A WORLD BANK STUDY

Economics of Climate Change in the Arab World

CASE STUDIES FROM THE SYRIAN ARAB REPUBLIC, TUNISIA, AND THE REPUBLIC OF YEMEN

THE WORLD BANK

Dorte Verner and Clemens Breisinger, editors

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Abbreviations and Acronyms

AEZ	Agroecological Zone
CERA	Climate and Environmental Retrieval and Archive
CGE	Computable general equilibrium
CMIP3	Coupled Model Intercomparison Project Phase 3
CNRMCM3	Centre National De Recherches Météorologiques Coupled Model Version 3
CSIRO-Mk3.0	The Commonwealth Scientific and Industrial Research Organisation Mark 3.0
DCGE	Dynamic computable general equilibrium
DSSAT	Decision Support System for Agrotechnology Transfer
FPU	Food production unit
GCM	Global climate model
GDP	Gross domestic product GHCN Global Historical Climatology Network
GHG	Greenhouse gas
HIES	Household Income and Expenditure Survey
IBLI	Index Based Livestock Insurance
IFPRI	International Food Policy Research Institute's
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
MENA	Middle East and North Africa
NAPC	National Agricultural Policy Center
NCDC	National Climatic Data Center
PDSI	Palmer Drought Severity Index
SADB	Syrian Agricultural Database
SAM	Social accounting matrix
SPAM	Spatial Production Allocation Model

SRES	Special Report Emissions Scenarios
TFP	Total factor productivity
WAT	Water availability coefficient
WCRP	World Climate Research Program

CHAPTER 1

Introduction

Dorte Verner

Photograph by Dorte Verner

Scarce water and high temperatures have shaped the cultures of the Arab region over thousands of years. Today, however, the region is confronting climate variability and change that could alter and threaten development in the region. Most Arab countries are projected to become much hotter and drier in this century as a result of climate change. While climate change will ultimately affect the social and economic development of the entire region, the most drastic impacts will be felt by the approximately 100 million poor people who lack the resources to adapt (Verner 2012).[1] This book presents detailed case studies on the impacts of climate change in the Syrian Arab Republic, Tunisia, and the Republic of Yemen that were summarized in Verner (2012).

Climate change is no longer a distant threat. The Arab region is already being impacted by climate change through more frequent cyclones, floods, and prolonged droughts. Thousands of rural producers have seen their crops and herds devastated by extreme conditions, and have been forced to abandon their traditional way of life and migrate to crowded urban areas. Those who stay behind in rural areas struggle to cope with shortages of food and water.

Climate change affects countries' economies and households through a variety of channels. Rising temperatures and changes in rainfall patterns affect agricultural yields of both rainfed and irrigated crops, and thus global and local food markets (Nelson et al. 2009, 2010). Countries that are already experiencing water stress, especially those in the Arab World, are likely to experience additional declines in agricultural yields, resulting in negative effects on rural incomes and food security (Breisinger et al. 2010). A decline in precipitation will change hydropower production, and increased frequencies and magnitudes of floods and droughts can significantly increase the need for public investment in physical infrastructure (Garnaut 2008; Stern 2006; World Bank 2007; Yu et al. 2010).

Without appropriate adaptation responses, it is projected that the Arab region—particularly its least resilient populations—will endure severe hardship. This report shows that over the next 30–40 years climate change is likely to lead to a cumulative reduction in household incomes ranging from close to US$2 billion in Syria and Tunisia to up to US$9 billion in the Republic of Yemen. Rural areas throughout the region will suffer the most as climate change is projected to reduce incomes from farms and livestock. A lack of opportunities in rural areas will lead to urban crowding: while 56 percent of Arab people currently live in urban centers, it is estimated that the share will rise to 75 percent by 2050. Climate-change adaptation should ideally be considered and incorporated into all development activities and government planning. Governments, with assistance from the private sector and civil society, can ensure that their development policies, strategies, and action plans build resilience to a changing climate. Investing in climate-change adaptation can create development cobenefits while also spurring job creation and green growth. Adaptation is a process that will take place over decades as new information

makes policy makers reevaluate their climate vulnerabilities. Still, by seizing the opportunity to act now and act together, the Arab region can not only meet the immense challenges of climate change but advance the development of all its people.

Climate Change Is Happening Now

Environmental challenges in the Arab world include: water scarcity, with the lowest freshwater resource endowment in the world;[2] very low and variable precipitation; and excessive exposure to extreme events, including drought and desertification. This demanding environment, combined with food insecurity makes the Arab region among the World's most vulnerable regions to climate change. If no drastic measures are taken to reduce the impacts of climate change, the region will be exposed to reduced agricultural productivity and incomes, a higher likelihood of drought and heat waves, a long-term reduction in water supplies, and the loss of low-lying coastal areas through sea-level rise. This climate exposure will have considerable implications for human settlements and socioeconomic systems (IPCC 2007).

Climate change is already being felt in Arab countries. Globally, 2010 tied 2005 as the warmest year since climate data began to be collected in the late 1800s. Of the 19 countries that set new national temperature highs in 2010, 5 were Arab countries. Temperatures in Kuwait reached 52.6°C only to be followed by 53.5°C in 2011.[3] In addition to the warming climate, the frequency of extreme weather events is increasing. For example, in June 2010, the Arabian Sea experienced the second-strongest tropical cyclone on record—Cyclone Phet—which peaked at category 4 strength with winds at 145 miles per hour, killing 44 people and causing US$700 million in damages to Oman.[4] A snapshot of climate change in Arab countries (Verner 2012) reveals that:

- Higher temperatures and more frequent and intense heat waves threaten lives, crops, terrestrial biodiversity, and marine ecosystems such as coral reefs and fisheries.
- Less but more intense rainfall causes both more droughts and more frequent flash flooding.
- Loss of winter precipitation storage in snow masses induces summer droughts.
- Increased frequency of prolonged droughts leads to losses in livelihoods, incomes, and human well-being.
- Sea-level rise threatens river deltas, coastal cities, wetlands, and small island nations such as Bahrain and the Comoros with storm surges, saltwater intrusion, flooding, and subsequent human impacts.
- More intense cyclones put human life and property at risk.
- Changing rainfall patterns and temperatures create new areas exposed to dengue, malaria, and other vector- and waterborne diseases affecting people's health and productivity.

There is increasing evidence that climate change will have severe negative impacts on the economic and social development of Arab countries. Climate change threatens to stall and reverse progress toward poverty reduction, better health, gender equality, and social inclusion in Arab countries. Yet research on the socioeconomic dimensions of climate change in the Arab region is only in the early stages (Tolba and Saab 2009).

Challenges to Addressing the Economic Impacts of Climate Change

Several authors have used the International Panel for Climate Change's (IPCC) Special Report Emission Scenarios (SRES) data in combination with global economic models to analyze the varied impacts of climate change. Most of these studies downscale the global climate models' results to finer country or region specific units (Frontier Economics 2008; van Vuuren, Smith, and Keywan 2010). Analysts have also used computable general equilibrium models (CGE) to capture the links between different sectors and the spillover effects of climate change from one sector to the other (Burniaux and Truong 2002; Darwin and Tol 2001; Deke et al. 2001). More recent applications of global CGE models to climate change link a global partial and general equilibrium model (IMPACT and GTAP) to assess changes in agricultural productivity and production in Sub-Sahara Africa (Calzadilla et al. 2011).[5] CGE's have also been used to analyze the costs and effectiveness of pledges taken during the Copenhagen Accord by several countries to reduce their greenhouse emissions (Dellink, Briner, and Clapp 2011), and to assess the role of global land use as a tool for climate-change mitigation and adaptation (Hertel, Rose, and Tol 2009).

Given the large differences in location-specific factors, however, studies at the national and subnational level are needed to assess location-specific climate change challenges. Several analyses have used models that focused on quantifying the costs of climate change on the economies of single countries (Frontier Economics 2008). Recently, the World Bank conducted a series of studies to analyze the economics of adaptation to climate change for several countries including Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam (World Bank 2012). In addition to economic costs, two of these papers discuss some welfare impacts of climate change on households.

While much of the work on the impacts of climate change has focused on either the global or national economic effects, this report is among the first to present a comprehensive modeling suite that combines biophysical, subnational, and global economic models to assess the global and local effects of a changing climate on growth and household incomes. We feed the downscaling of the GCM scenarios (Jones, Thornton, and Heinke 2009) into the Decision Support System for Agro technology Transfer (DSSAT) (Jones et al. 2003), which assesses the changes in yields for selective crops and agro ecological zones for our three countries of study: Syria, Tunisia, and the Republic of Yemen.

Output from DSSAT informs the International Food Policy Research Institute's (IFPRI's) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model (Rosegrant et al. 2008) and serves as a direct input into the country-specific dynamic computable general equilibrium (DCGE) models. Changes in world food prices derived from IMPACT, along with alternative global energy price futures, also flow into the DCGE models to assess the global impacts of climate change on the respective economies.

Cross-country comparison is important given these countries' location in a region that is consistently projected to be among the hardest hit by climate change. All three are net food- and energy-importing countries; both global and local effects will impact their development. Syria is a net importer of oil and major food items such as rice, maize, barley, soybeans, fish, and poultry (Breisinger et al. 2011). Tunisia, also a net importer of food, imports between 50 and 88 percent of cereals and many other food items resulting in a moderate risk of food insecurity (Al-Riffai et al. 2012). The Republic of Yemen is the largest net importer of food of the three countries, importing between 70 and 90 percent of cereals as well as many other food items (Breisinger et al. 2011, 2012; Ecker et al. 2010; Wiebelt et al. 2011). The Republic of Yemen is also the poorest country in the Arab world—with an estimated 43 percent of its people living in poverty before the conflict in 2011—and is among the most food-insecure countries in the world, with 32 percent of the population without access to enough food (Breisinger et al. 2011; Ecker et al. 2010; Wiebelt et al. 2011). It is against this background that this report assesses how severely climate change will affect these three countries and stresses the necessity of considering the impacts of climate change in future development strategies.

Notes

1. Major climate change publications have split the Arab region between Africa and Asia. Verner (2012) seeks to provide a coherent assessment of climate change in the Arab region as a whole. It describes the likely impacts of climate change in key sectors such as water, agriculture, tourism, gender equity, and health, in both urban and rural settings. The report also proposes a new framework for adaptation governance that allows the region's policy makers to integrate climate risks and opportunities into development activities.
2. The yearly median value is 403 cubic meters per capita.
3. The highest temperature was measured in Pakistan (53.5°C, or 128.3°F); the other four Arab countries were Iraq (52.0°C), Saudi Arabia (52.0°C), Qatar (50.4°C), and Sudan (49.7°C); see http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=1831. Oman, specifically Khasab Airport, recorded a new world high minimum temperature with a scorching 41.7°C (107°F) low on June 23, 2011.
4. Only Cyclone Gonu of 2007, a category 5 storm, was a stronger Arabian Sea cyclone, killing about 50 people in Oman, with damage estimated at roughly US$4.2 billion.
5. See Frontier Economics (2008) for a detailed listing of CGE models used for climate change applications.

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CHAPTER 2

Modeling Suite

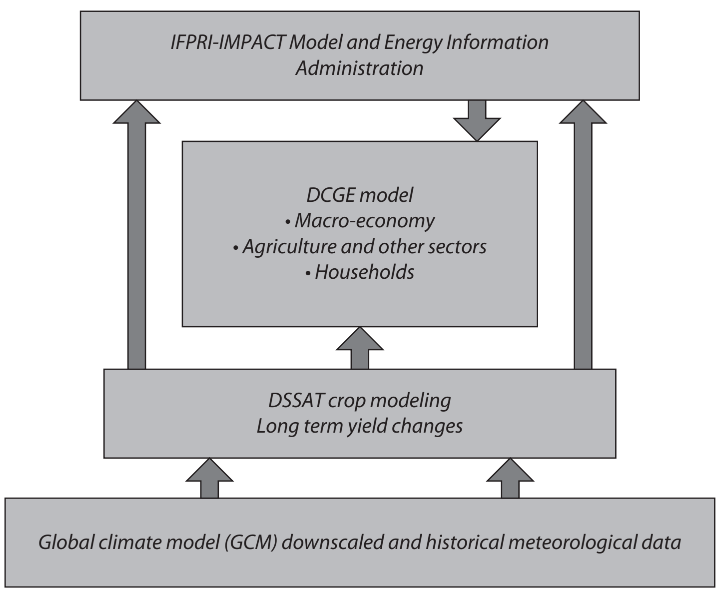
Clemens Breisinger, Olivier Ecker, Gerald Nelson, Manfred Wiebelt, and Tingju Zhur

Photograph by Dorte Verner

This report links results from crop models with global and national-level economic models to quantify the impacts of climate change and climate variability in the Syrian Arab Republic, the Republic of Yemen, and Tunisia. This modeling suite allows for a comprehensive assessment of global and local impacts of climate change and variability on important economic indicators, such as changes in agricultural growth and household income distribution. Figure 2.1 provides an overview of the different types of models and data used and shows how they inform each other.

The major components of the modeling suite used in this report are the downscaling of global climate models (GCMs), crop modeling, global economic modeling, and subnational-level economic modeling. The downscaling of the GCM scenarios (Jones, Thornton, and Heinke 2009) are fed into the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al. 2003), which assesses the changes in yields for both rainfed and irrigated crops in the three countries' regions of analysis. Output from DSSAT then informs the International Food Policy Research Institute's (IFPRI's) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model and serves as a direct input into the country-specific dynamic computable general equilibrium (DCGE) models. Changes in world food prices derived from IMPACT, along with alternative global energy price futures, also flow into the DCGE model to assess the global impacts of climate change on the economy. Finally, the DCGE model is used to assess the impacts of droughts in combination with a drought index analysis, a semi-empirical crop model with a regional

Figure 2.1 Modeling Suite



Source: World Bank data.

modeling perspective, and historical data. The impacts of floods in the Republic of Yemen are assessed using historical and projected future precipitation data. The following sections and some of the appendices referred to in the text describe components of the modeling suite in detail.

Biophysical Impact Assessment

The IMPACT climate-change-modeling system combines a biophysical model (the DSSAT crop-modeling suite) of responses of selected crops to climate, soil, and nutrients with the IFPRI Spatial Production Allocation Model dataset of crop location and management techniques (You and Wood 2006). These results are then aggregated and fed into IMPACT.

Downscaling of GCMs

Jones, Thornton, and Heinke (2009) used GCM simulations available from the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset. This dataset contains model output from 22 of the GCMs used for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) for a range of scenarios, including the three Special Report Emissions Scenarios (SRES) used in the IPCC's Fourth Assessment Report: AR4: A2, one family of scenarios, is a high-greenhouse-gas-emission scenario; A1B, a subset of the A1 family of scenarios, is a medium-emissions scenario; and B1, the fourth family of scenarios, is a low-emissions scenario.

Model output data—including the basic core variables for many crop and pasture models such as precipitation, maximum daily temperature, and minimum air temperature—are not available for all combinations of the GCM and emissions scenarios. This severely restricted the choice of GCMs. From the CMIP3 dataset, Jones, Thornton, and Heinke (2009) used three GCMs—Centre National de Recherches Météorologiques Coupled Model Version 3 (CNRMCM3), the Commonwealth Scientific and Industrial Research Organisation Mark 3.0 (CSIRO-Mk3.0), and MIROC 3.2 (medium resolution). They obtained maximum and minimum temperatures for the ECHam5 model from the Climate and Environmental Retrieval and Archive (CERA) database at Deutsches Klimarechenzentrum (DKRZ) for the three SRES scenarios. Because of data restrictions, we focused on the MIROC A1B and the CSIRO A1B for Tunisia and the Republic of Yemen, and the MIROC A1B GCM was used for Syria. In Syria, comparisons between precipitation and daily minimum and maximum temperature projections for 2050 from 12 climate scenarios (four models, each with three emissions scenarios) show that MIROC A1B projects lower rainfall and higher temperatures than most of the other 11 scenarios. Therefore, results from this report should be interpreted as high-range impact scenarios.

Data for GCM deviations for average monthly precipitation, and maximum (t_{max}) and minimum (t_{min}) temperatures were obtained for the GCM and

scenario combinations for five time slices 1991–2010 (denoted as 2000), 2021–40 (denoted as 2030), 2041–60 (denoted as 2050), 2061–80 (denoted as 2070), and 2081–2100 (denoted as 2090) (Jones and Thornton 2013). Processing this data resulted in different calculated mean monthly climatic conditions for each time slice and for each variable from the original transient daily GCM time series. The mean monthly fields were then interpolated from the original resolution of each GCM to 0.5 degrees latitude–longitude using conservative remapping, which preserves the global averages. They then calculated monthly climate anomalies (absolute changes) for monthly rainfall, mean daily maximum temperature, and mean daily minimum temperature, for each time slice relative to the baseline climatology (1961–90). The point of origin was designated as 1975, being the midpoint of the 30-year baseline. In the current case, they made a preliminary investigation of the functional forms of the projections using cluster analysis. All pixels from each of the four models for scenario A1B were clustered for precipitation, t_{max}, and t_{min} using the values of the five time periods as clustering variants. Fourth-order polynomial fits were made for all models at all scenarios, and another set was made for the average of the four models. The gridded anomalies were then downscaled to a higher resolution, and daily weather data were generated that are roughly characteristic of the future climates produced using a stochastic daily weather generator.

In general, ground-based observations of meteorological records from national meteorological agencies of the country under investigation are preferable to a global dataset in analyzing subnational crop water use and crop productivity; however, those data are not adequately available for all three countries throughout this report.[1] For Syria, the weather-station-based records also come from a global dataset rather than from local authorities. As a result, we used Jones, Thornton, and Heinke (2009) pixel-level global data, which were also used in global climate change analysis in the IMPACT model.

Crop Yield Simulation

We use the DSSAT crop modeling suite, version 4.5 throughout this report. The DSSAT crop simulation model is an extremely detailed, process-oriented model of the daily development of a crop, from planting to harvest-ready (Jones et al. 2003). It requires daily weather data, including maximum and minimum temperature, solar radiation, and precipitation; physical and chemical characteristics of the soil; and crop management data, including crop, variety, planting date, plant spacing, and inputs such as fertilizer and irrigation. The DSSAT model is applied to maize, wheat, rice, groundnuts, and soybeans in Syria. We map these results to other crops in IMPACT using the primary assumption that plants with similar photosynthetic metabolic pathways will react similarly to any given climate change effect in a particular geographic region. Millet, sorghum, sugarcane, and maize all use the C4 pathway and are assumed to follow the DSSAT results for maize in the same geographic regions. The remainder of the crops use the C3 pathway. The climate effects for the C3 crops not directly modeled in

DSSAT follow the average of wheat, rice, soy, and groundnuts from the same geographic region, with two exceptions: the IMPACT commodities of other grains and dryland legumes are directly mapped to the DSSAT results for wheat and groundnuts, respectively. We considered three crops important to Tunisia: wheat, barley, and potatoes and four crops for the Republic of Yemen: maize, millet, sorghum, and wheat.

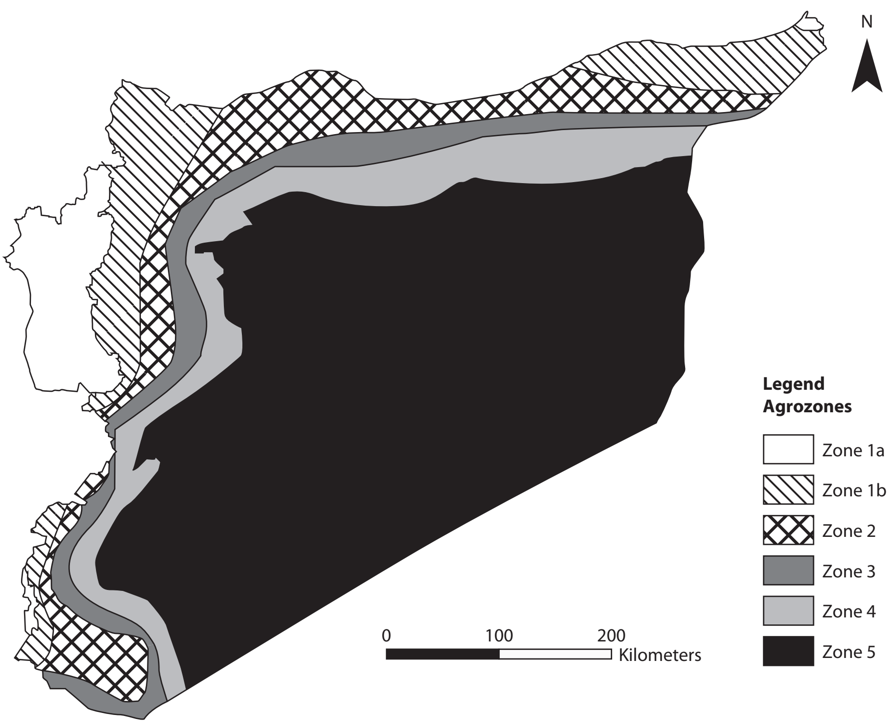
Two critical inputs for this application are the choice of planting dates and the climatic conditions. For Tunisia it was assumed that wheat was mostly planted in November. Determining the appropriate planting month for barley and potatoes was more difficult. Those crops were planted in all months, so the highest yielding month was chosen as the most likely. In the Republic of Yemen, the evidence suggests that planting occurs roughly in July in the higher altitudes and roughly in March in the lower ones. This target planting month was used as the middle of a three-month window, with yields predicted for each month in the window. Within each month, two planting dates were used and the resulting yields averaged together. Finally, the overall yield was taken as the highest of the three-monthly yields. This approach allows for some diversity in the timing of planting (as is expected in the real world) as well as some flexibility since the target planting month might not be quite correct in all locations. In general, the seasonal patterns of temperature and precipitation do not change much between the baseline and 2050 projections, so the same planting date window was used for both. Climatic conditions were chosen to be consistent with those in the IMPACT world-market price projections: baseline 2000 and 2050 climates as projected by the CSIRO A1B and MIROC A1B downscalings from the FutureClim product (Jones, Thornton, and Heinke 2009). The temperatures and rainfall amounts vary, resulting in sometimes dramatically different yields.

Since the crop simulation models require daily weather data and the climate data are available as monthly averages, a random weather generator within the DSSAT framework (SIMMETEO) was used to create daily realizations consistent with the monthly averages. To simulate today's climate, we use the Worldclim current conditions dataset, which is representative of 1950–2000 and reports monthly average minimum and maximum temperatures and monthly average precipitation. This specificity makes crop models a powerful tool for assessing the potential effects of climate change on local crop yields, which can then be aggregated for use in economic models. In Syria, 30 iterations were run at each location, and the mean of the yield values was used to represent the effect of the climate variables; in Tunisia, 80 years of simulations were run using different weather for each one, and the final yield for each location was based on the average across these 80 repetitions. Finally, in the Republic of Yemen, 40 years of simulations were run for each individual planting date using different weather for each one. In other words, for one planting month, the final average yield was based on 80 separate weather realizations (40 realizations times two dates).

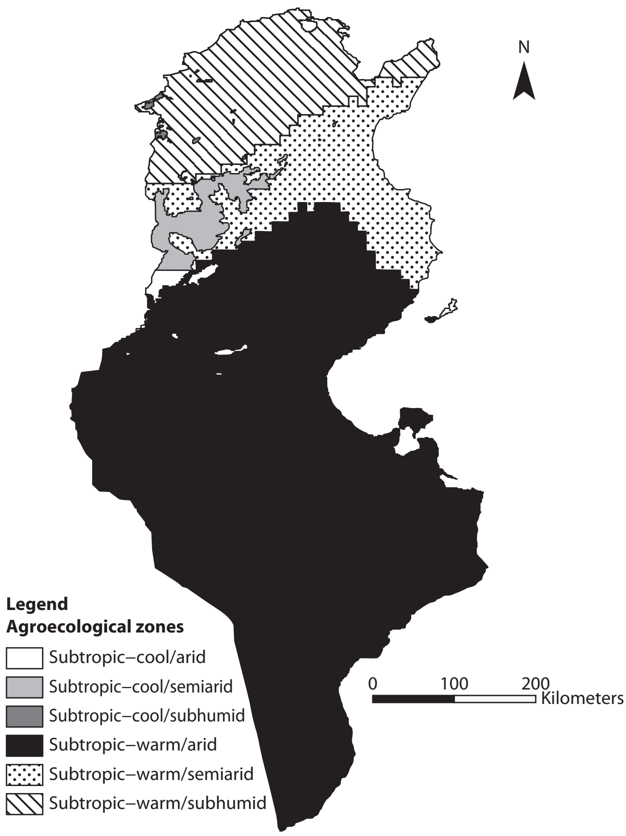
Finally, the crop yield changes from the DSSAT model at the pixel level are aggregated to match each country's agroecological zones (AEZ): five for Syria, seven for Tunisia, and six for the Republic of Yemen (figure 2.2). Yield changes for six crops under two production systems (irrigated and rainfed) were combined at the agroecological zone level from the baseline dataset and from two climate change scenarios (CSIRO A1B and MIROC A1B) at 30 arc-minute grid cells spatial resolution. The AEZ yields are then computed as the area-weighted average yield. The projected yields for each pixel were multiplied by the production area thought to be present within that pixel. Aggregating across these provides the total production. Totaling only the production areas provides the total area. The average yield is calculated as the total production divided by the total area. For Tunisia, the production areas by crop within each pixel were assigned by using the maps from the Spatial Production Allocation Model (SPAM) (You and Wood 2006), and for the Republic of Yemen, the production areas by crop within each pixel were assigned by looking in the the Republic of Yemen Food Security Atlas (IFPRI and MOPIC 2010) and spreading out the area evenly within each district.

Figure 2.2 Agroecological Zones in Syrian Arab Republic, Tunisia, and the Republic of Yemen

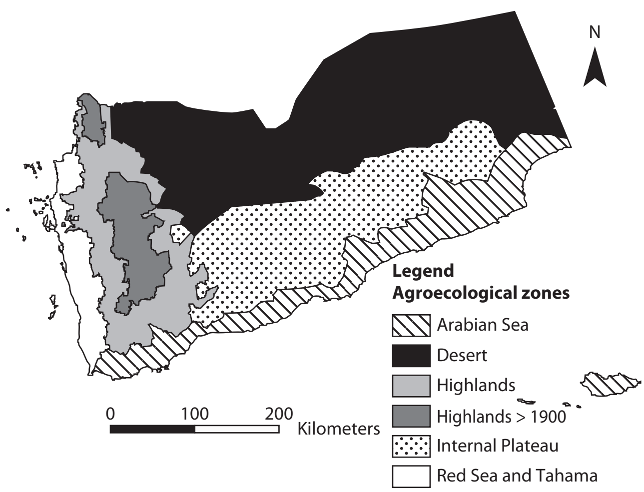
a. Syrian Arab Republic



b. Tunisia



c. The Republic of Yemen



Source: IFPRI based on FAO/IIASA 2000 and World Bank data.

In all cases, we assume that the values of all climate variables change linearly between 2000 and 2050. This assumption eliminates any random extreme events such as droughts or high rainfall periods and also assumes that the forcing effects of greenhouse gas (GHG) emissions proceed linearly; that is, we do not see a gradual increase in climate change. The effect of this assumption is to underestimate negative effects from climate variability. To address this limitation, we analyze the impacts of the most relevant climate variability events—droughts and floods—in chapter 4.

Economic Impact Assessment

Global Impacts: IFPRI IMPACT Model

The challenge of modeling climate change effects arises in the wide-ranging nature of processes involved in the working of markets, ecosystems, and human behavior. The analytical framework used in this book integrates various modeling components that range from the macro to the micro and from processes that are driven by economics to those that are essentially biophysical in nature. This section draws on Nelson et al. (2009) and gives an overview of the model, data, and assumptions.[2]

The IMPACT model is a partial equilibrium agricultural model with 32 crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes and meals, sugar, and fruits and vegetables. IMPACT has 115 country (or country-aggregate) regions, and within each region, supply, demand, and prices for agricultural commodities are determined. Large countries are further divided into major river basins; these divisions are called *food production units* (FPUs). The model links countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand relationships. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, exogenous rates of productivity growth and area expansion, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth and contains four categories of commodity demand: food, feed, biofuels feedstock, and other uses.

Modeling Climate Change in IMPACT

The effects of climate change on crop production enter into the IMPACT model by altering both crop area and yield. Yields are altered through the intrinsic yield growth coefficient (gy_{tni}) in the yield equation (2.1) as well as the water availability coefficient (WAT) for irrigated crops. These growth rates vary depending on crop, management system, and location. For most crops, the average of this rate is about 1 percent per year from effects that are not modeled; but in some countries the growth is assumed to be negative, while in others it is as high as 5 percent per year for some years.

Following is the yield equation:

$$YC_{tni} = \beta_{tni} \times (PS_{tni})^{\gamma_{iin}} \times \prod_k \left(PF_{tnk}\right)^{\gamma_{ikn}} \times (1 + gy_{tni}) - \Delta \mathrm{YC}_{tni}\,(WAT_{tni}) \qquad (2.1)$$

where β_{tni} is the yield intercept for year t, determined by yield in the previous year; PS_{tni} is the output price in year t; PF_{tni} is the input price in year t; and ε represents input and output price elasticities.

Climate change productivity effects are produced by calculating location-specific yields for each of the five crops modeled with DSSAT for the 2000 and 2050 climates as described above and converted to a growth rate that is then used to shift gy_{tni} by a constant amount. Rainfed crops react to changes in precipitation as modeled in DSSAT. For irrigated crops, changes in water availability and crop evapotranspiration potential from climate change is captured by a semi-distributed macroscale hydrological model that covers the global land mass (except Antarctica and Greenland). It conducts continuous hydrological simulations at monthly or daily time steps at a spatial resolution of 30 arc-minutes. The hydrological module simulates the rainfall-runoff process, partitioning incoming precipitation into evapotranspiration and runoff that are modulated by soil moisture content. A unique feature of the module is that it uses a probability distribution function of soil water holding capacity within a grid cell to represent spatial heterogeneity of soil properties, enabling the module to deal with the subgrid variability of soil. A temperature-reference method is used to judge whether precipitation comes as rain or snow and determines the accumulation or melting of snow in conceptual snow storage. The model parameterization was done to minimize the differences between simulated and observed runoff processes using a genetic algorithm. The effects are modeled for five years at the beginning for each of the simulations run in order to minimize any arbitrary assumption of initial conditions. Finally, simulated runoff and evapotranspiration at 30 arc-minute grid cells are aggregated to the 281 FPUs of the IMPACT model.

FPUs are large areas; for example, the India Ganges FPU is the entire length of the Ganges River in India. There can be large variations in climate and agronomic characteristics within an FPU. A major challenge was to come up with an aggregation scheme to take outputs from the crop modeling process to the IMPACT FPUs. The process we used is as follows: First, within an FPU, we choose the appropriate SPAM dataset, with a spatial resolution of 5 arc-minutes (approximately 10 kilometers at the equator) that corresponds to the crop–management combination. The physical area in the SPAM dataset is then used as the weight in order to find the weighted average yield across the FPU. This is done for each climate scenario (including the no-climate-change scenario). The ratio of the weighted average yield in 2050 to the no-climate-change yield is used to adjust the yield growth rate in equation (2.1) to reflect the effects of climate change.

In some cases, the simulated changes in yields from climate change are large and positive. This usually results from two major causes: (1) starting from a low base (which can occur in marginal production areas), and (2) unrealistically large effects from carbon dioxide fertilization. To avoid these artifacts, we place a cap on the changes in yields at 20 percent gains over the no-climate-change outcome at the pixel level.

Harvested areas in the IMPACT model are also affected by climate change. In any particular FPU, land may become more or less suitable for any crop and will impact the intrinsic area growth rate, ga_{tni}, in the area growth calculation. Water availability will affect the *WAT* factor for irrigated crop area.

Area Supply Function:

$$AC_{tni} = \alpha_{tni} \times (PS_{tni})^{\varepsilon_{iin}} \times \prod_{j \neq 1} \left(PS_{tnj}\right)^{\varepsilon_{ijn}} \times (1 + ga_{tni}) - \Delta \mathrm{AC}_{tni}(WAT_{tni}) \quad (2.2)$$

Crop calendar changes due to climate change cause two distinct issues. When the crop calendar in an FPU changes so that a crop that was grown in 2000 can no longer be grown in 2050, we implement an adjustment to ga_{tni} that will bring the harvested area to zero—or nearly so—by 2050. However, when it becomes possible to grow a crop in 2050 that could not be grown in 2000, we do not add this new area. As a result, our estimates of future production are biased downward somewhat. The effect is likely to be small, however, as new areas have other constraints on crop productivity, in particular, soil characteristics.

For future climate, we use the fourth assessment report A2 that runs using the CSIRO A1B and B1 and MIROC A1B and B1 models. At one time the A2 scenario was considered an extreme scenario, although recent findings suggest that it may not be.

Local Impacts

DCGE Model

Table 2.1 presents the equations of a simple DCGE model illustrating how changes in economic output affect employment and household incomes.[3] Producers of each commodity *c* produce a level of output *Q* by employing the factors of production *F* under constant returns to scale (exogenous productivity α) and fixed production technologies (fixed factor input shares δ) (equation [1]). The factor substitutions are assumed to be 3.0 throughout the analysis.

The DCGE model includes three main factors of production: labor, capital, and land (table 2.2). In the Syria and the Republic of Yemen models, labor is disaggregated into unskilled, semi-skilled, and skilled labor across both the private and public sectors. For Tunisia, there are three labor accounts: agricultural labor, non-agricultural labor, and family labor. There is one land factor in the Syria and the Republic of Yemen models; for Tunisia cultivated land is divided

Table 2.1 Mathematical Presentation of Dynamic Computable General Equilibrium (DCGE) Model: Core Model Equations

Production function	$Q_{ct}\ \alpha_{ct} \bullet \prod_f F_{fct}^{\delta fc}\ Q_{ct} = \alpha_{ct} \bullet \prod_f F_{fct}^{\delta fc}$		(1)
Factor payments	$W_{ft} \bullet \sum_c F_{fct} = \sum_c \delta_{fc} \bullet P_{ct} \bullet Q_{ct}$		(2)
Import supply	$P_{ct} \le E_t \bullet W_c^m \perp M_{ct} \ge 0$		(3)
Export supply	$P_{ct} \ge E_t \bullet W_c^e \perp X_{ct} \ge 0$		(4)
Household income	$Y_{ht} = \sum_{fc} \theta_{hf} \bullet W_{ft} \bullet F_{fct} + r_h \bullet E_t$		(5)
Consumtion demand	$P_{ct} \bullet D_{hct} = \beta_{hc} \bullet (1 - v_h) \bullet Y_{ht}$		(6)
Investment demand	$P_{ct} \bullet I_{ct} = \rho_c \bullet \left(\sum_h V_h \bullet Y_{ht} + E_t b\right)$		(7)
Current account balance	$W_c^m \bullet M_{ct} = W_c^e \bullet X_{ct} + \sum_h r_h + b$		(8)
Product market equilibrium	$Q_{ct} + M_{ct} = \sum_h D_{hct} + I_{ct} + X_{ct}$		(9)
Factor market equilibrium	$\sum_c F_{fct} = S_{ft}$		(10)
Land and labor expansion	$S_{ft} = S_{t-1} \bullet (1 + \varphi_f)$	*f* is land and labor	(11)
Capital accumulation	$S_{ft} = S_{t-1} \bullet (1 - \eta) + \sum_c \frac{P_{ct-1} \bullet I_{ct-1}}{k}$	*f* is capital	(12)
Technical change	$\alpha_{ct} = \alpha_{ct-1} \bullet (1 + Y_c)$		(13)

Notes:

Subscripts

- *c* Commodities or economic sectors
- *f* Factor groups (land, labor, and capital)
- *h* Household groups
- *t* Time periods

Endogenous variables

- *D* Household consumption demand quantity
- *E* Exchange (local and foreign currency units)
- *F* Factor demand quantity

Exogenous variables

- *b* Foreign savings balance (foreign currreny units)
- *r* Foreign remittances
- *s* Total factor supply
- *w* World import and export prices

Exogenous parameters

- α Production shift paramter (factor productivity)
- β Household average budget share
- γ Hicks neutral rate of technical change

Source: Thurlow 2004.

into rainfed, irrigated, and perennial land. This land cannot be reallocated across crops in response to shocks, and cropping decisions are made before the effects of climate shocks are realized. For all three models, only agricultural land use is considered. Each model assumes one capital factor; capital is assumed to be fully

Table 2.2 DCGE Model specifications

	Syrian Arab Republic	*Tunisia*	*Yemen, Rep.*
SAM	2007	2001	2009
Number of Activities	23	21	26
Number of Commodities	19	21	26
Agricultural Activities	17	11	21
Crop Activities	12	8	15
Number of Regions/ Zones covered	5	National	6
Factors of Production	9	7	9
Labor Factors	6	3	6
Land Factors	1	3	1
Livestock Factors	1	0	1
Capital Factors	1	1	1
Households	20	10	18
Dynamics	2007–50	2001–30	2009–50

Source: Syria DCGE Model, Tunisia DCGE Model, Yemen DCGE Model and World Bank data.

employed and mobile to reflect the long-term perspective of this analysis. Within the DCGE model, profit maximization implies that factor payments W are equal to average production revenues (equation [2]). Total labor, land, and capital supply (s) is fixed, implying full employment and inter-sector mobility (equation [10]). Land is assumed to be specific to each agroecological zone, creating four land factors, one for each region in the model. In the model, declining farm/factory production causes factor demand to fall, which in turn lowers economy-wide factor returns and affects production in other sectors as well. As the spatial variation in climate change impacts within countries means that such effects can vary across subnational regions, we develop economy-wide models for Syria and the Republic of Yemen disaggregated by AEZs, five for Syria and six for the Republic of Yemen (figure 2.2). Due to the lack of data available at the AEZ level, the CGE model for Tunisia is at the national level.

Foreign trade is determined by comparing domestic and world prices, where the latter are fixed under a small country assumption. The simple model implements trade as a complementarity problem. If domestic prices exceed world import prices w^m (adjusted by exchange rate E) then the quantity of imports M increases (equation [3]). Conversely, if domestic prices fall below world export prices w^e then export demand X increases (equation [4]), where the elasticity of transformation is assumed to be 4.0 for the three countries and the Armington elasticity 6.0 for all goods and services.[4] To ensure macroeconomic consistency, a flexible real exchange rate adjusts to maintain a fixed current account balance b (measured in foreign currency units) (equation [8]). Total Factor Productivity (TFP) growth determines the growth of gross domestic product (GDP), the macroeconomy and the interactions between the economy's agents of production and consumption. If a negative shock occurs, for example, if crop yields fall due to local climate change, TFP growth will be

negative. The negative growth shock is translated into reduced sectoral production, reductions in the use of factors of production, and through the model's linkages, impacts on factor income, household income, exports and imports.

Factor incomes are distributed to households using fixed income shares θ based on households' initial factor endowments and are combined with foreign remittances r adjusted by the exchange rate (equation [5]). Incomes Y are then saved (based on marginal propensities to save υ) or spent on consumption C (according to marginal budget shares β) (equation [6]). The budget shares were calculated using detailed sectoral data from national sources, including the latest Household Budget Surveys for both Syria and the Republic of Yemen. Household-income elasticities for these two countries were econometrically estimated using a semi-log inverse function suggested by King and Byerlee (1978) and based on each country's household expenditure surveys, Syria's HIES 2006/07 (SPC 2007) and the Republic of Yemen's HBS for 2005/06 (CSO 2006), respectively, for rural and urban households separately (tables D.7 and D.8) These elasticities range from 0.31 for cereals to 2.2 for transport and 1.95 for fuel, with urban household elasticities tending to be lower than their rural counterparts. Income elasticities for Tunisia were assumed to vary from 0.3 for grains to 2.2 for services.

The model differentiates among household groups in order to capture the distinctive patterns of income generation and consumption as well as the poverty and distributional impacts of climate change. In Syria, the household groups are first broadly separated by rural or urban location, after which the urban are split into metropolitan and town households and the rural households into farm and nonfarm households. Each of these household types is then further split according to their respective expenditure quintile. In Tunisia, the household groups are separated into income deciles that can be grouped into three household categories, according to their dominant source of functional income: (rural) farm households (deciles 1–3) receive more than 50 percent of their labor income from family labor and agricultural labor; in rural nonfarm households (deciles 4–6) nonagricultural labor income dominates; the upper 4 income deciles (deciles 7–10) receive no labor income (but capital and land income) from agriculture and are classified as urban households. Finally in the Republic of Yemen, the household groups are first separated regionally by AEZ and, within each AEZ, into urban and rural households. We then split rural households in each AEZ into farm and nonfarm households.

In the DCGE model, household savings and foreign capital inflows are collected in a national savings pool from which investment demand I is financed (that is, a savings-driven investment closure) (equation [7]). Finally, prices P equilibrate product markets so that demand for each commodity equals supply (equation [8]). 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 and capital allocation across

sectors and crops in response to shocks. The model therefore links production and trade to household incomes via changes in market prices, employment and factor returns. Thus if production falls, two mechanisms work together, factor income will fall as a result of reduced factor demand, at the same time supply falls leading to an increase in prices, which in turn raises consumption expenditure and in addition to reduced income from factors, reduces demand which may then reduce prices. The interaction between all the agents used in the model will eventually reach a stable equilibrium where, depending on the relationships specified, reduced output, wages, demand, and ultimately GDP may be the result.

The models' variables and parameters are calibrated to empirical data from their respective social accounting matrices (SAM) that capture the initial structure of each economy in its base year (tables D.1, D.2 and D.3). In Syria, we use a 2007 SAM—including a 2007 macro SAM developed by the National Development Planning Commission—the Household Income and Expenditure Survey for 2006/2007 (HIES 2006/07) (SPC 2007) and the National Agricultural Policy Center's (NAPC) comprehensive dataset on agricultural production, trade, and inputs. The NAPC database is used to build a new agricultural supply use table based on crop budgets by agroecological zone. These data sources have been complemented with information from FAOSTAT (FAO 2010). The Tunisia DCGE model is based on a 2001 SAM built by Chemingui (2011). Yemen DCGE model uses a 2009 SAM that was updated from the 2007 the Republic of Yemen SAM using various national and international datasets. In, all the detailed agricultural sector data relied on the 2011 Agricultural Yearbook from the Ministry of Agriculture and Irrigation and the data sources above have been complemented with the most recent data from the Government of the Republic of Yemen, the World Bank, and the United Nations Commodity Trade Statistics Database (UN Comtrade). The Social Accounting Matrices for all three countries are fully consistent with the structure of GDP at market prices:

$$\text{GDP} = \text{Private consumption } (C) + \text{Public consumption } (G) + \text{Investment } (I) + \text{Net Exports } (X\text{–}M)$$

After the calibration, the parameters are adjusted over time to reflect demographic and economic trends and then the model is re-solved for a new equilibrium each year. The model is recursive dynamic with the dynamics varying for the beginning and the end dates for each country (table 2.2). Between periods, the model is updated to reflect the exogenous rates of labor expansion φ (equation [11]). All labor force growth rates are expected to follow the average long-term trend of population growth as projected by the UN (UNPD 2010). The Syrian workforce is expected to grow at an average long-term trend of 1.5 percent growth and the Tunisian and Yemeni workforces at an average long term trend of 2 percent per year. The rate of capital accumulation is determined endogenously, with previous-period investment converted into new capital stocks using a fixed capital price κ (equation [12]). This is added

to previous capital stocks after applying a depreciation rate π. The model then captures the changes in crop yields due to local climate change impacts through their effect on total factor productivity. Yield changes from the DSSAT model enter through the production function where these crop-specific and AEZ-specific changes in productivity change the returns to factors and so alter output prices. For example, farm households can decide to employ their factors of production, such as labor, for nonfarm activities instead of growing crops and raising livestock. In response to changes in output prices, producers can substitute certain factors and inputs to react to changing relative costs of inputs. Alternatively, imported food can replace locally grown food when relative prices of locally grown food increase (and vice versa). Total factor productivity (TFP), through the production function's shift parameter α, along with the rate of technical change γ is determined exogenously and the changes in crop yields imply changes in TFP is the main driver of changes in output for the simulations conducted for this analysis. These different rates of TFP growth in the agricultural and nonagricultural sectors reflect the expected structural change under a business-as-usual scenario that is observed in all successfully transforming countries (Breisinger and Diao 2008). In, TFP growth for nonagricultural sectors is assumed to be 1 percent annually, and TFP for the agricultural sectors is assumed to grow at annual rates of 0.5 percent. As for Tunisia, TFP is assumed to grow at 1.7 percent annually for non-agricultural sectors and at 0.75 percent annually for agricultural sectors over the period 2001–30. Finally for the Republic of Yemen, TFP for nonagricultural sectors is assumed to grow at 1 percent annually, and for agricultural sectors at 0.5 percent annually.

In order to analyze in more detail the effect of drought on poverty reduction and to simulate the effect of climate change on food security, the DCGE models for Syria and the Republic of Yemen were further adapted. In Syria, the DCGE model was linked to a microsimulation model, allowing for endogenous estimation of drought impacts on poverty reduction. All the HIES sample households are included in the microsimulation model, and their total expenditure as well as their expenditure on each commodity or commodity group is linked to each of the 20 representative households included in the DCGE model according to their rural or urban location and income quintiles. For the Republic of Yemen, the DCGE model is linked to a nutrition-simulation model that allows for the endogenous estimation of climate change impacts on food insecurity, which we refer to as hunger due to the indicator chosen (see following section).

We use the DCGE models in order to design five sets of scenarios; three are common for the three countries and the other two are specific to Syria and the Republic of Yemen. The first set of scenarios captures the global impacts of climate change, the second set of scenarios assesses the local impacts of climate change, and the third set combines the two to assess the joint effects (table 2.3). For Syria we run a fourth scenario which considers the impacts of drought on

Table 2.3 Climate Change and Drought Scenarios

Scenarios	*Change in model*	*Input*
Baseline	See text	See text
1. Global impacts of climate change		
Scenario 1A	Perfect mitigation, compared to base	IMPACT, MIROC A1 B
Scenario 1B	Climate change, compared to perfect mitigation	IMPACT, MIROC A1 B
Scenario 1C	Climate change, compared to perfect mitigation (*Tunisia and Yemen, Rep.*)	IMPACT, CSIRO A1 B
2. Local impacts		
Scenario 2A	Crop yield changes	DSSAT MIROC A1 B
Scenario 2B	Crop yield changes (*Tunisia and Yemen, Rep.*)	DSSAT CSIRO A1 B
3. Joint impacts		
Scenario 3A	1B and 2A	IMPACT and DSSAT, MIROC A1 B
Scenario 3B	1C and 2B (*Tunisia and Yemen, Rep.*)	IMPACT and DSSAT, CSIRO A1 B
4. Drought impacts (Syrian Arab Republic)		
Scenario 4	Crop yields and livestock production	Palmer index and historical data
5. Flood Impacts (Yemen, Rep.)		
Scenario 5	Changes in cropland and livestock and fishery yields	DSSAT and historical data

the economy and poverty, and for the Republic of Yemen we run a scenario that analyzes the impact of floods on the economy, poverty, and food security. Under the first three scenarios, we design two subscenarios: Scenario 1A changes the world food prices consistent with the IMPACT model results under perfect mitigation; that is, it only considers global food price changes that stem from population growth and changes in dietary patterns that come with rising incomes. Perfect mitigation assumes that major climate change effects can be mitigated, a scenario that becomes increasingly unlikely given the recent outcomes of global climate negotiations. However, we chose this scenario as the reference (baseline) case, because it is the most transparent way to compare alternative futures. Choosing, for example, a reference scenario of "all countries meet their pledges," would in itself constitute a scenario with many uncertainties and assumptions. Scenario 1B explores climate change-related price effects under MIROC A1B, with the assumption that no climate change impacts are felt locally in the three countries, and scenario 1C analyzes climate change impacts (for Tunisia and the Republic of Yemen only) using IMPACT's CSIRO A1B scenario. Scenario 2 imposes the yield changes from the DSSAT model on a crop-by-crop level and by agroecological zones under the assumption that world food prices do not change; scenario 2A explores DSSAT model input using the MIROC A1B simulation for the three countries scenario 2B uses

the DSSAT's CSIRO A1B simulation for Tunisia and the Republic of Yemen only. Scenario 3 combines both the global as well as the local impacts for all three countries. Scenario 4 analyzes the impact of drought on the Syrian economy and scenario 5 explores the impact of floods on the Yemeni economy. Both scenarios 4 and 5 are also presented relative to the established baseline.

The Republic of Yemen Nutrition Model

For assessing changes in people's vulnerability to hunger as a response to changes in their income level, we use an expenditure-elasticity-based approach that captures the percentage change in per capita calorie consumption to a 1 percent change in household total expenditure (used as a proxy for household real income). The calorie consumption elasticities with respect to household expenditure are derived from a reduced-form demand model (Ecker et al. 2010). The model uses per capita calorie consumption of households as a dependent variable and total per capita expenditure (in logarithmic terms) as an independent variable and controls for structural differences between households in their gender and age composition, educational level, level of food self-sufficiency and qat consumption,[5] and regional and seasonal patterns.[6] Depending on the income level, we calculate household-specific calorie consumption elasticities. On average, a 1 percent increase in household per capita income is associated with an increase in people's per capita calorie consumption of 0.3 percent.[7]

To simulate the effects of climate change on hunger, we combine the annual real-income growth rates obtained from the DCGE model with the calorie consumption elasticities from the econometric models for each household individually. Assuming specific changes in different macroeconomic parameters under different climate change scenarios, we predict a new calorie consumption level for each household per annum, subject to the estimated annual income changes. The simulation equation is (neglecting subscripts for households):

$$\hat{y}_{i,j} = y_{i,j-1} \cdot (1+E \cdot c_{i,j}) \qquad (2.3)$$

where $\hat{y}_{i,j}$ is a household's predicted calorie consumption level under scenario i and in year j, $y_{i,j-1}$ is the calorie consumption level in the previous year, E is the household-specific calorie consumption–expenditure elasticity, and $c_{i,j}$ is the annual income change of the household the person belongs to under scenario i and in year j. A household's new calorie consumption level is then related to its individual requirement level to identify whether the household is suffering from hunger or is sufficiently supplied with dietary energy. The household-specific requirement levels are calculated based on the household's sex and age composition and the individual physiological dietary energy requirements of the household members, using standard reference levels (FAO/WHO/UNU 2001). Households with calorie consumption levels below the household-specific threshold are considered calorie deficient, or hungry. Using household size and population estimates from the 2010 revision of World Population Prospects (UNPD 2010), we calculate the prevalence rate and number of hungry people.

Drought Analysis in Syria

As in many other countries in the Middle East and North Africa, Syria experiences periodic droughts as part of its climatic system. These extreme weather events usually have long-term consequences on people and their assets. Low levels of rainfall, especially when persisting for several months or even years, are one of the major characteristics of droughts. However, the time and space variations in rainfall often make it difficult to assess and compare the severity of droughts spatially, which is important both for drought monitoring and for drafting drought impact mitigation and adaptation policies.

The Palmer Drought Severity Index (PDSI) is a comprehensive drought measure that permits the comparison of droughts across time and space (Palmer 1965). PDSI allows for the averaging of monthly PDSI values over locations for large-scale assessment. Instead of being based purely on precipitation, PDSI is based on a water balance model that takes into account precipitation, water recharge, runoff, and loss. The basis of the index is the difference between the amount of precipitation required to retain a normal water balance level and the amount of actual precipitation (Wells, Goddard, and Hayes 2004). Palmer's original PDSI was calibrated using selected weather stations in the United States (Palmer 1965). Those calibrated parameters in PDSI have since become a fixed part of the calculations of the PDSI and a standard measure, regardless of the climate in which the index is used. Wells, Goddard, and Hayes (2004) proposed an improvement of PDSI by self-calibrating parameters in PDSI according to the characteristics of the local climate. This improvement allows the index to be more consistent and predictable as well as to more realistically represent the climates of diverse locations. We used the self-calibrating PDSI in analyzing drought occurrences and severity in Syria.

In order to analyze the severity and frequency of droughts, we divide Syria into five agroecological zones that are mainly defined by rainfall. In Syria, the climate, terrain, and soil characteristics of its five major agroecological zones (figure 2.2) largely determine the farming systems. As described by FAO (2010), zone 1 receives annual average rainfall of more than 350 millimeters. It makes up 14.5 percent of Syria's land area and consists of two subzones, with the first receiving more than 600 millimeters of rainfall annually and where the yields of rainfed crops are certain for all the years. Zone 2 receives 250–350 millimeters of precipitation annually. The main crops in zone 2 are wheat, barley, and summer crops. This zone makes up 13.3 percent of the country's land area. Zone 3 receives 250 millimeters of precipitation annually, with a 50 percent chance in any year that rainfall is no less than this amount, thus ensuring production in one to two years out of every three. This zone mainly grows grain crops, but legumes are also grown here. Zone 3 makes up 7.1 percent of Syria's total area. Zone 4 is a marginal zone, receiving 200–250 millimeters of precipitation annually. Only barley can be grown in this zone, and it can be used as permanent pastures. Zone 4 makes up 9.9 percent of the total land area. Zone

5 is the steppe lands that make up 54.7 percent of the country's total area and receive less than 200 millimeters precipitation annually (UNDP and GEF 2010). The land in zone 5 is not suitable for rainfed cultivation.

A negative value of the PDSI indicates dry conditions, and a positive value indicates wet conditions. The annual drought indices discussed below are mean annual values averaged over a calendar year using monthly index values. Monthly PDSI indices are calculated for 1961–2009 for the five agroecological zones and are then averaged over calendar years to create annual drought indices for each zone for the 1960–2009 period. Threshold values are chosen for the index, allowing for the classification of the growing seasons into very severe drought years (<–3.0), drought years (–2.99 < PDSI < –1.50), near-normal years (–1.49 < PDSI < 1.49), moderately wet years (1.5 < PDSI < 2.99) and very wet years (PDSI > 3.0). The threshold values are set as described in Palmer (1965) and Wells, Goddard, and Hayes (2004). It is worth noting that the original near-normal range given by Palmer (1965) was –0.49 to 0.49.

To estimate the responses of crop yields to water deficiency during droughts, we developed a semi-empirical model to simulate soil moisture dynamics and relative crop yields, following the approach recommended in Allen et al. (1998) and Doorenbos and Kassam (1979). This approach has been widely adopted to simulate relative yields of crops growing under water stress conditions. The generic process-oriented model is designed with an agro-meteorological perspective to be used at regional scales, accounting for the development, soil water balance and yields of selected crops (Lhomme, Mougou, and Mansour 2009). Relative yields were calculated for each crop for the period 1961–2009 in each agroecological zone.

Floods in the Republic of Yemen

Results from the spatially downscaled climate projections show that temperatures are expected to rise over their baseline counterpart under both the CSIRO and the MIROC Global Climate Model (GCM) scenarios. However, the variation in temperatures over their baseline equivalents—both minimum and maximum—differs under the CSIRO and the MIROC scenarios. Under the CSIRO scenario, variations are limited for both the minimum and maximum temperatures. CSIRO monthly maximum temperatures do not rise beyond 1.7°C above baseline maximum temperatures and rise 2.3°C above baseline for the average monthly temperatures. Under the MIROC scenario, the variations are far greater for both the minimum and maximum temperatures. For nine months out of the year, the MIROC scenario predicts a more-than-2-degree rise in temperatures by 2050 in minimum temperatures over the baseline, and in May, the MIROC scenario predicts that minimum temperatures will rise over their baseline values by more than 3°C. Maximum temperatures are also expected to increase over their baseline values under the MIROC scenario. For nine months out of the year, MIROC temperature highs are expected to rise by 10°C, or more, over their baseline equivalents.

Notes

1. For the Syria analysis, the Global Historical Climatology Network (GHCN) and National Climatic Data Center (NCDC) global databases, the long-term daily meteorological data, including precipitation data and the data required to compute crop water requirement, are available for only seven weather stations. Typically, weather station–based statistical downscaling models can downscale precipitation, maximum and minimum daily temperature for future climate change scenarios to those seven stations by taking into account historical meteorological records, however, seven stations may not sufficiently represent spatial climate variations in the agroecological zones. Various data tests also uncover potential consistency issues with these data. For example, we estimated dew point temperature with daily minimum temperature in downscaled climate change scenarios. However, historical records from global weather station datasets suggest that the correlation between these two variables is not very strong, indicating that estimating dew point temperature based on minimum temperature may not be appropriate for Syria.
2. More technical details can be found in appendix A, Rosegrant et al. (2001), and Nelson et al. (2009, 2010).
3. The model description draws on Breisinger, Engelke, and Ecker (2011) and Thurlow et al. (2010).
4. The Armington elasticity is the degree of substitution between imported and domestic goods.
5. Qat is a chewable narcotic produced in the Republic of Yemen. It is very popular and is widely consumed by men, women, and children.
6. See table E.1 for the regression results.
7. The standard deviation of the elasticity is 0.148.

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CHAPTER 3

Economic Impacts of Climate Change

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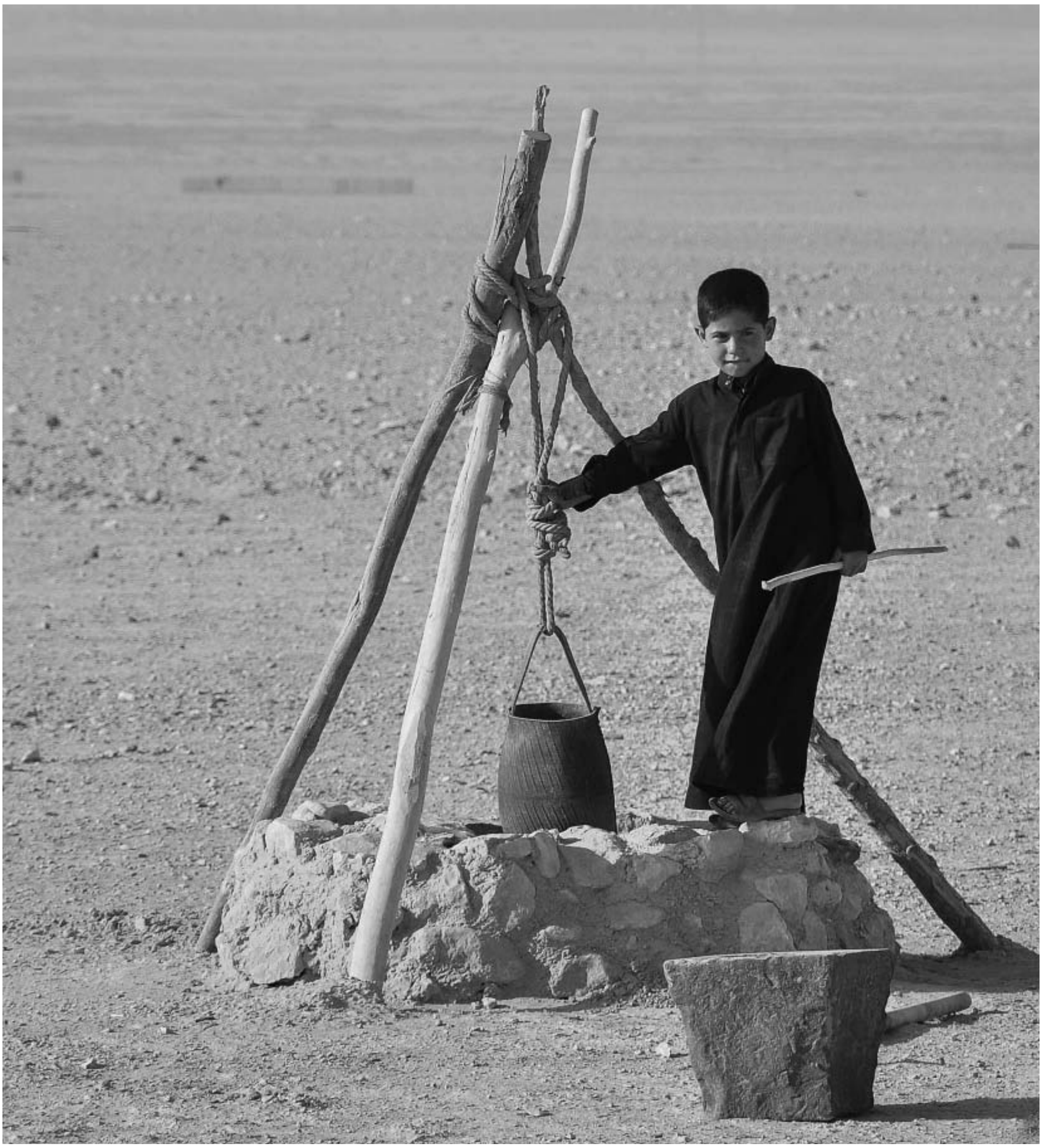


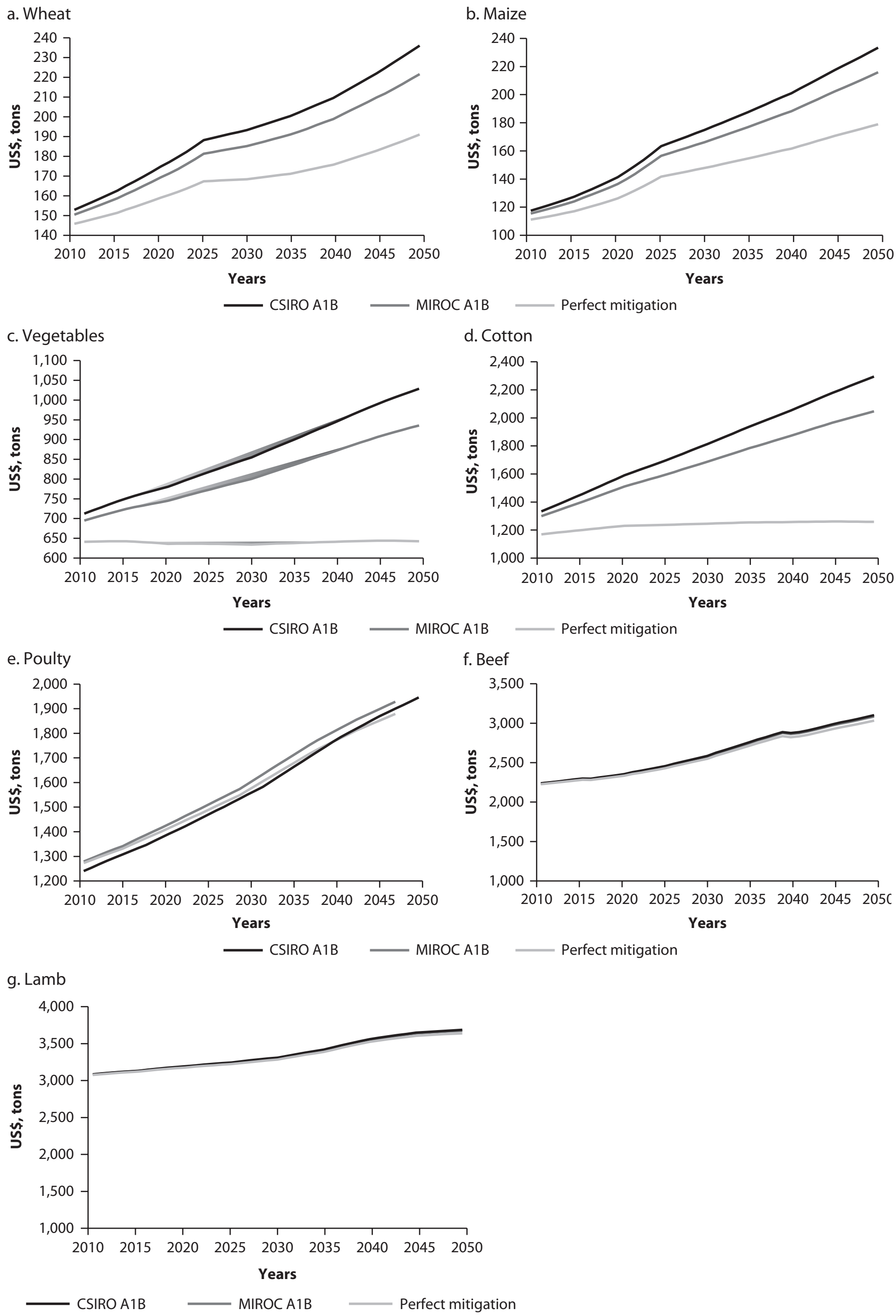
Photograph by Dorte Verner

The Syrian Arab Republic, Tunisia, and the Republic of Yemen have taken significant strides toward economic reform to accelerate growth, specifically in the fields of trade, taxes, subsidies, foreign direct investment, and the development of nonoil industries. But climate change may threaten any progress in development and pose a significant burden on economic growth and household incomes, especially for the poor, if the projected impacts are not incorporated into national planning. Climate change and extreme climate events such as droughts and floods will affect the economies of these three countries most through changes to global commodity prices and local agricultural production. But determinants of future water availability are likely to include more than climate change; there is uncertainty about the levels of future water allocation and river flows for many reasons including severe water constraints in Tunisia, droughts in Syria, and floods in the Republic of Yemen. Across all three countries, agriculture accounts for up to 90 percent of all water used,[1] and agricultural policy will be an important part of any plan. Ultimately it will be critical for all three countries to develop a comprehensive water strategy that addresses not only national water sources and uses but also regional water-sharing agreements with neighboring countries. By evaluating and quantifying projected global and local economic impacts of climate change and extreme climate events, this report provides additional information upon which to build such a strategy.

Global Climate Change Impacts

World food prices are projected to increase as a result of changes in demography and income; these increases are expected to be augmented by climate change. With no climate change, world prices for the most important agricultural crops—rice, wheat, maize, and soybeans—will increase between 2000 and 2050, driven by population and income growth and biofuels demand (figure 3.1). Even with no climate change (NoCC), the price of rice would rise by 62 percent, maize by 63 percent, soybeans by 72 percent, and wheat by 39 percent. Climate change would result in additional price increases of 32–37 percent for rice, 52–55 percent for maize, 11–14 percent for soybeans, and 94–111 percent for wheat (Nelson 2009).[2] One of the assumptions of IMPACT is that second-generation (cellulosic) biofuels will be phased in after 2025 and replace food feedstock-based biofuels, and this is reflected in the slower rates of price increases after 2025. Livestock are not directly affected by climate change in the IMPACT model; however, the effects of higher feed prices caused by climate change pass through to livestock, resulting in higher meat prices. It is from this background that we move forward with the country case studies in this report. Detailed modeling of each country is combined with these global assumptions to present a comprehensive picture of how global and local impacts will interact to affect economic and social conditions.

Figure 3.1 Global Food Price Scenarios, 2010–50



Source: IFPRI IMPACT model.

Syria

Syria has become a net importer of oil and petroleum products and of many food commodities in recent years, making the country vulnerable to global commodity price changes (tables 3.1 and 3.2). Oil has played an important part in the Syrian economy since the 1990s and still accounts for about 40 percent of government revenues, 25 percent of exports, and about 15 percent of gross domestic product (GDP) (IMF 2009a). However, the International Monetary Fund (IMF) projects that oil output will decline during the next few years, and other sectors in the economy will need to contribute to future growth (IMF 2009a). Syria is a net importer of major food items, including rice, maize, barley, soybeans, fish, and poultry. Syria remains a net exporter of olives, fruits, and vegetables.

Agricultural and related processing contributes about 19 percent to GDP, about half of which is produced in agroecological zone 1 (figure 2.2). Livestock makes up close to 6 percent of GDP, dominated by sheep production (3.1 percent). Vegetables and fruits contribute 2.5 percent and 3.0 percent to GDP, respectively, followed by cereals, with 3.3 percent. Nonirrigated cereals production is mostly concentrated in agroecological zones 1 and 2, as are

Table 3.1 Syrian Arab Republic Economy by Sector, 2007

	GDP	*Private consumption*	*Export share*	*Export intensity*	*Import share*	*Import intensity*
Wheat	2.8	0.1	0.1	1.1	0.5	7.9
Barley	0.4	—	1.1	87.1	0.6	42.1
Other cereals	0.1	1.1	0.0	0.7	2.0	72.9
Fruits	3	8.3	0.4	5.1	0.3	1.5
Vegetables	2.5	6.5	2.2	30.4	0.2	1.8
Olives	1	0.5	1.2	42.8	—	0
Cotton	1.1	—	0.0	—	—	—
Other crops	0.6	1	0.2	14	0.8	19.4
Sheep	3.1	5.1	0.0	0.5	—	0.1
Cattle	1.8	4.3	0.0	0.1	—	0.2
Camels	0.1	0	0.0	—	—	—
Poultry	0.7	3.6	0.0	—	—	0.1
Fish	0.2	0.5	0.0	—	—	—
Total Agriculture	**17.4**	**31.0**	**5.3**	—	**4.5**	—
Food processing	1.5	20.4	0.7	16.9	4.2	12.9
Manufacturing	12.9	13.1	29.8	80.3	49.7	77.2
Mining	24.5	—	30.2	42.9	27.7	87.9
Energy and water	6.2	4.8	0.0	—	—	—
Public services	11.7	0.8	0.0	—	—	—
Private services	25.7	29.7	33.9	45.8	13.8	17.8
Total Nonagriculture	**82.5**	**68.8**	**94.7**	—	**95.5**	—
Total	100	100	105	34.8	104	28.2

Source: DCGE model.

Note: Import intensities are calculated as shares of total domestic consumption (final and intermediate). Export intensities are the ratios of exports to domestic production. — = not available.

Table 3.2 Agricultural Value Added, by Zone and Crop in Syrian Arab Republic, 2007
share

	Zone 1	*Zone 2*	*Zone 3*	*Zone 4*	*Zone 5*	*Total*
Wheat	7.1	6.0	1.2	1.7	3.2	19.2
Durum	4.3	2.5	0.4	0.5	1.3	9.0
Irrigated	2.7	1.9	0.4	0.5	1.3	6.8
Nonirrigated	1.6	0.6	—	—	—	2.1
Soft	2.8	3.5	0.8	1.2	2.0	10.3
Irrigated	1.6	2.3	0.7	1.2	2.0	7.7
Nonirrigated	1.2	1.2	0.1	—	—	2.6
Barley	0.3	1.6	0.7	0.3	0.2	3.1
Irrigated	—	0.1	0.0	0.1	0.2	0.3
Nonirrigated	0.3	1.6	0.7	0.3	—	2.8
Other cereals	0.0	0.1	0.1	0.2	0.6	1.0
Fruits	17.9	4.3	1.8	0.7	0.9	25.6
Vegetables	12.5	6.8	1.6	2.1	5.3	28.3
Olives	4.9	1.9	0.4	0.3	0.5	7.9
Cotton	2.8	3.2	0.8	1.1	2.1	10.2
Other crops	2.7	1.1	0.2	0.2	0.4	4.7
Total		25.0	6.9	6.6	13.2	—

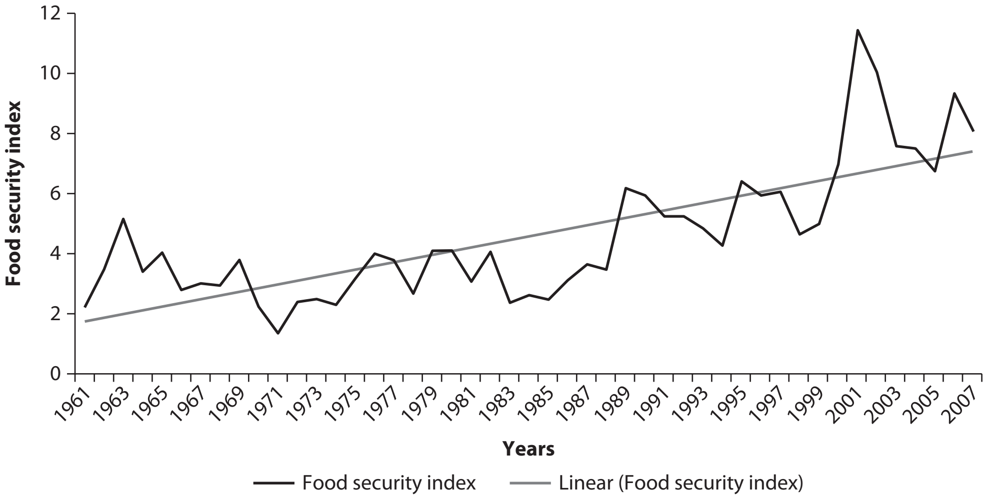
Source: Syria DCGE model.
Note: — = not available.

water-intensive crops such as fruits and vegetables. Zone 2 is the second largest contributor to GDP, followed by zones 5, 3, and 4.

Food- and agriculture-related processing make up about 50 percent of household consumption expenditure. Within this category, food processing constitutes the largest share of consumption, followed by meat, fruits, vegetables, and cereals. Energy and water constitute only 4.8 percent of total private consumption expenditures; however, rising energy prices are likely to indirectly affect household consumption. For example, higher World oil prices would raise domestic prices for fuel, which increases transport cost. Since transport is an important input in the production of many goods and services, overall price levels are expected to rise, causing real household incomes to fall.

An important dimension of development, especially in times of crisis like droughts, is food security.[3] Food security mainly depends on a country's ability to import or produce food (macro level), and on households' ability to produce or buy food (micro level). Macro-level food security can be measured as the ratio of total exports to food imports; food security does not equal food self-sufficiency since exports generate foreign exchange earnings and incomes, which help finance food imports at the macro level and food purchases at the household level (Breisinger et al. 2010; Diaz-Bonilla et al. 2002; Yu et al. 2010). A country can be food secure if it exports enough goods and services to finance food imports. However, this does not necessarily imply that all households, in all regions and income brackets, have access to sufficient food at all times.

Figure 3.2 Food Security in Syrian Arab Republic, 1961–2007



Source: World Bank data based on FAOSTAT.

Syria's food security index climbed steadily from 1961 to 2007 (figure 3.2), but lost ground during the 2008 global food crisis due to rising costs of food imports. This increase was mainly due to Syria's increase in total merchandise exports relative to its food imports, rising from an index of 2.2 in 1961 to 8.0 in 2007. Yet food security remains much lower than in neighboring Turkey and the international average (Breisinger et al. 2010).

Turkey's food security index has averaged about 30 since the 1990s, indicating that the country uses only about 4 percent of its export earnings to import food. Turkey's high levels of food security have been supported by a strong export performance and sound macroeconomic policies that have fostered growth (IMF 2005, 2010). From 2000 to 2005, Turkey had an 8 percent average annual GDP growth rate, registered the lowest inflation figures in over a generation, steadied and appreciated its lira, reduced its domestic debt, and maintained on average a steady annual increase in its agricultural value added by an average of 2 percent (IMF 2005).[4] Continuing policies of economic diversification and improving competitiveness will be important to improve food security in Syria.

Dividing households according to their location, occupation, and income quintiles allows for the analysis of income and distributional effects of climate change. The top 20 percent of households earn about 40 percent of all household income (as reported in HIES 2006/07), and the bottom quintile earns about 13 percent of all income. Broadly in line with the estimate of agricultural GDP, farm households earn about 21 percent of all household income, but there are large discrepancies among farm households. Farmers in the top quintile account for 44 percent of all income earned by farm households, but

Table 3.3 Household Income Sources by Type and Quintile, Syrian Arab Republic, 2007

	Labor				
	Skilled	*Unskilled*	*Capital*	*Land*	*Livestock*
City 1	3.3	70.0	26.7	—	—
2	6.8	61.2	32.1	—	—
3	13.2	59.3	27.5	—	—
4	19.9	40.8	39.3	—	—
5	11.3	13.1	75.6	—	—
Town 1	3.7	63.6	27.4	4.6	0.8
2	6.6	70.8	17.1	4.7	0.8
3	7.2	61.5	25.4	5.0	0.8
4	10.1	45.7	39.3	4.1	0.8
5	8.3	22.4	65.4	3.1	0.7
Rural nonfarm 1	2.0	55.4	42.6	—	—
2	4.2	46.5	49.3	—	—
3	6.3	50.8	42.8	—	—
4	6.2	44.8	49.0	—	—
5	5.1	25.6	69.4	—	—
Rural farm 1	0.9	35.1	21.7	35.3	7.0
2	1.8	34.1	21.0	36.7	6.4
3	2.1	36.8	19.3	36.2	5.5
4	3.0	39.4	13.8	37.7	6.1
5	1.4	12.8	71.1	12.8	2.0

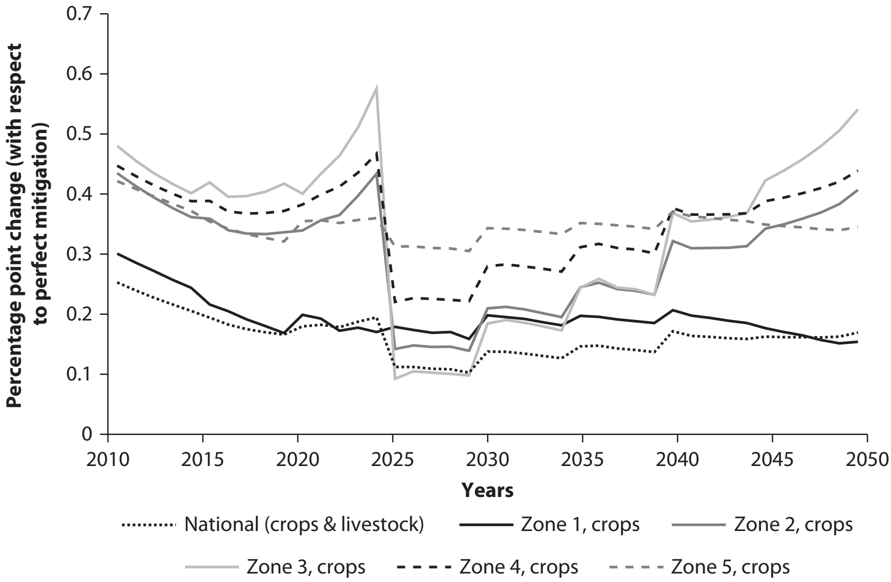
Source: Syria DCGE model.
Note: — = not available.

those in the bottom quintile earn only 13 percent of all income. As expected, household income levels are strongly related to skill levels for labor (table 3.3). Poor households earn most of their income from unskilled labor, and households in higher income quintiles rely more on skilled labor and capital earnings.

Impacts of Global Climate Change on the Economy and Households of Syria

The DCGE model for global climate change impacts, described in chapter 2, reveals that global food price increases caused by climate change may benefit the agricultural sector in Syria through higher prices, but they lead to overall negative effects on the economy as a whole. The annual average agricultural growth rate is between 0.2 and 0.4 percent higher than in the perfect mitigation scenario, but exhibits a declining trend over time (figure 3.3).[5] The positive effect on agricultural growth GDP cannot outweigh the negative effect on other sectors, which reduces the overall annual growth rate by 0.01–0.02 percent between 2010 and 2050, relative to the case of perfect global mitigation. This slower growth is mainly explained by an increase in the real exchange rate and higher costs for factors employed in the agricultural sector.

Figure 3.3 Impacts of Global Climate Change on Agricultural GDP in Syrian Arab Republic, 2010–50

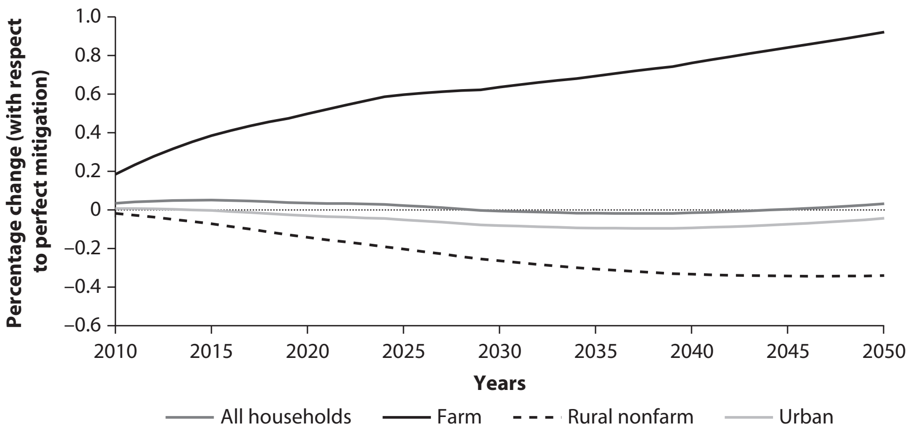


Source: Syria DCGE model.

Impacts on crop GDP growth vary by agroecological zone depending on the zone's production structure. In general, the zones that grow more crops which experience the largest world market price increases benefit the most (figure 3.3). Agricultural growth in zones 1–5 ranges between 0.1 and 0.5 percent above the perfect mitigation scenario during the entire period. Benefits to the agricultural sector accrue in two phases, a 0.1–0.6 percentage point growth rate acceleration compared to perfect mitigation until 2025, followed by a steady increase in agricultural output in most zones from 2025 to 2050.[6] The sudden change in agricultural GDP around the year 2025 underlines the importance of considering global effects on domestic agriculture. While the drop does not strongly affect the overall impact, it does show that the projected change in global biofuel policies and the expected slowing of food price rises have repercussions at the country and sector levels. Zone 5, for example, stays within the range of 0.4–0.3 percent higher than the baseline, while the zone 1 values do not rise beyond 0.3 percent higher than the baseline. The relatively low additional growth in zone 1 is explained by its high share of fruit and vegetable production, for which world market prices rise relatively less than prices of other crops. However, in absolute terms, zone 1 gains the most, given that about 50 percent of agricultural value added is produced in this zone.

Farm households benefit from higher food prices, while rural nonfarm and urban households see a decline in their real incomes. Both the rural nonfarm

Figure 3.4 Impacts of Global Climate Change on Household Income in Syrian Arab Republic



Source: Syria DCGE model.

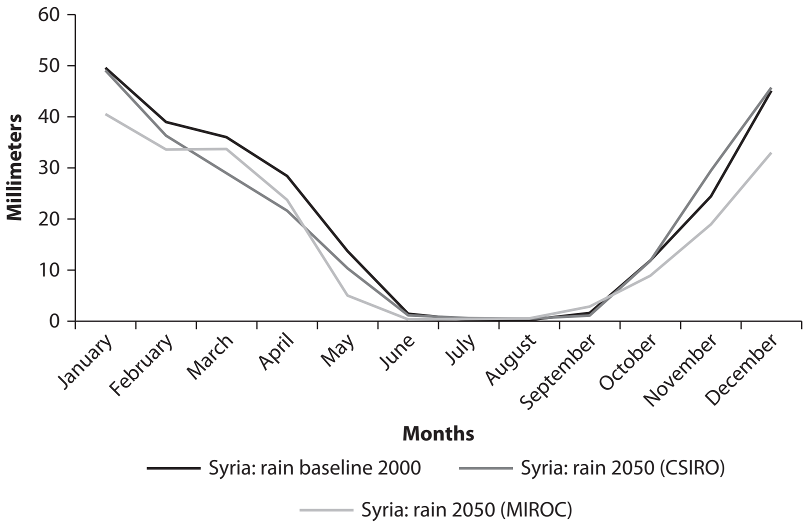
and urban households are negatively affected as a result of global climate change, with 0.01–0.4 percent lower annual incomes over time than incomes under perfect mitigation (figure 3.4). Urban households as a whole suffer from higher commodity prices, but, given that some urban households also earn income from agriculture, the overall negative effect is modest. The rural nonfarm households are hardest hit—including the Bedu population of Syria—due to their reliance on nonfarm incomes and their net food-buyer status. The only household group that benefits from the global rise in food prices is the rural farm household sector. The reduction in global agricultural yields, coupled with the fact that they are often net producers of food gives rural farm households income gains. Their real income is between 0.2 and 0.9 percent higher per year than in the perfect mitigation scenario. Overall, the benefit that accrues to rural farm households and the adverse effects on the rural nonfarm and urban sector almost balance each other out.

Climate and Yield Projections for Syria

Results from the spatially downscaled climate projections show that rainfall is expected to fall below the baseline for both the CSIRO and MIROC GCM scenarios for Syria (figure 3.5). For the first six months of the year, both GCM scenarios for precipitation fall below the 2000 baseline and for the latter three months of the year, the MIROC scenario projects lower rainfall than rainfall levels in 2000.

By 2050, both GCM scenarios project higher temperature highs over the baseline throughout the year, with the MIROC GCM scenario projecting higher temperature highs than its CSIRO counterpart (figure 3.6), as well as consistently higher average temperatures than the baseline throughout the year. The combination of higher average temperatures and lower

Figure 3.5 Projected Average Monthly Rainfall in Syrian Arab Republic, 2050

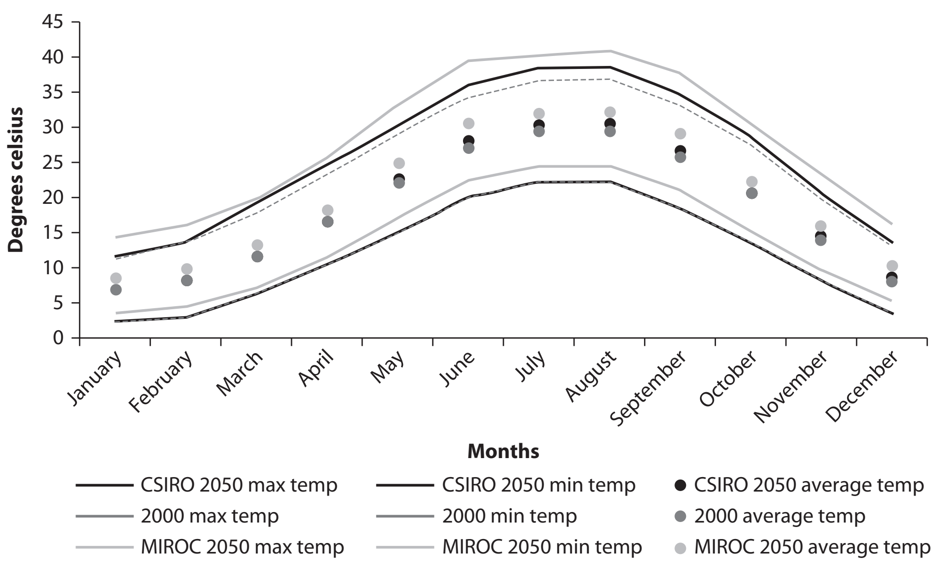


Source: Calculations based on Jones et al. 2010.

precipitation will reduce crop yields, damaging livelihoods and the economy overall.

The DSSAT crop model (described in chapter 2) projects that yields in all agroecological zones will decrease over time due to climate change (table 3.4).

Figure 3.6 Projected Average, Minimum, and Maximum Monthly Temperatures in Syrian Arab Republic, 2050



Source: Calculations based on Jones et al. 2010.

Table 3.4 Impacts of Climate Change on Yields for Selected Crops in Syrian Arab Republic by AEZ

	MIROC		
Yield change	*Annual yield change (kg)*	*Average annual yield change (%)*	*Yield change (2000–50, %)*
	Zone 1		
Wheat irrigated	−9.7	−0.8	−37.8
Wheat rainfed	−3.6	−0.6	−28.9
Maize irrigated	−0.8	0.0	−0.9
Potatoes irrigated	−14.3	−0.8	−27.3
	Zone 2		
Wheat irrigated	−4.4	−0.4	−19.7
Wheat rainfed	−3.3	−0.5	−23.5
Maize irrigated	−8.5	−0.1	−7.2
Potatoes irrigated	−9.0	−0.9	−22.7
	Zone 3		
Wheat irrigated	−2.9	−0.3	−12.6
Wheat rainfed	−7.4	−0.9	−46.4
Maize irrigated	−5.9	−0.1	−5.1
Potatoes irrigated	−14.6	−0.6	−17.7
	Zone 4		
Wheat irrigated	−3.3	−0.3	−14.4
Wheat rainfed	−6.7	−1.1	−57.2
Maize irrigated	−4.9	−0.1	−5.0
Potatoes irrigated	−29.6	−0.9	−40.0
	Zone 5		
Wheat irrigated	0.0	0.0	−0.2
Maize irrigated	−5.4	−0.1	−5.9
Potatoes irrigated	−17.1	−0.8	−29.9

Source: Calculations based on DSSAT.
Note: Results for crops with sufficient data by agroecological zones.

Yields of rainfed crops are hit the hardest, and decline between 29 and 57 percent from 2010 to 2050 compared with rates under perfect mitigation. A combination of lower rainfall and higher temperatures, in addition to changes in solar radiation, the physical and chemical characteristics of soil, and levels of fertilizer applications, explain these lower yields.

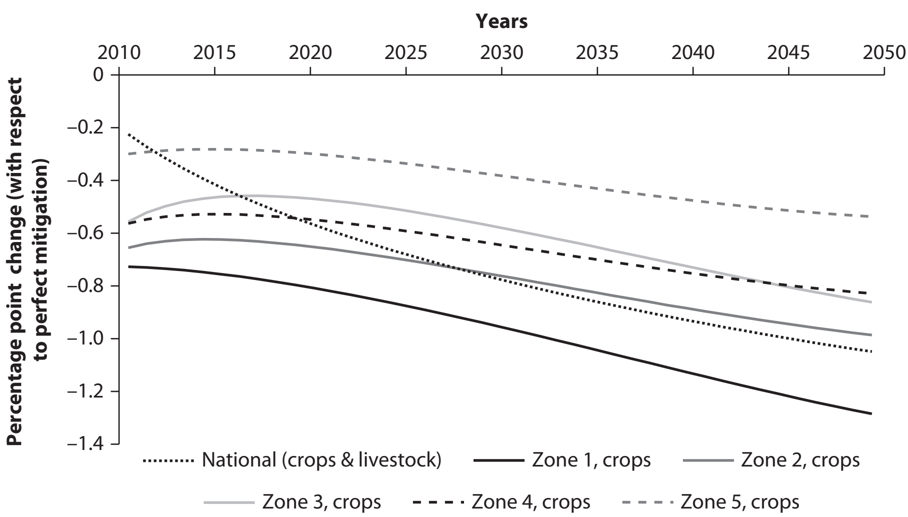
Yields for irrigated crops are also projected to fall significantly in all zones, mainly due to higher temperatures. The largest annual yield reductions for irrigated wheat occur in zones 1 and 2, which are the two most productive zones for agriculture in Syria. Reductions in annual maize yields are stable at 0.1 percent across all agroecological zones. Potato yields show the largest yield reductions across all zones relative to wheat and maize. The following section examines how these yield changes translate into changes in agricultural growth and household incomes. (For a mapping of DSSAT sectors and sectors in the CGE model, see Appendix C1.)

Impacts of Local Climate Change on the Economy and Households of Syria

Local effects of climate change reduce agricultural growth and accelerate structural change as the share of agriculture in Syria's economy decreases (figure 3.7). The decline in crop yields due to local climate variability lowers the annual agricultural GDP growth rate by 0.6 percent compared with perfect mitigation. Under perfect mitigation the agricultural sector in Syria would grow at 2.2 percent annually between 2010 and 2050, but local impacts of climate change reduce this growth rate to 1.6 percent. Over the long run, climate change accelerates structural change across the economy. Even under perfect mitigation, the share of agriculture in the economy decreases as part of the economic transformation process, but local climate change effects may accelerate this process. The model results show that the share of agricultural GDP declines from about 17 percent in 2007, to just less than 11 percent in 2030, to finally reach 7 percent by the end of the simulation period in 2050. Overall GDP decelerates under local climate change until 2030, and then in the process of structural transformation, when factors shift out of agriculture and into other sectors, starts accelerating in 2030.

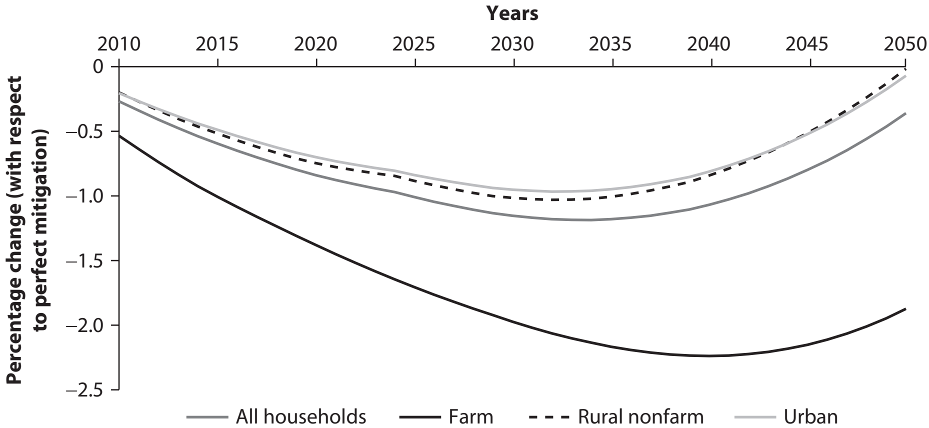
Across the five agroecological zones, crop GDP shows a long-term declining trend; however, the magnitude of change for each of the five zones differs depending on their crop mix (figure 3.7). When only local climate change is considered, the largest and steepest declines in crop GDP are in zone 1, which accounts for half of agricultural production in Syria. The least affected zone is zone 5, as it contributes only 13 percent to crop activity in Syria. Zones 1 and 2 are most affected by local climate change, both in relative and in absolute terms.

Figure 3.7 Impacts of Local Climate Change on Agricultural GDP in Syrian Arab Republic by AEZ, 2010–50



Source: Syria DCGE model.

Figure 3.8 Impacts of Local Climate Change on Household Income in Syrian Arab Republic, 2010–50



Source: Syria DCGE model.

Local climate change reduces welfare for all household groups, but households adapt to climate change over time. The hardest hit households are the farm households, whose annual income steadily declines from 0.2 to just under 3.5 percent lower than that in perfect mitigation throughout the period of study (figure 3.8). The loss of income from lower yields cannot be compensated by the higher prices they receive for their products. Agricultural price increases are also modest because the loss in domestic output is substituted by imports. Factor income for the rural nonfarm households also falls, as their income-generating potential is tied to the rural sector; with the overall decrease in wages, they too lose income. Urban households suffer the least because they earn most of their income through highly skilled labor and capital income and therefore are less affected than their lower-skilled-labor counterparts and landowners in rural areas (table 3.5). All households adapt to climate change by shifting their production factors to sectors of production that are less affected by climate change, both within and outside of agriculture.

The poorest in both rural and urban household groups suffer the most from local climate change. The poorest quintiles (lowest 20 percent) in all groups earn an average of between 1.2 and 2.8 percent less per year than under perfect mitigation, compared with a lower decline of between 1.3 and 1.8 percent for the richest household groups (table 3.5). The poorest among the nonfarm rural households group are the hardest hit among all groups, with an average annual income loss of 2.8 percent compared with perfect mitigation. Given that rural nonfarm households have an initial income of LS 209,000 per year, these households would lose an average of about LS 5,824 of income due to climate change (a 2.8 percent decline). While this annual decline may seem small, it is significant when accumulated over 40 years. In addition, this simulation

Table 3.5 Impacts of Local and Global Climate Change on Income Distribution in Syrian Arab Republic, 2010–50

	Average household income (thousand LS)	*Per capita income (thousand LS)*	*Average annual change, 2010–50 (%)*		
Households by quintiles	*2007*	*2007*	*Global climate change*	*Local climate change*	*Combined climate change*
Urban 1	199	28	0.1	−1.3	−2.3
2	222	37	0.1	−1.1	−2.0
3	236	44	0.1	−1.1	−1.9
4	294	63	0.0	−0.8	−1.7
5	563	160	−0.3	−0.1	−1.3
Rural Nonfarm 1	209	27	−0.2	−1.2	−2.8
2	277	40	−0.2	−0.9	−2.4
3	262	44	−0.2	−0.9	−2.3
4	337	62	−0.2	−0.8	−2.3
5	510	116	−0.3	−0.3	−1.7
Rural Farm 1	293	36	1.1	−2.8	−2.3
2	337	45	1.2	−2.7	−2.0
3	379	55	1.2	−2.6	−2.0
4	369	66	1.3	−2.9	−2.1
5	1,050	204	0.0	−0.7	−1.8

Source: Syria DCGE model.

assumes an optimistic scenario in which people can freely adapt to a changing climate by switching crop patterns and moving from agriculture into other sectors of the economy (see chapter 2).

Combined Impacts of Global and Local Climate Change on the Economy and Households of Syria

Considering the combined global and local effects of climate change shows that the two compound each other. Economic growth is on average 0.05 percentage points lower each year compared with perfect mitigation between 2010 and 2030. The economy adapts to climate change over time but never reaches the levels of the perfect mitigation scenario. Climate change speeds up structural change in the economy, as the share of agriculture declines to 8.3 percent in 2050, compared with 9 percent under perfect mitigation (table 3.6). Consequently, the industrial and services sectors gain in relative importance, moving from 45.2 and 37.5 percent of GDP, respectively, to 45.3 and 46.4 percent under the combined scenario by the end of the period.

Agricultural output declines with increasing speed over time under the combined climate change scenario (figure 3.9). While the impact of global climate change in isolation has positive impacts on agricultural production, when the negative impacts on agricultural GDP from local climate change are factored in, the agricultural growth rate is between 0.2 and 0.4 percentage points lower than under perfect mitigation. The overall reduction in yields due to the local impacts of climate change translates into higher domestic

Table 3.6 Impacts of Local and Global Climate Change on the Structure of the Economy in Syrian Arab Republic
percent of GDP

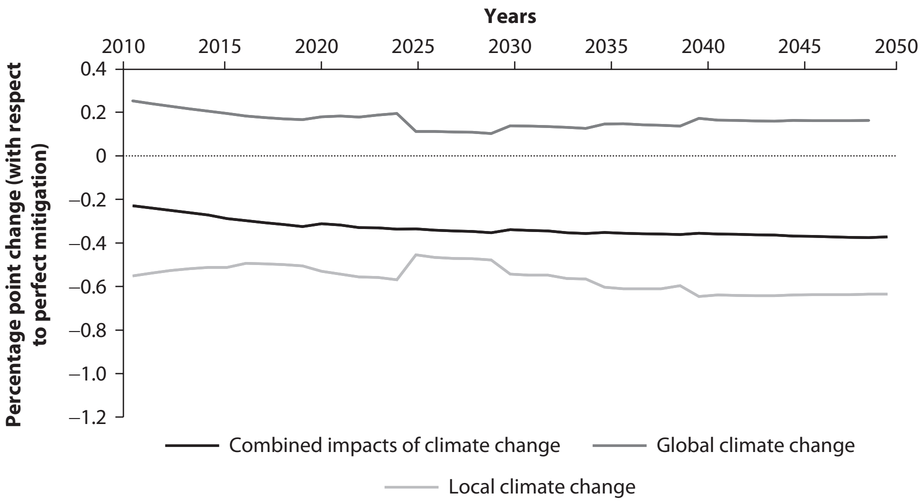
	Initial	*2030*	*2050*
Perfect mitigation			
Agriculture	17.3	11.7	9.0
Industry	45.2	45.1	44.8
Services	37.5	43.2	46.2
Global			
Agriculture	17.3	12.5	10.2
Industry	45.2	44.5	43.9
Services	37.5	42.9	45.9
Local			
Agriculture	17.3	10.6	7.3
Industry	45.2	45.8	46.1
Services	37.5	43.6	46.6
Combined			
Agriculture	17.3	11.3	8.3
Industry	45.2	45.3	45.3
Services	37.5	43.3	46.4

Source: Syria DCGE model.

agricultural prices and also into an increase in imports. Higher domestic prices reduce competiveness on the world market and thus also affect Syria's exports of agricultural crops. However, this latter effect is reduced when global climate change is factored in and globally higher crop prices provide a boost to the agricultural sector and improve agricultural export performance, leading to faster growth of the agricultural sector (compared with perfect mitigation). When these two opposite impacts are combined, agricultural GDP declines from 0.2 to 0.4 percentage points below perfect mitigation outcomes over the entire period. The decline accelerates over time, indicating that if no climate change adaptation action is taken, agriculture is likely to continue to suffer after 2050.

The combined effect of global and local climate change has detrimental effects on agricultural GDP across all zones, with the largest declines occurring in zones 1 and 2, which together account for three-quarters of agricultural production in Syria (figure 3.10). Despite the positive impacts that global climate change may provide to the Syrian agricultural sector due to the increased price of agricultural produce, the reduced local agricultural yields hurts output across all zones. In zones 1 to 4, growth rates of agricultural GDP growth are between 0.2 and 0.9 percentage points lower than the baseline, with the sharpest declines occurring in zones 1 and 2. Zone 5 is the least affected in terms of reduction in crop output, largely because of the absence of rainfed agriculture. However, if we factor in potential impacts on livestock (which was not possible in this report), zone 5 is likely to suffer losses in agricultural output, too.

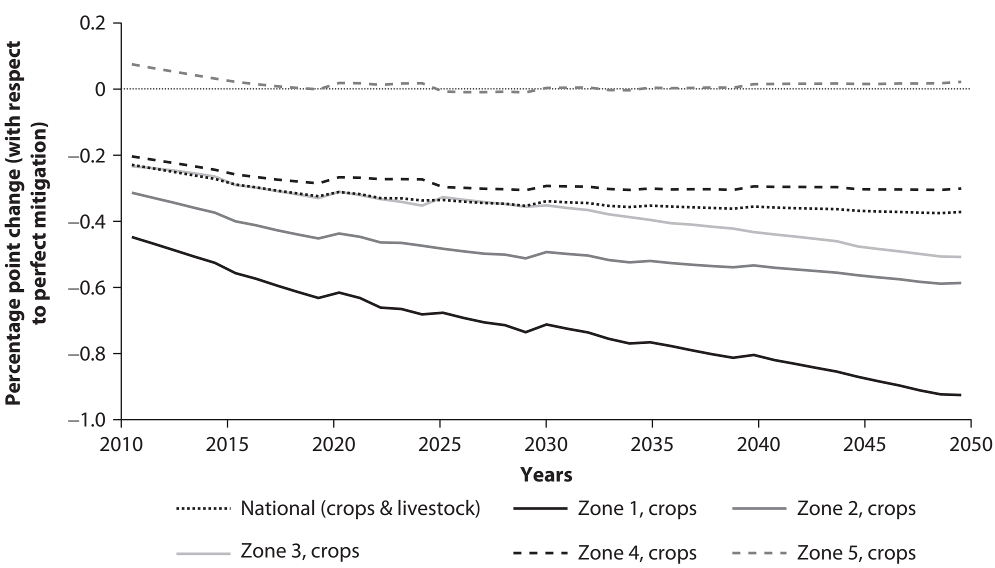
Figure 3.9 Impacts of Global and Local Climate Change on Agricultural GDP in Syrian Arab Republic, 2010–50



Source: DCGE model.

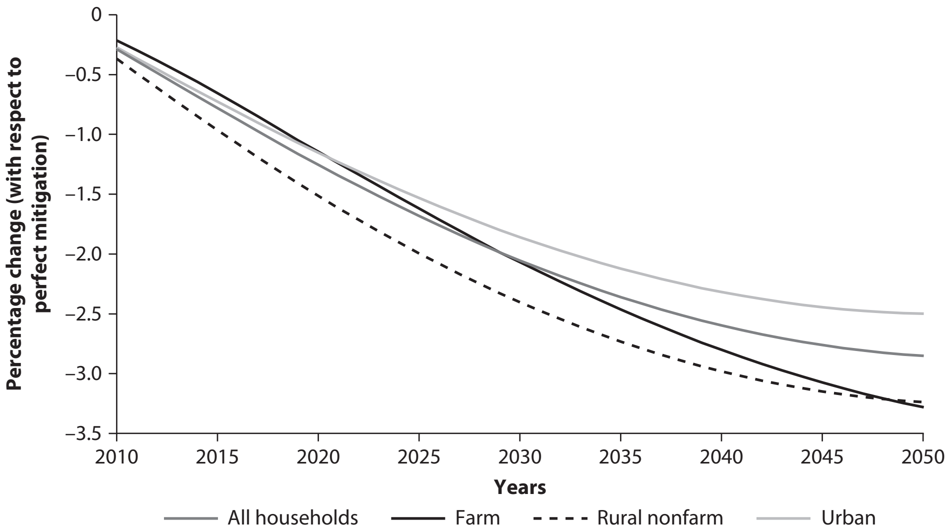
The combined global and local impacts of climate change lead to sharp declines in household welfare. The magnitude of these combined losses is far greater than when only local climate change impacts were modeled. There are two main effects of combining local and global impacts: an income effect and a

Figure 3.10 Impacts of Combined Local and Global Climate Change on Agricultural GDP in Syrian Arab Republic by AEZ, 2010–50



Source: Syria DCGE model.

Figure 3.11 Impacts of Combined Local and Global Climate Change on Household Income in Syrian Arab Republic, 2010–50



Source: Syria DCGE model.

price effect. Despite the fact that under a global climate change scenario farmers benefit from higher incomes generated by higher agricultural prices, when local yields decline due to local climate change, farmers are unable to increase their production and thus fail to benefit from this income potential. Additionally, if households need to increase their consumption of imported goods due to lower local yields, they will end up paying more for their food basket. Real income of rural farmers decreases by up to 3.2 percent compared with perfect mitigation (figure 3.11). As for rural nonfarm households, their real income falls by up to 3.2 percent compared to the baseline by 2050 as a result of being net food consumers who have to contend with their rising expenditure on food.

Overall, the poorest segments of the population are hardest hit under both local and global climate change (figure 3.5). Among rural and urban groups, the 20 percent lowest income groups lose most in relative terms, while the negative effect is less for wealthier people. The poorest 20 percent of rural nonfarm households are the hardest hit of any group when local and global impacts of climate change are combined, with an average annual decrease in income of 2.8 percent compared with the baseline. The poorest suffer most mainly due to the joint effect of being net food buyers, who spend a high share of their income on food, and of earning incomes from factors of production most affected by climate change, namely, land and unskilled labor.

These results suggest that climate change will negatively affect the economy and households of Syria, despite optimistic assumptions about the capabilities of households to adapt to climate change in the long run. It is also important to

note that specific household groups such as the Bedu and specific subregions of Syria, such as Badia are likely to be hit harder than the aggregate picture shown here suggests. In addition, the model may underestimate the emerging water scarcity and related negative effects on agriculture. The impacts of droughts, analyzed in chapter 4, are likely to compound the negative long-term effects already discussed.

Tunisia

Agriculture is an important part of the Tunisian economy, accounting for 12–16 percent of the GDP, depending on the size of the harvest. The sector provided jobs for 22 percent of the country's labor force in 1998. The two most important export crops are cereals and olive oil, with almost half of all the cultivated land used for cereals production and another third planted with olive trees. Tunisia is one of the world's biggest producers and exporters of olive oil, and it also exports dates and citrus fruits. Tunisia remains one of the few Arab countries that produces most of the dairy products, vegetables, fruit, and red meat consumed domestically (table 3.7). Since the 1980s, agricultural output has increased by about 40 percent, and exports of food have risen significantly.

Tunisia is a net importer of major food items, including cereals, forage crops, and processed food. Overall agriculture's trade orientation is very low and uneven, with imports accounting for more than 15 percent of total domestic consumption, and exports accounting for less than 5 percent of domestic production. Agriculture and related processing contribute about 17 percent to GDP. Food and agriculture-related processing make up about 30 percent of household consumption expenditures. Within this category, food processing constitutes the largest share of consumption, followed by fruits and vegetables (table 3.7).

Tunisia's labor-intensive agricultural sector uses very low levels of fertilizers and pesticides. Most of the land is split into small farms making production much less efficient than large-scale farming. Some 80 percent of farms are smaller than 20 hectares, and only 3 percent are larger than 50 hectares.

Tunisia is water poor. Rainfall is scarce as well as spatially and temporally variable (Mougou et al. 2002). Combined with high temperatures, water scarcity makes rainfed agriculture difficult and unpredictable. This affects cereal production most acutely as most cereal production in Tunisia is rainfed. Severe droughts, like the one experienced in 2000, have also proven to be enormously costly.

Farm households, which make up 30 percent of Tunisia's total population, earn about 9 percent of all household income, while the population and income shares are 30 and 19 percent for rural non-farm households and 40 and 70 percent for urban households (tables 3.8 and 3.9). Farm households receive most of their income from family and agricultural labor (each about 30 percent), while urban and rural non-farm households rely on nonagricultural labor and capital.

Table 3.7 Tunisian Economy by Sector, 2001

	GDP share	*Private consumption share*	*Export share*	*Export intensity*	*Import share*	*Import intensity*
Wheat	1.2	0.1	0.1	3.7	1.9	47.5
Other cereals	0.2	0.1	—	—	2.1	87.8
Legumes	0.4	0.3	—	—	0.1	8.3
Forage crops	0.2	0.0	0.0	3.6	0.6	67.7
Olives	0.8	0.0	—	—	—	—
Other fruits	2.7	3.8	1.1	13.3	0.1	1.5
Vegetables	2.4	3.5	—	—	0.2	2.5
Other agriculture	0.1	0.1	0.1	16.9	0.1	32.8
Livestock	4.2	1.6	—	—	0.1	1.5
Forestry	0.3	0.3	—	—	0.0	7.4
Fishing	1.1	1.6	0.2	4.9	0.2	5.6
Total agriculture	**13.4**	**11.3**	**1.5**	**3.5**	**5.4**	**16.4**
Meat	0.3	4.9	—	—	—	—
Milk and its products	0.6	2.1	—	—	0.2	9.5
Flour milling and its products	0.8	4.1	0.4	3.9	0.2	2.7
Oils	0.4	1.1	1.7	36.2	1.1	35.7
Canned food products	0.2	0.8	1.1	33.6	0.1	10.7
Sugar and its products	0.3	1.4	0.1	2.8	0.7	32.1
Other food products	0.5	4.9	0.7	5.8	0.8	12.1
Beverages	0.6	1.2	0.3	4.8	0.3	9.2
Other industries	29.7	33.2	79.8	35.3	85.6	46.2
Services	53.3	35.0	14.5	9.9	5.8	5.5
Total nonagriculture	**86.6**	**88.7**	**98.5**	**23.0**	**94.6**	**29.7**
Total			**100.0**	**21.2**	**100.0**	**28.4**

Source: Tunisia DCGE model.
Note: Import intensities are calculated as shares of total domestic consumption (final and intermediate). Export intensities are the ratios of exports to domestic production. Shares are calculated based on the social accounting matrix for 2001. — = not available.

Impacts of Global and Local Climate Change on the Economy of Tunisia

Results of the CGE modeling for Tunisia show that the economy-wide impacts of climate change on the Tunisian economy are negative; the estimates, however, vary significantly depending upon which GCM scenario is considered and whether or not climate change is global or local.[7] Global climate change creates modest total losses in GDP of US$2-3 billion over the projection period of 30 years,[8] compared to the baseline of perfect mitigation (figure 3.12). Given that higher global food prices can benefit exporters of agricultural goods and thus raise agricultural GDP, the combined effects of climate change cost the Tunisian economy US$2–2.6 billion. As Tunisia is also reliant on food imports, global food price increases outweigh the tiny benefits from higher export prices and so generate the greatest losses in the economy.

The economy-wide losses are mainly driven by the impacts of climate change on agriculture. Results of the DCGE model show that climate change related global food price increases may have a slightly positive effect on the agricultural sector through higher returns to production factors. Agriculture benefits from

Table 3.8 Household Income Sources by Income Type and Household Category in Tunisia, 2001
million Tunisian dinars

Households	*Agricultural labor*	*Family labor*	*Non-agricultural labor*	*Capital*	*Rainfed land*	*Irrigated land*	*Perennial land*	*Enterprises*	*ROW*	*Total*	*Population*	*Per-capita income*
Decile1	97	250	111.7	8.1	0.1	0.2	0.2	0.1	7.1	475	945,600	502
Decile2	121.2	194.9	220.9	91.7	1.3	1.9	2.7	1.1	95.6	731	945,600	773
Decile3	143.4	151.4	321.5	168.6	2.4	3.5	5	2.1	165.5	963	945,600	1019
Decile4	119.1	157.8	438.0	257.8	3.6	5.4	7.6	3.2	238.2	1231	945,600	1302
Decile5	—	120.3	554.6	347.0	4.9	7.3	10.2	4.3	450.8	1499	945,600	1586
Decile6	—	79.3	904.3	769.2	10.8	16.1	22.6	9.6	26.0	1838	945,600	1944
Decile7	—	—	1083.3	906.2	12.8	19	26.6	11.3	226.3	2286	945,600	2417
Decile8	—	—	1315.2	1083.6	15.3	22.7	31.8	13.5	335.7	2818	945,600	2980
Decile9	—	—	1789.4	1446.4	20.4	30.3	42.5	18	579.7	3927	945,600	4153
Decile10	—	—	3369.8	2655.8	27.4	65.4	77.9	33.1	1388.2	7618	945,600	8056
Farm	361.6	596.3	654.1	268.4	3.8	5.6	7.9	3.3	268.2	2169	2,836,800	765
Non-farm	119.1	357.4	1896.9	1374.0	19.3	28.8	40.4	17.1	715.0	4568	2,836,800	1610
Urban	—	—	7557.7	6092.0	75.9	137.4	178.8	75.9	2529.9	16648	3,782,400	4401
Total rural	480.7	953.7	2551.0	1642.4	23.1	34.4	48.3	20.4	983.2	6737	5,673,600	1188
Total	480.7	953.7	10108.7	7734.4	99	171.8	227.1	96.3	3513.1	23385	9,456,000	2473

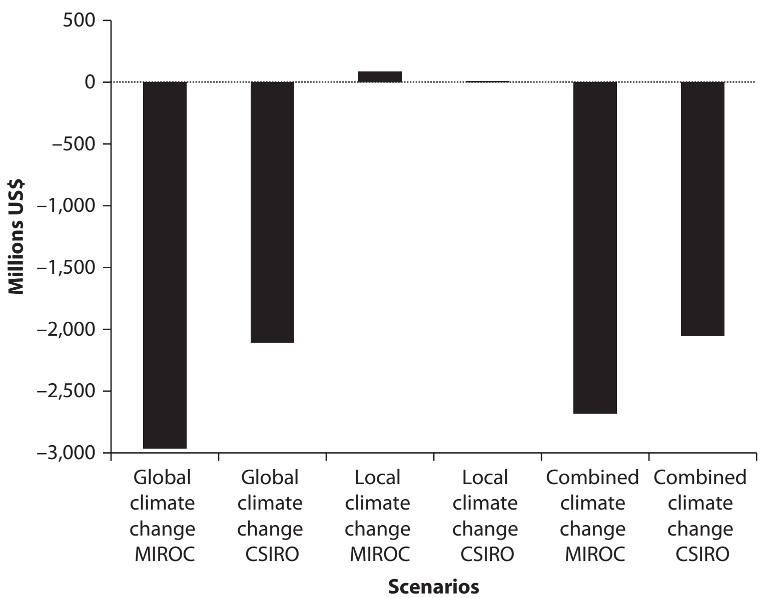
Source: Tunisia DCGE model.
Note: ROW = Rest of the World; — = not available.

Table 3.9 Household Income Sources by Income Type and Household Category in Tunisia, 2001
percent

Households	*Agricultural labor*	*Family labor*	*Non-agricultural labor*	*Capital*	*Rain-fed land*	*Irrigated land*	*Perennial land*	*Enterprises*	*ROW*
Decile1	20.4	52.7	23.5	1.7	0.02	0.04	0.04	0.02	1.5
Decile2	16.6	26.7	30.2	12.5	0.18	0.26	0.37	0.15	13.1
Decile3	14.9	15.7	33.4	17.5	0.25	0.36	0.52	0.22	17.2
Decile4	9.7	12.8	35.6	20.9	0.29	0.44	0.62	0.26	19.4
Decile5	—	8.0	37.0	23.1	0.33	0.49	0.68	0.29	30.1
Decile6	—	4.3	49.2	41.9	0.59	0.88	1.23	0.52	1.4
Decile7	—	—	47.4	39.6	0.56	0.83	1.16	0.49	9.9
Decile8	—	—	46.7	38.5	0.54	0.81	1.13	0.48	11.9
Decile9	—	—	45.6	36.8	0.52	0.77	1.08	0.46	14.8
Decile10	—	—	44.2	34.9	0.36	0.86	1.02	0.43	18.2
Farm	16.7	27.5	30.2	12.4	0.18	0.26	0.36	0.15	12.4
Nonfarm	2.6	7.8	41.5	30.1	0.42	0.63	0.88	0.37	15.7
Urban	—	—	45.4	36.6	0.46	0.83	1.07	0.46	15.2
Total rural	7.1	14.2	37.9	24.4	0.34	0.51	0.72	0.30	14.6
Total	2.1	4.1	43.2	33.1	0.42	0.73	0.97	0.41	15.0

Source: Tunisia DCGE model.
Note: ROW = Rest of the World; — = not available.

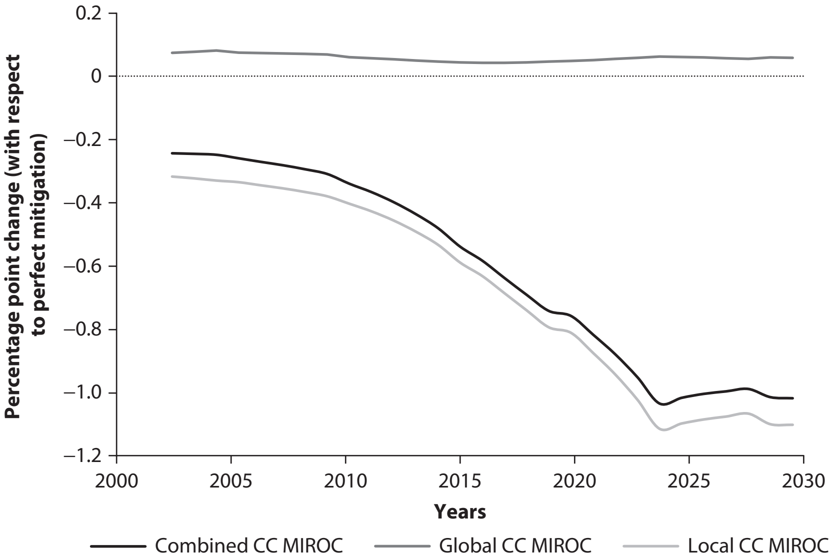
Figure 3.12 Economy-Wide Losses of GDP in Tunisia Compared to Perfect Mitigation



Source: Tunisia DCGE model.

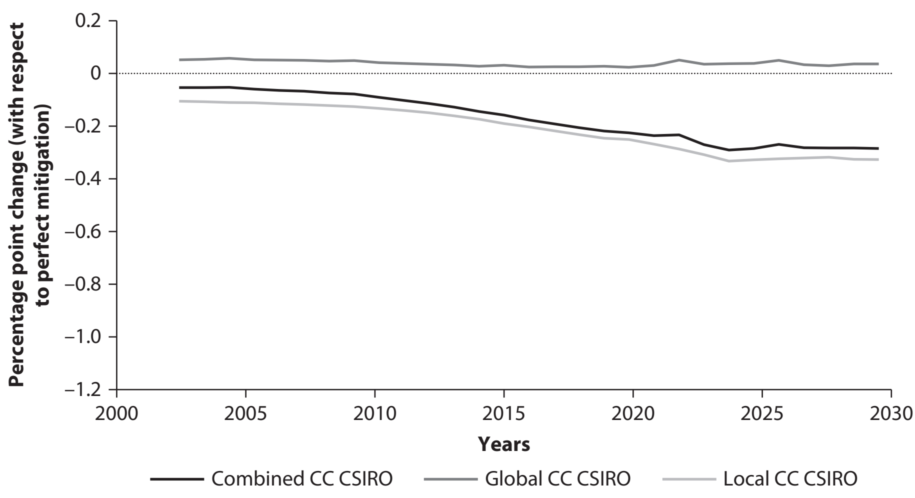
the price increases, as they attract additional capital and labor, and thereby increase production. Compared with perfect mitigation, the annual average agricultural growth rate is 0.1 percentage points higher across both GCM scenarios (figures 3.13 and 3.14). However, when local climate change is factored

Figure 3.13 Climate Change Impacts with MIROC Scenario on Agricultural GDP, Tunisia



Source: Tunisia DCGE model.
Note: The Tunisia DCGE Model runs from 2001 to 2030.

Figure 3.14 Climate Change Impacts with CSIRO Scenario on Agricultural GDP, Tunisia



Source: Tunisia DCGE Model.
Note: The Tunisia DCGE Model runs from 2001 to 2030.

in, these relatively small positive effects are outweighed by the strong negative effects of reduced yields.

Results from the Tunisia DCGE model show that agricultural growth may drop between 0.3 and 1.1 percentage points annually by the end of the

study period. During the initial years, the losses are more severe and agricultural growth recovers over time as the model contains some endogenous mechanisms for climate change adaptation. For instance, people can freely adapt to a changing climate by switching crop patterns and moving out of agriculture and into other sectors of the economy that have development potential.

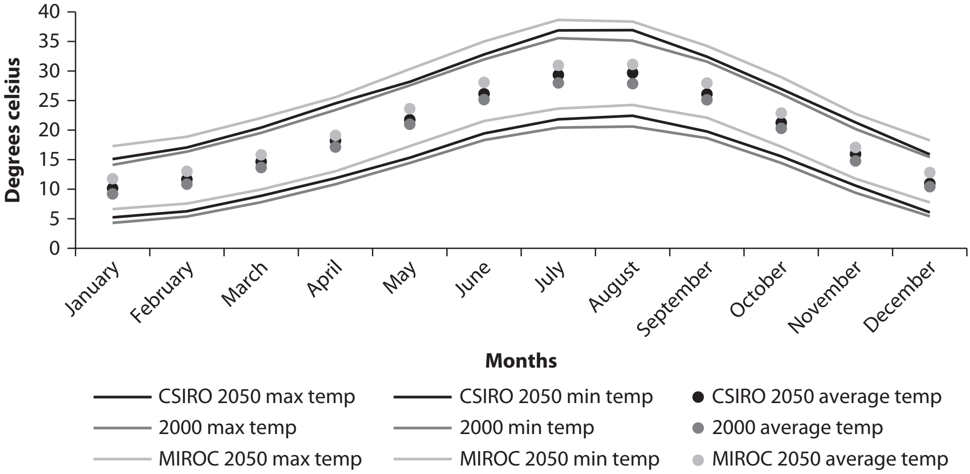
Combining the local and global effects shows that the slightly positive effects of higher World market prices on agriculture do not cushion the large negative effects of lower yields enough. The overall effect of climate change on agriculture is negative, where despite the losses being slightly less than the losses to the sector under local climate change impacts alone, agricultural GDP still falls between 0.1 and 1 percentage points annually by 2030 for the CSIRO and MIROC scenarios, respectively. The overall impact on agricultural GDP due to global climate change impacts does not differ among the two GCM scenarios. The difference appears when considering the local impact of climate change on the agricultural sector. The negative effects are amplified under that scenario mainly due to the reduced crop yields.

Climate and Yield Projections for Tunisia

Results from the spatially downscaled climate projections show that temperatures are expected to rise compared to the baseline under both the CSIRO and the MIROC Global Climate Model (GCM) scenarios. However, the variation in temperatures over their baseline equivalents differs under the CSIRO and the MIROC scenarios (figure 3.15). In August, the MIROC monthly maximum temperatures rise 3.4°C above the baseline maximum temperatures for that month and rise 3.1°C above the baseline for the average monthly temperatures in July. Under the MIROC scenario, the variations are far greater for both the minimum and maximum temperatures. Over the course of the year, the MIROC scenario projects a more than 2.2°C rise in temperatures by 2050 in minimum temperatures over the baseline, and from June to September, the MIROC scenario projects that minimum temperatures will rise over their baseline values by more than 3.2°C. Maximum temperatures are also expected to increase over their baseline values under the MIROC scenario. For the entire year, the MIROC maximum temperatures rise by more than 2°C and for four months out of the year, MIROC temperature highs are expected to rise more than 3°C over their baseline equivalents.

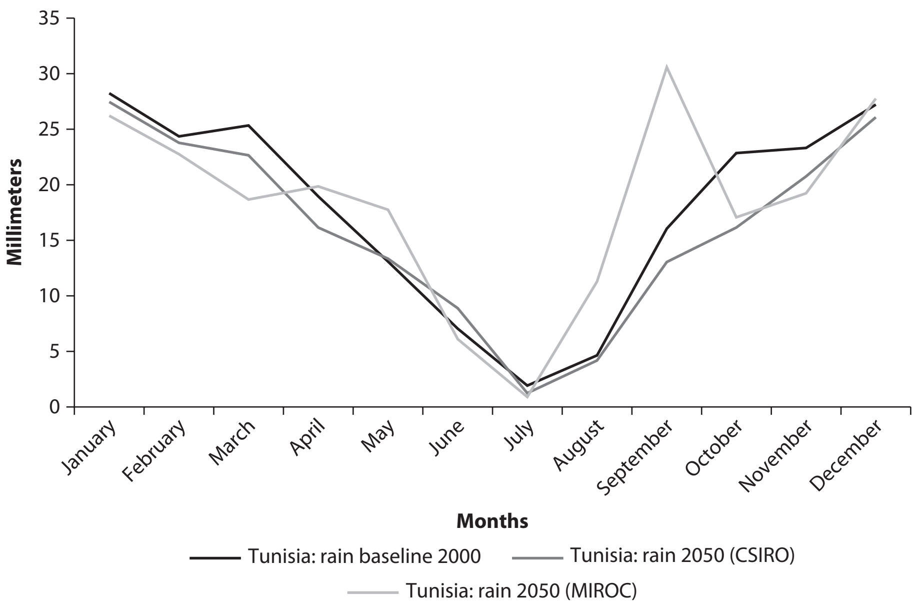
Variation in average monthly rainfall across Tunisia, as projected by the CSIRO and MIROC GCM scenarios, is relatively higher only for the latter scenario (see figure 3.16). Average monthly rainfall in the CSIRO scenario roughly follows the baseline except from September to November where it falls slightly below. However, the MIROC scenario projects an *increase* in rainfall from June to October across Tunisia. From October to December, rainfall under the MIROC scenario is slightly below that projected under the baseline.

Figure 3.15 Projected Average, Minimum, and Maximum Monthly Temperatures in Tunisia, 2050



Source: Calculations based on Jones et al. 2010.

Figure 3.16 Projected Average Monthly Rainfall in Tunisia, 2050



Source: Calculations based on Jones et al. 2010.

Yield changes over time due to climate change are projected to vary strongly across the three crops studied (wheat, barley, and potatoes).[9] Driven mainly by diverging rainfall patterns, projected yield changes for wheat and potatoes differ substantially between the MIROC and CSIRO scenarios (table 3.10). Wheat

Table 3.10 Average Annual Yield Changes for Selected Crops in Tunisia, 2000–50

	MIROC (% yield changes)		*CSIRO (% yield changes)*	
Crop	*Irrigated*	*Rainfed*	*Irrigated*	*Rainfed*
Wheat	−0.17	−0.18	−0.03	−0.11
Barley	n.a.	−0.10	n.a.	−0.12
Potato	−0.04	0.20	−0.02	0.05

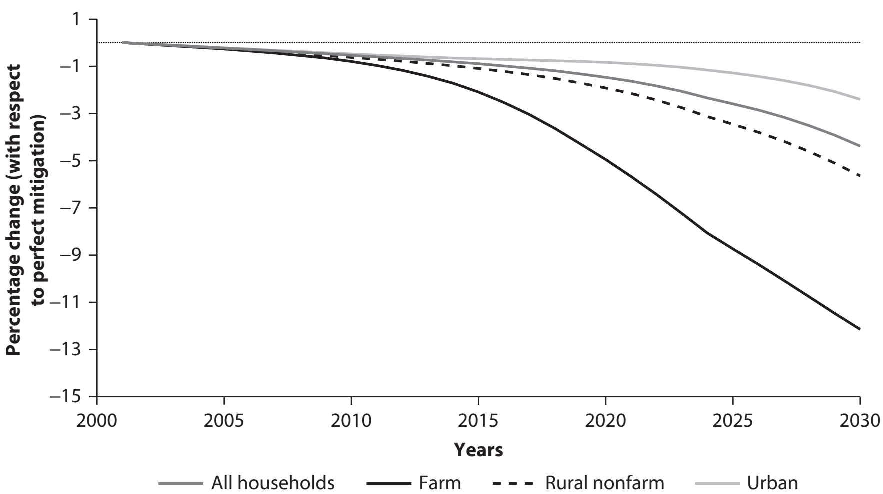
Source: Calculations based on DSSAT.
Note: n.a. = not applicable.

and barley yields drop under both GCM scenarios, with average annual wheat yields falling more under the MIROC scenario than under the CSIRO for both irrigated and rainfed wheat. Rainfed potatoes fare better under the wetter MIROC scenario, but the average annual yield for irrigated potatoes is lower under MIROC. In the absence of more specific information, and consistent with the literature, we assume that other agricultural crops such as fruits and olives would also experience declines in yields.

Impacts of Global and Local Climate Change on Households in Tunisia

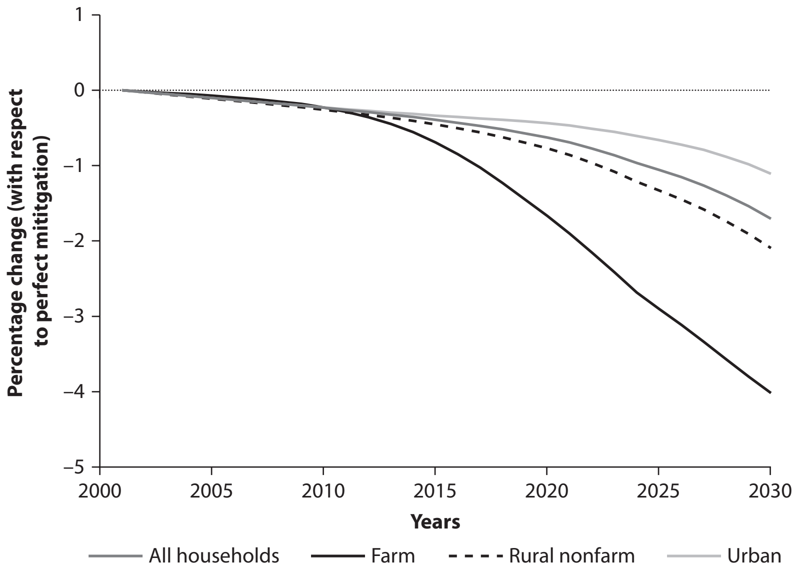
Local climate change is welfare reducing for all household groups under both GCM scenarios, but the effects are greater under the MIROC scenario and for farm households (figure 3.17). Households are affected through two major channels: farm households see their incomes fall due to lower agricultural activity. In addition, lower yield raises domestic food prices thus negatively affecting real incomes of households.

Figure 3.17 Impacts of Combined Global and Local Climate Change under MIROC Scenario on Household Incomes, Tunisia 2000–30



Source: Tunisia DCGE Model.

Figure 3.18 Impacts of Combined Global and Local Climate Change under CSIRO Scenario on Household Incomes, Tunisia 2000–30



Source: Tunisia DCGE Model.
Note: The Tunisia DCGE Model runs from 2001 to 2030.

The long-term impacts of combined local and global climate change in Tunisia will lead to an overall reduction in household incomes due primarily to the strong impact on household welfare of local climate change (figures 3.17 and 3.18). These welfare reductions accumulate over time. In 2030, all household incomes are projected to be 1–2 percent lower than in a perfect mitigation scenario. Farmers are hardest hit. The negative effects under the MIROC scenario reduce farmer incomes by close to 13 percent compared to perfect mitigation by the end of the period. Under the CSIRO scenario, farmer welfare losses are less, reaching a more modest, but still significant, 4 percent reduction compared with perfect mitigation. Although farmers suffer the most from climate change in Tunisia, incomes of rural nonfarm and urban households are also projected to fall.

The Republic of Yemen

Oil and agriculture are the two mainstays of the Yemeni economy, but both are threatened, increasing the country's vulnerability to global commodity price changes. Oil reserves may run out by the beginning of the next decade, and aquifers, used for irrigated agriculture, have been seriously depleted in recent years. Although oil is still the largest source of revenue, oil production is declining, and other sectors in the economy will have to contribute increasingly to growth. In the absence of new oil discoveries, it is estimated that the

Republic of Yemen may become a net importer of oil as early as 2016. This will have a significant impact on the economy given that oil revenues account for 60 percent of government receipts and almost 90 percent of exports (IMF 2009b) (table 3.11). The Republic of Yemen is also a net importer of major food items, including maize, wheat, other grains, livestock, fish, and processed food. Agriculture's trade position is uneven, with imports accounting for more than a third of total domestic consumption and exports accounting for less than 5 percent of domestic production.

Agriculture and related processing contribute about 13 percent to GDP, about three-quarters of which is produced in the highly populated AEZs 1 and 2 (the Upper and Lower Highlands, with 30 and 40 percent of the total population living in these zones). Qat accounts for more than one-third of agricultural GDP and about 40 percent of total water resource use. Vegetables and fruits make up another one-third of agricultural GDP. Livestock and cereals contribute about

Table 3.11 Structure of the Yemeni Economy by Sector, 2009

	GDP	*Private consumption*	*Export share*	*Export intensity*	*Import share*	*Import intensity*
Sorghum	0.3	0.6	0	1.4	0	0.4
Maize	0.1	0.8	0	1.3	1.1	68.9
Millet	0.1	0.2	—	—	—	—
Wheat	0.2	5.4	0.1	6.2	8.7	93.6
Barley	0.1	0.2	—	—	—	—
Other grains	0	2.4	—	—	3.8	99.8
Fruits	0.9	1.5	0.5	12	0.3	10
Potatoes	0.4	0.7	0.2	9.3	0	1.1
Vegetables	1.1	2.3	0.1	2	0.1	3.2
Pulses	0.2	0.4	—	—	—	—
Coffee	0.2	—	0.5	54.7	0	2.6
Sesame	0	—	0	10.4		
Cotton	0.1	—	0	5.3	0	3.3
Qat	2.8	5.5	—	—	—	—
Tobacco	0.2	0.8	—	—	0.8	61.1
Camel	0.1	—	0.5	71	0	15.5
Cattle	0.4	—	0.1	2.3	0.2	10
Poultry	0.6	—	—	—	0.5	10.5
Goats and sheep	0.4	—	0.1	3.1	0.3	15.7
Fish	0.3	—	0	0.1	0	0.3
Total Agriculture	**8.4**	**21.5**	**2.1**	**4.5**	**16.3**	**34.4**
Forestry	0.2	0.7	—	—	0.5	41.9
Mining	22.5	1	88.7	95	—	—
Food processing	4	26.5	1.5	3.6	13.9	33.8
Other industry	10.9	18.8	1.2	1.9	69.7	61.3
Utilities	1.2	1.9	—	—	—	—
Services	53.1	30.4	6.6	2.2	—	—
Total nonagriculture	**91.6**	**78.5**	**97.9**	**19.2**	**83.7**	**22.7**
Total:	100	100	100	18	100	24

Source: Yemen DCGE Model.
Note: Import intensities are calculated as shares of total domestic consumption (final and intermediate).
Export intensities are the ratios of exports to domestic production. — = not available.

20 and 10 percent to agricultural GDP, respectively (table 3.12). Qat cultivation is almost exclusively concentrated in AEZs 1 and 2, whereas other water-intensive crops such as fruits and vegetables are also grown in zone 3 (the Red Sea and Tihama Plain Zone). AEZs 1 and 2 are the two main contributors to agricultural and overall GDP, followed by zones 3, 5, 4, and 6. The latter three zones together account for only 8 percent of agricultural GDP, although zones 5 and 6 are the major producers of sesame and camel. Food and agriculture-related processing makes up about 50 percent of household consumption expenditures. Within this category, food processing constitutes the largest share of consumption, followed by cereals, qat, vegetables, and fruits (table 3.11).

Farm households, which make up about 24 percent of total population, earn about 16 percent of all household incomes, whereas the population and income shares are 49 and 47 percent for rural nonfarm households and 27 and 37 percent for urban households (table 3.13). Farm households receive most of their income from unskilled labor and land (each about 30 percent), whereas urban households rely more on skilled labor (about 55 percent). The dominant income source of rural nonfarm households is unskilled and semi-skilled labor.

The food security situation in the Republic of Yemen is highly vulnerable to shocks such as food price surges and climate variability. The vulnerability is demonstrated by the relatively small difference between what Yemenis consume every day and what they need to stave off hunger at their current level of activity—less than 300 kilocalories per day (kcal/day) nationwide (table 3.14). This means that the average Yemeni consumes only 15 percent more than the 2,019 kilocalories per day needed to avoid hunger.

People living in rural areas are more likely to fall into food insecurity than people living in urban areas (table 3.14). Although the average per capita calorie consumption is higher by 200 kilocalories per day in rural areas than in urban areas, the average per capita calorie gap is lower by about 130 kilocalories per day. This difference is the result of the significantly higher calorie needs of rural people (2,106 kilocalories per day on average) compared with urban people (1,708 kilocalories per day on average). Rural people need more calories for fetching water from wells, carrying goods to and purchases from markets over long distances, and working hard on farms and in fisheries.

At the regional level, the food-insecurity rate varies strongly between AEZs and is alarmingly high in the Internal Plateau. The food-insecurity rate is lower along the Red Sea coast (Red Sea and Tihama Zone) and in the Upper Highlands Zone (which starts at 1,900 meters above sea level), where the country's capital, Sana'a, is located. The food-insecurity rate rises toward the eastern inland region, which comprises the Internal Plateau Zone and the Desert Zone. The food-insecurity rate is lowest in the Lower Highlands Zone (located at an altitude of 1,500–1,900 meters above sea level), home to less than 20 percent of the population. It is highest in the Internal Plateau, where more than half the population is food insecure. The AEZs that are better off in

Table 3.12 Agricultural Value-Added by Zone and Crop in the Republic of Yemen, 2009

Activity	*Zone 1*		*Zone 2*		*Zone 3*		*Zone 4*		*Zone 5*		*Zone 6*		*Total*	
	Billion YRl	*Percent*	*Billion YRl*	*Percent*	*Billion YRl*	*Percent*	*Billion YRl*	*Percent*	*Billion YRl*	*Percent*	*Billion YRl*	*Percent*	*Billion YRl*	*Percent*
Sorghum	7.4	5.3	5.1	3.1	3.7	4.7	0.1	0.7	0.1	0.5	0.0	0.0	16.3	2.7
Maize	2.5	1.8	4.1	2.5	0.4	0.5	0.0	0.1	0.0	0.0	0.0	0.0	7.0	1.1
Millet	1.8	1.3	0.6	0.3	2.6	3.4	0.0	0.3	0.0	0.0	0.0	0.0	5.0	1.0
Wheat	1.0	0.7	6.1	3.7	0.2	0.2	0.0	0.0	0.2	1.0	0.1	2.0	7.5	1.2
Other grains	0.2	0.1	3.5	2.1	0.0	0.1	—	—	0.0	0.1	0.0	0.0	3.8	0.9
Fruits	4.6	3.3	8.4	5.1	23.9	30.8	0.2	1.4	8.8	45.8	0.0	0.8	45.8	13.9
Potatoes	15.8	11.3	0.8	0.5	0.9	1.1	0.0	0.1	0.2	0.9	0.0	0.0	17.6	2.6
Vegetables	8.9	6.3	11.7	7.1	7.4	9.5	2.3	20.7	1.3	6.9	0.0	1.3	31.6	8.3
Tomatoes	10.8	7.7	3.6	2.2	5.2	6.7	0.2	1.8	2.0	10.6	0.0	1.3	21.9	4.7
Pulses	5.8	4.1	0.7	0.4	1.5	2.0	0.2	1.7	0.1	0.3	0.0	0.3	8.2	1.3
Coffee	0.3	0.2	7.4	4.5	0.0	0.0	—	—	—	—	—	—	7.7	1.2
Sesame	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.6	3.1	0.3	10.5	1.3	0.5
Cotton	—	—	0.2	0.2	5.0	6.5	0.1	0.4	0.0	0.0	—	0.0	5.3	5.2
Qat	56.0	39.9	84.2	51.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.6	140.2	18.9
Tobacco	—	—	0.1	0.1	8.5	11.0	0.0	0.1	—	—	—	—	8.7	2.0
Camel	0.2	0.2	0.5	0.3	0.3	0.4	0.5	4.7	1.2	6.2	1.3	51.1	4.1	1.8
Cattle	3.8	2.7	10.3	6.2	3.7	4.7	0.5	4.6	0.1	0.6	0.1	2.5	18.4	4.7
Poultry	17.4	12.4	10.2	6.2	1.4	1.8	0.4	3.7	0.6	3.1	0.0	1.2	30.0	4.7
Goats and sheep	3.8	2.7	7.7	4.7	2.5	3.2	2.6	23.3	4.0	20.9	0.7	28.4	21.4	7.3
Fish	—	—	—	—	10.1	13.0	4.1	36.7	—	—	—	—	14.2	16.2
Total	140.1	100	165.1	100	77.5	100	11.1	100	19.2	100	2.6	100	415.7	100
Percent	33.7	—	39.7	—	18.6	—	2.7	4.6	—	—	0.6	—	100	—

Source: Yemen DCGE Model.
Note: YRl = Yemeni rials. — = not available.

Table 3.13 Household Income Sources by Income Type and Household Category in the Republic of Yemen, 2009
percent

	Private sector			*Public sector*						
	Unskilled	*Semiskilled*	*Skilled*	*Unskilled*	*Semiskilled*	*Skilled*	*Land*	*Livestock*	*Government*	*Row*
Zone 1, rural farm	32.6	0.4	18.5	0.8	0.6	12.2	25.3	1	2.9	5.8
Zone 1, rural nonfarm	31.7	21.4	10.3	5.7	3.7	17.1	1.2	0	1.7	7.2
Zone 1, urban	11.3	5.5	27.9	4.2	2.5	36.8	1.4	0	3.3	7.1
Zone 2, rural farm	21	2	17.8	0.3	0.3	3.7	33.4	1.2	5.1	15.1
Zone 2, rural nonfarm	31.7	15.8	21.9	2.5	1.3	15.9	1.8	0	2.7	6.5
Zone 2, urban	16	3.9	20.8	5.7	1.1	33	2.3	0	4.6	12.5
Zone 3, rural farm	34.5	9.9	0.8	0	0	1.2	35.4	0.9	1.9	15.5
Zone 3, rural nonfarm	67.1	4.7	21	0.2	0.1	2.2	1.5	0	0.6	2.7
Zone 3, urban	24.6	17.8	26.5	6.1	1.2	15.8	1.6	0	2.2	4.2
Zone 4, rural farm	4.6	45.1	7	1.7	0	2.8	6.5	2.4	17.3	12.6
Zone 4, rural nonfarm	26.9	9.8	11.8	4	9.8	12.5	0.1	0	12.4	12.7
Zone 4, urban	14.2	9.1	10.7	8.1	5.6	30.2	0.1	0	11.2	10.7
Zone 5, rural farm	30	1.8	0	0.5	0.2	0.3	31.1	2.3	7.7	26.1
Zone 5, rural nonfarm	9.5	27.3	29.5	1.8	7.2	7.6	1	0	3.4	12.7
Zone 5, urban	20.4	22.8	36.2	1.1	1.4	8.5	1.5	0	2.1	6.1
Zone 6, rural farm	82.9	0.3	0	1.1	1.1	2.9	1.1	0.7	3.3	6.5
Zone 6, rural nonfarm	49.9	4	14.1	2	1	20.2	0	0	2.7	6
Zone 6, urban	51	1.9	6.5	17.1	0.1	17	0.1	0	3	3.3
Rural farm	29	3.5	14.4	0.5	0.4	6.5	28.8	1.1	4.2	11.6
Rural nonfarm	36.4	15.6	19.7	2.7	2.2	12.9	1.5	0	2.3	6.6
Urban	14.7	8.1	24.2	5.2	2.6	31.2	1.3	0	4.6	8.1

Source: Yemen DCGE Model.

Table 3.14 Food Insecurity by Residential Area and Agroecological Zone in the Republic of Yemen, 2009

	Food insecurity rate (%)	*Number of food-insecure people (thousand)*	*Per capita calorie consumption (kcal/day)*	*Per capita calorie gap (kcal/day)*
All Yemen, Rep.	**32.1**	**7,481**	**2,301**	**282**
Urban	17.7	1,102	2,160	380
Rural	37.3	6,378	2,352	246
Agroecological zones				
Upper Highlands	36.5	3,739	2,323	252
Lower Highlands	19.4	1,197	2,411	443
Red Sea and Tihama	27.7	920	2,362	360
Arabian Sea	35.3	568	2,027	142
Internal Plateau	56.5	868	1,909	−142
Desert	44.0	189	2,167	119

Source: IFPRI estimation based on 2005–06 *Household Budget Survey* data.

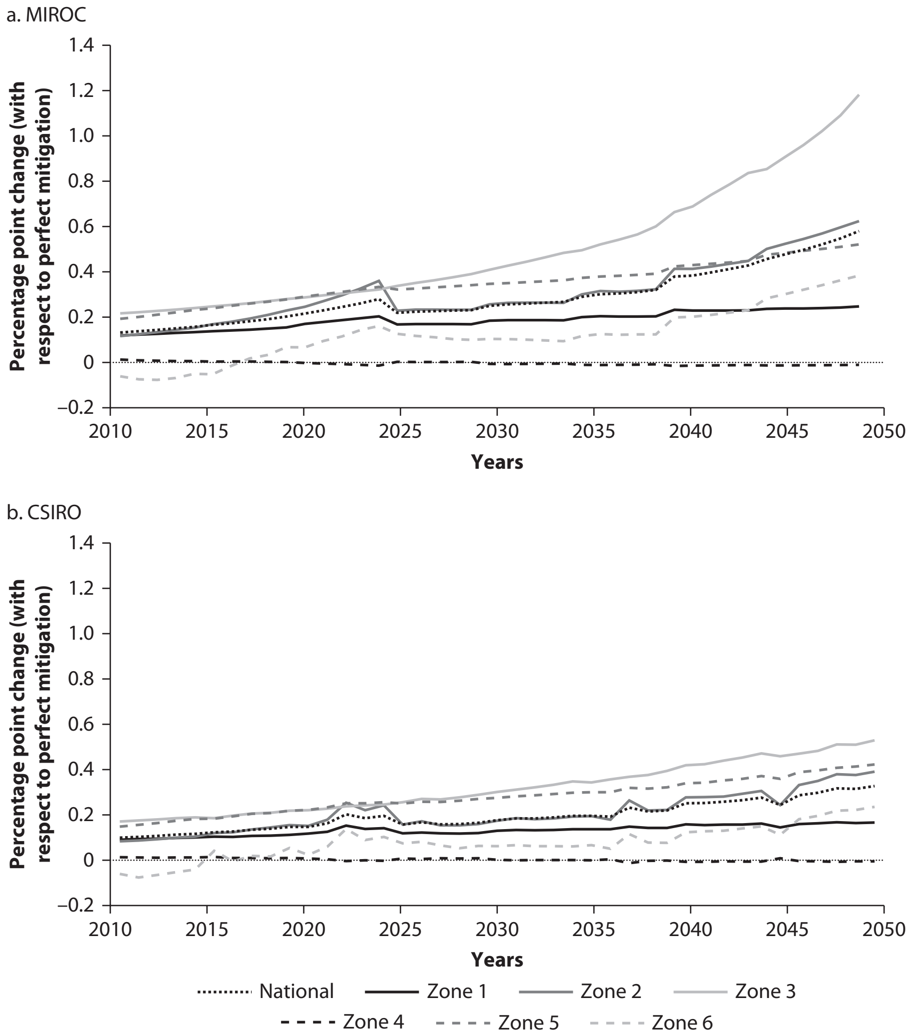
terms of food security also have high percentages of urbanized population. The Internal Plateau is the only zone with an average calorie deficit that exceeds 140 kilocalories per day; the availability of dietary energy (at affordable prices) in this zone is insufficient to supply all people there with adequate calories.

Although the rate of prevalence of food insecurity in the Lower and Upper Highlands zones is low, in absolute numbers most food-insecure people live in that region, which is the most densely populated region in the country. Seventy percent of the Yemeni population and 66 percent of the food insecure live in this region, and most of them live more than 1,900 meters above sea level. Half of all the Republic of Yemen's food-insecure people reside in the Upper Highlands.

Impacts of Global Climate Change on the Economy and Households of the Republic of Yemen

Results of the DCGE model for the Republic of Yemen show that climate-change-related global food price increases may benefit the agricultural sector in the Republic of Yemen through higher returns to production factors. Despite the fixed supply of land (reflecting water scarcity), agricultural activities benefit from price increases, attract additional capital and labor, and thereby increase production. Compared with perfect mitigation, the annual average agricultural growth rate is between 0.1 and 0.5 percent higher in the MIROC scenario and between 0.1 and 0.2 percent higher in the CSIRO scenario and exhibits an increasing trend over time (Figure 3.19). The positive effect on agricultural GDP growth cannot outweigh the negative effect on other sectors, which reduces the overall annual growth rate by 0.01 percent between 2010 and 2050, relative to perfect global mitigation. This slower growth can be explained by the Republic of Yemen's particular structure of agricultural trade, where import intensities are far higher than export intensities (table 3.11). As a consequence, the impact of rising import prices on domestic costs of living is

Figure 3.19 Impacts of Global Climate Change on Agricultural GDP in the Republic of Yemen by AEZ, 2010–50



Source: Yemen DCGE Model.

greater than the impact of rising export prices on domestic revenues—that is, the terms of trade worsen.

Impacts on agricultural GDP growth vary by AEZ depending on the zone's production structure. In general, zones that produce more of the commodities that experience the largest world market price increases relative to other commodities benefit the most (figure 3.19). The average annual agricultural growth rate in zones 1 through 6 ranges between –0.06 percent below and 1.2 percent above the perfect mitigation scenario over the entire period. Producers in zone 3 disproportionately benefit from rising prices for a range of commodities such as

fruits, vegetables, and cotton, whereas at the other extreme, agricultural GDP in zone 4 does not rise at all because a large share of its value-added is not affected by price changes. The pattern of responses of agricultural growth to global climate change is the same irrespective of which of the two climate scenarios we adopt. However, impacts are generally somewhat dampened in the CSIRO scenario, since this scenario projects a more moderate rise in global food prices (figure 3.19). Most notably, agricultural growth in zone 3 still rises more strongly than in the other zones, but no longer in such an exceptional way as in the MIROC scenario. In absolute terms, zones 1 through 3 clearly benefit most given that more than 90 percent of agricultural value-added is produced in these zones.

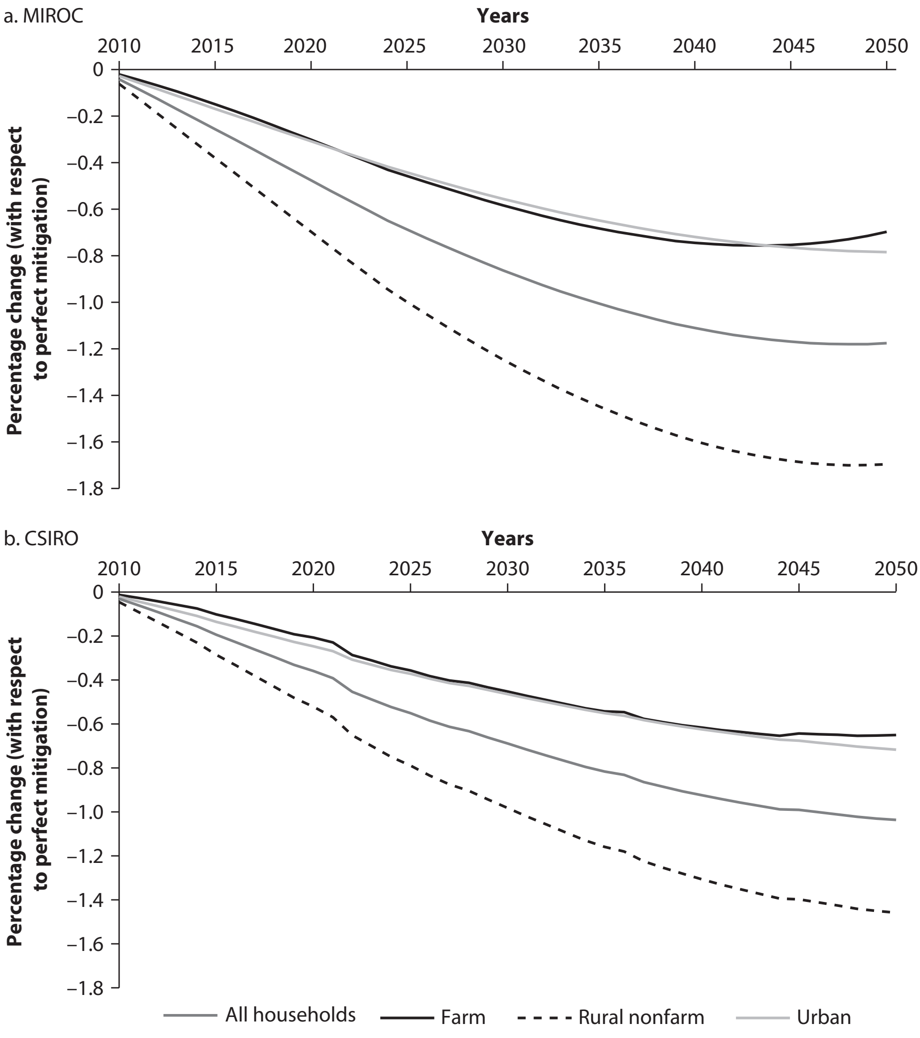
Despite the positive effects on agriculture, all household groups—rural farm and nonfarm households as well as urban households—witness a decline in their real incomes. Consistent with changes in agricultural output, the effect is somewhat less pronounced under the CSIRO scenario. The household group that could be expected to benefit from the global rise in food prices is the rural farm household sector. However, the fact that many farm households are net consumers of food means that their real income is on balance between 0.01 and 0.7 percent lower per year compared with perfect mitigation (figure 3.20). Urban households are also negatively affected, but their losses are not higher than those of rural farm households. This is because urban households spend a much lower share of their budget on food, which partly offsets the higher vulnerability to rising food prices resulting from a more pronounced net food buyer status. The rural nonfarm households are by far the hardest hit as they tend to be net food buyers with high food budget shares. Overall, the adverse effects of global climate change on households are nonnegligible, with incomes lowered by more than 1 percent on average in the year 2050.

Climate and Yield Projections for the Republic of Yemen

The variation in temperature and precipitation in the Republic of Yemen over their baseline equivalents differs under the two GCM scenarios; CSIRO and MIROC (figure 3.21). Under the CSIRO scenario, monthly maximum temperatures do not rise above 1.7°C over the baseline maximum temperatures and rise 2.3°C above baseline for the average monthly temperatures. Under the MIROC scenario, the variations are far greater for both the minimum and maximum temperatures. For nine months out of the year, the MIROC scenario projects a more than 2° rise in temperatures by 2050 in minimum temperatures over the baseline, and in May, the MIROC scenario projects that minimum temperatures will rise over their baseline values by more than 3°C. Maximum temperatures are also expected to increase over their baseline values under the MIROC scenario. For four months out of the year, MIROC temperature highs are expected to rise more than 2°C over their baseline equivalents and by more than 3°C over their baseline equivalents.

Variation in average monthly rainfall across the Republic of Yemen, as projected by the CSIRO and MIROC GCM scenarios, is significant only for the

Figure 3.20 Impacts of Global Climate Change on Household Incomes in the Republic of Yemen, 2010–50

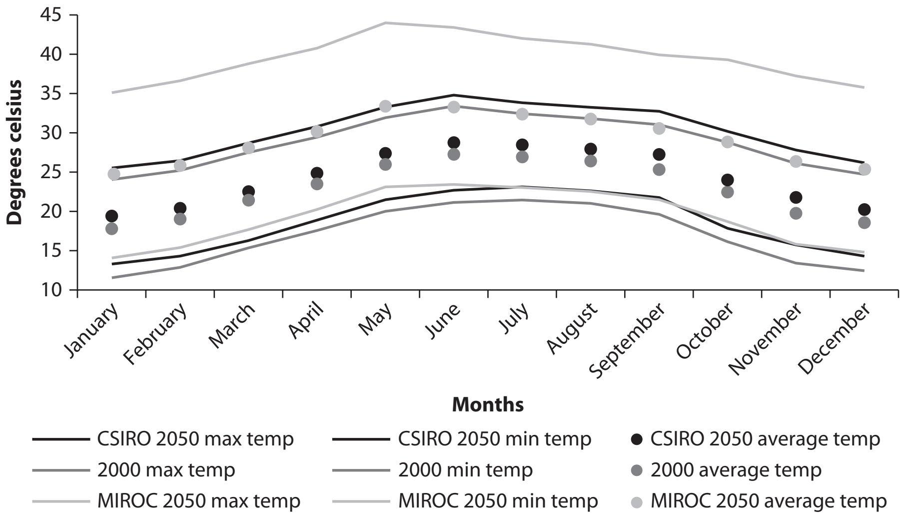


Source: Yemen DCGE Model.

latter scenario. Average monthly rainfall of the CSIRO scenario roughly follows the baseline (figure 3.22). However, the MIROC scenario projects an *increase* in rainfall from June to October across the Republic of Yemen.[10] From October to December, rainfall under the MIROC scenario is below that projected under the baseline. This pattern of variation (or lack thereof for the CSIRO scenario) is consistent across all the Republic of Yemen's regions with the exception of the Upper Highlands, where the rainfall projections under the CSIRO scenario are significantly lower than their baseline equivalents.[11]

Changes in rainfall and temperature are the main drivers of projected yield changes; all else was kept the same for the simulations. Yield changes over time

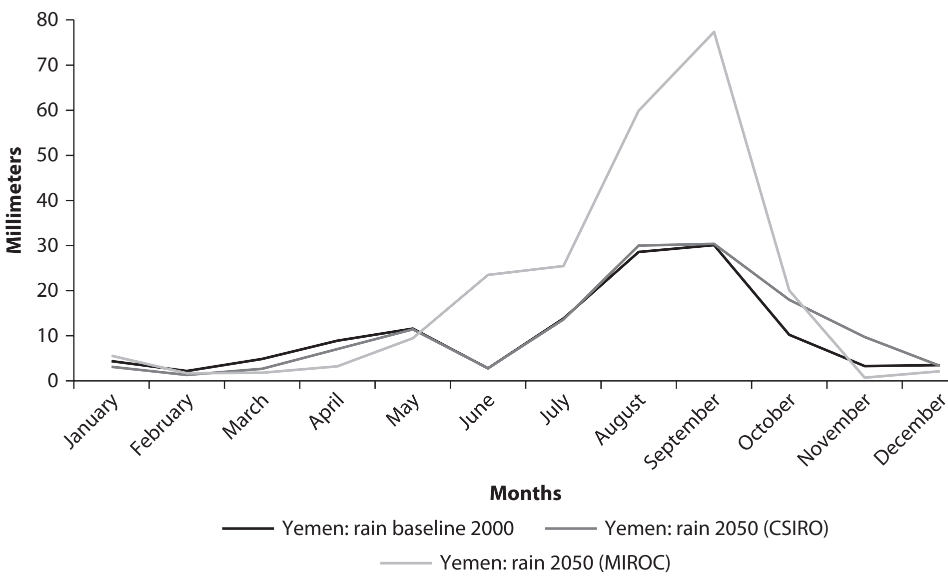
Figure 3.21 Projected Average, Minimum, and Maximum Monthly Temperature in the Republic of Yemen



Source: Calculations based on Jones, Thornton, and Heinke 2010.

due to climate change are projected to vary strongly across all the major grains as well as over AEZs. Driven mainly by the diverging rainfall patterns, projected yield changes for sorghum and millet differ substantially between the MIROC and CSIRO scenarios in the DSSAT crop model (table 3.15). Clearly, in an arid

Figure 3.22 Projected Average Monthly Rainfall in the Republic of Yemen, 2050



Source: Calculations based on Jones, Thornton, and Heinke 2010.

Table 3.15 Projected Average Annual Yield Changes for Selected Crops in the Republic of Yemen, 2000–50

	Maize		*Millet*		*Sorghum*		*Wheat*	
	Irrigated	*Rainfed*	*Irrigated*	*Rainfed*	*Irrigated*	*Rainfed*	*Irrigated*	*Rainfed*
			MIROC (% yield changes)					
All Yemen, Rep.	0.1	1.4	2.6	4	2.4	2.7	−0.3	0.1
Upper Highlands	0.3	1.3	3.4	3.6	2.3	2.4	−0.3	0.1
Lower Highlands	0	1.7	2.6	3.3	2.1	2.4	−0.4	0.3
Red Sea and Tihama	−0.2	−0.5	1.7	4	3.5	4	−0.9	−1
Arabian Sea	−0.1	0.2	1.8	4	4	4	−0.2	−0.3
Internal Plateau	−0.1	0.7	4	4	4	4	−0.1	1.6
Desert	−0.1	−0.4	1.5	4	2.9	4	−0.1	−0.8
			CSIRO (% yield changes)					
Yemen, Rep.	0.1	0.1	−0.1	0.1	0.3	0.3	−0.2	−0.1
Upper Highlands	0.2	0.3	0.8	1	0.8	0.8	−0.2	−0.1
Lower Highlands	−0.1	−0.1	−0.1	0	0.1	0.1	−0.5	−0.3
Red Sea and Tihama	−0.1	−0.4	−0.2	0.1	0.1	0.2	−0.5	−0.5
Arabian Sea	−0.1	−0.3	−0.2	0.2	0.1	0.3	−0.1	−0.3
Internal Plateau	0	−0.7	0.3	0.8	0	0.2	−0.1	−0.4
Desert	0	−0.5	−0.3	−0.9	−0.5	−0.8	−0.1	−0.6

Source: Calculations based on DSSAT.

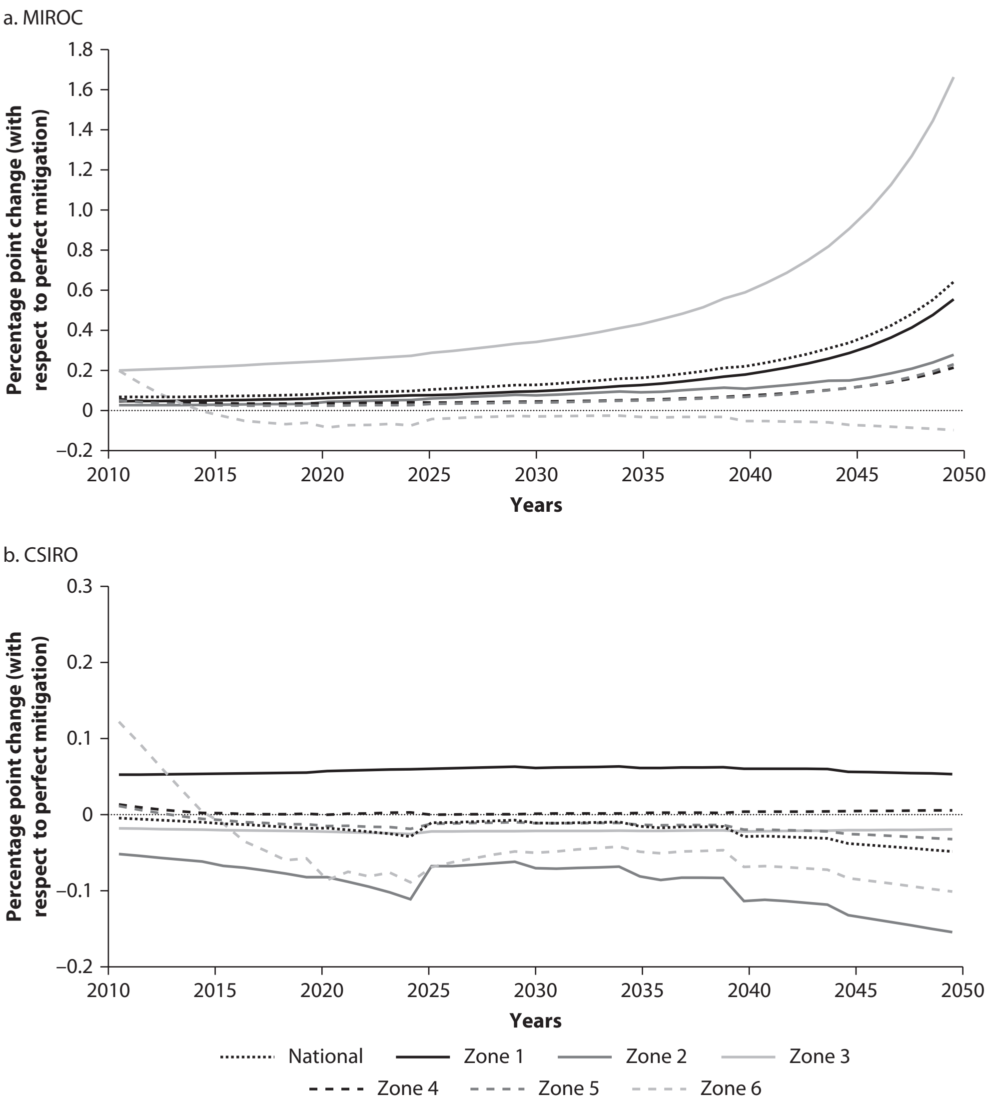
region, having more abundant water could greatly increase yield potentials. Average sorghum and millet yields increase substantially under the MIROC scenario, whereas under the CSIRO scenario they stay relatively stable and even decline by 0.6 percent per year in the Desert Zone.

Impacts of Local Climate Change on the Economy and Households of the Republic of Yemen

Results of the Yemen DCGE model show that the local effects of climate change depend to a large extent on the scenario used. Under the MIROC scenario, local climate change slightly raises agricultural growth; the direction and magnitude of the change for the six AEZs differs depending on their crop mix (figure 3.23). The agricultural GDP growth rate is between 0.05 and 0.6 percent higher than under perfect mitigation, whereas average annual economy-wide growth rises by only 0.01 percent. Among the regions, zone 3 benefits most from local climate change; sorghum and millet experience high yield increases and at the same time account for a larger share of agricultural value-added than in any other zone, whereas the grains with declining yields (maize and wheat) are hardly produced. Losses are incurred in the Desert Zone (6) where grain production is limited to wheat. Under the CSIRO scenario, positive and negative yield changes cancel each other out, and overall agricultural GDP is almost the same as under the perfect mitigation scenario.

Local climate change is welfare enhancing for all household groups when we consider the MIROC scenario. The largest beneficiaries are rural farm households, whose annual income is between 0.03 and 1.3 percent higher than under perfect mitigation (figure 3.24). Those households are affected through

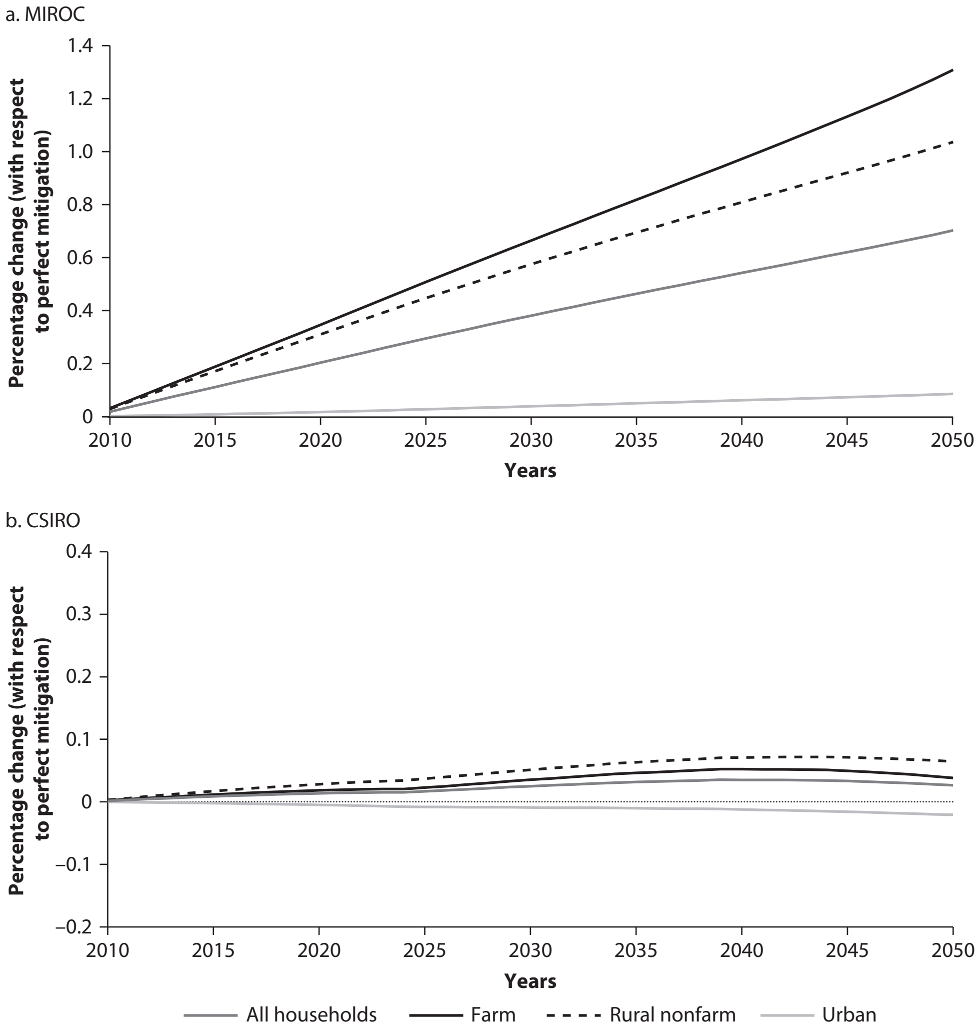
Figure 3.23 Impacts of Local Climate Change on Agricultural GDP in the Republic of Yemen, 2010–50



Source: Yemen DCGE Model.

two major channels: first, their income gains from higher agricultural yields are not fully compensated for by lower prices they receive for their products. Second, as net consumers they benefit from decreasing prices for millet and sorghum. The price effect also explains the considerable increase in real incomes for rural nonfarm households. Urban households, in contrast, hardly consume the commodities that have become cheaper and therefore realize only negligible income gains. Under the CSIRO scenario, real-income changes are close to zero for all three household groups.

Figure 3.24 Impacts of Local Climate Change on Household Incomes in the Republic of Yemen, 2010–50



Source: Yemen DCGE Model.

Combined Impacts of Global and Local Climate Change on the Economy and Households of the Republic of Yemen

Considering the global and local effects of climate change jointly shows that the effects cancel each other out at the macro level. Economic growth on average is the same as under perfect mitigation. Whereas the share of agriculture in the economy falls as part of the general economic transformation process (table 3.16), that pattern of structural change is even slightly reversed due to the global effects of climate change, which render the production of various agricultural commodities more profitable.

Table 3.16 Structural Change under Climate Change Scenarios in the Republic of Yemen
percent of GDP

		MIROC		CSIRO	
	Initial	*2030*	*2050*	*2030*	*2050*
Perfect mitigation					
Agriculture	8.4	6.0	4.6	6.0	4.6
Industry	38.5	39.3	39.3	39.3	39.3
Services	53.1	54.7	56.1	54.7	56.1
Global					
Agriculture	8.4	6.2	5.1	6.1	4.9
Industry	38.5	39.2	39.0	39.3	39.1
Services	53.1	54.6	55.9	54.6	56.0
Local					
Agriculture	8.4	5.9	4.5	5.8	4.2
Industry	38.5	39.4	39.4	39.4	39.5
Services	53.1	54.8	56.1	54.8	56.3
Combined					
Agriculture	8.4	6.3	5.4	6.1	4.8
Industry	38.5	39.2	38.9	39.3	39.2
Services	53.1	54.5	55.8	54.6	56.0

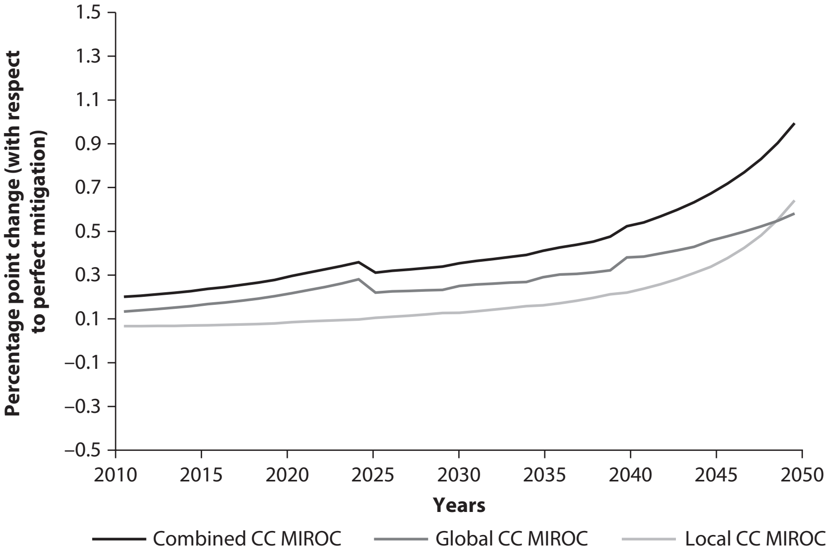
Source: Yemen DCGE Model.

Results for the agricultural sector differ noticeably between the MIROC and CSIRO scenarios. Agricultural output rises under the combined MIROC climate change scenario with increasing speed over time. As shown in the previous section, the impacts of both local and global climate change in isolation have positive implications for agricultural production. The agricultural growth rate in the combined scenario is between 0.02 and 1.0 percent higher each year than under perfect mitigation (figure 3.25). The overall rise in yields due to the local impacts of climate change translates into lower domestic agricultural prices and also a fall in imports. Lower domestic prices enhance competiveness on the world market and thus also affect the Republic of Yemen's exports of agricultural crops. This latter effect is amplified when global climate change is factored in as globally higher crop prices provide a boost to the agricultural sector and improve agricultural export performance, leading to faster growth of the agricultural sector (versus perfect mitigation). In contrast, due to less optimistic yield projections, agricultural growth in the CSIRO scenario is only slightly higher than with perfect mitigation when both local and global climate change effects are taken into account.

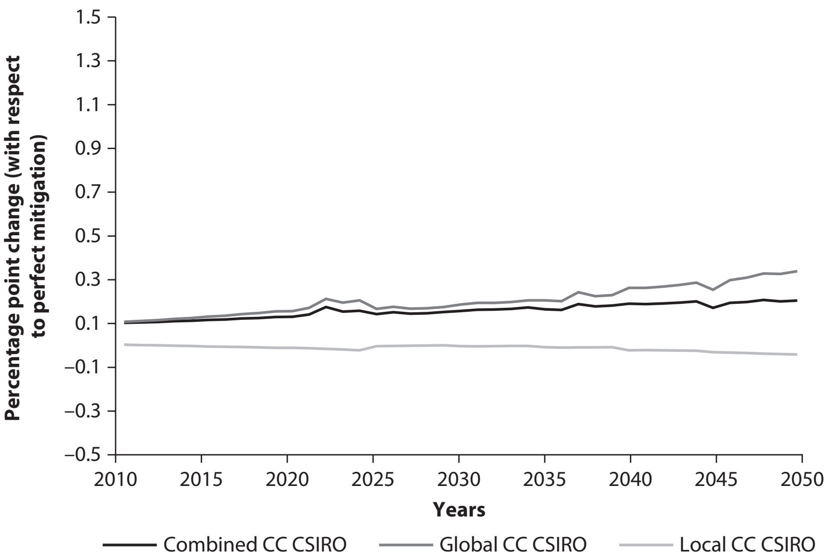
The combined effects of global and local climate change turn out to be favorable for agricultural production in all economically important zones (figure 3.26), but again much less so under the CSIRO scenario than under the MIROC scenario. In zone 3, the positive impacts of local and global climate change in the form of rising agricultural yields and rising world food prices add up to agricultural growth that in the year 2050 is between 0.5 percent (CSIRO scenario) and 2.4 percent (MIROC scenario) higher than with perfect

Figure 3.25 Impacts of Local, Global, and Combined Climate Change on Agricultural GDP in the Republic of Yemen, 2010–50

a. MIROC



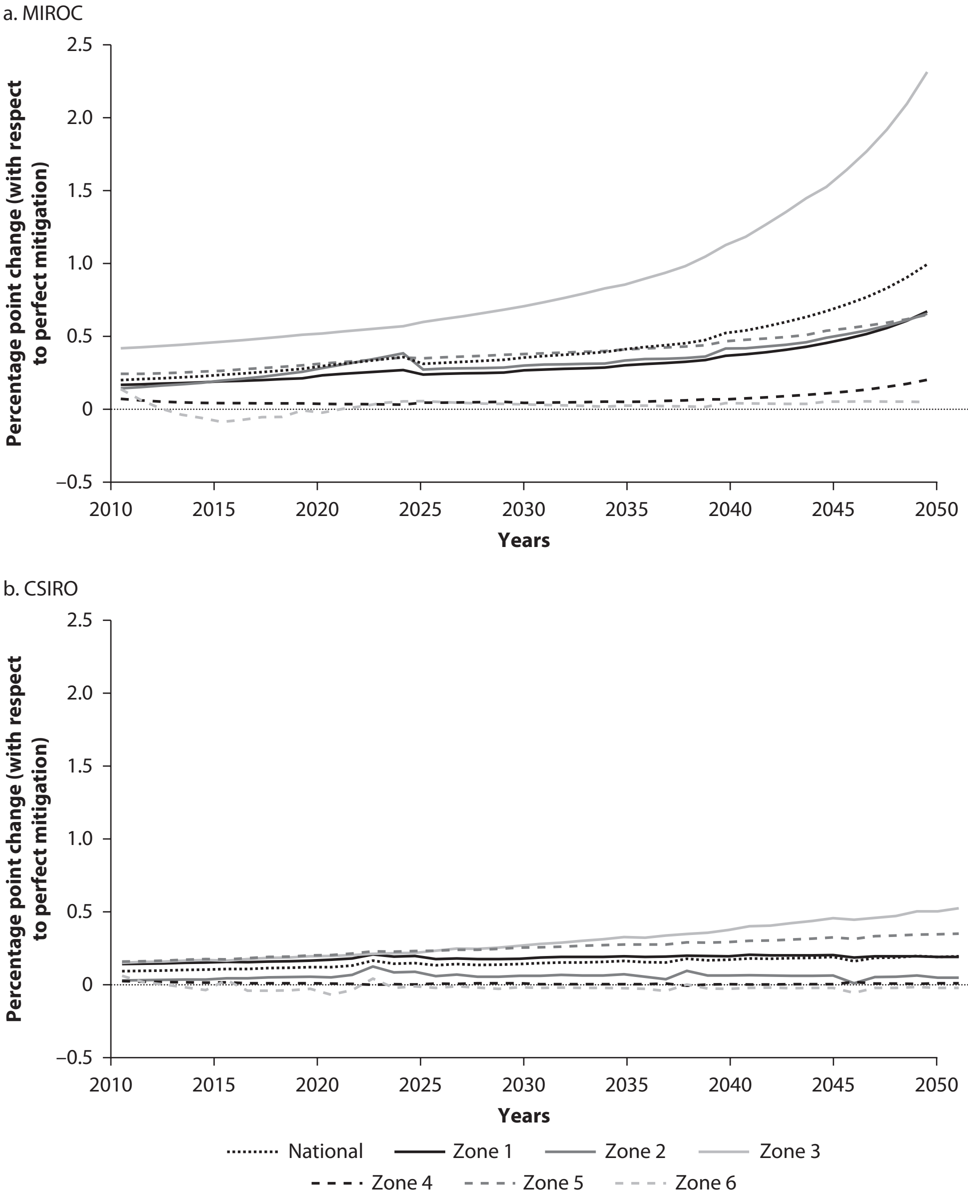
b. CSIRO



Source: Yemen DCGE Model.

mitigation. For the two biggest regions in terms of agricultural value-added, zones 1 and 2, effects are more modest, with a rise in production by up to 0.4 percent in the CSIRO scenario and 0.6 percent in the MIROC scenario. Only in zones 4 and 6, which together account for not more than 3 percent of total

Figure 3.26 Impacts of Combined Local and Global Climate Change by AEZ in the Republic of Yemen, 2010–50

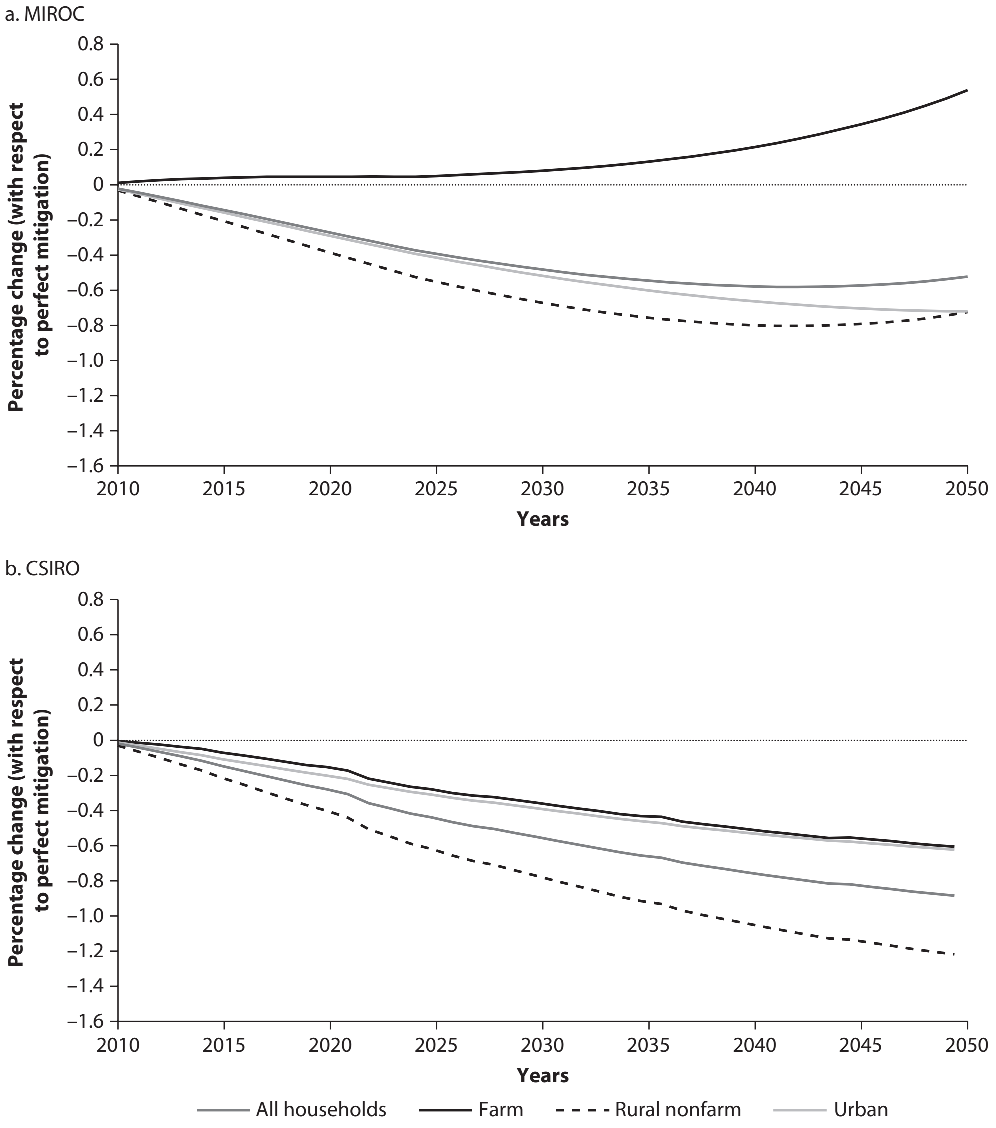


Source: Yemen DCGE Model.

agricultural value-added, agricultural GDP is hardly affected by the combined effects of climate change.

Taking the global and local impacts of climate change together in general results in a reduction of household welfare under both scenarios. Only farm households may benefit under MIROC projections, but incomes for rural non-

Figure 3.27 Impacts of Combined Local and Global Climate Change on Household Incomes in the Republic of Yemen, 2010–50



Source: Yemen DCGE Model.

farm households and urban households fall (figure 3.27). Even though as net consumers farm households end up paying more for their food basket when world food prices rise, they on balance realize income gains because of the substantial yield increases for sorghum and millet. Rural nonfarm households and urban households, in contrast, are hit harder by the price effects of global climate change and benefit only indirectly—via falling prices—from the yield effects of local global climate change. As a consequence, their real income falls

by up to 0.8 and 0.7 percent, respectively. Under the CSIRO scenario, the gains of farm households turn into losses, and rural nonfarm households see much stronger reductions in real household income as they no longer benefit from lower prices induced by higher yields.

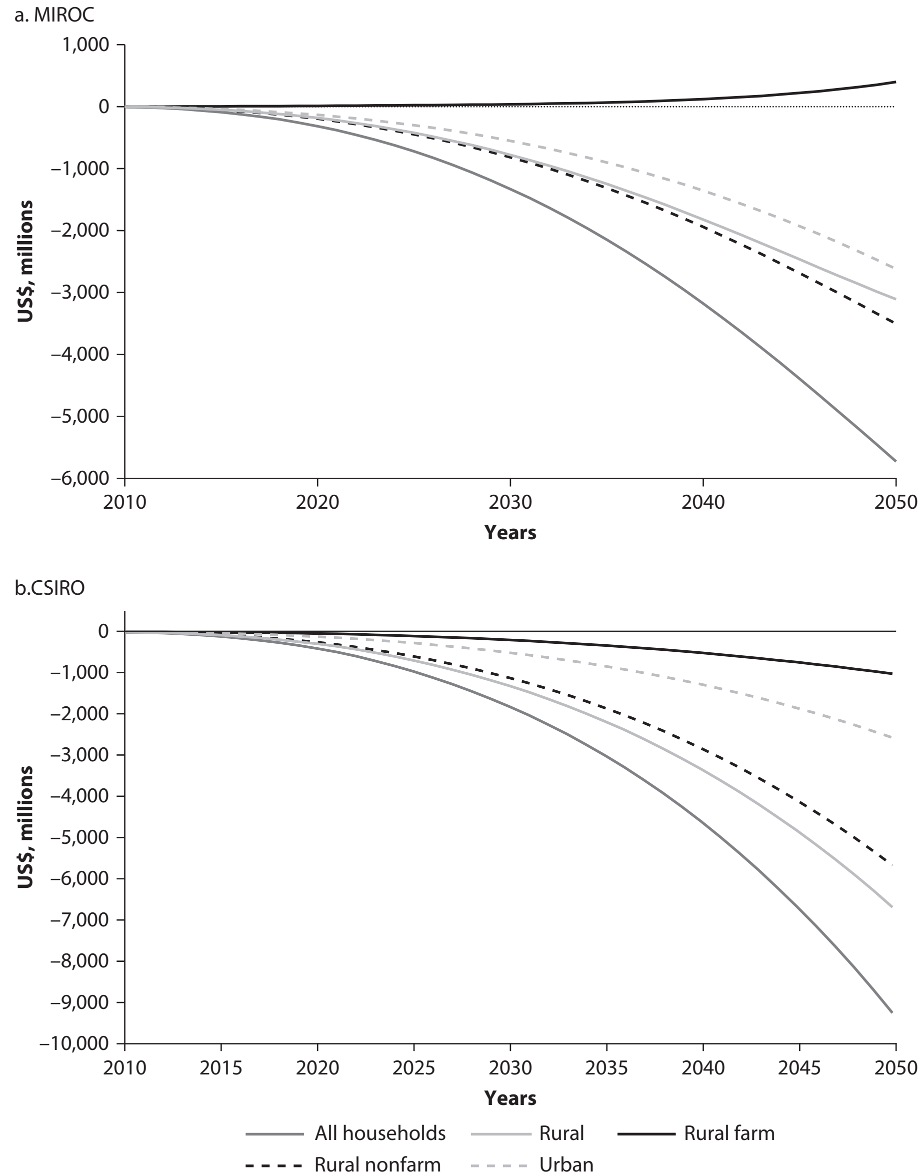
Changes in real incomes differ between household groups as well as across regions. With the exception of rural farm households in zone 3 (and in zone 2 under the MIROC scenario), all households suffer real income losses as a result of the combined local and global impacts of climate change (table 3.17). Although the effects of climate change do not reveal a clear distributional pattern, some of the poorest sections of Yemeni society are among the hardest hit. Most notably, farm households in the Desert Zone have the lowest initial per capita income and are expected to experience the biggest income losses. They suffer most mainly due to the joint effect of being net food buyers, spending a high share of income on food, and specializing in agricultural activities that do not benefit from higher prices and increasing yields. Nonfarm households in zones 4 and 6 are other examples of poor groups incurring considerable losses.

Table 3.17 Distributional Impacts, Local and Global Climate Change, and World Price Changes in the Republic of Yemen

Household group by AEZ	*Population*	*Per capita income (thousand YRI)*	*Average annual change, 2010–50 (%)*				
		2009	*Perfect mitigation*	*Global climate change[a]*	*Local climate change[a]*	*Combined climate change[a]*	*Combined climate change plus World price changes[a]*
Urban 1	2,669,219	242	−0.5	−0.1	0	−0.4	−0.1
2	1,203,688	161	−0.6	−0.1	0.1–0.0	−0.5	−1.1
3	774,200	177	−0.3	−0.4	0.1–0.0	0.1	0.1
4	1,157,983	170	−0.3	−0.1	0	−0.5	−0.8
5	302,989	159	−0.8	−0.1	0	−0.8	−1.6
6	41,809	137	−0.8	−0.1	0	−0.1	−0.1
Rural nonfarm 1	1,946,109	152	−1.8	−0.3	0.1–0.0	−0.1	−0.1
2	5,836,100	118	−1.8	−0.3	0.9–0.1	0.6	0.5
3	1,616,578	133	−1	−0.1	0.6–0.0	0.5	0.5
4	320,780	100	−0.6	−0.1	0	−0.8	−0.1
5	999,507	127	−1.1	−0.2	0	−0.1	−0.1
6	174,557	105	−1.3	−0.2	0	−0.1	−0.1
Rural farm 1	1,601,351	147	−1.8	−0.2	0.0–0.1	−0.5	−2.4
2	2,544,789	90	−2	−0.2	1.2–0.1	0.6–0.3	1
3	737,259	108	−1	0.1	1.6–0.2	1.6–0.1	0.6–0.9
4	134,268	111	−0.9	−0.7	0	−0.7	−1.6
5	208,785	105	−1	−0.4	0.0–0.1	0.1	0.1
6	189,342	87	−1.5	-0.2	0.0–0.1	−0.2	−0.2

Source: Yemen DCGE Model.
a. The first number in the cell indicates the MIROC result; the second number indicates the CSIRO result.

Figure 3.28 Impacts of Combined Local and Global Changes on Household Incomes



Source: Yemen DCGE Model.

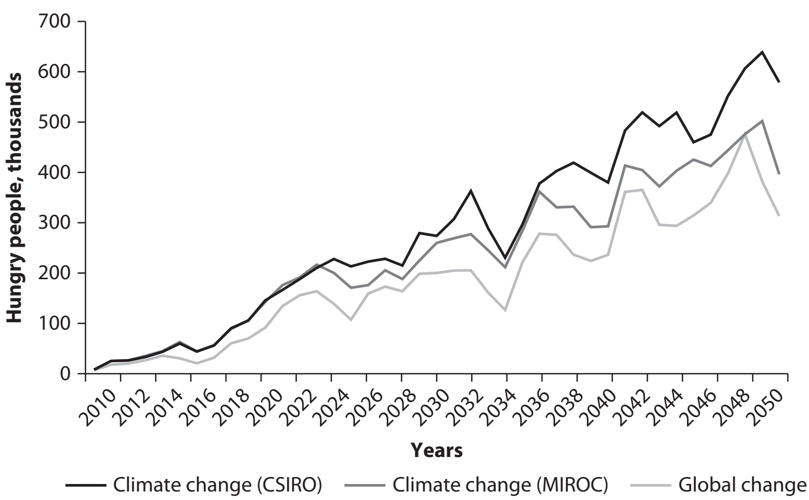
The long-term implications of climate change (local and global) lead to a total reduction of household welfare of YRl 1,161.2 (US$5.7 billion) or YRl 1,873.6 billion (US$9.2 billion) by 2050 under MIROC or CSIRO conditions, respectively (figure 3.28). These reductions in welfare accumulate over time. In 2020, household incomes are projected to be YRl 63.8 billion (US$314.4 million) or YRl 82.0 billion (US$404.2 million) lower than under a perfect mitigation scenario, and

those losses increase to YRl 269.6 billion (US$1.3 billion) or YRl 366.8 billion (US$1.8 billion) by 2030. Rural households suffer more from climate change than urban households. Rural households' incomes by 2050 are YRl 630.1 billion ($3.1 billion) or YRl 1,353.7 billion (US$6.7 billion) lower than under perfect mitigation compared with urban households with incomes lower by YRl 531.1 billion (US$2.6 billion) or YRl 519.9 billion (US$2.5 billion) under perfect mitigation. Whereas farm households benefit from increasing yields that result from local climate change in the MIROC scenario, rural nonfarm households suffer both in relative and absolute terms in the MIROC and CSIRO scenarios. This household group is projected to lose an accumulated YRl 711.0 billion (US$3.5 billion) or YRl 1,147.7 billion (US$5.7 billion) as a consequence of climate change by 2050.

Climate change also raises the number of hungry people in the Republic of Yemen. By 2050, between 80,000 and 270,000 people could go hungry due to climate change (figure 3.29). Even under perfect mitigation, the number of hungry people is projected to rise, which can be explained mainly by rising global food prices caused by global increases in demand.

Rural households are harder hit than urban households, and among the rural households the nonfarm households suffer most (Table 3.18). The negative effect on rural nonfarm households is explained through two major channels. Unlike farm households, rural nonfarm households do not benefit from higher prices for agricultural goods. At the same time, they spend the highest share of their income on food of all household groups, which makes them particularly vulnerable to food price changes. Urban households in contrast spend a lesser share of their income on food and derive most of their income from sectors that are largely unaffected by climate change.

Figure 3.29 Impact of Climate Change on Food Security in the Republic of Yemen, 2010–50



Source: The Republic of Yemen Combined DCGE and Nutrition Model.

Table 3.18 Impact of Climate Change on Food Security in the Republic of Yemen

	Change in hungry people (thousands)		
	Initial	*2030*	*2050*
Global change			
Rural farm	1,836.1	67.7	93.0
Rural nonfarm	4,541.2	93.3	213.7
Urban	1,106.1	39.1	6.6
Total	7,483.3	200.1	313.3
Climate change (MIROC)			
Rural farm	1,836.1	−21.2	−14.8
Rural nonfarm	4,541.2	16.1	89.7
Urban	1,106.1	64.7	8.0
Total	7,483.3	59.6	82.8
Climate change (CSIRO)			
Rural farm	1,836.1	0.0	39.5
Rural nonfarm	4,541.2	23.3	218.1
Urban	1,106.1	50.5	8.0
Total	7,483.3	73.8	265.6

Source: The Republic of Yemen Combined DCGE and Nutrition Model.

Notes

1. In Syria, 47 percent of water used for agriculture is surface water that Syria shares with its neighbors, mainly from the Tigris, Euphrates, and Orontes Rivers (World Bank 2010).
2. In addition to various GCMs, Nelson et al. (2009) also include low, medium, and high assumptions on population and GDP percent growth. For this study, we use the medium-level assumptions.
3. The most widely accepted definition of food security is the one adopted by the 1996 World Food Summit (WFS): “Food security, at the individual, household, national, regional and global levels [is achieved] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO 1996).
4. Despite substantial macroeconomic improvements, Turkey still maintains some vulnerabilities such as a high unemployment rate (at 10 percent), dollarization of its economy, high public debt figures, a growing capital account, and decreasing exports (IMF 2010).
5. In the DCGE model it was not possible to separate livestock by agroecological zones. Therefore, totals in the graphs refer to total GDP, while the zone-level results exclude livestock.
6. As discussed previously, the change in world-market prices due to projected changes in biofuels policies has repercussions on the country level. A slower increase in global food prices leads to a slower increase in producer prices in Syria and thus slower agricultural growth.
7. The model results should be interpreted as an optimistic scenario, in which the policy and economic environment allows for and supports climate change adaptation. Specifically, producers are assumed to be freely able to substitute labor, capital, land,

and inputs to react to changing relative costs of inputs, or imported food can replace locally grown food when relative prices of locally grown food increase (and vice versa).

8. The Tunisia model runs from 2000 to 2030 due to data availability.
9. Due to data constraints we could only do the DSSAT modeling for wheat, barley, and potatoes. In order to cover all the agricultural SAM sectors, some assumptions about yields were made (table B.1).
10. As previously described, variations in average monthly rainfall are compared with the equivalent baseline estimates.
11. See tables F.1–F.12.

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CHAPTER 4

Economic Impacts of Droughts in the Syrian Arab Republic and Floods in the Republic of Yemen

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Photograph by Dorte Verner

In the long term, climate change will have a detrimental impact on the economies and people of Syria, Tunisia, and Yemen, but the most severe negative effects may take some time to materialize even without mitigation or adaptation measures. In Syria and Yemen, however, extreme climate variability has already weakened the agricultural sector, the economy, and people's livelihoods. Syria suffers frequently from drought. Low rainfall leads to lower crop yields or, in extreme cases, to complete loss of the harvest, especially for rainfed agriculture. Droughts also harm the livestock sector, particularly animals that rely on pastures for feed. Prolonged periods of low rainfall exacerbate the impacts. Droughts are also likely to have an indirect effect on nonagricultural sectors of the economy and nonfarm households. Yemen, on the other hand, is prone to damaging floods.[1] Whereas regular flooding has traditionally been beneficial for agriculture in Yemen, high-magnitude flooding often leads to losses of cropland, uprooting of fruit trees, death of animals caught in high floodwater surges, and destruction of infrastructure, such as irrigation facilities and rural roads. Flood damage is exacerbated by ongoing desertification and land degradation. In addition, several GCMs predict higher rainfall for Yemen, potentially increasing the frequency and severity of floods in the future.

Droughts in Syria

Syria's experience of the 2007–09 droughts confirms that the impacts of climate variability reach beyond the agricultural sector and the rural poor in Syria. Recent droughts have been especially damaging for small-scale farmers and herders, while affecting nonfarm households through reductions in real incomes from higher food prices.[2] In addition, reductions in wheat yields have made Syria a net wheat importer since 2007, creating macroeconomic changes to the balance of payments and concerns about macro-level food security. Although the damaging impacts of drought in Syria are clear, the potential size of losses to GDP and increases in poverty are not as well understood.

Characteristics

Quantifying the impacts of drought is important to incorporate appropriate responses into development strategies. This may become even more important in the future, given that climate change may increase the severity and frequency of extreme weather events (Salinger 2005). However, conducting drought impact assessments is complicated by the complex nature of the impacts and the availability of data. Isolating drought effects can be challenging when data are incomplete or inaccurate. Computable general equilibrium (CGE) models have become an increasingly popular tool for disaster impact assessments (Pauw, Thurlow, and van Seventer 2010). CGE models can be

ex-ante, to assess the impacts of hypothetical events (Boyd and Ibarraran 2009), or ex-post, to evaluate the impacts of historical events (Horridge, Madden, and Wittwer 2005).

This drought impact assessment uses the CGE model presented in chapter 2 to assess the potential impacts of future droughts in Syria. We use an ex-post approach by using the data from a historical drought event in Syria: the changes in yields and losses in livestock that occurred during the 1999–2001 drought. This approach allows us to look beyond the reductions in agricultural production to isolate the impacts on the broader economy and households.

From an agricultural perspective, a drought's spatial extent can prove as important as its severity, and disaster risk management is especially challenging when droughts occur in different zones at the same time. The more a drought spreads across multiple zones, the more serious the implications may be on the country's food security and economic stability. Food self-sufficiency is not a necessary condition for food security; however, a longer-lasting nationwide drought event severely impacts not only rural livelihoods and the agricultural sector but all livelihoods, with consequent implications for poverty. Dwindling foreign currency earnings from fewer exports can also severely diminish food security.

Normal weather conditions (with a Palmer Z index between –1.5 and 1.5) were simultaneously observed across all five agroecological zones only during the 1960s and sporadically in the 1980s. Apart from these exceptions, normal weather only occurred simultaneously in two to three zones, indicating that Syria is prone to extreme weather events, especially during the past 20 years.

Moderately wet conditions, with a Palmer Z index of greater than 1.5 and less than 3, are very rare in Syria and have only once been experienced by all five zones simultaneously, in 1969 and in 1988. Very wet events, with a Palmer Z index of greater than 3, never occurred across all zones.

Droughts have occurred frequently during the past 50 years in Syria; from 1961 to 2009, Syria suffered 22 years of drought (table 4.1). On average, drought events lasted close to four and a half years. The frequency and length of droughts varies significantly by agroecological zone. Zones 1, 2, 3, and 4 have witnessed longer drought periods ranging from four to nine and a half years. Except for zone 1 and to a lesser extent zone 5, droughts have become more frequent and have lasted longer in Syria from 1970 onward. The drought of the 1970s was especially severe because it affected four out of the five agricultural zones in Syria and lasted 10 consecutive years. These extended droughts can be

Table 4.1 Drought Characteristics in Syrian Arab Republic, 1961–2009

	Zone 1	*Zone 2*	*Zone 3*	*Zone 4*	*Zone 5*	*National*
Number of drought years	13.0	19.0	19.0	21.0	16.0	**22.0**
Number of droughts ≥ 2 years	2.0	3.0	2.0	2.0	5.0	**5.0**
Average length of drought period	6.0	5.3	4.0	9.5	2.6	**4.4**

more harmful because water storage (in reservoirs, soil, and aquifers) and food storage may likely be depleted, forcing herders to reduce their animal stocks. Zone 4 also suffers from extended droughts. The International Disaster Database of the Center for Research on Epidemiology of Disasters (CRED 2009) ranked the droughts in 1999 and 2008 among the top 10 natural disasters in Syria since 1990.

Droughts have become more frequent during the past twenty years in zone 2, yet no clear evidence indicates that droughts have become more frequent in other zones. This seems to contradict the general perception of people suffering from droughts, especially the Bedu and farmers. One possible explanation is that the *impacts* of droughts may have become more severe due to higher population densities and groundwater depletion. For example, the number of farm animals has increased, reducing the available pasture for herders and their animals to migrate to during droughts, with devastating consequences for the survival of their animals. Even for the same severity of drought, the socioeconomic consequences can be much greater than in the past.

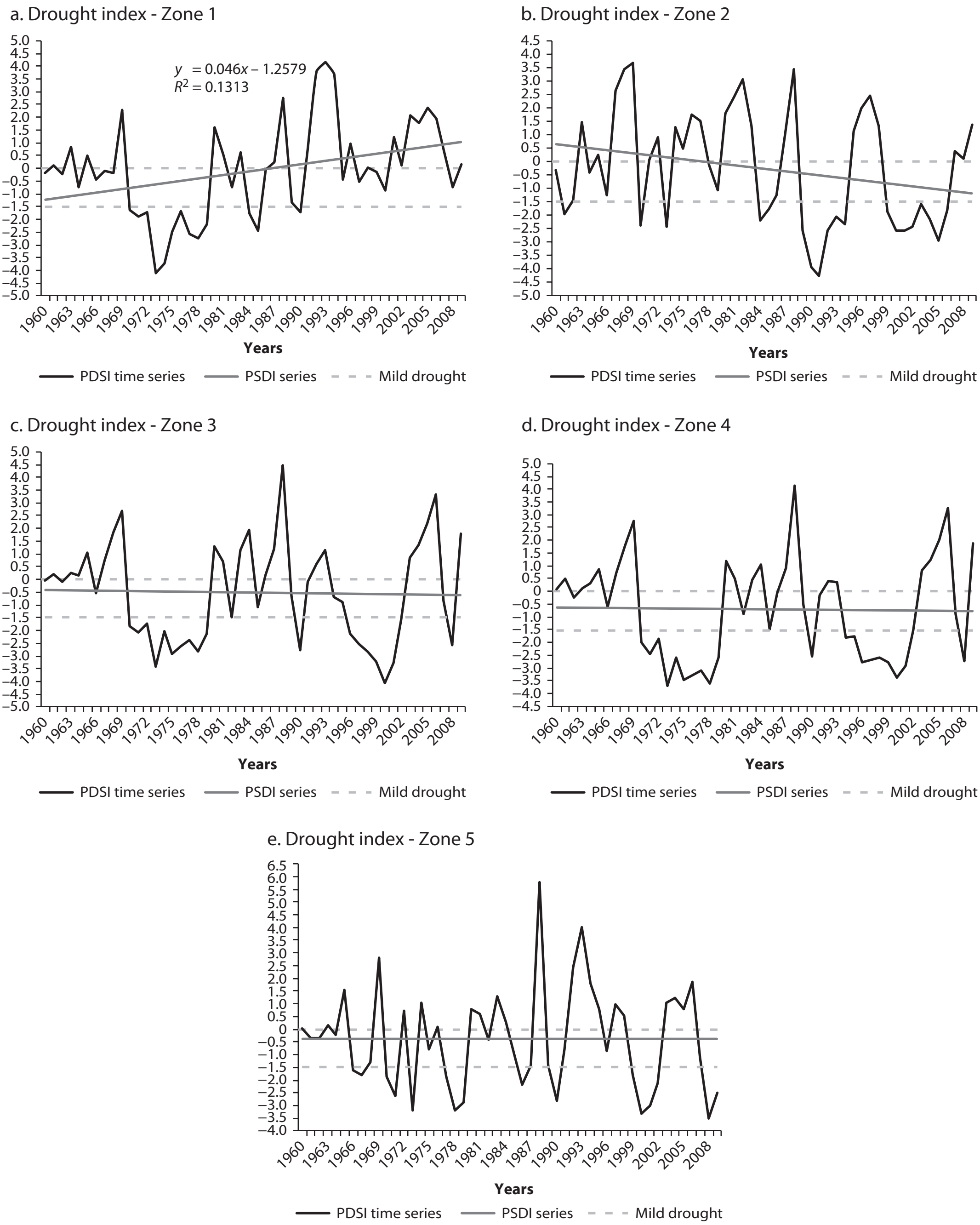
The three most severe droughts affecting the majority of zones occurred in 1970–1973, 1977–1979, and 1999–2001. The 1970s droughts were intensified, despite a regional oil boom, by the occurrence of the Iraq–Iran war, rising tensions with the Western world, and the reduction in Syrian worker remittances that led to a slower economic performance. The drought at the turn of the century exacerbated the negative effects of declining oil prices (at that time Syria was still a net oil exporter) and reduced foreign exchange earnings, which were the result of international sanctions against Syria.

Drought Impacts on Agriculture

We use an ex-ante approach to assess the impact of droughts on agriculture, the economy, and poverty. We focus on the 1999–2001 drought for this impact assessment. The 1999–2001 drought lasted three years, consistent with the average drought period during the past 50 years, and it affected four out of five agroecological zones, making it a nationwide event (figure 4.1 and table 4.1). We also chose this drought for practical reasons; crop data are available by agroecological zone for the whole drought period from the Syrian Agricultural Database (SADB). In essence, we use an average historical event to assess the impact of a similar event in the future.

We use historic data for changes in crop yields and livestock numbers (goats, sheep, cattle, and camels) to implement the drought shocks in the dynamic CGE (DCGE) model, and we assume that the changes in yields and livestock numbers are entirely caused by the drought event. For the three years following 1998, this drought had a severe impact on three of Syria's strategic crops: wheat, barley, and cotton (table 4.2). Most crops experienced sharp decreases in yields in the initial years of drought and then slow recovery. The most severely affected zones were 4 and 5, and consequently, crops grown in those zones fared the worst, especially wheat and barley.

Figure 4.1 Drought Index in Syrian Arab Republic by AEZ, 1960–2009



Source: IFPRI 2010 and World Bank data.

Table 4.2 Yield Variability During the 1999–2001 Drought in Syrian Arab Republic

Tons/Ha		*Zone 1*	*Zone 2*	*Zone 3*	*Zone 4*	*Zone 5*
Wheat, nonirrigated	1998	2.3	1.13	0.46	0.08	0.33
	1999	1.04	0.38	0.07	0	0
	2000	1.19	0.34	0.07	0.02	0
	2001	2.57	1.59	1.46	1.28	0.78
Wheat, irrigated	1998	3.8	3.58	3.14	3.45	3.55
	1999	3.13	3.31	2.69	3.26	3.23
	2000	3.66	4.08	3.05	3.83	3.37
	2001	4.2	4.27	3.64	4.05	3.75
Barley, nonirrigated	1998	2.09	1.05	0.4	0.09	0.3
	1999	1.31	0.6	0.12	0.01	0.07
	2000	0.71	0.25	0.08	0.02	0
	2001	2.59	2	1.39	1	0.91
Barley, irrigated	1998	0	3.22	3.11	2.99	2.81
	1999	2.4	2.32	1.66	2.11	2.46
	2000	2.52	1.93	1.87	1.79	0.89
	2001	3.46	2.97	2.95	2.75	2.22
Cotton	1998	3.96	3.9	3.61	3.36	3.25
	1999	4.34	4.05	3.89	3.37	2.92
	2000	4.38	4.09	4.19	3.84	3.38
	2001	4.36	3.89	4.38	3.76	3.21

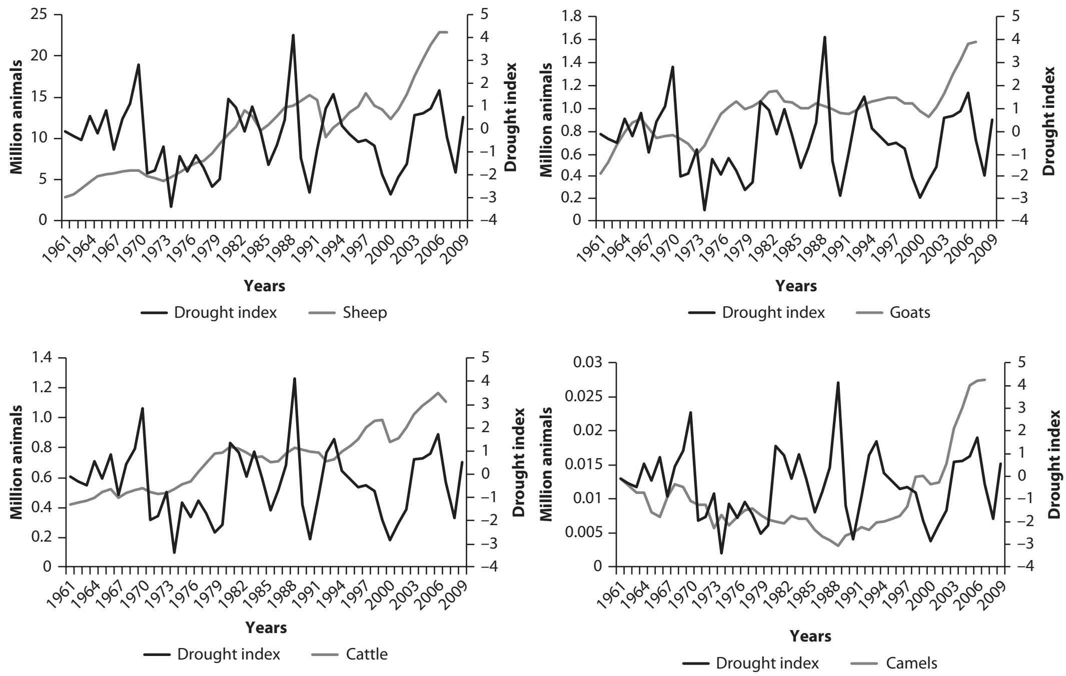
Source: Syrian Agriculture Database (SABD) 2008.

The 1999–2001 droughts led to severe yield reductions and in some zones even to complete crop failure. Yields for irrigated wheat plummeted from between 3.1 and 3.8 tons per hectare in the pre-drought year of 1998 to 2.7 to 3.1 tons per hectare in 1999, and between 0.8 and 2.3 tons per hectare to 1.0 tons per hectare and complete crop failure in 1999 for non-irrigated wheat across all zones. Barley was also hard hit, with reductions between 13 and 47 percent between 1998 and 1999. In the second drought year, yields continued to fall in most zones, yet yields started to recover in zones 1 and 3. The yields for cotton were also volatile every year from 1998 to 2001, although they fared better than barley and wheat.

Both rainfed crops and irrigated crops are affected by droughts (table 4.2). While the impact of droughts on rainfed crops is straightforward, the impact on irrigated yields is more modest and depends on how droughts may affect groundwater levels, river flows, or both. While yields for irrigated wheat and barley drop sharply in 1999 and 2000, cotton yields appear to be largely unaffected. For both irrigated and rainfed crops, yields quickly rebound when the drought is over.

Livestock made up more than 5 percent of Syrian gross domestic product (GDP) and about 30 percent of agricultural GDP in 2007; the number of sheep, goats, camels, and cattle had reached historic highs in 2009 (see figure 4.2) and thus drought-related reductions in number of livestock have economy-wide implications. Sheep and goats make up the largest share of

Figure 4.2 Number of Livestock in Syrian Arab Republic, 1961–2009



Source: Calculations based on Syrian Agriculture Database (SADB) 2008.
Note: The drought index is a simple average of agroecological zones 1 through 5.

GDP (3.2 percent), followed by cattle (1.5 percent), camels (0.1 percent), and poultry (0.6 percent). The CGE model reflects this structure and includes these livestock categories as separate production activities. The relative reduction in livestock production is based on the reduction of livestock numbers observed during 1999–2001, which are then translated into reduction of livestock-specific capital and TFP (table 4.3).

Table 4.3 Changes in the Number of Animals During 1999–2001 Drought in Syrian Arab Republic

	Sheep	*Goats*	*Sheep and goats*	*Cattle*	*Camels*
1997	**5.4**	**1.7**	**5.1**	**5.8**	**5.1**
1998	**11.5**	**0.1**	**10.7**	**8.7**	**19.2**
1999	−9.2	−5.0	−9.0	4.9	49.2
2000	−3.5	0.4	−3.3	0.7	0.3
2001	−8.5	−6.7	−8.3	−15.0	−8.7
2002	9.2	−4.8	8.2	3.6	2.5
2003	13.3	9.2	13.0	8.1	21.6

Source: Calculations based on Syrian Agriculture Database 2008.

Historical evidence shows that while livestock may be more resilient than crops during short droughts, multiyear droughts can severely reduce the availability of fodder (McDonald 2000). In addition, the livestock density per square kilometer matters. This density has dramatically increased during the past few decades due to rapidly rising numbers of livestock, leaving Bedu with fewer options to migrate and less land available for each herding family with their animals. Vulnerability to drought is likely to increase in the future.

The effect on livestock during the drought event of 1999–2011 varied (table 4.3). Camels were the least vulnerable during these drought years, confirming the conventional wisdom that camels are water-stress resistant. Sheep and goat herds suffered big losses during 1999–2001, from 3.3 percent to 9.0 percent annually. Cattle were less affected, probably because some cattle rely on feed rather than pasture.

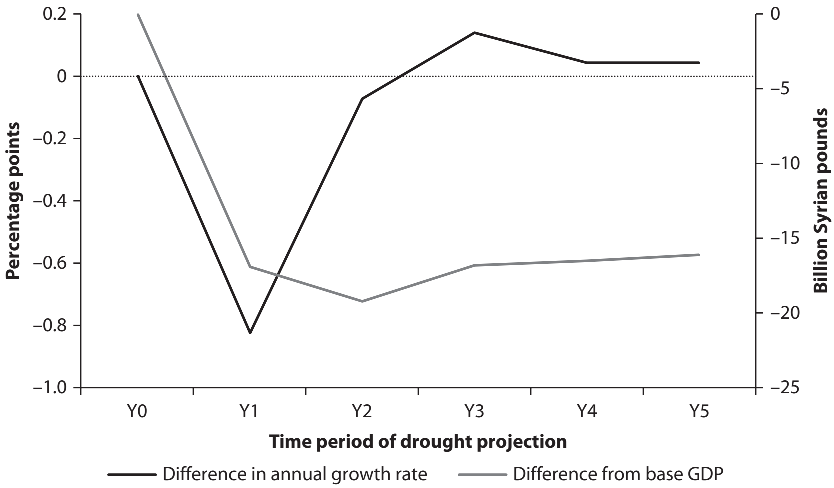
Drought Impacts on the Economy, Food Security, and Poverty

Droughts have implications for the macroeconomy. Aggregate private consumption is reduced, driven by a loss of real income through both higher prices and loss of income. Demand for imports increases, especially for agricultural goods and food processing to substitute for previously domestically produced goods. Higher inflation leads to a depreciation of the real exchange rate, which makes imports more expensive. The depreciation of the exchange rate helps exports, yet the overall effect on the trade balance remains negative. Investment increases during the entire period, reflecting the necessity to replace stocks that have been lost during drought.

The reduction in economic output during drought years ranges between 0.0 and 0.8 percentage points of annual GDP. Drought leads to a sharp reduction in GDP growth rate and economic output (figure 4.3). While both indicators (growth and annual GDP) decline in the first year relative to a situation without drought, the growth rate increases more quickly than economic output. In fact, this phenomenon is common for all kinds of economic shocks: during initial phases the decline in growth is sharpest, because even when economic output in subsequent years is as low as in the initial phase the growth rate remains flat. However, relative to a situation without crisis or drought, output remains lower throughout the whole period. In fact, the GDP growth resumes to predrought levels after three years, yet annual output only slowly catches up with levels that had been achieved without drought.

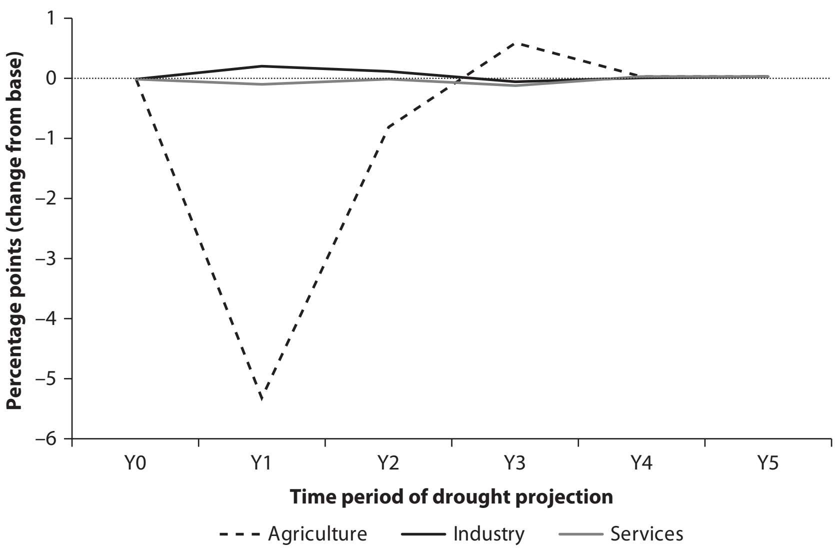
Agriculture is the sector hardest hit by drought, whereas the industry and service sectors are relatively more resilient (figure 4.4). The loss in yields and animals cannot be compensated by the resulting higher prices of agricultural commodities, leading to a sharp contraction in agricultural GDP growth. In the initial year of drought, the service sector also contracts due to a decrease in aggregate demand. However, model results suggest that industrial sectors may benefit from drought, albeit only slightly. This can be explained mainly by

Figure 4.3 Drought Impacts on GDP in Syrian Arab Republic



Source: DCGE model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought.

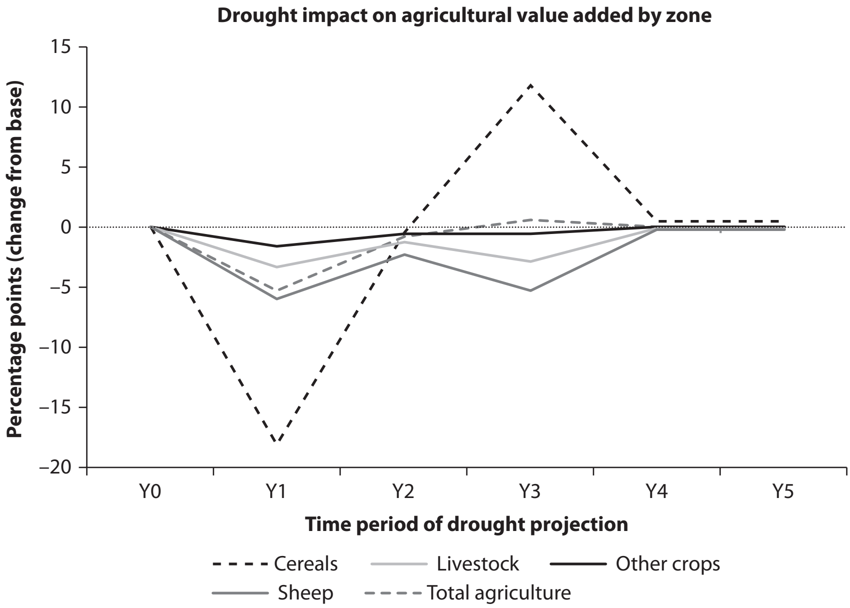
Figure 4.4 Drought Impacts by Sector in Syrian Arab Republic



Source: DCGE model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought.

changes in factor rents. Droughts lead people to migrate out of agricultural activities to seek jobs in other sectors. This lowers the economy-wide wage rates, especially for low-skilled labor. The industrial and service sectors, which use this type of labor extensively, benefit from the lower labor costs and become more competitive.

Figure 4.5 Loss in Agricultural GDP from Drought by Subsector in Syrian Arab Republic



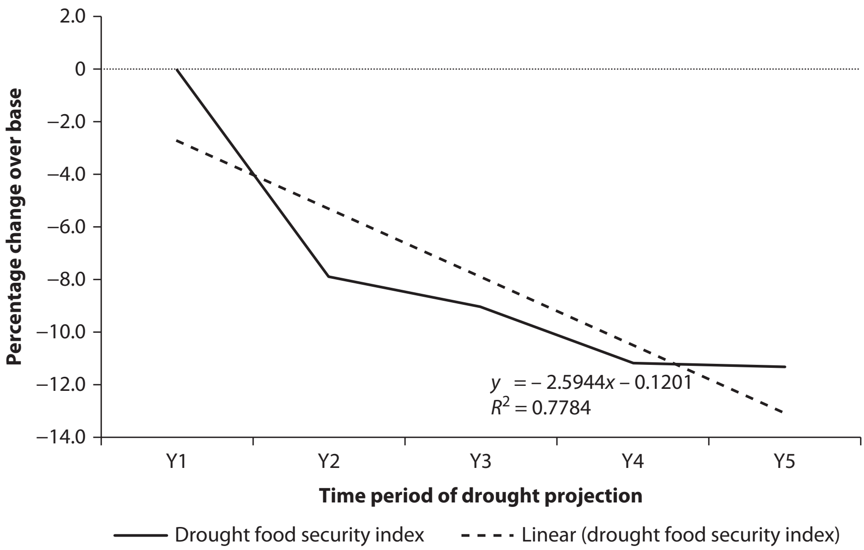
Source: DCGE model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought.

Within agricultural subsectors, cereals are the hardest hit by drought, followed by sheep production (figure 4.5). Rainfed wheat in Syria is mainly grown in zones 2 and 3, while barley is grown in zones 4 and 5. Given the severity and duration of the drought in these zones, yields of rainfed cereals suffer more than other farm activity. This is especially the case during the initial years of drought where value added for cereals decreased by nearly 20 percent from 2007 to 2009. Other crop and livestock activities also decline, rebounding a little only to decrease again with the prolonged drought.

Macro-level food security is a serious concern during drought, as the reduction in food production requires a sharp increase in food imports. At the same time, since the rate of exports remains the same—and cannot make up the difference in export revenues—the food security index decreases under drought conditions (Figure 4.6). Household-level food security is also likely to decline, especially among the poorest household groups, an issue that we capture with changes in poverty levels.

Poverty increases across Syria among all household groups as a result of drought (table 4.4). This increase in poverty is explained by a combination of declining incomes and a higher cost for consumption. In the absence of any mitigation policies, by the third drought year, the national poverty rate would have increased by 0.64 percentage points over the baseline scenario. After the peak of the drought, poverty declines but remains above baseline levels for several years.

Figure 4.6 Drought Food Security Index, Syrian Arab Republic



Source: DCGE model.
Notes: The annual food security index has been adjusted by the annual consumer price index (CPI). Y1-Y5 stands for year one to year 5 of the projected drought.

Table 4.4 Poverty Impact of Drought in Syrian Arab Republic percentage point change from baseline

		Change from baseline					
	Initial	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6*
National	12.3	0.48	0.46	0.64	0.43	0.46	0.37
Rural	15.1	0.69	0.57	0.69	0.52	0.67	0.45
Farm	18.7	1.24	0.37	0.60	0.36	0.28	0.30
Nonfarm	13.3	0.41	0.84	0.94	0.58	1.35	0.67
Urban	9.9	0.30	0.43	0.56	0.49	0.32	0.34

Source: DCGE model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought

Poverty increases the most in rural areas, where, at the peak of the drought in year 3, impacts cause the number of people living below the poverty line to increase by 0.69 percentage points compared with 0.56 in urban areas. Of all groups, the nonfarm sector shows the highest increase in poverty rate. This can be explained by the fact that Bedu, who are likely to be among the hardest hit, are not considered farmers in the underlying model.[3] However, it is important to note that the most vulnerable household groups, such as the Bedu, see much higher increases in poverty than the aggregate results suggest. It is estimated that about 1.5 million Bedu live in Syria. The livelihood of Bedu households is based mainly on sheep herding and to a lesser extent camel herding.

Droughts have been especially damaging for small-scale farmers and herders. Interviews with communities in the Badia steppe region suggest that households with 200 sheep or fewer were often forced to give up herding and move to the large towns and cities, losing their livelihood in the process. In some Bedu communities, 70–80 percent of households left their traditional livelihood behind. Bedu with larger numbers of sheep, camelherders, and households with diversified sources of income such as remittances and off-farm incomes, are more resilient. However, the impacts of drought are felt across all households and communities in reduced nutrition levels, lower school attendance levels, and reduced mobility (Tikjøb and Verner, pers. comm. 2010).

Floods in the Republic of Yemen

Experience from the October 2008 tropical storm and flood confirms that the impact of such a disaster often reaches beyond the affected regions, the agricultural sector, and the rural population in Yemen (table 4.5). A recent joint assessment by the Government of Yemen and several international organizations suggests that the floods have been especially damaging for farmers and herders in the Wadi Hadramout and to a lesser extent in the Sahel Hadramout and the Al-Mahara governorate, while affecting nonfarm households through higher prices and thus reductions in real incomes (GY/WB/UNISDR/IFRCC 2009). Whereas the immediate local flood impacts in Yemen are well known, the potential size of flood impacts in terms of overall and agricultural GDP—and the impacts on hunger—are less well understood.

Characteristics

Quantifying the impacts of flooding is important for designing appropriate mitigation strategies. This may become even more important in the future, given that climate change may increase the severity and frequency of extreme weather events (Salinger 2005). However, conducting flood impact assessments is complicated by the complex nature of the impacts and the availability of data. Isolating flood effects can be challenging, and if data are incomplete it may not always be possible to assess both the direct and indirect effects. Computable general equilibrium models have become an increasingly popular tool for disaster impact assessments (Pauw, Thurlow, and van Seventer 2011). Within the CGE literature, the most common analyses are ex-ante—to assess the impacts of hypothetical events (see, for example, Boyd and Ibarraran 2009)—and ex-post—to evaluate the impacts of historical events (for example, Horridge, Madden, and Wittwer 2005).

This flood impact assessment uses the DCGE model presented in chapter 2 to assess the potential impacts of floods in Yemen. We use an ex-ante approach by using historical data from the 2008 Hadramout flood to quantify the economy-wide repercussions and impacts on hunger incurred by the losses of cropland, fruit trees, and livestock and the changes in fishery yields over a period of

five years. This approach allows us to look beyond the reductions in regional agricultural production as well as to isolate the impacts on the broader economy and households.

According to the Emergency Events Database of the Centre for Research on the Epidemiology of Disasters (CRED, http://www.emdat.be/), approximately 100,000 people are affected annually by disasters triggered by natural hazards in Yemen. Over the past two decades, Yemen has become increasingly vulnerable to natural disasters, mainly due to high population growth, largely uncontrolled urbanization, and lack of environmental controls. In addition, the concentration of physical assets and vulnerable populations in high-risk areas has led to an increased exposure to adverse natural events.

Floods are the most significant and recurring disaster in Yemen. Over the last two decades and since the unification of the Arab Republic of Yemen and the People's Democratic Republic of Yemen in May 1990, Yemen suffered 19 floods or flash floods. CRED's International Disaster Database (http://www.emdat.be/) ranked floods as the top four natural disasters in Yemen since 1990 with regard to economic damages. Floods also account for the highest death tolls (8 of the top 10 are floods) and affected people (nine of the top 10 are floods).

Table 4.5 Human Toll and Damages Due to Floods and Flash Floods in Yemen, 1993–2008

Year	*Month*	*Type*	*Duration (days)*	*Location*	*Killed*	*Affected*	*Damage (million US$)*
1993	February	Flood	5	Lahej, Abyan, Aden	31	21,500	1.5
1996	May	Flood	4	Taiz, Hodeida	7	5,000	10
	June	Flood	12	Shabwa, Mareb, Hadramout	338	238,210	1,200
1998	August	Flash flood	16	Shihab Valley, Red Sea Port	70	240	n.a.
	March	Flood	3	Tihama Valley, Hodeidah		3,000	n.a.
1999		Flood		Socotra archipelago		19,750	n.a.
2002	August	Flood	1	Hodeidah, Taiz, Hadramout	28		n.a.
	July	Flood	2	Raima	13	700	n.a.
	July	Flood	2	Salafiyah	10		n.a.
	April	Flood		Salafiyah, Hadramout	2		n.a.
2003	June	Flood	3	Haija, Taiz	15		n.a.
2005	August	Flash flood	1		12	721	n.a.
	April	Flash flood	3	Sanaa, Hodeidah	10		n.a.
2006	April	Flash flood	2	Dhamar, Hodeidah, Manakha	25	320	n.a.
	February	Flash flood	3	Dhamar, Maabar	5	2,000	n.a.
2007	August	Flood			50		n.a.
	March	Flash flood	3	Hadramout, Ibb	36	618	n.a.
	January	Flood	3	Raima, Dhamar	7	2,000	n.a.
2008	October	Flash flood	2	Hadramout, Al-Mahara	75	25,000	1,235

Source: GY/WB/UNISDR/IFRCC 2009.
Note: n.a. = not applicable.

This impact assessment quantifies the agricultural, economy-wide, and nutritional impacts of floods in Yemen and focuses on the October 2008 Tropical Storm 03B, for which a joint assessment of the Government of Yemen, the World Bank, the United Nations International Strategy for Disaster Reduction, and the International Federation of the Red Crescent and Cross serves as the basis (GY/WB/UNISDR/IFRCC 2009). This storm caused severe rain and flooding over the eastern parts of Yemen for about 30 hours, resulting in total rainfall of almost 91 millimeters (versus 5–6 millimeters during normal periods). The total catchment area of about 2 million hectares collected some 2 billion cubic meters of water. Given the topography of the affected area (mountainous terrain, rivers, and flat valleys), this large quantity of water in the catchment area led to severe flash floods in the valleys, with water surges reaching up to 18 meters in some areas. The storm also damaged boats and fishing equipment along the coastline of the Arabian Sea. Overall, Tropical Storm 03B resulted in one of the largest natural disasters to hit Yemen in the last decade (GY/WB/UNISDR/IFRCC 2009). The heavy rain and flooding seriously affected the Hadramout and Al-Mahara governorates, which were declared disaster areas on October 27, 2008. The Wadi Hadramout region (which is part of the Internal Plateau, or AEZ 5 in the model) was hit the worst by the disaster, sustaining 67.5 percent of the total damage and losses. Hadramout's coastal areas (called Sahel and included in AEZ 4 in the model) sustained 28.6 percent of total damage and losses, whereas Al-Mahara (parts of which are divided between zone 4 and zone 5) sustained 3.9 percent of the total damage and losses (GY/WB/UNISDR/IFRCC 2009).

Table 4.6 shows the changes in cropped area (as a result of soil erosion) and livestock numbers (goats and sheep, cattle, and camel killed by the high floodwater surge). These numbers serve as the base for implementing the flood shock in the DCGE model with the assumption that changes in cropland and livestock are entirely caused by the flood event. Moreover, we differentiate between immediate damages and longer-term losses of stocks. The damage estimates are based on quantities of the damaged assets such as planted and unplanted area for seasonal crops and livestock numbers. Losses refer to potential production losses from perennials and livestock spread over four years, since it takes time for replanted trees to start bearing fruit and for young animals to produce meat and milk.

Floods Impacts on Agriculture

Agricultural activities of the Internal Plateau (zone 5) and the Arabian Sea Coast (zone 4) together contribute about 7 percent to total agricultural value added in Yemen, whereas agriculture makes up about 8.5 percent of the country's GDP. Thus, any supply-side shock affecting agriculture in these zones will have only a modest impact on national GDP but may have a substantial effect on the local economy. Yet this does not mean that income losses are confined to those engaged in agriculture in the flood area.

Table 4.6 Changes in Cropland, Number of Animals, and Fishery Yields During and After October 2008 Hadramout Flash Flood by Agroecological Zone

	Base year stocks	*Damages*	*Production losses (2010–13)*			
	2007	*2009*	*2010*	*2011*	*2012*	*2013*
	Yemen		Internal Plateau (Zone 5)			
Cropped area (acres)	1,480,000	−81.6	7.7	56.1	24	22.6
Sheep and goats (head)	17,003,000	−3.4	−1.6	−1	6.2	0
Cattle (head)	1,495,000	−1.4	1	−0.2	0.2	0.4
Camel (head)	366,000	−6.3	4.8	−0.6	0.6	0
		Arabian Sea Coast (Zone 4)				
Cropped area (acres)		−39.3	3.7	27	11.5	10.9
Sheep and goats (head)		−0.8	0.6	−0.8	1	0
Cattle (head)		−1.6	1.3	−1.6	2.1	0
Camel (head)		−3.2	2.8	−3.4	4.4	0
Fish (real value added)		−6.7	5.7	−7	9.1	0

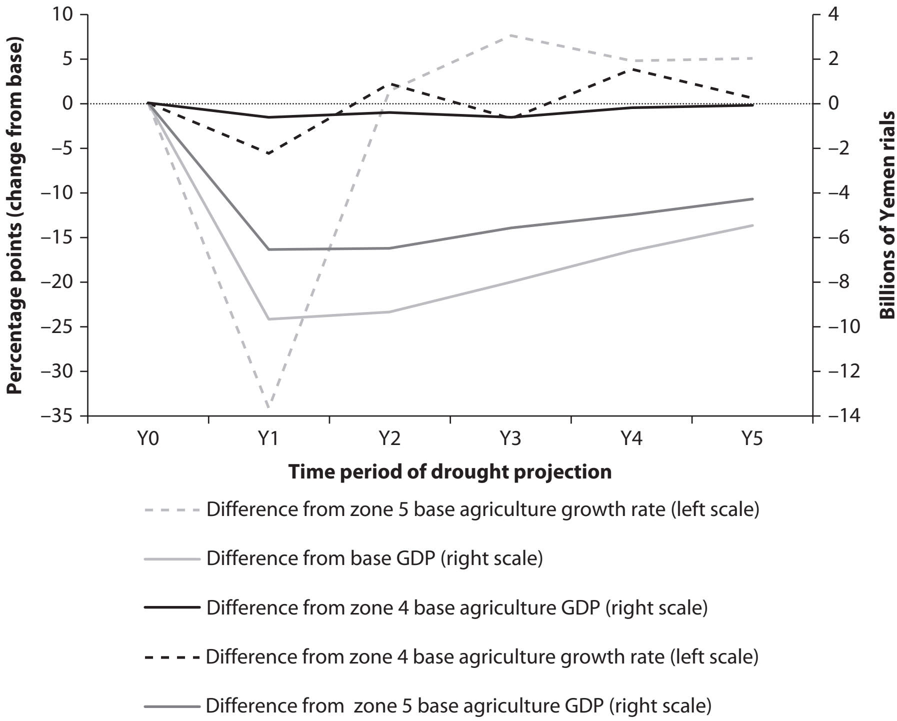
Source: Calculations based on GY/WB/UNISDR/IFRCC 2009.

In fact, between 26 and 20 percent of total annual income losses occur outside the affected zones' agricultural sectors. The flood drastically changes the factor endowments in zones 4 and 5 with spillover effects to national goods and factor markets. Aggregate private consumption is reduced, driven by a loss of real incomes both through higher prices and the loss of income from land, capital, and labor. Demand for imports increases, especially for agricultural goods and food processing to substitute for previously domestically produced goods. Imported food and domestically produced food are not perfect substitutes, which leads to an increase in domestic food prices, albeit at lower levels than would be the case without international trade. Higher inflation leads to an appreciation of the real exchange rate, which discriminates against exports, and together with increasing imports leads to a worsening of the trade balance. Investment picks up over the whole period, reflecting the necessity to replace stocks that have been lost during the flood.

Real-income losses in zone 5's agricultural sector range between YRl 6.6 and YRl 4.3 billion annually (US$33 and US$22 million) during and in the aftermath of the flood; the losses are much lower in zone 4's agriculture (between YRl 0.6 and 0.1 billion). The total cumulated real income loss over a period of five years amounts to 180 percent of preflood regional agricultural value added. Annual real-income losses are slightly lower in total agriculture as lower wages in zone 5 induce outmigration into other zones' agricultural sectors. Moreover, total real GDP losses range between YRl 10 and 6 billion, driven by general equilibrium repercussions resulting from losses of incomes in affected zones and higher prices.

Figure 4.7 shows that the flood leads to a sharp reduction in zone 5's growth rate and economic output, while the reduction is much lower in zone 4.

Figure 4.7 Loss in Regional Agricultural and Overall GDP from Flood in Yemen in Zones 4 and 5



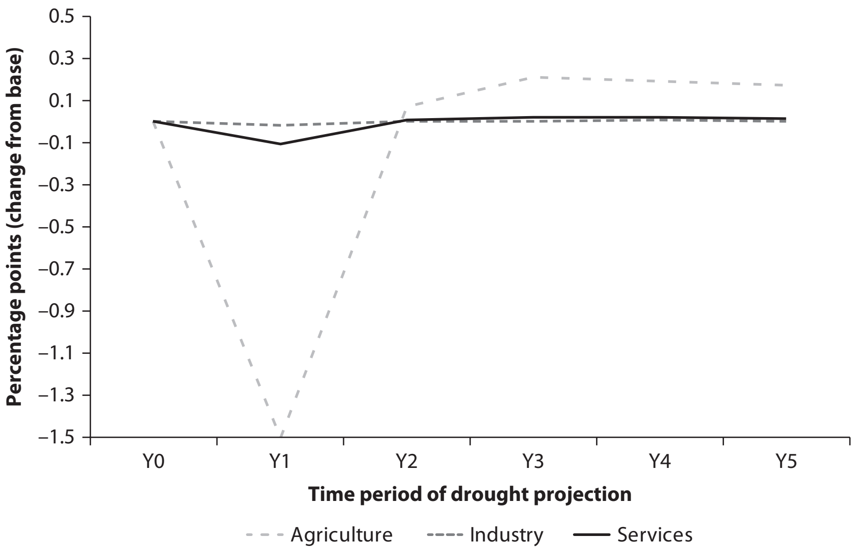
Source: Yemen DCGE Model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought.

Although both indicators (growth and annual real value added) in both regions decline in the first year relative to a situation without flood, the growth rates pick up more quickly than economic output. In fact, this phenomenon is common for all kinds of economic shocks: during initial phases, the decline in growth is sharpest, since even when economic output in subsequent years is as low as in the initial phase the growth rate remains flat. However, relative to a situation without the flood, output remains lower throughout the whole period. In fact, growth in both zones returns to preflood levels after two years, yet annual output only slowly catches up with levels that had been achieved without flood.

Flood Impacts on the Economy, Food Security, and Poverty

Agriculture is the sector hardest hit by flood, whereas the industrial and the service sectors are relatively more resilient (figure 4.8). The loss in cropland and animals, and the yield reductions in fisheries caused by the destruction of boats and fisheries equipment, cannot be compensated for by the resulting higher prices of agricultural commodities and lead to a contraction in

Figure 4.8 Flood Impacts on GDP by Sector in Yemen

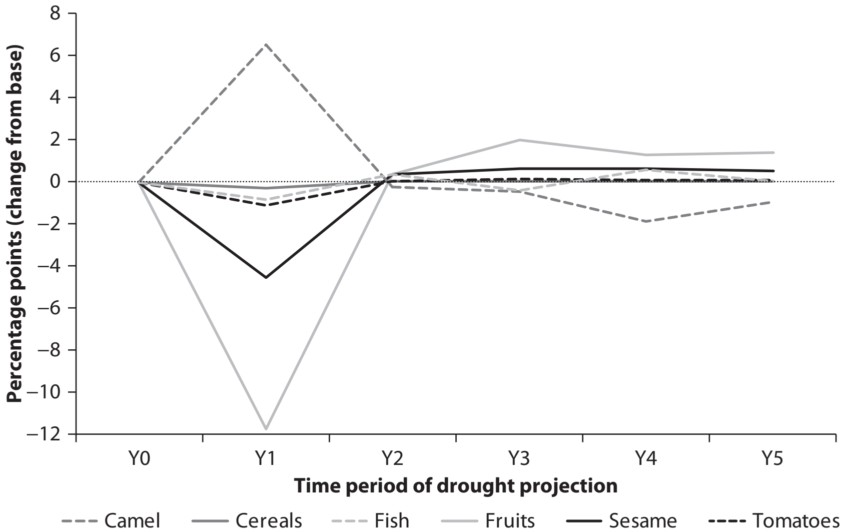


Source: Yemen DCGE Model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought.

agricultural GDP growth. In the year of the flood, the service sector also contracts slightly due to a fall in aggregate demand. However, model results suggest that industrial sectors—with the exception of food processing, which contracts slightly during the flood year and expands slightly afterward—are hardly affected by the flood. This can be mainly explained by changes in factor rents. Floods lead people to migrate out of agricultural and fishing activities seeking jobs in other sectors. This lowers the economy-wide wage rates, especially for low-skilled labor. Industrial and service sectors that use this type of labor extensively benefit from the lower labor costs and so become more competitive.

Within agricultural subsectors, fruits are the hardest hit by the flood, followed by sesame and tomatoes (figure 4.9). Fruits make up about 45 percent of zone 5's value added (but only 1.5 percent in zone 4)—followed by goats and sheep (about 20 percent), tomatoes (10 percent), vegetables and camel (each about 7 percent), and sesame (3 percent)—but given their high land intensity, fruit crops suffer more than other farm activities from the loss of soils and the uprooting of fruit trees. This is especially so during the flood year where valueadded for fruits falls by 11 percent from 2007 to 2008. Other crop activities, fishing, and total livestock also fall during the flood but regain growth momentum over the longer run with the rehabilitation of agricultural land, replanting of fruit trees, restructuring of fishing infrastructure, and animal rearing. In contrast, camel production benefits from the flood. The reason is that camel production is the most export-oriented agricultural sector in Yemen;

Figure 4.9 Loss in Agricultural GDP from Flood by Subsector in Yemen

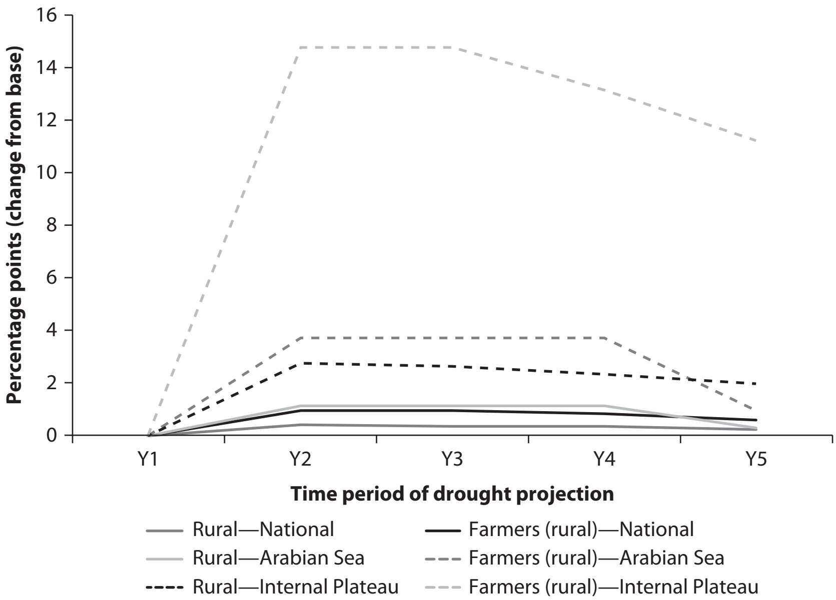


Source: Yemen DCGE Model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought.

70 percent of production is exported. As a result, the domestic producer price for camel is largely determined at the world market. Moreover, the sector uses low-skilled labor very intensively. Thus, although the sector is hurt by the real exchange rate appreciation in the base run, lower wages for unskilled labor accompanying the change in Yemen's factor endowment actually lead to lower real producer wages in camel production and provide an incentive to expand production, despite decreasing animal stocks. This result should be interpreted cautiously, as the model assumes high factor substitution elasticities between, for example, camel stocks and unskilled labor.

The countrywide hunger impacts of the flood are minor, however, there are substantial consequences at the local level and particularly among farmers in the Internal Plateau zone. Under the simulated flood scenario, the prevalence of hunger in Yemen's rural areas and among all Yemeni farmers rises by less than one percentage point compared to the baseline level (figure 4.10). Yet on the local level, the consequences are severe, especially in the areas that are directly affected by the flood. The rural population, especially farmers in the Internal Plateau zone, are hardest hit and, to a much lesser extent, the rural population in the neighboring Arabian Sea and Desert zones. In the Internal Plateau, the percentage of hungry people living from farming surges by about 15 percentage points compared to a situation with no flood. This contributes to an increase in the overall prevalence of hunger in this zone by more than 2 percentage points in the years after the flood. Moreover, the consequences for food security are long-lasting in the flooded areas. During the four years after the flood year, the prevalence of hunger among farming

Figure 4.10 Percentage Change in the Prevalence of Hunger Due to Floods in Yemen



Source: Yemen DCGE Model and microsimulation model.
Note: Y1-Y5 stands for year one to year 5 of the projected drought.

households in the Internal Plateau will decline by only less than 4 percentage points, leaving still 11 percent more suffering from hunger in the fifth year after the flood compared to the baseline level. In contrast, recovery in the less, or only indirectly, affected areas such as in the Arabian Sea zone is faster; the prevalence of hunger almost returns to its preflood levels four years after the flood occurrence.

The pace of the recovery process depends on the structure of the local economy and the characteristics of the main economic activities, in addition to the compensation measures and reconstruction efforts to be undertaken. Farm incomes and thus farmers' food security are expected to be compromised over several years mainly due to the time needed for the reconstruction of destroyed infrastructure and the rehabiliation of cropland and agricultural productivity. Given that many farmers earn large shares of their income from (perennial) fruit tree cultivation and as it takes several years until replanted fruit trees start bearing fruit, income losses and food insecurity are expected to extend over several years. The negative medium-term impacts on household income and food sufficiency can be minimized if farmers can replace the dead fruit trees with modern varieties of seedlings for fruit trees that start bearing fruit sooner than the traditional varieties. Investments for reconstruction in the areas damaged by the flood may also create income-earning opportunities and generate a development push, but this is likely to be of limited benefit to the poor farming population.

Notes

1. The top-four natural disasters in Yemen for the period 1990–2011 with regard to economic damages were all floods; see http://www.emdat.be/database.
2. Based on interviews from a fieldtrip in April 2010.
3. The household survey did not allow for identifying Bedu households.

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CHAPTER 5

Conclusions and Proposed Actions for Adaptation

Dorte Verner and Clemens Breisinger

Photograph by Dorte Verner

This book has assessed the impacts of global and local climate change on the economy, agriculture, and households of three Middle East and North Africa (MENA) countries: Syria, Tunisia, and Yemen. All three countries are currently net importers of oil and of many food commodities; this places them at risk because the major impacts of global climate change will be felt through changing world food and energy prices. Local climate change will decrease crop yields and agricultural productivity, which will affect the livelihoods of those dependent on the sector as well as the rest of the economy. The analysis has also shown that the combined effects of global and local climate change are even more damaging to the overall economy and livelihoods. The prevalence of extreme variations in climate, such as the droughts affecting Syria and the floods impacting Yemen, is likely not only to slow strides toward economic growth and development, but may reverse such strides if policies are not put in place to weather this storm.

Even under perfect climate change mitigation, world market prices for food are projected to increase. The results of this book suggest that higher global prices for food negatively affect most sectors of the economy in Syria, except for agriculture, which benefits from the higher prices. However, Syrian real household incomes decline, particularly those of poor rural nonfarm households. In Tunisia, higher food prices pose challenges to its poor. In Yemen, results from the DCGE model suggest that higher global prices for food may raise agricultural gross domestic product (GDP) in some zones, but it will lower Yemen's overall GDP growth, and decrease real household incomes.

Local climate change impacts alone will lead to lower crop yields for all three countries. In Syria, the agricultural sector suffers as a result of long-term declines in yields, and different agroecological zones will be affected differently. In Tunisia, local climate change shocks operate on the sector and on households through reduced crop yields. Results from the Tunisian DCGE model show that local climate change is welfare reducing for all household groups under both the GCM scenarios, however, farm households are most adversely affected by these yield reductions. Those households suffer income losses due to lower agricultural yields that reduce their livelihoods. Finally for Yemen, the local impacts of climate change are different under the two climate scenarios: under the MIROC scenario, agricultural GDP is somewhat higher compared to the baseline, and rural incomes are expected to rise due to the higher yields and the lower prices for sorghum and millet, whereas the urban households are largely unaffected because they hardly consume those commodities; under the CSIRO scenario, positive and negative yield changes cancel each other out, and agricultural GDP and incomes for all three household groups hardly change over the period of analysis compared to the baseline.

Over the long term, the adverse effects of both global and local climate change impacts are felt throughout the three countries. In Syria, combining local and global climate change effects slows GDP growth in all sectors. Rural households (both farm and nonfarm households) suffer the most from

climate change, but urban households are also worse off when compared with the perfect mitigation scenario. Across Tunisia, the combined climate change effects lead to negative impacts on the overall economy, the agricultural sector, and a total reduction of household incomes. In Yemen, the long-term impacts of climate change (local and global) lead to a reduction in household welfare under both the MIROC and the CSIRO scenarios. Those reductions in welfare accumulate over time and rural households suffer more from climate change than urban households. Under the MIROC scenario, farm households benefit from increasing yields, but rural nonfarm households do not and suffer both in relative and absolute terms under the MIROC and CSIRO scenarios.

The analysis also explores the impact of extreme climate variability in the form of droughts and floods that act to weaken Syria and Yemen's agricultural sector, the economy, and overall welfare. An increase in the frequency and severity of droughts in Syria would not only hurt its agricultural sector but would also hurt the Syrian economy and its poor people. Results show that the loss in economic output during drought years may reach as much as 0.8 percentage points below baseline GDP. Food security and the poor are hard hit by droughts as spiking food imports further act to increase food insecurity. Furthermore, poverty increases during a drought, and the rural nonfarm poor are hardest hit leading to an increase in the poverty rate by 0.6 percentage points over the baseline. In Yemen, climate variability may also induce heavy economic losses and spikes in food insecurity and hunger. For example, the impact assessment of the October 2008 tropical storm and floods in the Wadi Hadramout shows that agriculture in Yemen is the sector hardest hit by floods, whereas the industry and the service sectors are relatively more resilient. Due to the direct flood losses, farmers in the flooding areas suffer most in the year of the flood occurrence, where the percentage of hungry people living from farming rises by about 15 percent as an immediate result of the flood. Regional spillover effects lead to increases in hunger even in regions where the flood has no direct impact. In the neighboring Arabian Sea Coast and Desert AEZs, the percentage of hungry people in rural areas still increases due to the flood.

When interpreting the results, it is important to bear in mind some of the limitations of the modeling suite presented in this paper. While technological progress will likely be the key for successful adaptation, the model can only capture part of the adaptation, such as shifts from one existing technology to the other. However, it cannot capture potential future "breakthrough" technological advances that are not yet known. Such breakthroughs in technology in any of the sectors may have positive spillover effects into the rest of the sectors, resulting in a possible structural transformation nationwide. It is therefore possible that the estimates used and results produced may fall on the conservative side. Another limitation is that the IMPACT model (Rosegrant et al. 2008) is a longer-term model whose results focus on climate change and not on shorter-term climate variability.[1] Ideally, crop yield projections and scenarios would be

used for all major crops in Syria, Tunisia, and Yemen, however, due to the unavailability of detailed and consistent biophysical data, the model is forced to assume proxies for some of the crops. The authors also recognize the need for further research about modeling land property and inheritance, as well as capturing longer-term socioeconomic trends—such as rural–urban migration—and their impact on the adaptation of the rural and urban sectors to climate change.

Given the strong global and local impacts of climate change, and climate variability, a diverse set of policies at different levels will be required to mitigate the negative socioeconomic effects. Global price increases, declining crop yields, and droughts affect sectors and households differently, and a variety of mitigation and adaptation tools including global and national action plans, investments in agriculture, social protection, and disaster risk management must be considered.

Advancing a Global Action Plan

Richer and more developed nations have contributed the most to the greenhouse gas emissions that are causing climate change, but developing nations are more vulnerable to climate change. Developed nations bear a responsibility to support developing nations in finding ways to adapt through financing, and technical expertise. Globally and locally, some measure of redistribution may become inevitable in the near future.

The international community, including individual countries, needs to increase investment in international research and development in the agricultural sector. Research and development should not only emphasize productivity of crops and livestock but also support modified crop and livestock varieties in a climatically changing world. In general, a greater emphasis should be placed on increasing the knowledge pool at the global level.[2] This enhanced international effort should create global public goods and knowledge to help all countries increase agricultural productivity in a changing climate.

Low carbon growth should become an objective for all countries. Syria, Tunisia, and Yemen may each make a contribution toward reducing global greenhouse gas (GHG) emissions by following a more fuel-conscious policy, adopting mitigation measures such as revising their fuel-subsidy policy, limiting carbon dioxide, capturing and storing CO_2 from the atmosphere, and possibly encouraging and developing alternative fuel possibilities (Hainoun 2008a). The agricultural sector is typically the largest contributor to GHG emissions; however, this sector is also a potential mitigator of these emissions and of overall global warming if it is part of a comprehensive national development plan. International organizations and partner countries should support these efforts.

Reform of the global food system should become a priority in order to make it more resilient to climate change and other shocks and to make trade freer and better. With the inevitability of increased climate variability, trade is a crucial

mitigation and adaptation channel that would allow "…regions of the world with fewer negative effects to supply those with more negative effects" (Nelson et al. 2010). The heterogeneity with which climate change will impact countries, and regions within countries, means that Syria, Tunisia, and Yemen must rely increasingly on healthy and open trade relationships to fulfill the increasing demand for food. The result may provide the additional channels necessary to face climate variability.

Including Climate Change in National Strategies, Policies, and Investment Plans

Acknowledging and incorporating global climate change and variability—and their appropriate mitigation and adaptation measures—into national development targets and policies is critical for successful adaptation and mitigation. In general, wealthier countries and households are likely to find it easier to adapt to new challenges. Therefore, general policies and investments that foster sustainable growth will also broaden the options for adaptation for governments and citizens. In the case of food security, for example, this book has shown that prices of global food commodities are likely to rise due to general global population and income growth, to be compounded even further by climate change. Improved food security can be achieved through broad-based development, specifically by increasing and diversifying nonfood exports and increasing household incomes. Nonfood exports generate much-needed foreign exchange to purchase food commodities on international markets; accelerating growth that is export oriented and that benefits all household groups should therefore also be a primary objective to Syria, Tunisia, and Yemen to further develop in a changing climate.

Agricultural and Rural Development Policies

Crop yields are hit especially hard by the long-term impacts of climate change. Agricultural research and development and scientific advancement in breeding more drought-resistant varieties will therefore be critical to the future of rainfed agriculture and the region's increasing water scarcity challenge. Investing in the development of drought-resistant seeds and encouraging farmers to adopt these seeds may mitigate adverse consequences to rainfed agriculture and safeguard farmers from drought-induced yield losses. On-farm management practices may include shifting the planting date, switching crop varieties or crops, expanding the area of production, and increasing irrigation coverage (Burke and Lobell 2010).

Irrigation efficiency must be improved, where economically viable, to get "more crop per drop." Irrigated crops are less affected by droughts, but expanding irrigation is possible only to a limited extent in our three target countries and other countries in the MENA region that have severely constrained water

resources; increasing irrigation efficiency is necessary for the future of irrigated agriculture in Syria, Tunisia, and Yemen. While increasing irrigation efficency can increase yields, it translates only partly into water savings. A system that conserves rainfall and efficiently distributes water in other zones should also be a part of national plans for further investment in water, an increasingly scarce resource.

An important part of investment, research, and development in agriculture involves changes in crop practices, including re-evaluating optimum sowing dates, the choice of cultivars, planned plant density (Hainoun 2008b), re-evaluation and redesign of irrigation, and water-harvesting practices to sustain a healthy agricultural sector.

In addressing climate variability such as drought and floods in Syria and Yemen, it is essential to distinguish between short-term measures that improve the resilience of the agricultural sector, and long-term measures that introduce structural changes and affect the sector's profile (Easterling 1996). An example of short-term mitigation practices includes varying the planting season from year to year as necessary, as practiced by some farmers in Africa and Asia (Burke and Lobell 2010). Longer-term mitigation measures may include changing the crop varieties farmers use to adapt to changes in precipitation or temperature (Burke and Lobell 2010). If Syria is expecting a decrease in precipitation, then using faster-maturing seed varieties would reduce the time the plant has to withstand lower moisture; farmers in Yemen may require flood-resistant varieties instead. If precipitation levels are not expected to change, but temperatures are expected to increase, then longer-maturing seed varieties may be appropriate (Burke and Lobell 2010).

Structuring and legislating the livestock sector to maximize its income-generating potential in Syria and Yemen will contribute significantly to mitigation and adaptation. With the expected continuation of climate variability and increased number of drought events, the livestock sector requires extensive adaptation policies to continue contributing to rural livelihoods. Overall principles of climate-variability adaptation will be important including collecting and structuring information and data, conducting research, disseminating the findings, and monitoring the impacts. Specific sector adaptations include improving grazing management, animal bio-capacity, and market access; enhancing rural livelihoods; and increasing the studies on climate change and its impact on the Syrian and Yemeni economies (Batima 2006).

Grazing management techniques and practices need to have the conservation of the country's ecosystems as a primary objective. Land used for grazing should be used for one season, after which the herd should be moved to another piece of land and the previously grazed land restored for its next cycle of grazing. Grazing times may also be modified for the well-being of the animals by avoiding times of day when extreme weather conditions occur. Other grazing management techniques include increasing reliance on cultivated pasture lands, improving pasture yields, and increasing the conservation of pasture water sup-

ply. It will be necessary to adopt legislation that will organize the possession of land for pasture to heighten a sense of ownership and encourage pastureland development (Batima 2006).

It will also be important to improve animal bio-capacity to withstand climate change and maintain good health and productivity. This may be done by increasing supplementary feeding of animals, improving veterinary services, and introducing high-productivity breeds to withstand the expected and unexpected changes in weather (Staal 2010).

The physical, financial, social, and risk-management infrastructure will need to be improved to enhance rural livelihoods in a changing climate. This may be achieved by promoting education for rural households and increasing nonfarm income opportunities through market access to the major cities in their vicinity. These developed and sustainable channels are fundamental to developing and disseminating new technologies, information, and support to herders. One way to help mitigate risks may be to establish index based livestock insurance (IBLI) (Ayantunde, Herrero, and Thornton 2010) to provide the herders with the necessary coverage to maintain their livelihoods. Overall, any financial support scheme must not propagate moral hazard or passivity among herders but instead must increase independence and proactiveness as individuals and as herder communities (Seo and Mendelsohn 2008).

Social Protection Policies

Even if the severity and frequency of climate variability remains constant, the vulnerable are likely to suffer increasingly negative socioeconomic impacts as a result of higher population and livestock densities coupled with increasing groundwater depletion and flooding. Herders in Syria and Yemen in particular are increasingly at risk, mainly because of the sharp spike in livestock density and the competition for pastureland. Social safety nets are essential to provide the necessary channels of outreach and mitigation to the poor and vulnerable, both for critical support in times of crisis and for ongoing dissemination of information and technology.

The poorest of the poor are hardest hit by climate change and variability; improving the targeting of existing safety nets and building new ones is critical to protecting the poor. In this process, it is important to know who the vulnerable are, where they are, what they need, how to reach them, and how to receive feedback from them. Improving or extending already existing channels cuts down on new outreach costs and helps integrate national and sectoral policy into an overall objective of poverty mitigation.

Drought management and flood mitigation should be combined with social safety nets and long-term development goals. Both should become part of the overall economic development planning framework by recognizing the role of social transfers in building economic resilience among vulnerable communities; planning can be implemented by the relevant national authorities, international

agencies, and donors. Such initiatives include direct transfers, cash-for-work programs, community asset building through public works, assistance in undertaking microenterprises, and nutrition and health programs. These initiatives would work at the field level and play a key role in providing immediate relief after disasters as well as assist in recovery and rehabilitation. The effectiveness of their roles in past droughts should be evaluated to estimate present and future needs for capacity building, funding, and the possible expansion of their role in disaster management.

Disaster Risk Management Strategies

A network of extension services is crucial to risk management in the agricultural community. The network disseminates relevant information, techniques, and cultivars; and guarantees that national policies are implemented down to the individual farmer. A network also provides a strong link between farmers, scientists, and policy makers to collect information relevant to new technologies and policy making. The existence of a strong social safety net also allows for outreach and dissemination to the vulnerable in the event of a national disaster, such as an all-encompassing drought.

Index-based weather insurance can be a powerful tool to mitigate the risk to small farmers' livelihoods of weather variability and consequent crop loss. The most conventional method followed is single insurance policies that cover a single crop for a specific weather failure (Hill 2010a; Robles 2010). However, farmer uptake has been quite low and basis risk has been high. One reason for low uptake in many countries is that the crop models for these schemes operate under generic assumptions that simulate typical cropping practices within favorable environments; as such, they may not be applicable to practices on small farms in developing countries, especially if they face several input constraints and shortages not accounted for in the models (Robles 2010). Furthermore, these weather insurance policies are usually too complex for the average, poorly educated, liquidity-constrained farmer to be comfortable with. To address these challenges, innovative methods of weather insurance have been introduced in some countries (Hill 2010a, 2010b) and could be introduced in Syria, Tunisia, and Yemen as well. One tool is simple weather securities designed to insure against different weather events for different months or different phases of the crop cycle. The securities are set up against a relevant weather index, such as rainfall, and a range of weather occurrences is chosen. If the weather event falls within that range, then the farmer receives a fixed payment, which the farmer decides upon. The amount paid to the farmer will depend on how severe the weather event occurrence is, based on the weather index. The farmer decides how much to insure for and pays a percentage of that amount for the weather insurance ticket. The larger the range of weather incidents chosen, the larger the percentage of the insured amount paid for the ticket (Robles 2010).

There are several advantages to these simple weather security schemes. The insurance would be provided through groups to reduce the transaction costs for the insurance company (Martins-Filho et al. 2010), and the company would increase coverage on weather variability to small farmers, which translates to less risk to livelihoods. This would eventually eliminate the need to provide the sometimes distorted subsidies extended to farmers as a risk and income-loss mitigation tool (Robles 2010). These schemes would also provide a means to correctly quantify the benefits and drawbacks of weather variability and the accompanying insurance markets (Robles 2010). In order to operate successfully, this type of insurance requires a reliable weather index to provide timely and accurate information. Given the reliance on the group insurance structure of these schemes, strong farmer extension channels for product and information dissemination also need to be in place or in development.

It is imperative that the impacts of climate change and variability be made part of the vision and objectives of each of these three countries. Comprehensive and integrated policies to mitigate and adapt to this reality are critical to each country's growth and development path to ensure healthy livelihoods for their people.

Notes

1. The authors try to make up for that by analyzing two extreme forms of climate variability in a separate analysis affecting two of the countries under study: droughts and floods.
2. An example of research that is currently inconclusive in its application to the inevitable increase in GHG emissions is carbon dioxide (CO_2) fertilization. Further tests may shed light on how crops may fare in a world with rising CO_2 (The Economist 2010).

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APPENDIX A

Inputs Used for DSSAT Model

Agronomic Inputs

Six agronomic inputs are needed for the Decision Support System for Agrotechnology Transfer (DSSAT) model: soil characteristics, crop variety, planting dates, carbon dioxide (CO_2) fertilization effects, water availability, and nutrient levels.

Soil Characteristics

DSSAT uses many different soil characteristics in determining crop progress through the growing season. John Dimes of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Jawoo Koo of the International Food Policy Research Institute (IFPRI) collaborated to classify soil types of the FAO-harmonized soil map of the world (FAO/IIASA/ISRIC/ISSCAS/JRC 2009) into 27 meta-soil types. Each soil type is defined by three factors: soil organic carbon content (high/medium/low), soil rooting depth as a proxy for available water content (deep/medium/shallow), and major constituent (sand/loam/clay). The dominant soil type in a pixel is used to represent the soil type for the entire pixel.

The Crop Models

The crop models within DSSAT have the flexibility to represent some of the characteristics between different varieties of the same crop. For each crop, we selected a single representative variety by country. While this is not ideal, data availability challenges made it infeasible to identify and calibrate more specific varieties.

Planting Date

Climate change will alter the month when crops can be safely planted in some locations. In some locations, crops that could be grown in 2000 may not be able to be grown in 2050 (or vice-versa) as a result of climatic changes over time.

Three sets of calendars have been developed for use with the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)—one for general rainfed crops, one for general irrigated crops, and one for spring

wheat. For rainfed crops, we assume that a crop is planted in the first month of a four-month contiguous block when monthly average maximum temperature (tmax) does not exceed 37°C (about 99°F), monthly average minimum temperature (tmin) does not drop below 5°C (about 41°F), and monthly total precipitation is not less than 60 millimeters. In the tropics, the planting month begins with the rainy season. For irrigated crops, the first choice is the rainfed planting month. When that month is not feasible, a series of special cases is considered for South Asia, Egypt, and the rest of the northern hemisphere. Otherwise, the planting month is based on the dry season.

Spring wheat has a complicated set of rules. In the northern hemisphere, the planting month is based on finding a block of months that are sufficiently warm but not excessively so. If all months qualify, then the month is based on the dry season schedule. In the southern hemisphere, spring wheat is usually grown during the meteorological wintertime as a second crop. Hence, the planting month depends not on what is optimal for wheat but on when the primary crop is harvested. The planting date for the model is chosen based on a shift from the rainfed planting month. With this exception, the planting month is based on the rainy season. Developing a climate-based growing season algorithm for winter wheat was challenging. Our solution was to treat winter wheat differently than other crops. Rather than using a cropping calendar, we let DSSAT use planting dates throughout the year and choose the date that provides the best yield for each pixel.

For irrigated crops we assume that precipitation is not a constraint and that the only constraint is to avoid temperature freezing temperatures. The starting month of the irrigated growing season is identified by four contiguous months when the monthly average maximum temperature does not exceed 45°C (about 113°F), and the monthly average minimum temperature does not drop below 8.5°C (about 47°F).

Carbon Dioxide Fertilization Effects

Plants produce more vegetative matter as atmospheric concentrations of CO_2 increase. The effect depends on the nature of the photosynthetic process used by the plant species. C3 plants use CO_2 less efficiently than C4 plants, so C3 plants are more sensitive to higher concentrations of CO_2. It remains an open question whether these laboratory results translate to actual field conditions. A recent report on field experiments on CO_2 fertilization (Long et al. 2006) found that the effects in the field are approximately 50 percent less than in experiments in enclosed containers. Another report (Zavala et al. 2008) found that higher levels of atmospheric CO_2 increase the susceptibility of soybean plants to the Japanese beetle and maize to the western corn rootworm. Finally, a 2010 study (Bloom et al. 2010) found that higher CO_2 concentrations inhibit the assimilation of nitrate into organic nitrogen compounds.

DSSAT has an option to include CO_2 fertilization effects at different levels of CO_2 atmospheric concentration. For this study, all results use a 369 ppm setting.

Our aggregation process from Spatial Production Analysis Model (SPAM) pixels and the crop model results to IMPACT food production units (FPUs) results in some improbable yield effects in a few locations. To deal with these, we introduce the following caps: In the crop modeling analysis, we cap yield increases at 20 percent at the pixel level. In addition, we cap the FPU-level yield increase at 0.53 percent annually, or about 30 percent, during the period from 2000 to 2050. Finally, we limit the negative effect of climate on yield growth in IMPACT to–2 percent per year.

Water Availability

Rainfed crops receive water either from precipitation at the time it falls or from soil moisture. Soil characteristics influence the extent to which previous precipitation events provide water for growth in future periods. Irrigated crops receive water automatically in DSSAT as needed. Soil moisture is completely replenished at the beginning of each day in a model run. To assess the effects of water stress on irrigated crops, a separate hydrological model is used, as described in appendix D.

Nutrient Level

DSSAT allows a choice of nitrogen application amounts and timing. We vary the amount of elemental nitrogen from 15 to 200 kilograms per hectare depending on crop, management system (irrigated or rainfed), and country.

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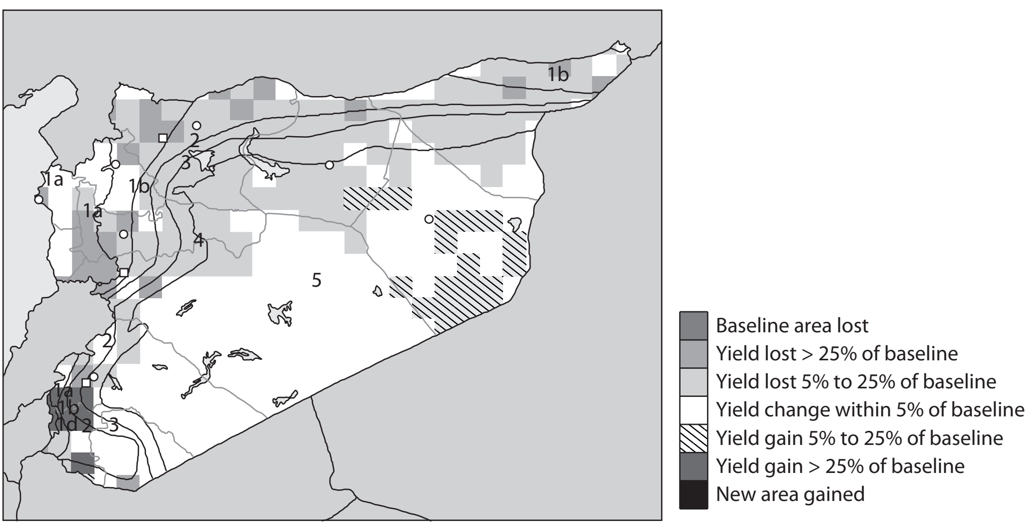
Methodology of Aggregation from Pixel Data to Agroecological Zones (the Syrian Arab Republic)

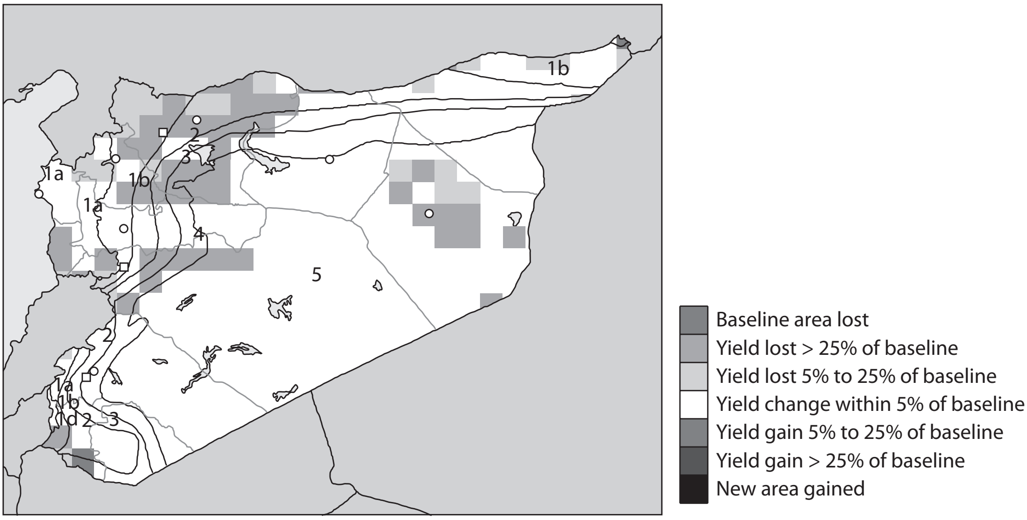
Within a Linux environment, we created a script to aggregate area and production from pixel data to agroecological zones. Yield changes for six crops under two production systems, irrigated and rainfed, were summarized at agroecological zones from a baseline dataset and two climate change scenarios (CSI and MRI) at 30 arc-minute grid cells spatial resolution. Scenarios were derived from the link among the partial equilibrium agricultural model, the hydrology modeling, and the crop modeling in International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) 2009 (see figures B.1 and B.2).

Figure B.1 Yield Change for Irrigated Wheat in Syrian Arab Republic



Source: FAO/IIASA 2000 and World Bank data.

Figure B.2 Yield Change for Rainfed Wheat in Syrian Arab Republic



Source: FAO/IIASA 2000 and World Bank data.

Reference

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APPENDIX C

Mapping Decision Support System for Agrotechnology Transfer (DSSAT) and International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) Crops to the Social Accounting Matrix (SAM) Sectors

Projected Crop Yields

The DSSAT model produced projected crop yields from 2000 to 2050, taking into account the biophysical and soil characteristics for each crop and the climatic conditions expected to prevail in the future. However, because these crop growth or yield paths are based on global assumptions, and given the paucity of the detailed information needed about Syrian crop growth and development and climatic and biophysical conditions, the current analysis makes some assumptions to adapt the yield results to the Syrian agricultural sector by agroecological zone. The results refine and adapt yield results produced by DSSAT to cover the crop sectors needed for the computable general equilibrium (CGE) analysis (see table C.1).

Durum and Soft Wheat

Yields for durum and soft wheat are not expected to differ by agroecological zone and type of irrigation used. In Syria, rainfed durum and soft wheat are grown in all zones except zone 5; we removed rainfed durum wheat grown in zones 3 and 4 and rainfed soft wheat grown in zone 4 from the analysis to satisfy the model's scaling requirements.

Table C.1 DSSAT and SAM Crop Activity Mapping for Syrian Arab Republic

DSSAT crops	*Sector in the social accounting matrix*
Durum wheat irrigated	Irrigated durum wheat
Durum wheat rainfed	Rainfed durum wheat
Soft wheat irrigated	Irrigated soft wheat
Soft wheat rainfed	Rainfed soft wheat
Barley rainfed	Barley
Other cereals	Other cereals
Vegetables	Vegetables
Fruit	Fruits
Other crops	Other crops

Source: DSSAT, SPC 2007.

Barley

Although irrigated barley is grown in all five zones in Syria, we discarded its production in zone 1 to resolve scaling issues when solving the CGE model. Rainfed barley is grown in all zones except zone 5. Furthermore, because we lacked information about barley yields in the DSSAT projections, we assumed that barley yields were the same as wheat yields.

Other Cereals

Figures for other cereals in the model are derived from yield projections for maize, and here no distinction is made for the type of irrigation used in cultivation.

Vegetables and Fruits

Yield figures for vegetables and fruits grown are assumed to be equal and to follow the yield projections for potatoes.

Other Crops

Yield projections for other crops are the simple average of the yields of irrigated groundnut and soybeans.

Given that not all the disaggregated agricultural sector activity was produced on a one-to-one basis from the IMPACT model, certain assumptions were made to map the sectors needed in the model to their equivalent in the IMPACT model. The only crops that received a one-to-one mapping were wheat and cotton (see table C.2).

Other cereals: Other cereals were represented by rice and maize.

Fruits: Figures for fruits were those projected for cotton.

Other crops: Other crops included soybeans and other grains calculated by the IMPACT model.

Sheep: Figures for sheep were assumed to equal to the figures for lamb.

Cattle: Figures for cattle were assumed to follow the projections for beef.

Chicken: The projections for poultry represented projections for chicken.

Table C.2 IMPACT and SAM Crop Activity Mapping for Syrian Arab Republic

IMPACT model crops	*DCGE model sectors*
Wheat	Wheat
Rice and maize	Other cereals
Cotton	Fruits
Cotton	Cotton
Soybeans and other grains	Other crops
Lamb	Sheep and goats
Beef	Cattle
Poultry	Chicken

Source: SPC 2007.

Table C.3 IMPACT and SAM Crop Activity Mapping for the Republic of Yemen

IMPACT crops	*Dynamic computable general equilibrium model (DCGE) traded agricultural model sectors*
Wheat	Wheat
Maize	Maize
Other grains	Other grains
Fruits	Fruits
Vegetables	Vegetables
Vegetables	Potatoes
Vegetables	Pulses
Cotton	Cotton
Lamb	Goats and sheep
Beef	Cattle
Poultry	Chicken

Source: Compilation of IFPRI IMPACT data.

Other grains: Other grains were represented by rice and maize.
Fruits, potatoes, pulses: Figures for these were those projected for vegetables.
Sheep: Figures for sheep were assumed to equal figures from lamb.
Cattle: Figures for cattle were assumed to follow projections of beef
Chicken: The projections for poultry represented projections for chicken.

Given that not all the disaggregated agricultural sector activity was produced on a one-to-one basis from the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), certain assumptions were made in order to map the sectors needed in the model to their equivalent in IMPACT. The only crops that received a one-to-one mapping were wheat, maize, and cotton (see table C.3).

Reference

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APPENDIX D

Supplementary Model Tables

Table D.1 Macro Social Accounting Matrix (SAM), Syrian Arab Republic 2007 LS billion

	Activities	*Commodities*	*Labor*	*Capital*	*Land*	*Households*	*Government*	*Direct taxes*	*Sales taxes*	*Tariffs*	*Savings-investment*	*Rest of the world*	*Total*
Activities		3,714											3,714
Commodities	1,462					1,205	248				619	772	4,306
Labor	650												650
Capital	1,553												1,553
Land	49												49
Households			650	1,141	49		21					10	1,872
Government				331				197	(262)	19		42	326
Direct taxes						197							197
Sales taxes		(262)											(262)
Tariffs		19											19
Savings-investment						470	57					93	619
Rest of the world		835		81									917
Total	3,714	4,306	650	1,553	49	1,872	326	197	(262)	19	619	917	

Source: Syria DCGE Model.

Table D.2 Macro Social Accounting Matrix (SAM), Tunisia 2001 TD million

	Activities	*Commodities*	*Factors*	*Households*	*Enterprises*	*Government*	*Rest of the World*	*Savings-Investment*	*Stock Changes*	*Direct tax*	*Import tariffs*	*Total*
Activities		52,400										52,400
Commodities	26,334			19,735		4,489	11,121	7,597	−491			68,786
Factors	24,862											24,862
Households			19,775		96		3,513					23,385
Enterprises			5,086				−1,353					3,733
Government							442			2,747	1,654	4,842
Direct tax	1,204			1,118	424							2,747
Tariffs		1,654										1,654
Savings-Investment				2,531	3,213	353	1,009					7,106
Rest of the World		14,732										14,732
Stock Changes								−491				−491
Total	52,400	68,786	24,862	23,385	3,733	4,842	14,732	7,106	−491	2,747	1,654	

Source: Tunisia DCGE Model.

Table D.3 Macro Social Accounting Matrix (SAM), the Republic of Yemen 2009 YRl billion

	Activities	*Commodities*	*Factors*	*Households*	*Government*	*Rest of world*	*Savings-investment*	*Direct tax*	*Import tariffs*	*Indirect tax*	*Total*
Activities		7,857									7,857
Commodities	2,768			3,201	854	1,415	1,378				9,616
Factors	5,089										5,089
Households			5,089		−812	104					4,381
Government						213		205	44	−279	183
Direct tax				205							205
Tariffs		44									44
Indirect tax		−279									−279
Savings-investment				975	141	262					1,378
Rest of world		1,994									1,994
Total	7,857	9,616	5,089	4,381	183	1,994	1,378	205	44	−279	

Source: Yemen DCGE Model.

Table D.4 Social Accounting Matrix (SAM) Disaggregation, Syrian Arab Republic

Activities	*Commodities (cont'd)*	*Institutions (cont'd)*
Durum wheat irrigated	Other Crops	Town household, quintile 3
Durum wheat	Sheep	Town household, quintile 4
Soft wheat irrigated	Cattle	Town household, quintile 5
Soft wheat	Camel	Rural nonfarm household, quintile 1
Barley irrigated	Chicken	Rural nonfarm household, quintile 2
Barley	Fish	Rural nonfarm household, quintile 3
Other cereals	Poultry	Rural nonfarm household, quintile 4
Fruits	Food processing	Rural nonfarm household, quintile 5
Vegetables	Manufacturing	Rural farm household, quintile 1
Olives	Mining	Rural farm household, quintile 2
Cotton	Energy and water	Rural farm household, quintile 3
Other crops	Public services	Rural farm household, quintile 4
Sheep	Other services	Rural farm household, quintile 5
Cattle	Factors	Other
Camel	Private sector, unskilled	Government
Chicken	Private sector, semi-skilled	Direct taxes
Fish	Private sector, skilled	Sales taxes
Food processing	Public sector, unskilled	Import tariffs
Manufacturing	Public sector, semi-skilled	Savings-investment
Mining	Public sector, skilled	Rest of the world
Energy and water	Capital	
Public services	Land	
Other services	Livestock	
Commodities	Institutions	
Wheat	Enterprises	
Barley	City household, quintile 1	
Maize	City household, quintile 2	
Other cereals	City household, quintile 3	
Fruits	City household, quintile 4	
Vegetables	City household, quintile 5	
Olives	Town household, quintile 1	
Cotton	Town household, quintile 2	

Source: Compilation based on disaggregation results.

Table D.5 Social Accounting Matrix (SAM) Disaggregation, Tunisia

Activities and commodities	*Factors*	*Institutions*
Wheat	Family workers	Enterprises
Other cereals	Agricultural workers	Rural farm households
Legumes	Non-agricultural workers	Rural non-farm households
Forage crops	Capital	Urban households
Olives	Rain-fed land	
Other fruits	Irrigated land	Other
Vegetables	Perennial land	Government
Other agriculture		Direct taxes
Livestock		Import tariffs
Forestry		Savings-Investment
Fishing		Rest of World
Meat		
Milk and its products		
Flour milling & its products		
Oils		
Canned food products		
Sugar and its products		
Other food products		
Beverages		
Other manufacturing and non-manufacturing industries		
Services		

Source: World Bank data.

Table D.6 Social Accounting Matrix (SAM) Disaggregation, the Republic of Yemen

Activities and commodities	*Factors*	*Institutions*
Sorghum	Private sector, unskilled	Enterprises
Maize	Private sector, semiskilled	Rural farm households
Millet	Private sector, skilled	Rural nonfarm households
Wheat	Public sector, unskilled	Urban households
Barley	Public sector, semiskilled	
Other grains	Public sector, skilled	Other
Fruits	Capital	Government
Potatoes	Land	Direct taxes
Vegetables	Livestock	Sales taxes
Pulses		Import tariffs
Coffee		Savings-investment
Sesame		Rest of World
Cotton		
Qat		
Tobacco		
Camels		
Cattle		
Chicken		
Goats and sheep		
Fish		
Forestry		
Mining		
Food processing		
Industry		
Electricity and water		
Services		

Source: World Bank data.

Table D.7 Income Elasticities Estimated for Dynamic Computable General Equilibrium (DCGE) Model, Syrian Arab Republic

	Cereals	*Fruits*	*Vegetables*	*Olives*	*Other crops*	*Sheep and goat*	*Cattle*	*Poultry*	*Fish*	*Food processing*	*Manufactures*	*Energy and water*	*Services*
City1	0.6	1.7	0.8	0.8	0.8	0.8	0.7	0.9	0.9	1.3	1.1	1.3	0.9
City2	0.6	1.2	0.7	0.7	0.8	0.8	0.7	0.8	0.8	1.2	1.1	1.2	0.9
City3	0.7	0.9	0.7	0.7	0.9	0.8	0.7	0.7	0.7	1.0	1.1	1.1	1.0
City4	0.7	0.8	0.6	0.6	1.0	0.8	0.7	0.7	0.7	1.0	1.1	0.8	1.0
City5	0.6	0.6	0.6	0.6	1.0	0.8	0.7	0.7	0.7	0.8	1.1	0.7	1.1
Town1	0.5	1.6	0.7	0.7	0.8	0.8	0.7	0.9	0.9	1.3	1.1	1.0	0.8
Town2	0.5	1.4	0.6	0.6	0.7	0.8	0.7	0.8	0.8	1.2	1.1	1.0	1.0
Town3	0.5	1.1	0.6	0.6	0.8	0.8	0.7	0.7	0.7	1.1	1.1	1.0	1.2
Town4	0.5	1.0	0.6	0.6	0.7	0.8	0.7	0.7	0.7	0.9	1.1	0.8	1.3
Town5	0.5	0.7	0.5	0.5	0.6	0.8	0.7	0.6	0.6	0.6	1.1	0.7	1.6
Rural nonfarm1	0.6	1.8	0.7	0.7	0.8	0.8	0.7	0.9	0.9	1.1	1.1	1.0	0.9
Rural nonfarm2	0.5	1.5	0.6	0.6	0.7	0.8	0.7	0.7	0.7	1.0	1.1	1.1	1.2
Rural nonfarm3	0.5	1.2	0.6	0.6	0.6	0.8	0.7	0.6	0.6	0.9	1.1	1.1	1.4
Rural nonfarm4	0.4	1.0	0.5	0.5	0.5	0.8	0.7	0.6	0.6	0.8	1.1	1.0	1.6
Rural nonfarm5	0.5	0.8	0.5	0.5	0.4	0.8	0.7	0.5	0.5	0.7	1.1	0.9	1.5
Rural farm1	0.7	1.6	0.7	0.7	0.8	0.8	0.7	1.1	1.1	1.1	1.1	1.1	0.9
Rural farm2	0.6	1.3	0.7	0.7	0.8	0.8	0.7	0.9	0.9	0.9	1.1	1.0	1.3
Rural farm3	0.4	1.2	0.6	0.6	0.6	0.8	0.7	0.7	0.7	0.9	1.1	1.1	1.4
Rural farm4	0.4	1.1	0.6	0.6	0.5	0.8	0.7	0.6	0.6	0.8	1.1	1.0	1.6
Rural farm5	0.4	0.9	0.5	0.5	0.5	0.8	0.7	0.6	0.6	0.7	1.1	0.9	1.6

Source: World Bank data.

Table D.8 Income Elasticities Estimated for the Dynamic Computable General Equilibrium Model, the Republic of Yemen

	Sorghum	*Maize*	*Millet*	*Wheat*	*Barley*	*Other grains*	*Fruits*	*Potatoes*	*Vegetables*
Rural farm	0.31	0.31	0.31	0.31	0.31	0.31	1.58	0.4	0.62
Rural nonfarm	0.31	0.31	0.31	0.31	0.31	0.31	1.58	0.4	0.62
Urban	0.28	0.28	0.28	0.28	0.28	0.28	1.39	0.4	0.57
	Pulses	Coffee	Sesame	Cotton	Qat	Tobacco	Camel	Cattle	Poultry
Rural farm	0.62	1.11	0.62	1.31	1.25	1.11	1.02	1.02	1.02
Rural nonfarm	0.62	1.11	0.62	1.31	1.25	1.11	1.02	1.02	1.02
Urban	0.57	0.81	0.57	1.14	0.93	0.81	0.49	0.49	0.49
	Goats and sheep	Fish	Forestry	Mining	Food process	Other industry	Utilities	Services	
Rural farm	1.02	1.02	0.38	1.95	1.02	1.72	0.98	2.18	
Rural nonfarm	1.02	1.02	0.38	1.95	1.02	1.72	0.98	2.18	
Urban	0.49	0.49	0.28	1.79	0.49	1.51	0.43	1.55	

Source: World Bank data.

APPENDIX E

The Republic of Yemen Nutrition Model Tables

Table E.1 Determinants of Per Capita Calorie Consumption in the Republic of Yemen

Variable	*Coefficient significance*	*Standard error*
Log of expenditure	0.857 ***	0.045
Log of expenditure squared	–0.057 ***	0.004
Log of household size	0.209 ***	0.024
Log of household size, squared	–0.061 ***	0.006
Children	–0.186 ***	0.012
Dependency ratio	–0.074 ***	0.007
Adult man	0.042 ***	0.016
Adult woman	0.077 ***	0.026
Adult gender ration	–0.020 ***	0.005
Log of household head's age	0.380 ***	0.139
Log of household head's age, squared	–0.056 ***	0.019
School attendance of household head	0.061 ***	0.305
Education level of household head	–0.024 ***	0.003
Qat consumption	–0.051 ***	0.012
Share of qat expenditure on total expenditure	–0.014 ***	0.004
Self-sufficiency level	0.122 ***	0.025
Constant	3.852 ***	0.421
Observations		12, 093
F-value		69.76
R-squared		0.271
Adjusted *R*-squared		0.267

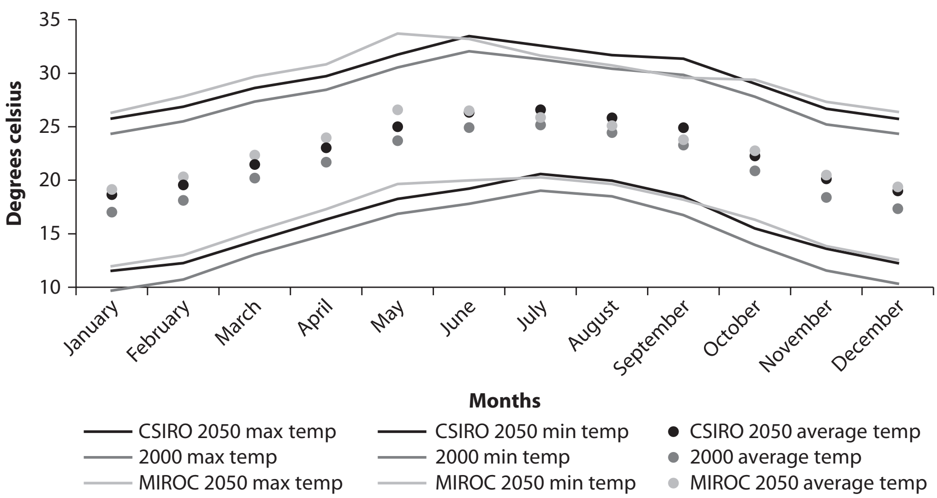
Source: Analysis of World Bank data.

Note: *** Coefficient is statistically significant at the 1 percent, 5 percent, and 10 percent level, respectively.

APPENDIX F

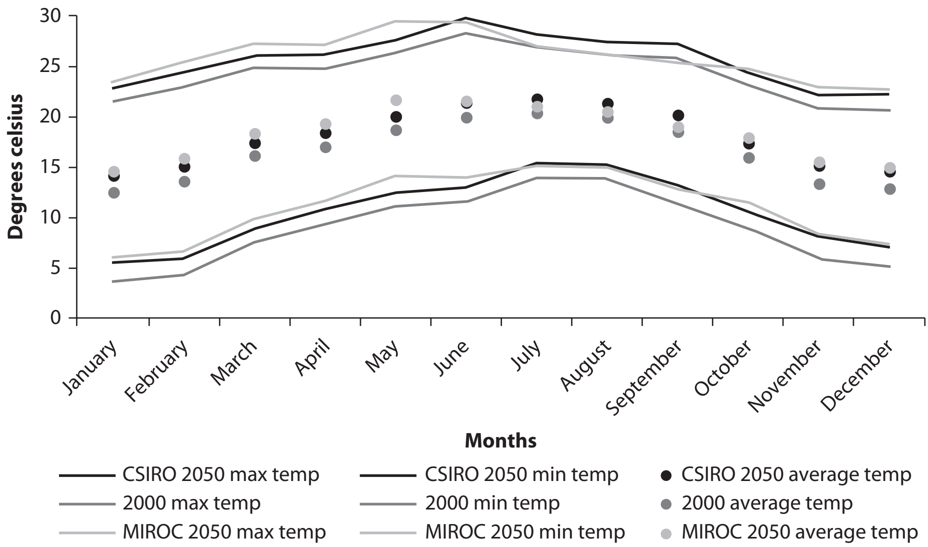
Precipitation and Temperature by AEZ (the Republic of Yemen)

Figure F.1 Lower Highlands: Monthly Temperature Highs and Lows



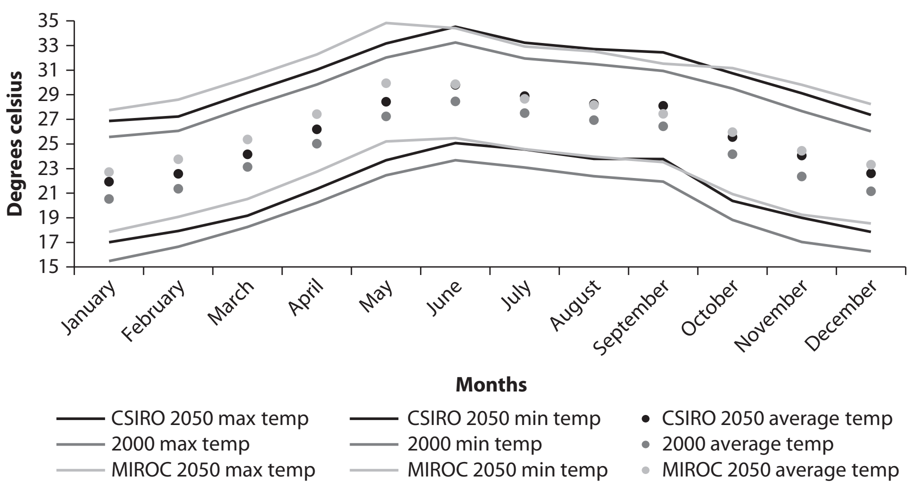
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.2 Upper Highlands: Temperature Highs and Lows



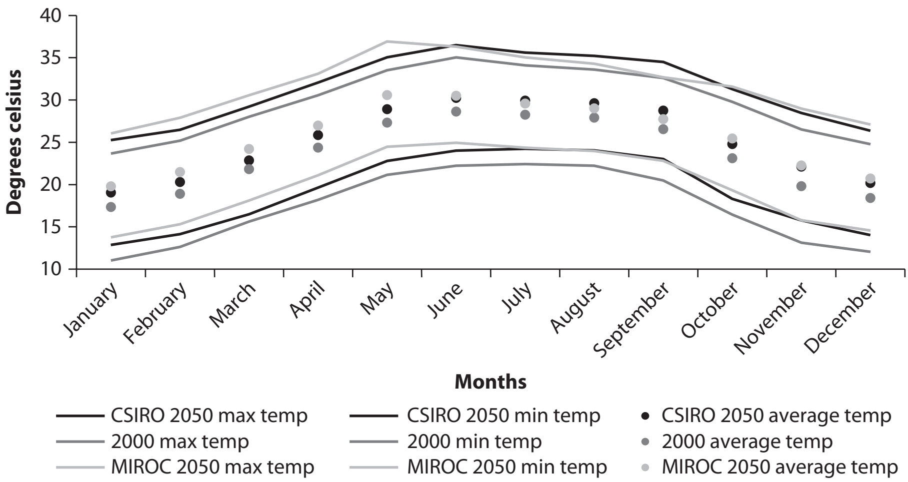
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.3 Arabian Sea: Temperature Highs and Lows



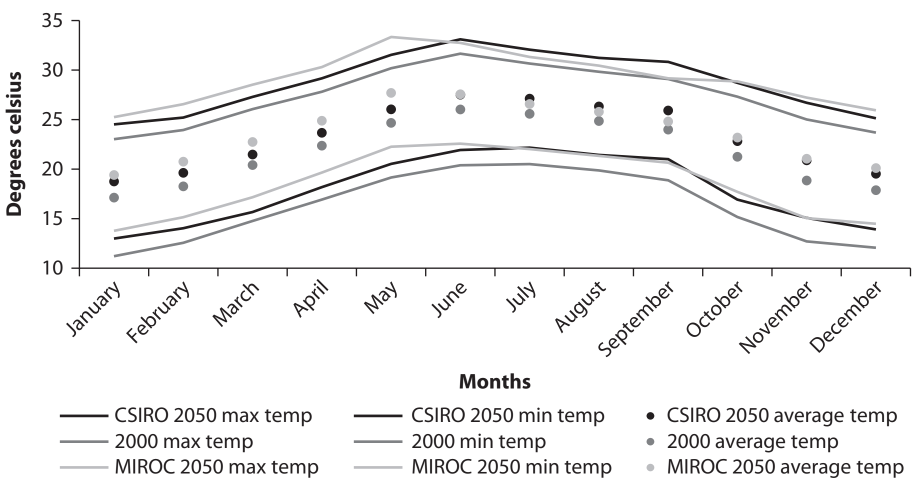
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.4 Desert: Temperature Highs and Lows



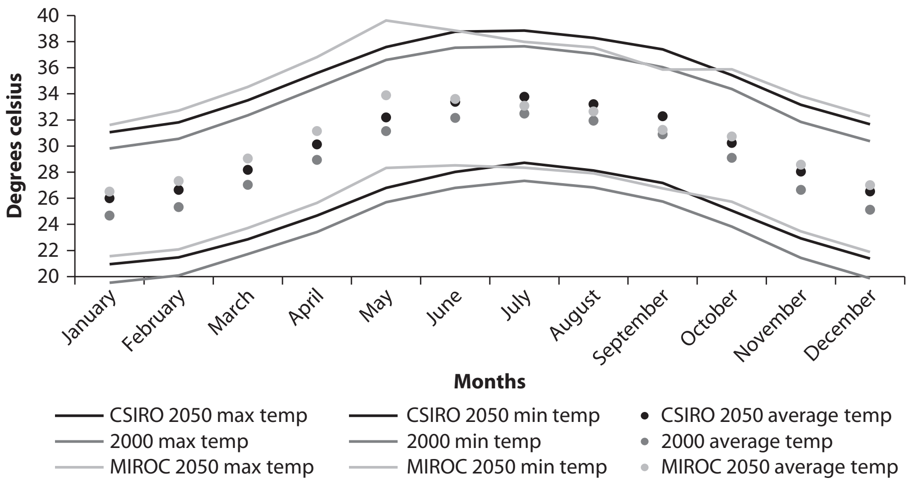
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.5 Internal Plateau: Temperature Highs and Lows



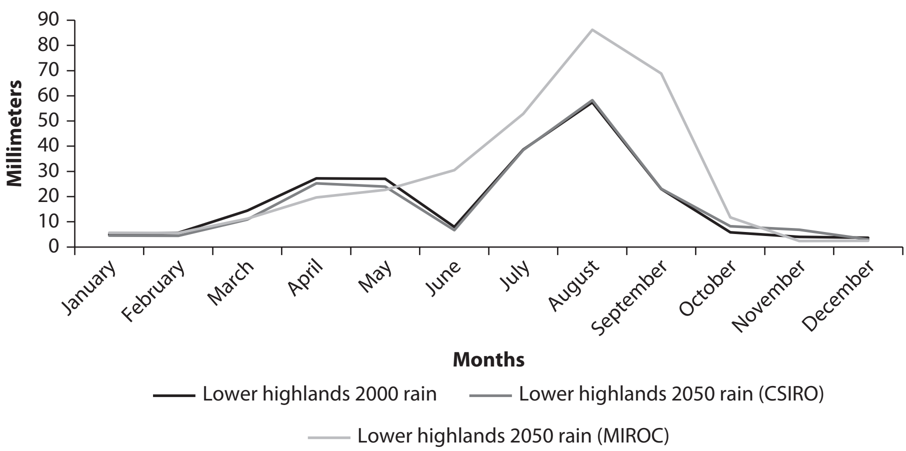
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.6 Red Sea and Tihama: Temperature Highs and Lows



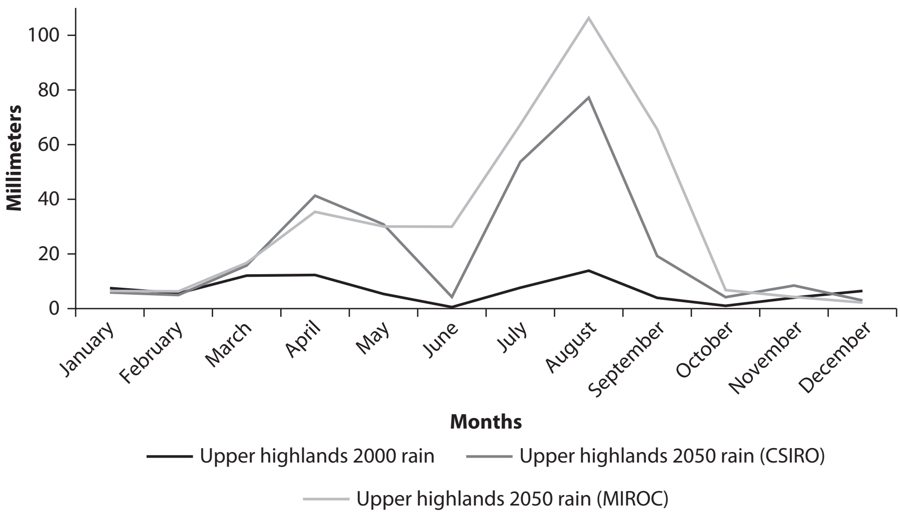
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.7 Lower Highlands: Average Monthly Rain



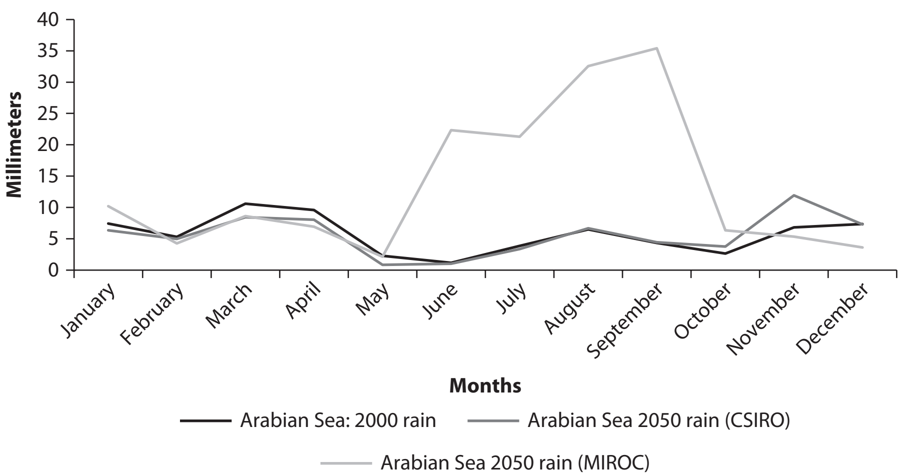
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.8 Upper Highlands: Average Monthly Rain



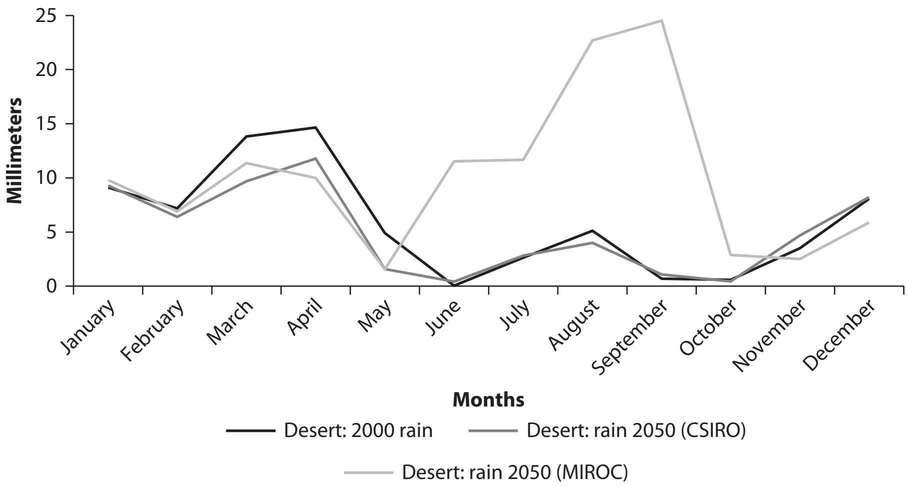
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.9 Arabian Sea: Average Monthly Rain



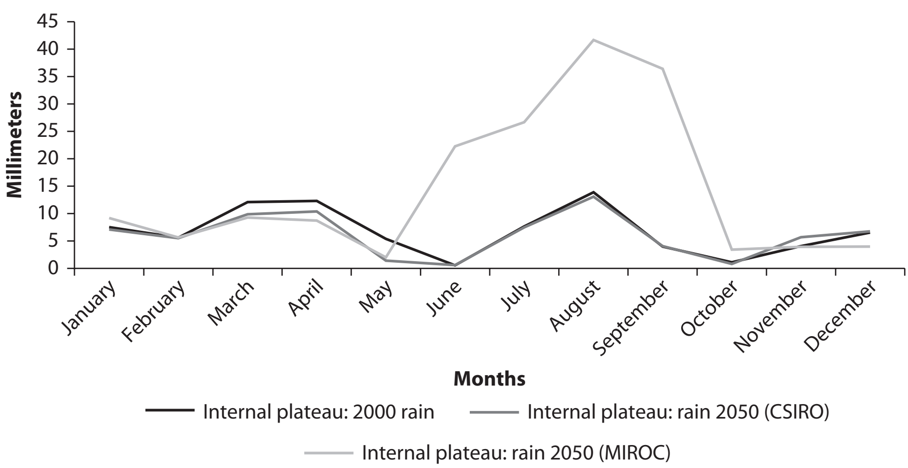
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.10 Desert: Average Monthly Rain



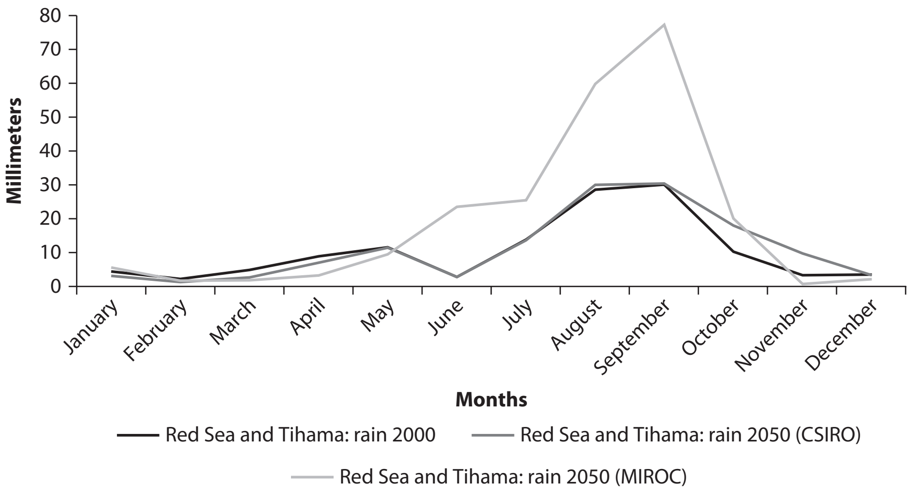
Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.11 Internal Plateau: Average Monthly Rain



Source: Calculations based on Jones, Thornton, and Heinke 2010.

Figure F.12 Red Sea and Tihama: Average Monthly Rain



Source: Calculations based on Jones, Thornton, and Heinke 2010.

Reference

Jones, P. G., P. K. Thornton, and J. Heinke. 2010. "Characteristically Generated Monthly Climate Data Using Downscaled Climate Model Data from the Fourth Assessment Report of the IPCC." Unpublished, CIAT. http://futureclim.info/.

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The major commodities affected by global climate change are food and energy prices, especially since the countries under analysis are, or have become, net importers of oil and petroleum products and many food products in recent years. Local climate change can result in decreased crop yields in the long run, which slows productivity in the agricultural sector and may have implications for the livelihoods of those dependent on the sector, not to mention the rest of the economy.

The analysis also covers what happens when both global and local climate change occur simultaneously for each country. Findings indicate that in all three countries the effects of climate change are negative for the population and the economy—GDP falls and livelihoods suffer. Furthermore, the prevalence of extreme variations in climate—such as the droughts affecting Syria and the floods impacting Yemen—highlights potentially significant drawbacks. Not only are these drawbacks likely to affect any strides toward economic growth and development, but also they may reverse such strides if appropriate policies are not in place to weather this storm.

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