togenerate damages throughoutthe 40-year period considered, whereas under the local wet scenario, damages (and hence adaptation costs) tend tocluster in the final decade.

Table 7: Average annual adaptation investment costs (US$ million)

| Adaptation investment | Local wet | Local dry | Global wet | Global dry |
|---|---|---|---|---|
| Irrigation | 16.0 | 30.0 | 32.0 | 50.0 |
| Drainage | 36.8 | 23.8 | 21.2 | 7.5 |
| R+D, farm management | 16.8 | 17.1 | 16.9 | 10.3 |
| Total agricultural | 69.6 | 70.9 | 70.1 | 67.8 |
| Road maintenance | 16.5 | 13.1 | 9.5 | 13.8 |
| Flood adaptation | 71.9 | 73.2 | 107.9 | 67.8 |
| Total road infrastructure | 88.4 | 86.3 | 117.4 | 81.6 |
| Total dams and hydropower | | 60 | | 22.5 |
| Total average annual | 158.0 | 217.2 | 187.5 | 171.9 |
| Total cumulated 2010–50 | 6,478.0 | 8,905.2 | 7,687.5 | 7,047.9 |

The following simulation scenarios—labeled global/local dryA/wetA—consider the combined implementation of these adaptation measures under the assumption that the adaptation investments are entirely funded by an external real resource transfer from abroad, so that no domestic resources need to be diverted from the baseline public investment path.

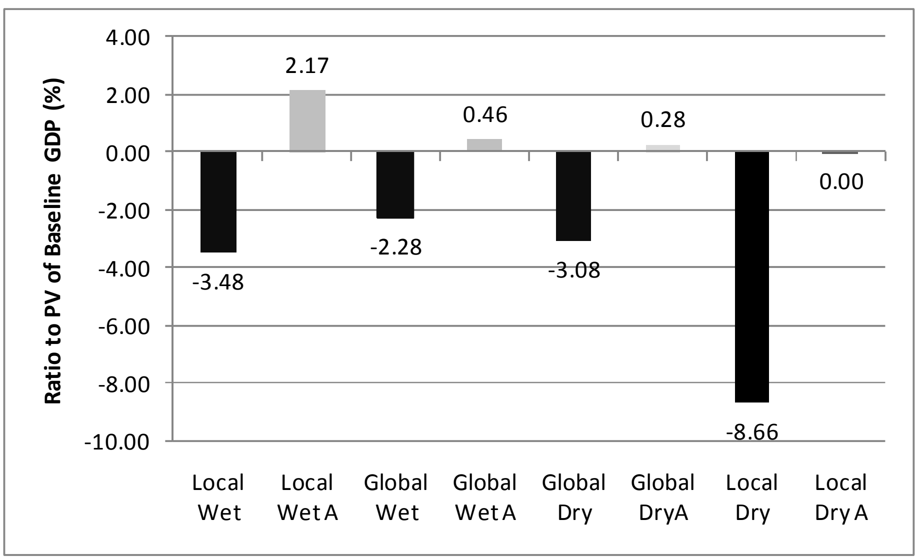
Table8displays the impact of the various scenarios on decadal average real GDP in comparison to the no-adaptation scenarios projected by the CGE model. The results suggest that in aggregate terms the adaptation strategy under consideration succeeds in returning the growth path close to the hypothetical no-climate change baseline. Adaptation investment is also found to have income smoothing benefits: it significantly reduces annual variability of GDP growth compared to the no-adaptation scenario (Table8, last column).

Table 8: Real GDP deviations from baseline with and without adaptation and standard deviation of year-to-year growth rates

| | 2010s | 2020s | 2030s | 2040s | SD Growth p.a. 2010-50 |
|---|---|---|---|---|---|
| Local dry | -6.2 | -9.5 | -10.3 | -10.6 | 2.58 |
| Local dryA | 0.5 | 0.5 | 0.0 | -0.9 | 1.92 |
| Local wet | -2.0 | -3.0 | -2.2 | -7.7 | 2.23 |
| Local wetA | 3.0 | 3.5 | 3.2 | -0.5 | 1.66 |
| Global dry | -2.5 | -4.5 | -3.6 | -3.0 | 2.33 |
| Global dryA | 0.4 | -0.5 | 0.5 | 0.2 | 1.91 |
| Global wet | -2.8 | -3.0 | -2.4 | -1.5 | 2.33 |
| Global wetA | 0.5 | 0.0 | 0.5 | 0.7 | 1.91 |
| Baseline | - | - | - | - | 1.49 |

Note: 10-year averages of annual real GDP deviations from baseline. global/local dry/wet: Without adaptation investments; global/local drya/wetA: With externally funded adaptation investments. Last column: Standard deviation (SD) of annual growth rates ofGDP 2010–50.

Figure 2: Aggregate welfare effects with and without adaptation




Note:Present value (PV) of annual differences in total absorption from the baseline aspercentage of PV Baseline GDP 2010–50.

Figure 2 compares the aggregate welfare (real absorption) impacts reported earlier in Table 3 with the corresponding impacts in the presence of the adaptation investment program. Under the stated assumption that the program is entirely financed through foreign transfers, the present value of absorption obtainable in the absence of climate change is restored under all four climate scenarios. In the case of the local wetA scenario, real absorption indeed overshoots the baseline level by a significant margin—so in this case the average annual resource transfer required to just compensate Ethiopia for the climate change-induced aggregate absorption losses up to 2050 would be noticeably less than the assumed average annual adaptation investment expenditure of US$ 158 million reported in Table 4.

In addition to being able to reduce welfare losses and GDP variability, the adaptation strategy analyzed here appears to be quite sensible from a cost-benefit perspective. For instance, the present value of cumulated avoided welfare losses under the local dryA adaptation scenario over the period 2010 to 2050 amounts to US$61 billion, while the cumulated *undiscounted* adaptation investment expenditure required to achieve this adaptation gain is only US$9 billion (Table 7). Under the other three adaptation scenarios the benefit-cost ratios suggested by the simulation analysis are likewise high.

Additional simulation results not reported here due to space constraints indicate that a domestically financed adaptation package of equal scope and scale without additional transfers from abroad relative to the baseline would reduce the climate change-related losses to some extent, but would leave a sizeable amount of residual damage. In this case, domestic resources for adaptation measures would have to be diverted from other uses with high social rates of return.

While the externally funded adaptation scenarios under consideration fully compensate for climate change losses in an aggregate macro-economic sense, there is no guarantee that adaptation gains are aligned to climate change damages at the micro level in the absence of effective redistribution mechanisms between net winners and losers.

Table 9 compares the means and year-to-year variability of real household consumption growth rates for different household groups under the wettest and the driest climate across the baseline, impact, and adaptation scenarios. For the disaggregation in terms of poverty status, the results suggest that mean annual consumption growth returns close to baseline rates for both poor and non-poor household groups. Adaptation reduces year-to-year variability significantly compared to the no-adaptation scenarios for both household groups, but variability under the wet climate remains higher than in the baseline in which weather variability follows historically observed patterns. Similar conclusions emerge for the disaggregation of households along a rural-urban divide. Compared to urban residents, rural households aremore reliant on agriculture for their income, buturban households' real consumption also suffersfrom climatechange-induced rises in food prices and shocks to road infrastructure and energy supply.The baseline growth rate differentials between non-poor and poor households as well as between urban and rural households remain largely unaffected, which implies that the baseline pattern of divergence between poor and non-poor, and between rural and urban, households over time continues with a similar speed under the climate change scenarios.

Table 9: Statistics on year-to year growth rates of real household consumption

| % | Mean<br>Base | Local wet | Local wetA | Base | Local dry | Local dryA |
|---|---|---|---|---|---|---|
| Poor | 5.29 | 5.18 | 5.32 | 5.29 | 5.09 | 5.27 |
| Non-Poor | 5.57 | 5.44 | 5.61 | 5.57 | 5.34 | 5.56 |
| Rural | 5.21 | 5.15 | 5.25 | 5.21 | 5.05 | 5.20 |
| Urban | 6.26 | 5.99 | 6.30 | 6.26 | 5.91 | 6.25 |
| | Standard Deviation | | | | | |
| %-points | Base | Local wet | Local wetA | Base | Local dry | Local dryA |
| Poor | 1.82 | 3.37 | 2.47 | 1.82 | 2.50 | 1.76 |
| Non-Poor | 1.78 | 3.23 | 2.49 | 1.78 | 2.43 | 1.96 |
| Rural | 1.90 | 3.44 | 2.50 | 1.90 | 2.54 | 1.88 |
| Urban | 1.72 | 2.91 | 2.58 | 1.72 | 2.33 | 2.17 |

## 5 Concluding remarks

This paper applies a new approach to the economic analysis of climate change impacts and adaptation options suitable for developing countries with a high dependence on climate-sensitive sectors and climate-sensitive infrastructure. Climate projections across the range of high-resolution global circulation models are handed down to a linked system of country-specific hydrology, crop, and engineering models to generate time series of yield impacts by crop type and agro-ecological zone as well as road infrastructure and hydropower impacts. These time series are used to shock a multi-sectoral regionalized dynamic computable general equilibrium model to determine economy-wide outcomes. By construction, the results take consistent account of inter-sectoral linkages as well as agents' autonomous adaptation responses to changes in relative prices and real incomes.

The dynamic simulation analysis suggests that in the absence of externally funded policy-driven adaptation investments Ethiopia's GDP in the 2040s will be up to 10 percent below the counterfactual baseline, which assumes no climate change. Moreover, the year-to-year variability in real income and real household consumption rises significantly under climate change.

The presence of considerable initial uncertainty about the future climate calls for a pragmatic and flexible adaptation strategy that favors no-regret and low-regret measures that promise net benefits under any climate scenario until uncertainty is gradually resolved with the passage of time. Given the pre-existing readily observable adaptation deficits to historical weather variability in Ethiopia's agriculture, road network and hydropower infrastructure, investments aimed at increasing the resilience to climate change in these areas are obvious components of such a no-regret adaptation strategy.

Stylized illustrative simulations of externally funded adaptation investment programs along these lines indicate that the social benefits—as measured by the avoided aggregate welfare losses due to climate change attributable to the adaptation program—are potentially a large multiple of the investment costs. The results suggest that with support from developed countries, suitably scaled adaptation measures could restore aggregate welfare to baseline levels at a cost that is substantially lower than a lump sum compensation payment equal to the welfare loss.

**References**


Ahmed, H., C. Arndt, S. Robinson, and D. Willenbockel, 'Ethiopia: A Country Study on the Economic Impacts ofClimate Change,' World Bank Report 46946-ET, Washington, DC: World Bank, 2009.

Arndt, C., S. Robinson, and D. Willenbockel, 'Ethiopia's Growth Prospects in a Changing Climate: A Stochastic General Equilibrium Approach', *Global Environmental Change* 21 (2011):701–710.

Arndt, C., K.Strzepek,F. Tarp, J. Thurlow,C.Fant, and L. Wright, 'Adapting to Climate Change:An Integrated Biophysical and EconomicAssessment for Mozambique', Working Paper 2010/101, Helsinki: UNU-WIDER, 2010.

Block, P. and K. Strzepek, 'Economic Analysis of Large-scale Upstream River Basin Development on the Blue Nile in Ethiopia Considering Transient Conditions, Climate Variability, and Climate Change. *Journal of Water Resource Planning and Management* 136 (2010):156–166.

Block, P. and K. Strzepek, 'Power Ahead: Meeting Ethiopia's Energy Needs under a Changing Climate,' UNU-WIDER Working Paper 2011/90, Helsinki.

EDRI, *Ethiopia: Input-Output Table and Social Accounting Matrix*. Addis Ababa: Ethiopian Development Research Institute, 2010.

Fankhauser, S. andTol, R.S.J., 'On Climate Change and Economic Growth',*Resource and Energy Economics* 27(2005): 1–17.

IPCC-TGICA, *General Guidelines on the Use of Scenario Data for Climate Impact andAdaptation Assessment*, Version 2, Intergovernmental Panelon Climate Change, Task Group on Data and Scenario Support for Impact and Climate Assessment, 2007.

Mideska, T. K., 'Economic and Distrinutional Impacts of Climate Change: The Case of Ethiopia,'*Global Environmental Change* 20(2010): 278–86.

Robinson, S., D. Willenbockel, H. Ahmed, and P. Dorosh, 'Implications of Food Production and Price Shocks for Household Welfare in Ethiopia: A General Equilibrium Analysis', Report for the World Food Programme, Addis Ababa, Ethiopia: World Food Programme, 2010.

Robinson, S., A. Yunez-Naude, R. Hinojosa-Ojeda, J. D. Lewis, and S. Devarajan, 'From Stylized to Applied Models: Building Multisectoral CGE Models for Policy Analysis', *North American Journal of Economics and Finance* 10 (1999):5–38.

Seo, S.N. and R. Mendelsohn, ‘Measuring Impacts and Adaptations to Climate Change: A Structural Ricardian Model of African Livestock Management’, *Agricultural Economics* 38 (2008):151–165.

Sieber, J. and D.Purkey,‘User Guide for WEAP21,’ Somerville,MA: Stockholm Environment Institute, US Center, 2007.

World Bank, *Economics of Adaptation to Climate Change: Ethiopia*, Washington, DC: World Bank (2010a).

World Bank, *Economics of Adaptation to Climate Change: Synthesis Report*, Washington, DC: World Bank (2010b).