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Climate change and economic growth prospects for Malawi

An uncertainty approach

Channing Arndt,[1] Adam Schlosser,[2] Kenneth Strzepek,[2] and James Thurlow[3]

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Abstract: Malawi confronts a development imperative in a context of rising temperatures and deep uncertainty about precipitation trends. We evaluate the implications of climate change for overall growth and development prospects to 2050. We focus on three impact channels: agriculture, road infrastructure, and hydropower generation while accounting explicitly for the uncertainty in climate forecasts. We find that climate change is unlikely to substantially slow overall economic growth over the next couple of decades. However, climate change implications become more pronounced over time and may become substantially more severe after 2050, especially if effective global mitigation policies fail to materialize.

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[1]University of Copenhagen and UNU-WIDER; [2]Massachusetts Institute of Technology; [3]International Food Policy Research Institute, corresponding author: channingarndt@gmail.com

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1 Introduction

As one of the world's poorest countries, Malawi confronts a growth and development imperative, one that must be met within a 21st century context. Climate change marks one salient difference between the previous and current centuries. Based on the best available scientific understanding and combined with an ongoing failure to effectively limit global emissions, this century appears highly likely to be characterized by rising temperatures. At the regional or country level, these temperature increases will be combined with deeply uncertain implications for the timing and quantity of precipitation. Indeed, as pointed out by Quiggin and Horowitz (2003), one of the most profound implications of climate change may be its role as a destroyer of information. In almost any region of the world, decades or even centuries of accumulated knowledge about the nature of local climate may gradually (or even suddenly) cease to be relevant as the fundamental global distribution of climate outcomes evolves.

This paper evaluates the potential implications of climate change for Malawi with a focus on overall economic growth and development prospects. To develop, Malawi must grow (a necessary but insufficient condition). It is therefore pertinent to consider the likely implications of climate change for growth and the potential channels through which climate change may alter growth prospects either positively or negatively. In this analysis, we take an inter-disciplinary and structural approach. We focus efforts on three primary impact channels: agriculture, road infrastructure, and hydropower generation. In the process, we make substantial efforts to account explicitly for the uncertainty in climate forecasts by exploiting the best available information on the likely distribution of climate outcomes for Malawi.

This paper is structured as follows. Section 2 considers any background and relevant literature. Section 3 discusses the methods employed. Section 4 presents results. A final section concludes that, based on the impact channels considered, climate change is unlikely to substantially slow overall economic growth and undermine development prospects over the next couple of decades. However, assuming that global emissions remain effectively unconstrained, climate change implications become more profound with time. As early as the 2030s and into the 2040s, climate change impacts are likely to become much more noticeable. Reduced agricultural yields and increased damage to road infrastructure due to increased frequency and intensity of extreme events are the two principal impact channels.

In sum, the next decade or two represent a window of opportunity to develop smart and forward- looking adaptation policies. As many of these policies take time to develop, implement, and then execute, there is little cause for complacency.

2 Background and literature review

Malawi is a land-locked country lying within the great African rift valley system. A number of features distinguish Malawi and are relevant to an analysis of the economic implications of climate change. First, Malawi is one of the poorest countries in the world. Like most low-income countries, it is characterized by weak institutions and relatively weak educational attainment (about three quarters of the adult population is considered literate) (World Bank 2013). These limitations are likely to reduce Malawi's adaptive capacity. Second, Malawi's economy is strongly agrarian even by African standards. Agriculture generates about one-third of gross domestic product (GDP), half of total export earnings and two-thirds of employment (Douillet et al. 2012). The sector is dominated by rain-fed maize and tobacco grown by smallholders. This reliance on a climate-sensitive sector should expand vulnerability to climate change. Indeed, the agricultural sector in general, and maize in particular, is vulnerable to frequent droughts (Pauw et al. 2011).

Third, most of Malawi's population resides on plateaus of about 1000 meters of elevation. The elevation results in cooler temperatures than would otherwise be the case at the same latitude. The elevation provides some insulation to the effects of climate change and may facilitate adaptation options. For example, it is possible that crop varieties and cropping practices from lower elevations can be relatively easily imported to higher elevations as temperatures warm. Aside from the somewhat cooler temperatures resulting from elevation, the topography of northern and Central Malawi places it largely 'upstream'. This makes Malawi somewhat less vulnerable to flooding than, for example, its downstream neighbor, Mozambique.

Fourth, Malawi is relatively densely populated at about 160 inhabitants per square kilometer (the average for low-income countries is about 40) with relatively favorable agricultural land located in close proximity to urban centers (World Bank 2013). Compared with countries with dispersed populations across broad areas (e.g., Tanzania), critical road infrastructure is more concentrated and redundancy is likely to be easier to achieve. On an isotropic plain characterized by equal flood probabilities, transportation between two distant points would be more likely to be interrupted by a flood event than transportation between two proximate points. Malawi is, in this sense, less vulnerable to flooding, although concentration of infrastructure within a zone may increase the scope for damages from a single flood event.

Finally, Malawi abuts to the east one of the largest freshwater lakes in Africa. The potential implications of climate change for Lake Malawi are not clear, although negative implications are certainly possible by 2050 (Allison et al. 2009; Ficke, Myrick and Hansen 2007). Lake Malawi also potentially offers modes for adapting to climate change by serving, for example, as a source for irrigation water.

The existing literature on the implications of climate change for Malawi tends to focus on specific features of Malawi with the large majority focused on the implications for crops and crop yields. A recent study by Saka et al. (2012) considers the implications of two climate futures for maize yields in Malawi out to 2050. They find that maize yields are expected to increase by between 5 and 25 percent in the northern and central regions (characterized by higher elevation). In the southern region, some areas are projected to experience yield increases though the majority are expected to experience yield declines.

These results for the northern and central portions of Malawi are similar to earlier results for maize yields reported by Thornton et al. (2006); their study covers East Africa in general. The divergence of results for Malawi with the average for East Africa is noteworthy in that, on average across the region, maize yields are expected to decline using the same crop modeling approach and climate modeling scenarios.

One of the sources of uncertainty in crop models of climate change is the implications of higher atmospheric concentrations of carbon dioxide (CO_2) for plant growth. For maize, this uncertainty tends to be relatively small. Parry et al. (2004) report that an increase in CO_2 concentrations of 150 parts per million (ppm) increases maize yields by about 2.5 percent. The greater uncertainty revolves around the nature and extent of changes to the climate with a particular emphasis on temperature and rainfall on key periods in the growing season. The analysis presented in this paper is particularly well-suited to respond to this uncertainty.

Overall, Malawi lacks a comprehensive evaluation of the implications of climate change for economic growth and development. Other studies that exist tend to consider multiple countries and/or specific climate change impact channels. For example, Brooks and Adger (2003) use historical data to classify Malawi as a country with a high level of risk to natural disasters. Smith and Lazo (2001) focus, for Malawi, on implications for water resources and forests in the context of a very large cross-country study. Stringer et al. (2009) draw together available information on climate impacts to consider potential adaptation policies while Brown (2011) performs a similar exercise with a focus on urbanization and spatial planning.

We turn now to our approach for developing a comprehensive risk-based assessment.

3 Methods

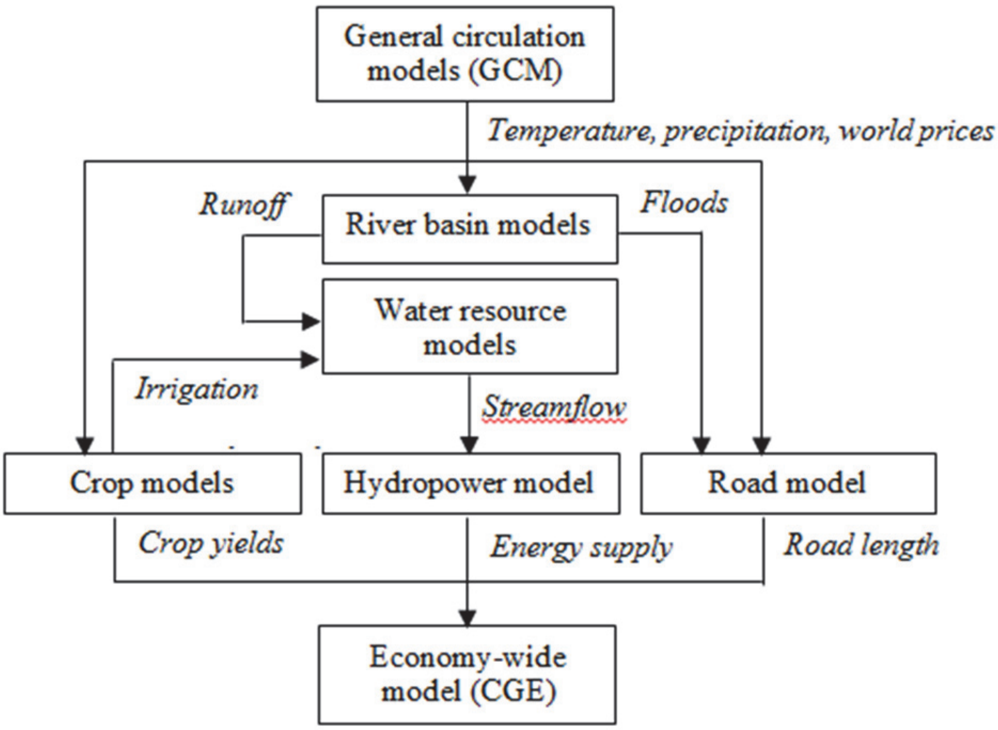
Figure 1 provides an overview of the methods employed for this assessment of climate change impacts in Malawi. The assessment starts with global change outcomes. These outcomes are chiefly temperature, rainfall, and world prices for fuels and agriculture. The implications of changes in temperature and rainfall patterns for the Malawian economy are not immediately clear and may in some instances be offsetting. For example, reductions in the frequency and severity of flooding events may be accompanied by a generalized reduction in rainfall with positive implications for road infrastructure, but negative implications for agriculture and hydropower. The interactions are complex. Higher temperatures increase rates of evaporation which may offset increases in rainfall leading to reduced runoff and hydropower output. At the same time, higher temperatures and reduced annual rainfall can actually be associated with *increases* in agricultural production if the rainfall that does arrive tends to fall during critical periods for crop growth. The following subsections provide a short, intuitive description of the three major rows of the modeling schema – global change, biophysical outcomes, and economywide modeling – along with references to more detailed descriptions.

3.1 Global change

Global change projections are derived from the Integrated Global Systems Model (IGSM), which has been developed and maintained by the Joint Program for Global Change at the Massachusetts Institute for Technology (Sokolov et al. 2009; Webster et al. 2012). The IGSM tracks global emissions and climate variables from the pre-industrial era to the present and then projects both emissions levels and resulting climate outcomes. Emissions projections are derived from a general equilibrium model of the global economy – the emissions policy and predictions analysis or EPPA model – contingent on a particular emissions policy scenario. In this paper, we focus on the 'unconstrained emissions' scenario whereby effective policies to limit emissions of greenhouse gases are absent. This is the current global path.

Particularly in the absence of emissions policies, future emissions trajectories are uncertain. Distributions of future emissions concentrations are obtained from the EPPA model by selecting from defined distributions of key exogenous parameters such as rates of technical change, rates of substitution in production, and rates of change in stocks of natural resources and applying these parameters to the EPPA model. In this way, 400 coherent global emissions pathways are obtained. These pathways are then applied to a linked model of the earth, oceans, and atmosphere. The IGSM is considered to be a model of intermediate complexity. It differs from full scale general circulation models (GCMs) of the global climate in that it produces climate projections by latitude band and ignores longitude. Despite this simplification, the model performs well in capturing the major elements of the global climate system (Webster et al. 2009).

Figure 1: General modeling framework



Source: authors' compilation.

As a consequence of the focus on zonal outcomes (outcomes by latitude band), the IGSM is computationally far less burdensome than a full scale GCM. This permits the IGSM to consider the 400 coherent emissions scenarios derived from the EPPA model. In addition, the IGSM is able to simultaneously consider a range of possible values for critical climate parameters.[1] This methodology represents the current best attempt to define ranges and an associated measure of likelihood for climate outcomes of interest (e.g., temperature and precipitation). These outcomes are produced for each latitude band at fine time steps. In sum, the IGSM differs from other climate models in that it produces a range of potential outcomes for temperature, precipitation, and other variables and associates a measure of likelihood for values within the range.

This formal treatment of uncertainty is very valuable in the context of impact analysis in that, with the further modeling efforts described in Figure 1, it permits one to develop ranges of biophysical and economic outcomes. As noted by Arndt and Thurlow (2013), this represents a substantial step forward from a policy analysis perspective. Analyses to date have normally provided a limited number of impact scenarios with no measure of likelihood associated with each scenario. A finding that climate change is *likely* to cause substantial damages (conditional on a set of global emissions and local adaptation policies) is more powerful than a finding that climate change *could* cause substantial damages if a particular climate outcome is realized.

[1] The 400 emissions scenarios are randomly paired with 400 draws from the joint distribution of key climate variables.

Due to the lack of longitudinal detail, outputs from the IGSM on their own are not suitable for impact analysis, especially at the regional or country level. Schlosser et al. (2011) develop an approach whereby regional trends can be extrapolated from zonal trends by applying relationships between these two sets of variables derived from 17 GCMs that underlie the Intergovernmental Panel on Climate Change's Fourth Assessment Report (AR4). As these extrapolations are performed for each GCM, the 400 climate futures derived from the IGSM are converted to 6800 regional climates (i.e., 17 × 400), causing one to pass from a situation of paucity of coherent climate forecasts to a situation of surplus (see also Schlosser and Strzepek 2013). For the case of Malawi, the relevant 6800 regional climates are 'thinned' to a more manageable 426 using an approach described in Arndt et al. (2012b), which takes advantage of the properties of the parent distribution (the 6800) to derive an informed subsample (the 426). This subsample of 426 climates represents our best understanding of the range and likelihood of potential climate changes for Malawi under the assumption that significant policies to restrain emissions globally do not materialize.

A final step involves the incorporation of annual fluctuations in weather outcomes (as opposed to climate change trends) into the climate projections. This is accomplished by overlaying projected changes in temperature and precipitation due to climate change on top of the historical series of observed climate outcomes for Malawi during the 20th century. More details on this approach can be found in Arndt et al. (2012c). With these distributions of changes in climate in hand, we can proceed to biophysical modeling of climate impacts.

3.2 Biophysical models of climate outcomes

In contrast to climate models, which represent a specialized (but large-scale) effort to examine the implications of the changing chemical composition of the atmosphere in the long run (at least on human time scales), the fundamentals of the biophysical models were typically developed without reference to climate change. Issues of water resource availability and use, agricultural yields, and infrastructure vulnerability have been of interest purely as a consequence of natural variability of climate outcomes in the absence of any anthropogenic trend increase in global atmosphere and ocean temperatures. As such, a reasonably well established set of models and modeling practices exist in each domain that climate impact analysis can draw upon.

However, these models typically cannot be applied to climate change impact analysis without some modification for a variety of reasons. Chief among these is often scale. For example, crop yield models were typically developed on the basis of detailed field trials at agricultural experiment stations. As complements to field trial research, the models contain detailed representations of soils and other growing conditions alongside very short time steps and detailed specifications of the genetic potential of particular seed varieties. This level of detail is critical for advancing understanding of crops and crop growth.

Climate change poses a different challenge. Even a highly detailed climate model produces temperature and precipitation projections over grids that contain thousands of square kilometers. Per necessity, conditions within a grid are effectively assumed to be uniform. Due to considerations of scale alone, existing biophysical models must be significantly adapted to respond usefully to the questions posed by climate change.

The CliCrop model (Fant et al. 2013) was specifically developed for the purpose of examining climate change issues and is used to estimate crop yields for Malawi in this analysis. Nine crops were modeled: maize, wheat (used to represent other cereals), cassava (used to represent root crops), horticulture, tobacco, cotton, sugarcane, and tea (used to represent other export crops). CliCrop focuses on water deficits, which is appropriate in Malawi where water availability is frequently the chief limiting factor for crop yields. CliCrop is also used to estimate irrigation demand.

Surface water runoff was modeled with the rainfall-runoff model CliRun, the latest available model in a family of hydrologic models developed specifically for the analysis of the impact of climate change on runoff, first proposed by Kaczmarek (1993).[2] CliRun models runoff with a lumped watershed defined by climate inputs and soil characteristics averaged over the entire watershed, simulating runoff at a gauged location at the mouth of the catchment. In order to properly capture runoff, 29 catchments representing the entire Zambezi River Valley, including all of Malawi, were modeled. A monthly time step was used to simulate the runoff implied by projected weather variables. Maximum monthly runoff is used as an indicator for flood risk.

Runoff from CliRun and irrigation demands from CliCrop serve as inputs into the Water Evaluation and Planning (WEAP) model (Sieber and Purkey 2007). The WEAP model also incorporates information on existing and planned hydropower generation facilities and irrigation schemes. WEAP allocates water according to a hierarchy of uses prioritized as: (i) environmental flow; (ii) municipal and industrial demand; (iii) hydropower; and (iv) irrigation for agriculture. Hence, WEAP produces estimates of hydropower output and irrigation water supply, which can then be compared with the irrigation demands developed from CliCrop.

Finally, the implications of climate change for road networks are analyzed using the CliRoad model described in Chinowsky and Arndt (2012). Changes in the frequency or intensity of flooding events pose obvious implications for road networks. And, changes in the frequency or intensity of rainfall events can influence road maintenance costs for both paved and unpaved roads (with stronger implications for unpaved roads). Finally, for paved roads, increases in maximum temperatures may exceed design thresholds causing roads to degrade much more rapidly. All of these factors have implications for road maintenance costs and road construction budgets, which comprise a significant share of annual government expenditures in Malawi as elsewhere in Sub-Saharan Africa. Similar to Arndt et al. (2012a), this road model is directly incorporated into the economywide model of Malawi employed for this analysis. We turn to this model in the next subsection.

3.3 Economywide model

Results from the biophysical models are passed to an economywide model of Malawi. The economywide model (also known as a computable general equilibrium model) functions as an adding machine that accounts for diverse, sometimes offsetting, impacts within a coherent economic framework. The model employed for Malawi is similar in structure to the one of Mozambique described in Arndt and Thurlow (2013).

The economywide framework provides useful discipline for the analysis of climate change in that key accounting identities are respected. In the model, government expenditure must be financed through taxation or borrowing; investment must be financed from savings net of government borrowing; households must respect their budget constraints; factor use is limited by factor supply; and imports are limited by the quantity of foreign exchange available. The full set of accounting constraints assures that the model produces coherent futures. Within this set of accounting constraints, firms maximize profits and consumers maximize utility. For simplicity, perfect competition is assumed. The Malawi model adopts the Armington assumption whereby imports and domestic products are imperfect substitutes. A similar assumption is applied on the export side as firms shift imperfectly between supply to domestic and foreign markets.

[2] The specific version employed is called CliRun-II.

The model closure provides for a flexible exchange rate; a constant budget deficit through scaled income tax rates; and constant shares of government, investment, and consumption in total absorption. The model is recursive dynamic. Investment is allocated in a putty-clay fashion whereby new investment is allocated across sectors in accordance with returns to investment while existing investment is fixed within a sector. As in reality, farmers cannot foresee weather realizations in each crop year. To capture this, farmers allocate land, labor, and capital in accordance with expected weather outcomes and prices. Expected weather outcomes are defined as the simple average of productivity realizations over the past ten years. Productivity expectations are not permitted to change by more than 1 percent in a year, which reduces the influence of strongly negative or strongly positive weather realizations in a single year. Once expectations have been set and are reflected in factor allocations, these factor allocations are then fixed and agricultural productivity parameters are adjusted in accordance with outputs from CliCrop. A similar procedure is applied to hydropower.

As indicated, a model of the total road network of Malawi is included within the economywide modeling framework. In accordance with Arndt et al. (2012a), economywide productivity growth is a function of total road network length. Specifically, underlying total factor productivity (TFP) growth is changed proportionately with total road network length. So, for example, if the road network in 2047 is 95 percent of the baseline (no climate change) level and underlying TFP growth is 2 percent, then the underlying rate of TFP growth between 2047 and 2048 is reduced to 1.9 percent (0.95 times 2.0). Slower TFP growth directly reduces GDP growth, which in turn reduces the capacity of government to finance road network expansion, creating a mild negative (or positive) feedback loop. As discussed in detail in Arndt et al. (2012a), the modeled impacts are consistent with impacts estimated by Fernald (1999) and various papers by Fan and coauthors (see Fan and Chan-Kang, 2008; Fan and Hazell, 2001; Fan et al., 2004; Fan and Zhang, 2008).

The model is calibrated to a 2007 social accounting matrix (SAM) of Malawi (Douillet et al 2012). The SAM breaks economic activity into 34 commodities with 11 agricultural commodities (the nine crop sectors associated with CliCrop plus livestock and forestry). Agricultural activities are divided by the commodity produced and by region (north, center, and south). So, for example, there are three maize growing activities, one for each region. These activities sell the commodity maize into a single national market. Electricity is produced from multiple sources including diesel fired generators and hydropower. These production units sell into a single national electricity market. Factors of production include four labor types distinguished by educational attainment, land distinguished by region, and capital.

4 Results

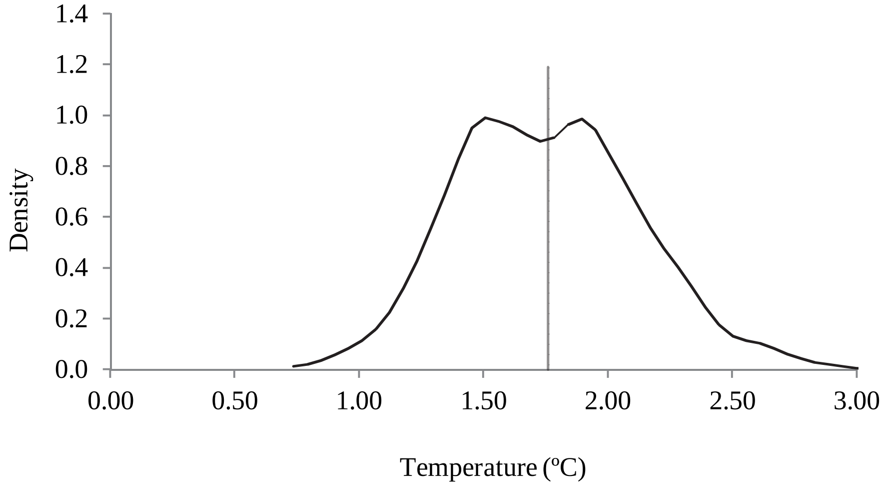
The modeling frameworks described above generate an extraordinarily large volume of results. In this section, we focus on the distribution of changes in temperature and precipitation, selected results from the biophysical models, and macroeconomic results from the economywide modeling.

4.1 Temperature and precipitation anomalies

Figure 2 illustrates the average rise in temperature for the period 2046-50 for the warmest month of the year. The format of Figure 2 will be reproduced in all remaining figures; hence, a more detailed description is offered in order to facilitate interpretation of this and all subsequent figures. The horizontal axis describes the range of possible values for the outcome considered. The vertical axis describes a measure of likelihood. In this case, densities are estimated using the

K-density function in STATA. Where the density value is greater than zero, these outcomes are possible. The maximum density value describes the mode of the distribution. It is possible to generate bi-modal distributions. The mean of the distribution is approximated by multiplying the range of possible outcomes by the measure of likelihood (appropriately scaled).

Figure 2: Increase in maximum monthly temperature (average for 2046-50)



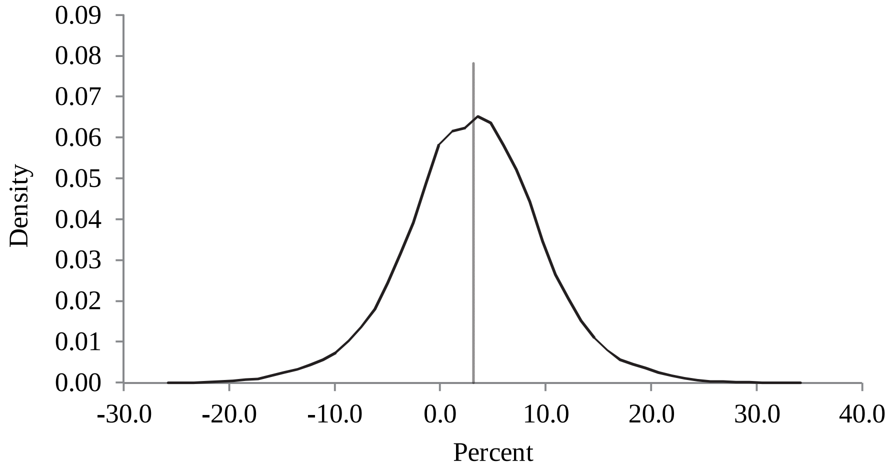
Note: The distribution is comprised of 426 projected climates. The increase for each climate is obtained by calculating the increase in temperature for the warmest month of the year for each year from 2046 to 2050 and taking the average of this increase over the five year increase in question. The vertical line illustrates mean temperature increase.

Source: authors' computation.

On average, across Malawi, temperature is expected to rise by about 1.75 ºC. The range of possible temperature increases runs from about 0.75 degrees at the minimum to nearly 3.5 degrees at the maximum. This is a wide range. However, about 80 percent of temperature outcomes falls within the range [1.34, 2.23] ºC. The distribution is relatively symmetric with the chances of falling above or below this range at about 10 percent for each tail of the distribution.

As is often the case, precipitation tends to be even more uncertain. Precipitation outcomes are shown in Figure 3. They are measured differently from temperature. Because annual changes in precipitation are also important, we consider annual precipitation outcomes, in terms of percentage change from baseline, for the period 2041-50 without averaging across the period. In addition, we pool the precipitation outcomes from the three regions of Malawi in focus here (north, central, and south). Hence, the distribution is comprised of 12,780 (weighted) observations [426 climates × 10 years × 3 regions]. The range of this distribution is broad with, on the lower end, a decline in annual precipitation of more than 25 percent and, on the upper end an increase of nearly 33 percent. Nevertheless, most outcomes are distributed much more closely to the mean outcome of about a 3 percent increase. Approximately 80 percent of outcomes lie in the range [-5, 10] percent with the tails roughly symmetrically distributed (about 10 percent in each tail).

Figure 3: Anomalies in annual precipitation due to climate change in percent (2041-50)



Note: The distribution is comprised of the percentage change in annual rainfall due to climate change for three regions (north, south, center), ten years, and 426 forecast climates. Hence, the distribution is comprised of 12,780 (3x10x426) observations. The vertical line illustrates the mean precipitation anomaly.

Source: authors' computation.

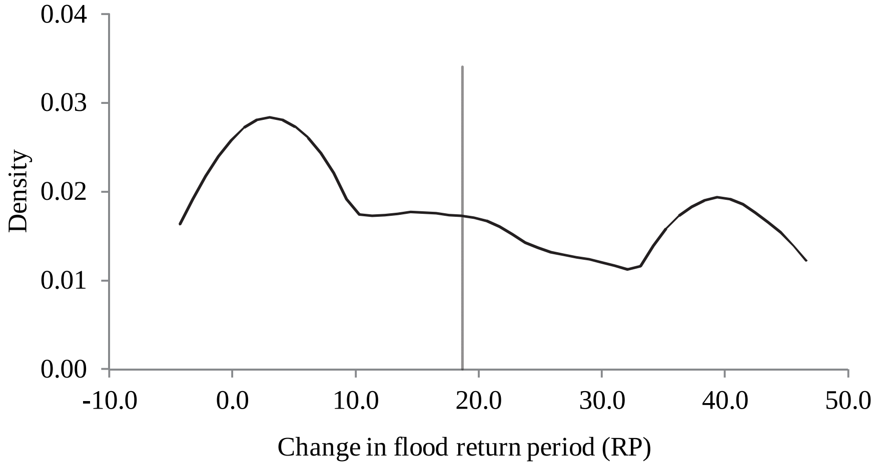
4.2 Selected results from biophysical models

As shown in Figure 1, the results from the climate models are passed to biophysical models in order to assess the implications for processes of strong relevance to economic growth and development. In this section, we focus on the frequency and intensity of flood events and expected maize yields.

Even if total rainfall declines, precipitation intensity can increase resulting in changes in the frequency or intensity of flood events. We estimate changes in flood return periods using the outputs of the CliRun model.[3] Because small increases in flood return periods are much less pertinent than large increases and because climate change rarely results in a substantial reduction in flood return periods, we consider the maximum increase in flood return periods over the period 2041-50 and across all three regions. The estimated distribution is illustrated in Figure 4. These implications for flood return periods are potentially significant. From 2041-50, about half of all future climates considered generate an increment to flood return periods of at least 15 years and about 10 percent generate increments of greater than 40 years. This marks an appreciable increase in the intensity of flooding events.

[3] The flood return period defines the period in which one would expect to see a flood of a given or stronger intensity. The measure employed increases the return period to reflect the likelihood of more intense flooding. So, if climate change converts a 50-year flood event to a (more severe) 70-year event (based on historical scales), the increment is 20 years. Alternatively viewed, climate change may convert a 70-year flood event into a 50-year event implying that events of that intensity or more will occur more frequently.

Figure 4: Maximum change in flood return period due to climate change, 2041-50

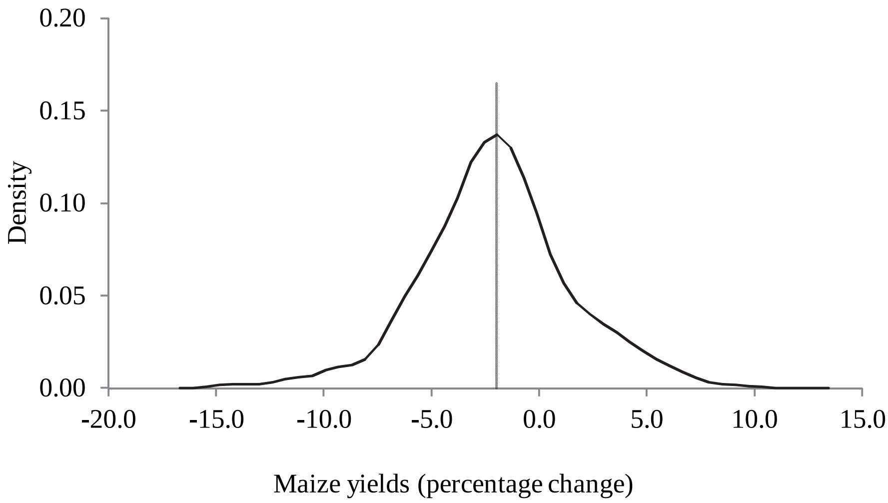


Note: The distribution is comprised of the maximum increment to the estimated flood return period over the period 2041-50 for any of the three regions in focus (north, center, or south). The distribution contains 426 observations corresponding with the 426 future climates under study. The vertical line illustrates the mean change in flood return period.

Source: authors' computation.

Figure 5 illustrates the estimated distribution of changes in maize yields. The changes are calculated in percentage terms relative to a no climate change baseline. The figure illustrates the average change in maize yields over the 2041-50 time period. Results from the north, center, and south are pooled such that there are three maize yield change estimates for each climate. Similar to the literature cited earlier, the implications of climate change for maize yields are typically mild, at least out to 2050. The mean percentage change (without weighting by production levels in each region) is a decline of about 2 percent. Consistent with other observations, a broad range of outcomes is possible with the minimum and maximum values stretching from a decline of about 17 percent to an increase of about 13 percent. Approximately 80 percent of outcomes lie in the interval [-5,4] percent.

Figure 5: Percent change in maize yields (average for 2041-50)



Note: Average maize yield changes, in percentage terms, for the period 2041-50 are pooled across the three regions of Malawi. Hence, the distribution is comprised of 1278 (3 regions x 426 climates) observations. The vertical line illustrates the mean percent change.

Source: authors' computation.

4.3 Macroeconomic implications

To assess the macroeconomic implications of climate change, we apply the changes derived from the biophysical modeling discussed above to an economywide model of Malawi. The simulations employed for Malawi are listed in Table 1.

Table 1: Economywide modeling scenarios

Scenario	Comments
Baseline	Baseline dynamic path with world prices as projected by Paltsev (2012) and historical climate variability that establishes baseline (no climate change) implications for agriculture, hydropower generation, and road network extent
Agriculture	Baseline + climate change implications for agricultural production are introduced. Climate uncertainty is captured through the use of the 426 climates selected by Arndt et al. (2012)
Roads	Agriculture + implications for roads
Energy	Roads + implications for hydropower

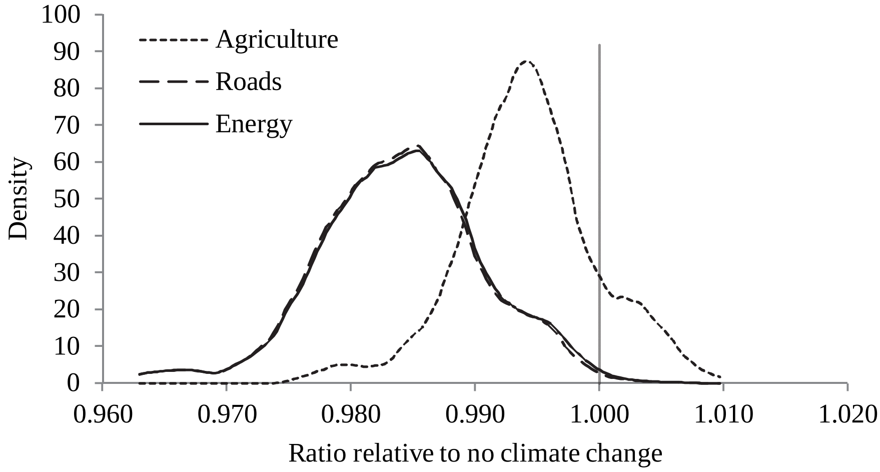
Source: authors' computation.

We begin with a Baseline scenario that applies historical climate variability for Malawi and world prices for fuels and agriculture as described by Paltsev (2012), who produces price projections for fuels and agriculture over the first half of the 21st century. The key desirable feature of the Baseline path is that it produces a reasonable counterfactual against which climate change scenarios can be compared. In the Baseline considered here, real GDP at factor cost grows at an average annual rate of 4.4 percent over the period 2007 to 2050. Consistent with global experience, the relative share of agriculture in GDP declines from a bit more than 30 percent in 2007 to about 22 percent in 2050.

In order to obtain insight into the relative importance of alternative impact channels, we consider multiple scenarios where impact channels are added one by one. In the Agriculture scenario, only implications for agriculture are considered. In the Road scenario, implications for road infrastructure and agriculture are considered simultaneously. Finally, the Energy scenario adds implications for hydropower generation thus incorporates all three major impact channels and represents our most detailed impact scenario.

The implications of climate change for GDP at factor cost are illustrated in Figure 6. This figure depicts GDP at factor cost for climate change scenarios divided by the Baseline level for GDP at factor cost. In order to minimize the influence of a particular year, we consider the average from 2046-50. Hence, a ratio greater than one implies that real GDP actually attains a higher level under climate change while a value less than one implies a lower level of GDP. A number of observations emerge from the figure. First, consistent with Figure 5, the implications of climate change for agriculture in Malawi may be positive or negative; however, the bulk of climate outcomes result in decreases in overall GDP. The distribution, when only agriculture is considered, is of relatively low variance with outcomes ranging from a decline of 2.5 percent to a rise of about 1 percent.

Figure 6: Ratio of real GDP at factor cost relative to Baseline for alternative scenarios



Note: The vertical line illustrates the ratio of 1.

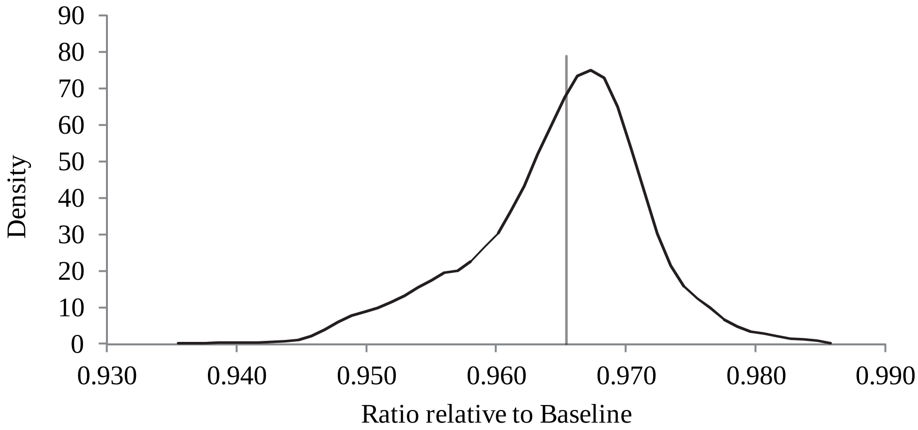
Source: authors' computation.

As emphasized, autonomous adaptation is present in the model. Resources move in and out of agriculture and across activities within agriculture in response to productivity trends. This is illustrated by the share of agriculture in GDP, which ranges from a low about 20 percent of GDP in 2050 to a high of 27 percent (not shown in the Figure). Two factors contribute to the flow of resources into or out of agriculture in general and individual activities within agriculture in particular. These factors are productivity and prices. If prices are constant, then resources will tend strongly to flow towards activities that are relatively favored by climate change. This is the canonical adaptation story. However, in general equilibrium, it is possible that resources may flow towards crops with relatively low productivity. For example, root crops, principally cassava, are neither exported nor imported implying that prices are determined on domestic markets. If a shortage of root crops causes its price to rise substantially, farmers would allocate resources to root crops as long as the percentage increase in price exceeds the percentage loss in productivity.

The next scenario, Roads, increases the variance of the distribution of GDP outcomes and shifts it to the left. Once the implications of climate change for road infrastructure is accounted for, the likelihood of positive impacts of climate change on GDP outcomes falls to nearly zero. Declines in GDP of a bit more than 3.5 percent are possible. As noted earlier, the Agriculture and Roads scenarios can interact in that wetter outcomes may favor agriculture but disfavor road infrastructure and vice versa.

The implications of climate change for total road infrastructure length is summarized in Figure 7. Similar to Figure 6, Figure 7 illustrates the impacts of climate change on road infrastructure by taking the ratio of projected total road network lengths to Baseline levels. As with GDP, the average of 2046-50 road network lengths is used. Figure 7 is consistent with Figure 4, which shows a fairly pronounced increase in flood return periods. The increase in flood return periods reflects greater precipitation intensity, which increases maintenance costs even in the absence of flood events. As noted, higher heat can also have negative implications for paved roads if appropriate steps to adapt the pavement mix to withstand higher temperatures are not taken. As a consequence of these effects, the road network length is uniformly shorter across all 426 simulated climate outcomes by 2050. By about 2050, the average road network length decline is slightly less than 3.5 percent. This reduction in road network length is assumed to reduce economywide productivity growth and hence slightly reduce the rate of growth of GDP.[4]

Figure 7: Road network length relative to baseline by the 2040s



Note: The vertical line illustrates the mean road network length ratio.

Source: authors' computation.

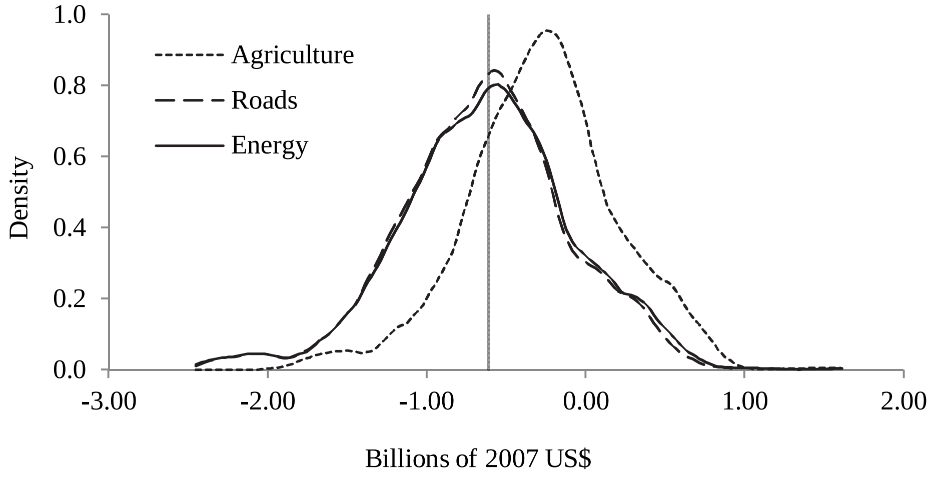
Energy is the final scenario illustrated in Figure 6. The implications of climate change for hydropower production in Malawi translated into only very small changes in the rate of GDP growth. This is because the implications of climate change for hydropower output are not particularly large. In addition, through time, Malawi tends to reduce domestically produced hydropower as a share of total generation due to a paucity of good locations for generating more hydropower. Finally, consistent with the projected increase in precipitation illustrated in Figure 3, implications for hydropower are often favorable.

Overall, the implications of climate change for economic growth in Malawi *out to about 2050* are slight. The total GDP loss by about 2050 amounts to less than a year of economic growth at the Baseline growth rate. In other words, even in the strong impact scenarios, the annual GDP level (12 months trailing) that would have been attained in the absence of climate change on 1 January 2050 would be attained before 1 January 2051 in all climate change simulations.

While the impact channels considered do not translate into substantial changes in the rate of overall economic growth, climate change does potentially impose consistent losses over long periods of time. Figure 8 considers the present discounted value of the gap between output with and without climate change. The average loss over the period 2007 to 2050, discounted at 5 percent, is about 610 million US$ at 2007 prices. A positive net present value over the full period is possible. In fact, nearly 14 percent of the climates considered yield a positive net present value of impacts when discounted back to 2007. Nevertheless, the large majority of climate outcomes result in negative net present value with about 25 percent of outcomes experiencing a net present value of loss of more than one billion US$ at 2007 prices. This is a significant number for a poor country whose GDP in 2007 amounted to about US$3.5 billion.

[4] For this analysis, road budgets are assumed to remain a fixed proportion of GDP. An adaptation measure that could usefully be considered would be to allocate additional investment funds to road infrastructure in response to climate change. This would maintain the road network but come at the cost of investment for other purposes.

Figure 8: Net present value of losses from climate change by scenario

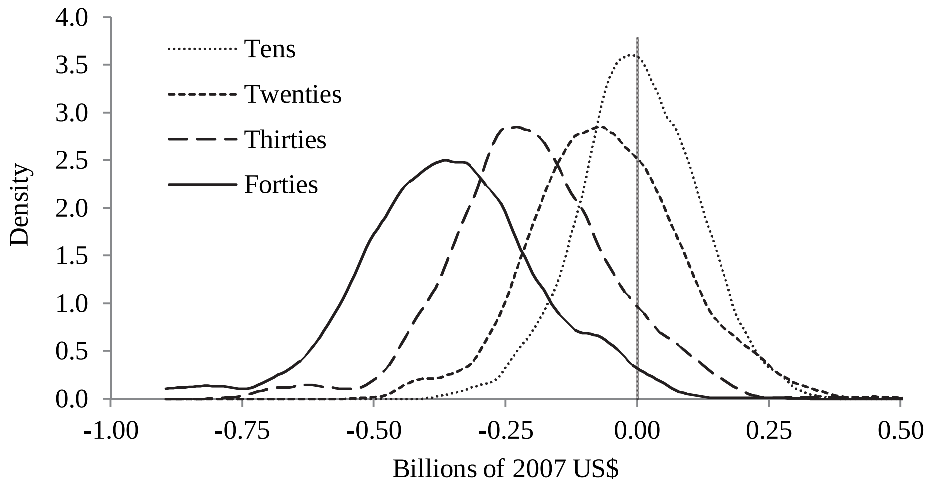


Notes: The discount rate applied is 5 percent and values are converted to real 2007 US$. The vertical line is the mean of the Energy scenario.

Source: authors' computation.

The progression of the net present value calculations through time is a highly relevant result. This progression is illustrated in Figure 9. The figure clearly shows increasingly negative climate change impacts. In the current decade, the effects of climate change are about as likely to be positive as they are to be negative. However, as time progresses the variance of impacts tends to increase and the central tendency shifts steadily to the left. By the 2040s, the likelihood of net gains from climate change decline to only about 2 percent. The other 98 percent of climate outcomes result in negative economic outcomes and the likelihood of relatively severe outcomes grows substantially relative to earlier decades. Importantly, this trend can be expected to continue beyond 2050 and may worsen dramatically if global efforts fail to contain emissions growth.

Figure 9: Net present value of losses from climate change by decade



Notes: The discount rate applied is 5 percent and values are converted to real 2007 US$. A vertical line is drawn at net present value of zero.

Source: authors' computation.

5 Summary and conclusions

Two elements are highly desirable in any analysis of the implications of climate change for overall economic growth and development. First, an interdisciplinary approach would appear to be indispensable. For this reason, the analysis presented moves from fundamental climate science through a series of biophysical models and finally on to an economic assessment. Second, any analysis of climate change should be presented with a degree of humility. Emanuel (2007) describes climate modeling as one of the most complex endeavors ever undertaken by humankind. Like any comprehensive climate change assessment, this assessment of Malawi derives from an uncomfortably tall and complex tower of modeling endeavors.

In the analysis conducted here, substantial explicit effort is directed to capturing the uncertainty inherent in climate projections. At the same time, the uncertainty inherent in the biophysical and economic models of Malawi is entirely set aside. This represents an explicit choice. The philosophy behind the modeling effort described here is to subject a mathematical representation of Malawi to a range of future climates. Neither the climate distributions nor the mathematical representations of Malawi are perfect. Nevertheless, something can be learned by imposing the best available representation of the distribution of future climate outcomes for Malawi on a detailed and coherent set of models designed to capture likely biophysical and economic implications of climate change for Malawi.

Based on this structure, we find mild implications of climate change for Malawi's economic growth prospects, at least over the next two decades. However, by 2030 and certainly into the 2040s, climate change impacts become more definitively negative and may begin to hinder overall growth prospects. In addition, under about one fourth of climate futures considered, consistent losses from climate change lead to losses of more than one billion real 2007 US$ in net present value terms. While the analysis conducted here ends in 2050, climate change will not end and may become substantially more severe, especially if effective global mitigation policies fail to materialize. The analysis indicates that the implications of climate change in the latter half of the 21st century should be cause for serious concern.

The climate change challenge is likely to both endure and become increasingly pointed with time. This paper provides a next step in improving comprehension of the implications of climate change. Sustaining productive inquiry into the likely impacts of and responses to climate change remains an important endeavor. Ample scope exists to improve understanding of the implications of climate change. This is true both with respect to the impact channels considered here and with respect to other impact channels, such as the implications for human health and the effects of warming on Lake Niassa, that were excluded from this analysis.

Finally, while understanding potential impacts is crucial for the design of appropriate policy responses, further specific analysis of adaptation policy options is merited. Because smart adaptation policies tend to be long term and/or structural, there is good reason to put priority on these efforts in the near term. For example, agricultural research to develop varieties and practices capable of coping with higher temperatures represents an obvious adaptation policy. However, time lags between the design of a research program and the extension of results into the field are long—10-15 years at least. In addition, policies to upgrade vulnerable road and urban infrastructure to make them more robust to intense rainfall and potential flooding also merit serious consideration. Because Malawi's future backbone economic infrastructure is being built today, consideration of climate change should form a part of these fundamental decisions.

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