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Climate Change and Floods in Yemen

Impacts on Food Security and Options for Adaptation

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ABSTRACT

This paper uses both a global and local perspective to assess the impacts of climate change on the Yemeni economy, agriculture, and household income and food security. The major impact channels of climate change are through changing world food prices as a result of global food scarcities, long-term local yield changes as a result of temperature and rainfall variations, and damages and losses of cropland, fruit trees, livestock, and infrastructure as a result of natural disasters such as recurrent storms and floods. Moreover, spatial variation in climate change impacts within Yemen means that such effects can vary across subnational regions. We develop a recursive dynamic computable general equilibrium (DCGE) model with six agroecological zones to capture linkages between climate change, production, and household incomes. We also capture changes in per capita calorie consumption in response to changing household expenditure for assessing changes in people's hunger situation as a measure for food security. Given the high uncertainty surrounding future global food prices and local yields, all simulations are run under two global climate scenarios.

The results of the CGE simulations suggest that climate-change-induced higher global prices for food will lower Yemen's overall GDP growth, raise agricultural GDP, decrease real household incomes, and increase the number of hungry people. Local impacts of climate change are different for the two climate scenarios. Overall, the long-term implications of climate change (local and global) lead to a total accumulated reduction of household welfare of between US$5.7 and $9.2 billion by 2050 under MIR or CSI conditions, respectively. Moreover, between 80,000 and 270,000 people could go hungry due to climate change. Rural households are harder hit than urban households, and among the rural households the non-farm households suffer most. This household group is projected to lose an accumulated 3.5 to 5.7 billion US$ as a consequence of longer term climate change by 2050. In addition to the longer-term climate change effects, climate variability is shown to induce heavy economic losses and spikes in food insecurity. The impact assessment of the October 2008 tropical storm and floods in the Wadi Hadramout puts the total cumulated real income loss over the period 2008-12 at 180 percent of pre-flood agricultural value added. Due to the direct flood loss, farmers in the flooding areas suffer most in the year of the flood occurrence, where the percentage of hungry people living from farming spiked by about 15 percentage points as an immediate result of the flood.

Action to mitigate the negative effects of climate change and variability should to be taken on the global and local level. A global action plan for improving food security combined with a better integration of climate change in national development strategies, agricultural and rural policies, and disaster risk management and social protection policies will be keys for improving the resilience of Yemen and Yemenis to climate change.

Keywords: Yemen, Middle East and North Africa, climate change, flood, food security, hunger, development, growth

ABBREVIATIONS AND ACRONYMS

AEZ	agroecological zones
CRED	Centre for Research on the Epidemiology of Disasters
CES	constant-elasticity-of-substitution
DSSAT	Decision Support System for Agrotechnology Transfer
DCGE	Dynamic Computable General Equilibrium
FAO	Food and Agriculture Organization
GCM	global climate model
GDP	gross domestic product
GY	Government of Yemen
HIES	household income and expenditure survey
IFPRI	International Food Policy Research Institute
IFRCC	International Federation for the Red Crescent and Cross
IMF	International Monetary Fund
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
Kcal	kilocalories
MIROC	Model for Interdisciplinary Research on Climate
MOPIC	Ministry of Planning and International Cooperation
SAM	Social Accounting Matrix
TFP	total-factor productivity
YER	Yemeni rials
WB	World Bank
WHO	World Health Organization
UNISDR	United Nations International Strategy for Disaster Reduction

1. INTRODUCTION

Climate change affects countries' economies and food security through a variety of channels. Rising temperatures and changes in rainfall patterns affect agricultural yields of both rainfed and irrigated crops. The unchecked rise of sea levels leads to loss of land, landscape, and infrastructure. A higher frequency of droughts may impair hydropower production and an increase in floods can significantly raise public investment requirements for physical infrastructure (Stern 2006; World Bank 2007; Garnaut 2008; Yu, Thurlow, et al. 2010; Yu, Zhu, et al. 2010). Such sector-level impacts will have knock-on effects on other sectors and thus influence economic growth, food security, and household incomes.

The global economic effects of climate change also affect individual countries through changes in food supply, trade flows, and commodity prices (Nelson et al. 2010; Breisinger et al. 2011). For example, Nelson et al. (2009, 2010) project that global food prices are bound to increase substantially as a consequence of continued high global population growth, changing food consumption patterns, and climate change. Taking higher food prices into consideration is therefore important for any climate change impact assessment at the country level. Depending on the net import or export position of countries and the net producing and consuming status of households of specific commodities affected, the agricultural sector, household incomes, and food security are likely to be affected differently.

For Yemen, both global and local climate change impacts are likely to matter for future development, given the country's high levels of food import dependency, food insecurity, and poverty. Yemen imports between 70 and 90 percent of cereals and is a net importer of many other food items (Ecker et al. 2010). Yemen is also the poorest country in the Arab world, with an estimated 43 percent of its people living in poverty, and is among the most food-insecure countries in the world, with 32 percent of the population hungry, that is, without access to enough food (Breisinger et al. 2010; Ecker et al. 2010). Rural–urban inequalities are high. The number of food-insecure people living in rural areas, at 37.3 percent, is more than five times higher than in urban areas (17.7 percent) (Ecker et al. 2010). Within rural areas, rural nonfarm households have higher food-insecurity rates than farm households.

The ongoing uprising is hitting the Yemeni economy and the poor hard. Although no recent estimates exist to date, it is clear that sharp declines in oil exports, foreign aid, and tourism plus double-digit inflation since the beginning of 2011 have further increased the number of poor and food-insecure people. Climate change may add to the already huge development challenges that Yemen is facing, including the lack of job-creating growth within the oil-dependent economic structure, a distorted economic incentive system coupled with an inefficient social transfer system, rapidly depleting oil and water resources, and the growing production and consumption of qat, a mild narcotic.

A post revolution Yemen may provide a huge opportunity for urgently needed reform of economic strategies and policies. In recent years, a number of reform initiatives have emerged, most of which have been implemented only partially and with significant delays. Advice from the International Monetary Fund and the World Bank on preparing for the transition to a non-oil economy has had limited traction, particularly in the context of record world oil prices and increasing political and security constraints. However, the sharp decline in oil output since 2007 and the global food crises in 2007–2008 and 2010–2011 have triggered several policy initiatives, including a National Food Security Strategy, developed jointly by the National Food Security Committee and the International Food Policy Research Institute (IFPRI).

Against this background, this paper assesses how far climate change is likely to affect Yemen and thus needs to be considered in future development strategies. It focuses on the impacts of climate change on agriculture and household-level food security (taking economywide effects into consideration) and the effects of rising global food prices between 2011 and 2050. The remainder of the paper is structured as follows. Section 2 presents the analytical and empirical framework of the study and describes each of its components. Section 3 presents the results of the local, global, and combined climate change impact assessment, and Section 4 analyzes the effects of floods. Section 5 concludes with recommendations for climate change adaptation action.

2. ANALYTICAL AND EMPIRICAL FRAMEWORK

Global Impacts: IFPRI IMPACT Model

The challenge of modeling climate change impacts arises in the wide-ranging nature of processes that underlie the working of markets, ecosystems, and human behavior.[1] The analytical framework used in this paper integrates various modeling components that range from the macro to the micro and from processes driven by economics to those that are essentially biophysical in nature. This section gives an overview of the model, data, and assumptions; more technical details can be found in Rosegrant et al. (2008) and Nelson et al. (2009, 2010).

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is a partial equilibrium agricultural model incorporating 32 crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes and meals, sugar, and fruits and vegetables. IMPACT distinguishes 115 countries (or in a few cases country aggregates), within each of which supply, demand, and prices for agricultural commodities are determined. Large countries are further divided into major river basins. The results are called food production units. The model links the various 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.

The IMPACT climate-change-modeling system combines a biophysical model (the Decision Support System for Agrotechnology Transfer [DSSAT] crop-modeling suite, Jones et al. 2003) 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. For future climate, we use the Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change that runs using the Commonwealth Scientific and Industrial Research Organisation (CSIRO) A1B and the Model for Interdisciplinary Research on Climate (MIROC) A1B models. For more information on the downscaling methodology, please refer to Breisinger et al. (2011). We assume that all climate variables change linearly between their values in 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 emissions proceed linearly; that is, we do not see a gradual speedup in climate change. The effect of this assumption is to underestimate negative effects from climate variability.

Local Impacts: Impacts on Yields

Yield changes are determined for the six major agroecological zones (AEZs) making up Yemen. The projected yields come from simulations using crop models in the DSSAT crop-modeling framework. 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). We considered four crops important to Yemen: maize, millet, sorghum, and wheat.[2] The DSSAT crop models are process-based crop simulation models. They require a large amount of input data but then can step through the prospective growing

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[1] This section draws on Nelson et al. (2009).

[2] The dynamic computable general equilibrium (DCGE) model described in the following section uses several outputs from the global partial equilibrium IMPACT model as drivers for agricultural and climate-change-related aspects. As a global-scale model, the climate change drivers in IMPACT are based on a resolution that is relatively coarse when compared with a medium-sized country such as Yemen. Thus, even though the global projections are useful as the *boundary conditions* for the country-level CGE model, the production shifters for the intracountry regions can be improved upon, if sufficient local data are available.

season on a daily basis and model how the plant grows, uses water and nutrients, responds to the weather, and ultimately accumulates mass in the harvested portion of the plant. This specificity makes the crop models a powerful tool for assessing the potential effects of climate change on crop yields at a very local geographic level, which can then be aggregated for use in the economic models.

The most important inputs for this application were the choice of planting dates and the climatic conditions. The planting dates were chosen via a two-step process. First, the generally prevalent planting seasons were determined by region: 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 all 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.

The climatic conditions were chosen to be consistent with those in the IMPACT world market price projections: baseline 2000 and 2050 climates as projected by CSIRO A1B and MIROC A1B downscalings from the FutureClim product (Jones et al, 2010). 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. Of course, the temperatures and rainfall amounts do change, resulting in sometimes dramatically different yields. Since the crop simulation models require daily weather 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. For each individual planting date, 40 years of simulations were run using different weather for each one. Thus, for one planting month, the final average yield was based on 80 separate weather realizations (40 realizations times two dates).

Once the yields were determined for each 5-arcminute pixel in Yemen, they were aggregated up to the AEZ level. The AEZ yields were 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. Summing across these provides the total production. Summing only the production areas provides the total area. Then the average yield is simply the total production divided by the total area. The production areas by crop within each pixel were assigned by looking in the Yemen Food Security Atlas (IFPRI and MOPIC 2010) and spreading out the area evenly within each district.

Yemen Dynamic Computable General Equilibrium Model

Climate change affects world prices and local agricultural production with implications for the Yemeni economy. Moreover, spatial variation in climate change impacts within countries means that such effects can vary across subnational regions. We therefore develop an economywide model for Yemen with six AEZs (Figure 2.1) to capture the major linkages between climate change, production, and households. The dynamic computable general equilibrium (DCGE) model used in this paper is consistently constructed with the neoclassical general equilibrium theory. The early version of this DCGE model can be found in Thurlow (2004), whereas its recent applications to Yemen include Breisinger, Diao, and Thurlow (2009). A summary of the main equations can be found in Table A.1.

Producers in the model are price takers in output and input markets and maximize profits using constant-returns-to-scale technologies. Primary factor demands are derived from constant-elasticity-of-substitution (CES) value-added functions, whereas intermediate input demand by commodity group is determined by a Leontief fixed-coefficient technology. The decision of producers between production for domestic and foreign markets is governed by constant-elasticity-of-transformation functions that distinguish between exported and domestic goods in each traded commodity group in order to capture any quality-related differences between the two products. The export price is determined by the world price times the exchange rate adjusted for any taxes and subsidies. Under the small-country assumption, Yemen faces perfectly elastic world demand curves for its exports at fixed world prices. The revenue-maximizing equilibrium ratio of exports to domestic goods in any traded commodity group is determined by the endogenous interaction of the relative prices for these two commodity types.

Figure 2.1—Agroecological zones in Yemen

Zone 1: Upper Highlands
Zone 2: Lower Highlands
Zone 3: Red Sea and Tihama Plain
Zone 4: Arabian Sea Coast
Zone 5: Internal Plateau
Zone 6: Desert

Source: Authors' creation.

On the demand side, imported and domestic goods are treated as imperfect substitutes in both final and intermediate demand under a CES Armington specification. In line with the small-country assumption, Yemen faces an infinitely elastic world supply at fixed world prices. The equilibrium ratio of imports to domestic goods is determined by the cost-minimizing decisions of domestic agents based on the relative tax-inclusive prices of imports and domestic goods.

The model distinguishes among various institutions, including enterprises, the government, and 18 household groups comprising rural farm and nonfarm households as well as urban households residing in each of the six regional zones. Households and enterprises receive income in payment for the producers' use of their factors of production. Both institutions pay direct taxes and save according to their respective marginal saving propensities. Enterprises pay their remaining incomes to households in the form of dividends. Households use their incomes to consume commodities according to a linear-expenditure-system specification as derived from the Stone–Geary utility function. The government receives revenue from activity taxes, sales taxes, direct taxes, and import tariffs, and then makes transfers to households, enterprises, and the rest of the world. The government also purchases commodities in the form of government consumption expenditures, and the remaining income of the government is saved (with budget deficits representing negative savings). All savings from households, enterprises, the government, and the rest of the world (foreign savings) are collected in a savings pool from which investment is financed.

The model includes three macroeconomic accounts: government balance, current account, and a savings-investment account. To bring about balance in the macro accounts, it is necessary to specify a set of macro closure rules, which provide a mechanism through which balance is achieved. A savings-driven investment macro closure is assumed such that investment is endogenously determined by the sum of private, public, and foreign savings. Private savings are assumed to be fixed proportions of net enterprise and household income. In the government account, the fiscal deficit and therefore public savings are endogenous, with government demand fixed and all tax rates held constant, so that government savings or dis-savings depend on the level of economic activity. Finally, for the current account, both the time path of foreign savings in foreign currency terms and the nominal exchange rate are assumed to be fixed while the real exchange rate adjusts to maintain external balance. The model's numeraire is the nominal exchange rate.

There are six labor categories in the model, differentiated by their skills (unskilled, semiskilled, and skilled) and their dominating employment in public or private sectors. All types of labor are assumed to be fully employed and mobile across sectors. The assumption of full employment is consistent with widespread evidence that, whereas relatively few people have formal-sector jobs, the large majority of working-age people engage in activities that contribute to gross domestic product (GDP). Capital is also assumed to be fully employed and mobile across sectors reflecting the long-term perspective of this study. In agriculture, cultivated land is fixed and cannot be reallocated across crops in response to shocks. This assumption reflects the scarcity and overuse of water in Yemen and thus partly reflects the limited growth potential of the agricultural sector due to water constraints. Moreover, cropping decisions are made in the beginning of the period before the realization of climate shocks is imposed.

Long-run sectoral factor productivity growth is specified exogenously. Within the CGE model, the decisions of consumers, producers, and investors change in response to changes in economic conditions driven by different sets of climate outcomes, as do market outcomes. The model allows a degree of endogenous adaptation within periods, with changes in labor and capital allocation across sectors and crops in response to shocks.

The DCGE model is specifically built to capture the economic, distributional, and nutritional effects of climate change in Yemen. Given the importance of agriculture for income generation and the satisfaction of consumption needs, the model captures both the sectoral and spatial heterogeneity of crop production and its linkages to other sectors such as food processing, manufacturing, and services. The model includes 26 production activities and commodities, nine factors of production, and 18 household types. The 21 agricultural production activities are split into livestock (four), fishing (one), forestry (one), and crop production activities (15), where all agricultural production activities are specific to each AEZ. Other production sectors and commodities included in the model are mining, including oil (one), food processing (one), (other) industry (one), electricity and water (one), and services.[3] Major data sources for the social accounting matrix (SAM) construction include the latest supply-use table from the Central Statistics Organization, the balance of payments from the Bank of Yemen, government budget data from the Ministry of Finance, the 2008 *Agricultural Yearbook* from the Ministry of Agriculture and Irrigation (MOAI 2009), and the latest *Household Budget Survey* (2005–2006) (CSO 2006). These data sources have been complemented with information from the International Monetary Fund and the World Bank.[4]

The model runs from 2009 to 2050 and is recursive dynamic, that is, the dynamics occur between 2009 and 2050 in each year. Investments are savings driven, and savings grow proportionally to household income. In the baseline scenario, as well as in all other scenarios, we assume that the nominal exchange rate is fixed and serves as the numeraire. The government budget is flexible, which means that the government can adjust to changes in revenues and spending by increasing or decreasing the budget deficit. Government consumption, which is exogenous, is assumed to grow at 4 percent annually. The Yemeni workforce is expected to grow at the same rate as the population grows following an average long-term trend of 2 percent as projected by the United Nations Population Division (2010). Labor supply is thus assumed exogenous in the model, and labor is fully mobile across sectors. It is split into skilled, semiskilled, and unskilled labor and by occupation in government and the private sector. Accordingly, there are different wage rates for labor employed within the public and the private sectors determined by the market equilibrium between total labor supply and total labor demand. Capital is fully employed and mobile to reflect the long-term perspective of this paper. Land is fixed, which means that current cultivated land cannot be expanded in the future. This assumption reflects the scarcity and overuse of water in Yemen and thus partly captures the limited growth potential of the agricultural sector due to

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[3] For a detailed list of production activities and commodities, factors of production, household types, and other accounts of the SAM, see Table A.2.

4 The macro SAM is shown in Table A.3.

water constraints. Agriculture accounts for about 90 percent of total water usage in Yemen, and addressing the severe water constraint becomes imperative for Yemen's agricultural sector as well as its economy as a whole. Annual total-factor productivity (TFP) growth changes in all nonagricultural and agricultural sectors from 2009 to 2050 complete the set of values for the exogenous variables. TFP for nonagricultural sectors is assumed to grow at 1 percent annually, and TFP for the agricultural sectors is assumed to grow at annual rates of 0.5 percent. This two-speed TFP growth in agriculture and nonagricultural sectors reflects the expected structural change under a business-as-usual scenario that is observed in all successfully transforming countries (Breisinger and Diao 2008). Under this baseline scenario, the share of the agricultural sector in Yemen declines from an initial 8.4 percent of GDP to 4.6 percent of GDP by 2050.

The model captures some autonomous adaptation to climate change. Yield changes from the DSSAT model enter the production function of the CGE model. These crop-specific and AEZ-specific changes in productivity change the returns to factors and 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. Or imported food can replace locally grown food when relative prices of locally grown food increase (and vice versa). A set of several elasticities guides such changes. The main elasticities include the substitution elasticity between primary inputs in the value-added production function, which determines the ease with which, for example, capital can be substituted for by labor inputs; the elasticity between domestically produced and consumed goods and exported or imported goods such as rice and wheat; and the income elasticity in the demand functions. The income elasticity with regard to food, for example, decides how consumers react to higher prices. We estimated the income elasticity for Yemen from a semi-log inverse function suggested by King and Byerlee (1978) and based on the data from the household income and expenditure survey HIES (Table A.4). For the factor substitution elasticity we choose 3.0; the elasticity of transformation is 4.0; and the Armington elasticity is 6.0 for all goods and services.

The model includes 18 representative household groups for distributional and nutrition effects. 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. This differentiation of household groups allows us to capture the distinctive patterns of income generation and consumption and the distributional impacts of climate change. The DCGE model is also linked to a nutrition simulation model, which allows for the endogenous estimation of climate change impacts on food insecurity, which we refer to as hunger in the following text due to the indicator chosen.

Yemen Nutrition Model

For assessing changes in people's hunger situation 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. 2011). The model has households' per capita calorie consumption 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 and educational level, their levels of food self-sufficiency and qat consumption, and regional and seasonality patterns.[5] 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.[6]

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[5] See Table A.5 for the regression results.

[6] The standard deviation of the elasticity is 0.148.

To simulate the hunger effects of climate change, 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)

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

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). Thus, households with calorie consumption levels below the household-specific threshold are considered as calorie deficient, or hungry. Using household size and population estimates from the 2010 revision of World Population Prospects (UN Population Division 2010), we calculate the prevalence rate and number of hungry people.

Based on the DCGE and hunger microsimulation model, we design four sets of scenarios. The first set captures the global impacts of climate change, and the second set assesses the local impacts of climate change. The third set combines the two to assess the joint effects, and the fourth looks at the impacts of flood (Table 2.1). Within the first set of scenarios, we design three scenarios: scenario 1 changes the world food prices consistent with IMPACT results under perfect mitigation; scenario 1A explores climate-change-related price effects under MIROC A1B, with the assumption that no climate change impacts are felt locally in Yemen; and scenario 1B is a scenario to test the sensitivity of results to alternative price projections under CSIRO A1B (see Figure 3.1 for alternative price changes). Scenario 2 imposes the yield changes from the DSSAT model on a crop-by-crop level and by AEZ. The related matching between DSSAT results and CGE production activities is shown in Appendix B. Results for scenarios 1A–3B are reported as a change from the perfect global mitigation scenario to isolate the climate change effects, whereas those for scenarios 1 and 4 are presented relative to the baseline.

Table 2.1—Climate change scenarios

Scenario	Change in model	Input
Baseline	See text	See text
Global impacts of climate change		
Scenario 1	Perfect mitigation, compared to base	IMPACT, Perfect mitigation
Scenario 1A	Climate change	IMPACT, MIROC A1B
Scenario 1B	Climate change	IMPACT, CSIRO A1B
Local impacts		
Scenario 2A	Crop yield changes	DSSAT MIROC A1B
Scenario 2B	Crop yield changes	DSSAT CSIRO A1B
Joint impacts		
Scenario 3A	1A and 2A	IMPACT and DSSAT, MIROC A1B
Scenario 3B	1B and 2B	IMPACT and DSSAT, CSIRO A1B
Joint impacts		
Scenario 4	Changes of cropland and livestock, and fishery yields	See text

Source: Author’s compilation.

3. IMPACTS OF CLIMATE CHANGE IN YEMEN

Structure of the Yemeni Economy, Household Incomes, and Food Security

Oil and agriculture are the two mainstays of the Yemeni economy, but both are under threat, thereby increasing the country's vulnerability to global commodity price changes. Oil reserves are set to run out by the beginning of the next decade, and aquifers upon which irrigated agriculture depends have been seriously depleted in recent years. Although oil is still the dominant sector, oil production is on a declining trend, indicating that other sectors in the economy will have to contribute increasingly to growth. In the absence of new oil discoveries, it is estimated that Yemen may become a net importer of oil as soon 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 (International Monetary Fund 2009 and Table 3.1). Yemen is also a net importer of major food items, including maize, wheat, other grains, livestock, fish, and processed food. Agriculture's trade orientation 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 20 and 10 percent to agricultural GDP, respectively (Table 3.2). Qat 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. Zones 5 and 6 are the major producers of sesame and camel, however. 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 3.1).

A major determinant of food security at the household level is household income. Dividing up households according to socioeconomic characteristics, such as their location and occupation, allows for the analysis of income and distributional effects of climate change. 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. As expected, household income levels are strongly related to factor and human capital endowments. As Table 3.3 shows, 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 dominating income source of rural nonfarm households is unskilled and semiskilled labor.

Table 3.1—Structure of the Yemeni economy by sector, 2009

	GDP	Private consumption	Export share	Export intensity	Import share	Import intensity
Sorghum	0.3	0.6	0.0	1.4	0.0	0.4
Maize	0.1	0.8	0.0	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	0.0	2.4			3.8	99.8
Fruits	0.9	1.5	0.5	12.0	0.3	10.0
Potatos	0.4	0.7	0.2	9.3	0.0	1.1
Vegetables	1.1	2.3	0.1	2.0	0.1	3.2
Pulses	0.2	0.4				
Coffee	0.2		0.5	54.7	0.0	2.6
Sesame	0.0		0.0	10.4		
Cotton	0.1		0.0	5.3	0.0	3.3
Qat	2.8	5.5				
Tobacco	0.2	0.8			0.8	61.1
Camel	0.1		0.5	71.0	0.0	15.5
Cattle	0.4		0.1	2.3	0.2	10.0
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	0.1	0.0	0.3
Forestry	0.2	0.7			0.5	41.9
Mining	22.5	1.0	88.7	95.0		
Food processing	4.0	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, of which:	100.0	100.0	100.0	18.0	100.0	24.0
Agriculture	8.4	21.5	2.1	4.5	16.3	34.4
Nonagriculture	91.6	78.5	97.9	19.2	83.7	22.7

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.

Table 3.2—Agricultural value-added by zone and crop, 2009 (billions of Yemeni rials and percent)

	Zone 1		**Zone 2**		**Zone 3**		**Zone 4**		**Zone 5**		**Zone 6**		**Total**	
Activity	Billions YER	Per-cent	Billions YER	Per-cent	Billions YER	Per-cent	Billions YER	Per-cent	Billions YER	Per-cent	Billions YER	Per-cent	Billions YER	Per-cent
Sorghum	7.36	5.25	5.10	3.09	3.65	4.71	0.07	0.67	0.10	0.54	0.00	0.01	16.29	2.68
Maize	2.50	1.78	4.09	2.48	0.35	0.46	0.01	0.06	0.01	0.04	0.00	0.02	6.96	1.12
Millet	1.83	1.31	0.55	0.33	2.59	3.35	0.03	0.29	0.01	0.03	0.00	0.00	5.01	0.96
Wheat	1.03	0.73	6.05	3.66	0.17	0.22	0.00	0.00	0.19	0.97	0.05	1.95	7.48	1.23
Other grains	0.19	0.14	3.53	2.14	0.04	0.05			0.01	0.05	0.00	0.03	3.76	0.91
Fruits	4.55	3.25	8.35	5.06	23.87	30.80	0.15	1.35	8.81	45.81	0.02	0.84	45.76	13.86
Potatos	15.78	11.26	0.79	0.48	0.86	1.10	0.01	0.05	0.18	0.94	0.00	0.02	17.60	2.62
Vegetables	8.88	6.34	11.67	7.07	7.36	9.49	2.29	20.65	1.33	6.91	0.04	1.34	31.56	8.25
Tomatos	10.78	7.69	3.62	2.19	5.22	6.74	0.20	1.77	2.04	10.62	0.03	1.26	21.90	4.68
Pulses	5.77	4.12	0.70	0.43	1.51	1.95	0.19	1.70	0.05	0.25	0.01	0.34	8.23	1.26
Coffee	0.29	0.21	7.41	4.49	0.02	0.03							7.73	1.21
Sesame	0.03	0.02	0.04	0.02	0.34	0.44	0.00	0.03	0.59	3.07	0.27	10.45	1.27	0.48
Cotton			0.24	0.15	5.02	6.48	0.05	0.41	0.00	0.00		0.00	5.31	5.17
Qat	55.95	39.93	84.18	50.99	0.06	0.08	0.00	0.01	0.00	0.00	0.02	0.57	140.20	18.93
Tobacco			0.11	0.06	8.54	11.01	0.01	0.07					8.65	1.97
Camel	0.22	0.16	0.52	0.31	0.28	0.36	0.52	4.71	1.20	6.23	1.34	51.09	4.07	1.82
Cattle	3.75	2.68	10.25	6.21	3.66	4.72	0.51	4.61	0.12	0.64	0.06	2.45	18.36	4.65
Poultry	17.38	12.40	10.18	6.16	1.42	1.83	0.41	3.65	0.59	3.05	0.03	1.19	29.99	4.69
Goats and sheep	3.83	2.74	7.73	4.68	2.45	3.17	2.58	23.26	4.01	20.86	0.74	28.43	21.36	7.26
Fish					10.09	13.02	4.08	36.71					14.17	16.22
Total	140.11	100.00	165.09	100.00	77.50	100.00	11.10	100.00	19.23	100.00	2.61	100.00	415.66	100.00
Percent	33.71		39.72		18.64		2.67		4.63		0.63		100.00	

Source: Yemen DCGE Model.

Note: YER: Yemeni rials.

Table 3.3—Structure of household income sources (by income type and household categories), 2009

	Private sector			Public sector			Land	Livestock	Governm.	RoW	Total
	Unskilled	Semiskilled	Skilled	Unskilled	Semiskilled	Skilled					
Zone 1, rural farm	32.6	0.4	18.5	0.8	0.6	12.2	25.3	1.0	2.9	5.8	100.0
Zone 1, rural nonfarm	31.7	21.4	10.3	5.7	3.7	17.1	1.2	0.0	1.7	7.2	100.0
Zone 1, urban	11.3	5.5	27.9	4.2	2.5	36.8	1.4	0.0	3.3	7.1	100.0
Zone 2, rural farm	21.0	2.0	17.8	0.3	0.3	3.7	33.4	1.2	5.1	15.1	100.0
Zone 2, rural nonfarm	31.7	15.8	21.9	2.5	1.3	15.9	1.8	0.0	2.7	6.5	100.0
Zone 2, urban	16.0	3.9	20.8	5.7	1.1	33.0	2.3	0.0	4.6	12.5	100.0
Zone 3, rural farm	34.5	9.9	0.8	0.0	0.0	1.2	35.4	0.9	1.9	15.5	100.0
Zone 3, rural nonfarm	67.1	4.7	21.0	0.2	0.1	2.2	1.5	0.0	0.6	2.7	100.0
Zone 3, urban	24.6	17.8	26.5	6.1	1.2	15.8	1.6	0.0	2.2	4.2	100.0
Zone 4, rural farm	4.6	45.1	7.0	1.7	0.0	2.8	6.5	2.4	17.3	12.6	100.0
Zone 4, rural nonfarm	26.9	9.8	11.8	4.0	9.8	12.5	0.1	0.0	12.4	12.7	100.0
Zone 4, urban	14.2	9.1	10.7	8.1	5.6	30.2	0.1	0.0	11.2	10.7	100.0
Zone 5, rural farm	30.0	1.8	0.0	0.5	0.2	0.3	31.1	2.3	7.7	26.1	100.0
Zone 5, rural nonfarm	9.5	27.3	29.5	1.8	7.2	7.6	1.0	0.0	3.4	12.7	100.0
Zone 5, urban	20.4	22.8	36.2	1.1	1.4	8.5	1.5	0.0	2.1	6.1	100.0
Zone 6, rural farm	82.9	0.3	0.0	1.1	1.1	2.9	1.1	0.7	3.3	6.5	100.0
Zone 6, rural nonfarm	49.9	4.0	14.1	2.0	1.0	20.2	0.0	0.0	2.7	6.0	100.0
Zone 6, urban	51.0	1.9	6.5	17.1	0.1	17.0	0.1	0.0	3.0	3.3	100.0
Rural farm	29.0	3.5	14.4	0.5	0.4	6.5	28.8	1.1	4.2	11.6	100.0
Rural nonfarm	36.4	15.6	19.7	2.7	2.2	12.9	1.5	0.0	2.3	6.6	100.0
Urban	14.7	8.1	24.2	5.2	2.6	31.2	1.3	0.0	4.6	8.1	100.0

Source: Yemen DCGE Model.

The food security situation in 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 3.4). This means that the average Yemeni consumes only 15 percent more than the 2,019 kcal/day needed to avoid hunger.

Table 3.4—Food insecurity by residential area and agroecological zones, 2009

	Food insecurity rate (percent)	Number of food-insecure people (thousand)	Per capita calorie consumption (kcal/day)	Per capita calorie gap (kcal/day)
All	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 & 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 2005–2006 *Household Budget Survey* data.

People living in rural areas are more likely to fall into food insecurity than people living in urban areas. Although the average per capita calorie consumption is higher by 200 kcal/day in rural areas than in urban areas, the average per capita calorie gap is lower by about 130 kcal/day. This difference is the result of the significantly higher calorie needs of rural people (2,106 kcal/day on average) compared with urban people (1,708 kcal/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 strongly varies between AEZs and is alarmingly high in the Internal Plateau. The food-insecurity rate presented in Table 3.4 reveals large differences in the spread of food insecurity across AEZs. The prevalence 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 to 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 terms of food security also have high percentages of urbanized population. The Internal Plateau is the only zone showing an average calorie deficit, which exceeds 140 kcal/day. Thus the availability of dietary energy (at affordable prices) in this zone is insufficient to supply all people there with adequate calories. However, districts have considerable differences in the prevalence of food insecurity.

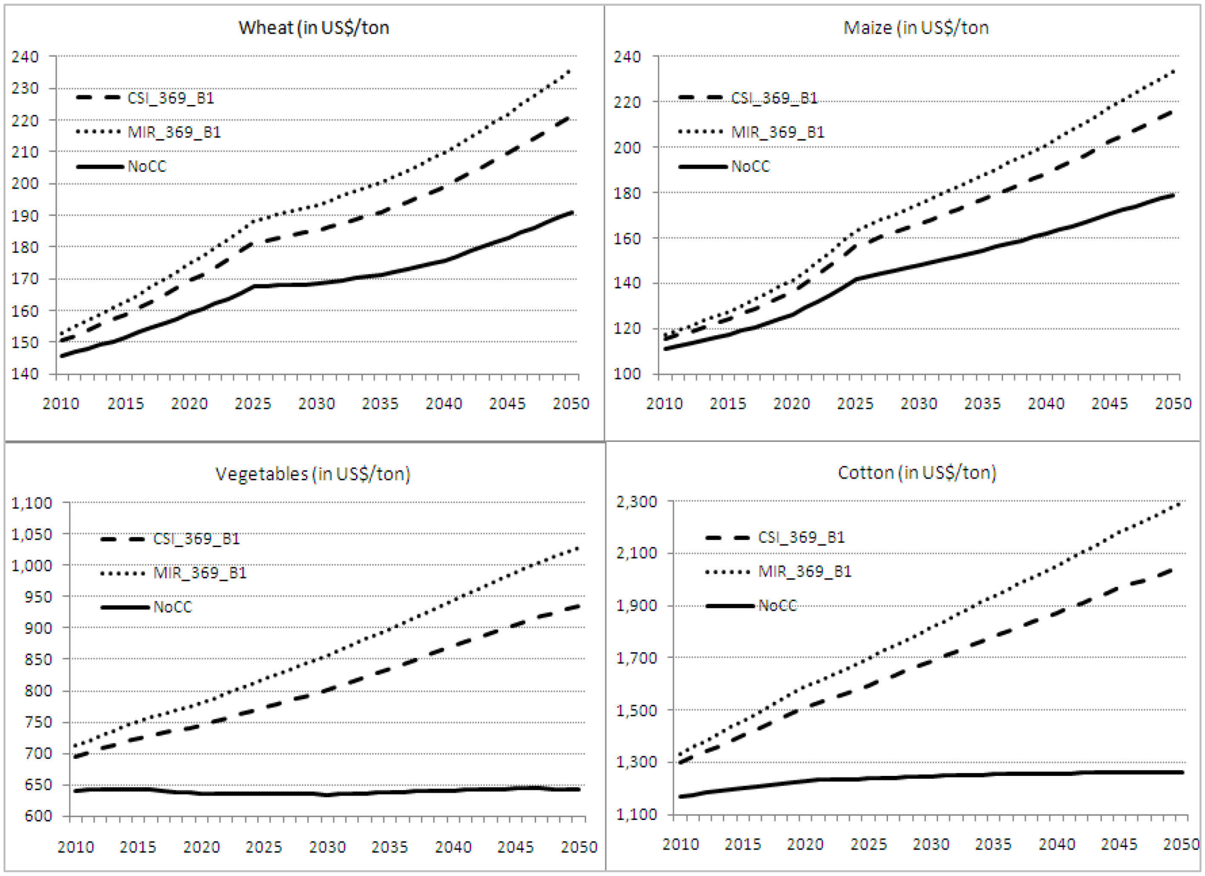
Although the rate of prevalence of food insecurity in the highlands is low, in absolute numbers most food-insecure people are living there. Yemen's highland region (comprising the Lower and Upper Highlands Zones) is the most densely populated region in the country. Seventy percent of the Yemeni population 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 of Yemen's food-insecure people reside in the Upper Highlands.

It is against these structural characteristics of the Yemeni economy and its households that the next sections analyze the potential impacts of climate change.

Global Impacts of Climate Change

World food prices are projected to increase through demographic and income effects, which are augmented by climate change. Figure 3.1 reports the effects of the climate change scenarios of two global climate models on world food prices (CSIRO A1B and MIROC A1B). It also reports the price effects under perfect mitigation. With perfect mitigation, world prices for important agricultural crops such as wheat and maize will increase between 2000 and 2050 under both scenarios, driven by population and income growth and biofuels demand. The price of maize and wheat is projected to rise by 63 percent and 39 percent, respectively. Climate change results in additional price increases—a total of 52 to 55 percent for maize and 94 to 111 percent for wheat (Nelson et al. 2009).[7] Prices of vegetables and fruits as well as cotton hardly change over time in the perfect mitigation scenario but are expected to rise considerably as a consequence of climate change. Livestock are not directly affected by climate change in IMPACT. However, the effects of higher feed prices caused by climate change pass through to livestock, resulting in somewhat higher meat prices.

Figure 3.1—Global food price scenarios



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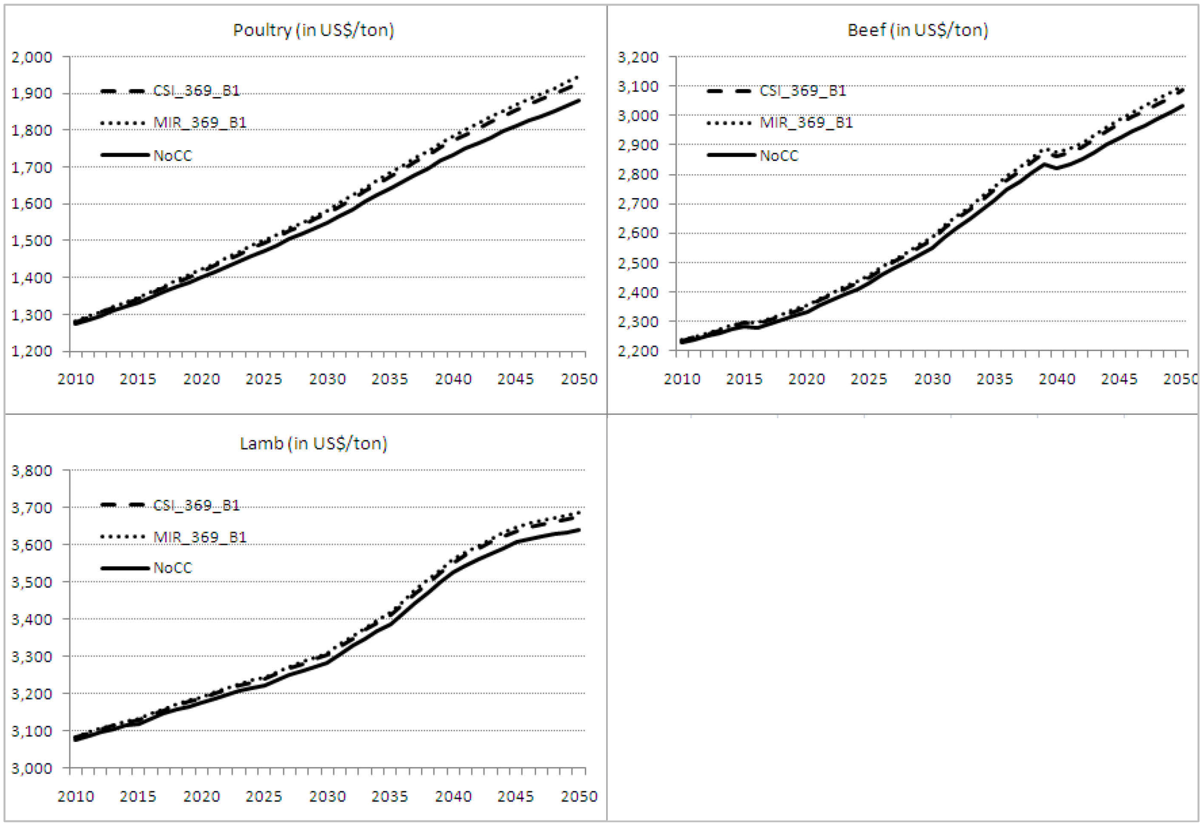
[7] In addition to various Global Climate Models (GCMs), Nelson et al. (2010) also include low, medium, and high assumptions on population and GDP per capita growth. For this study, we use the medium-level assumptions.

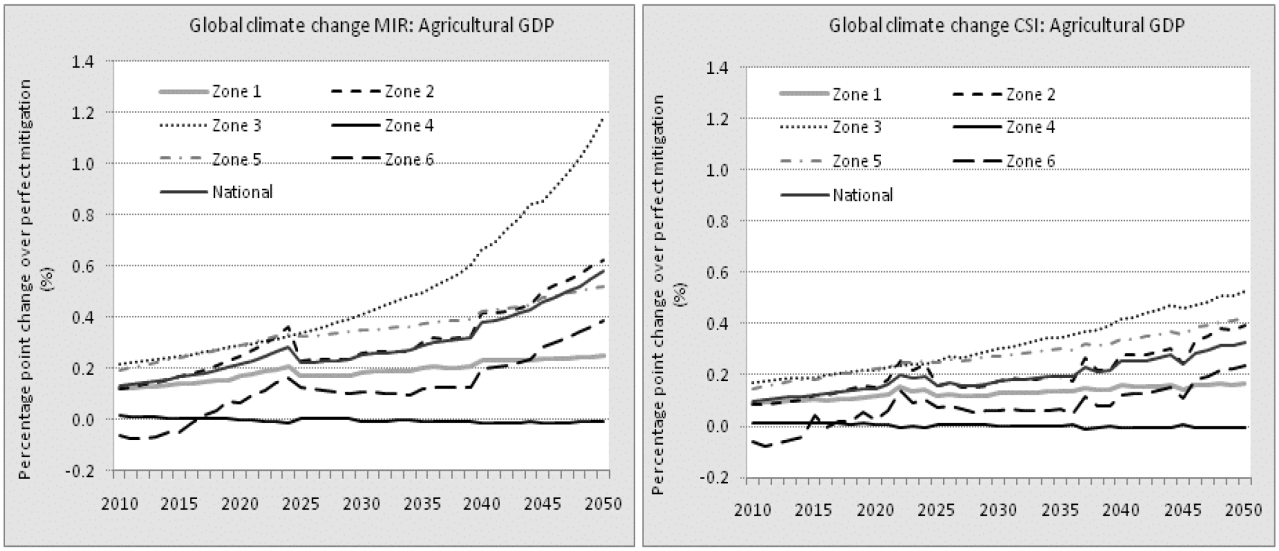
Figure 3.1—Continued



Source: IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT).
Note: NoCC stand for no climate change or perfect mitigation. Tons are in metric tons.

Results of the DCGE model for Yemen show that climate-change-related global food price increases may benefit the agricultural sector in Yemen through higher returns to production factors. Despite the fixed supply of land (to reflect 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 3.2). 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 the case of perfect global mitigation. This slower growth can be explained by Yemen's particular structure of agricultural trade, where import intensities are far higher than export intensities (Table 3.1). As a consequence, the impact of rising import prices on domestic costs of living dominates the impact of rising export prices on domestic revenues—that is, the terms of trade worsen.

Figure 3.2—Impacts of global changes on agricultural GDP, 2010–2050

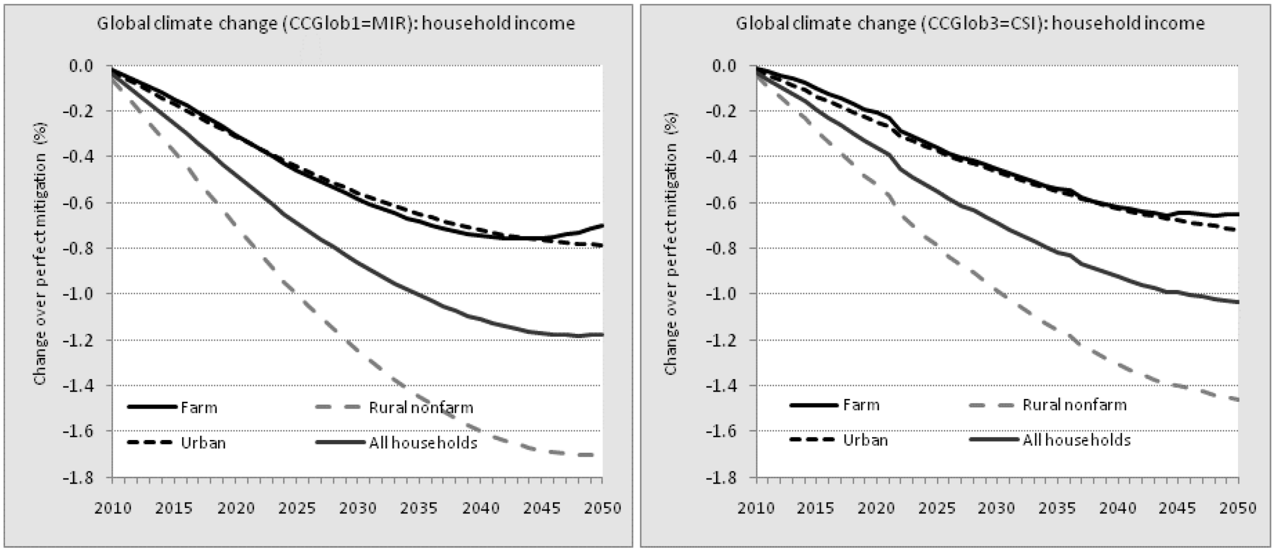


Source: Yemen DCGE Model.

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 3.2). The average annual agricultural growth rates in zones 1 through 6 range 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 predicts a more moderate rise in global food prices (Figure 3.1). 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.

But despite the positive effects on agriculture, all household groups—rural farm and nonfarm households as well as urban households—see 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 implies that their real income is on balance between 0.01 and 0.7 percent lower per year compared with the perfect mitigation case (Figure 3.3). Urban households are also negatively affected as a result of global climate change, but their losses are not higher than those for 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 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 non-negligible, with incomes lowered by more than 1 percent on average in the year 2050.

Figure 3.3—Impacts of global changes on household incomes, 2010–2050



Source: Yemen DCGE Model.

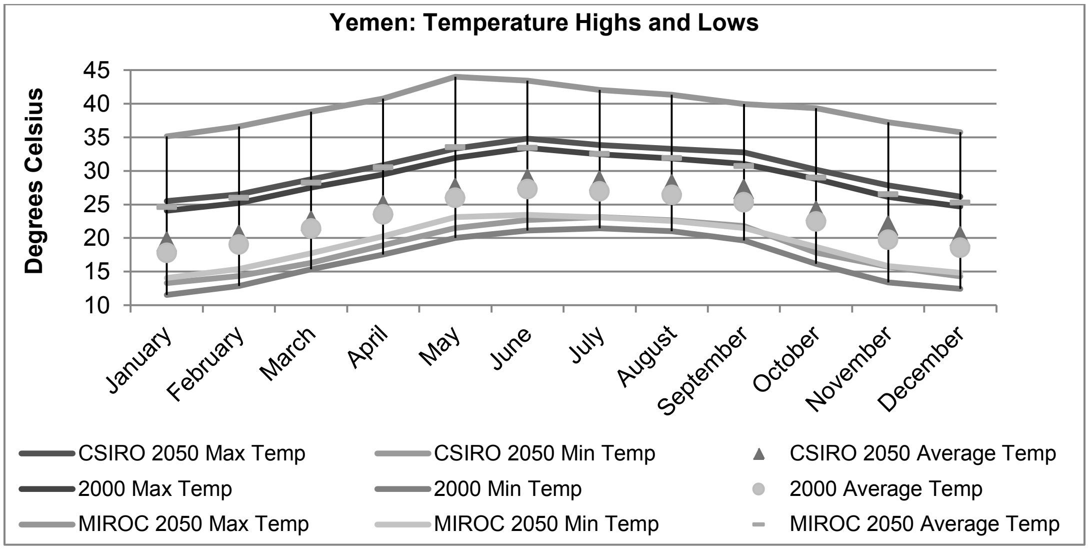
When interpreting the results of the global scenario, it is important to keep in mind that climate change affects world food prices only through changes in global production and consumption. However, this scenario did not capture how Yemeni farmers are affected by locally changing yields and related spillover effects, effects that are analyzed in the next section.

Local Impacts of Climate Change

Temperature and Rainfall Variations in 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 (Figure 3.4). Under the CSIRO scenario, variations are limited for both the minimum and maximum temperatures. CSIRO monthly maximum temperatures do not rise beyond 1.7 degrees Celsius above baseline maximum temperatures and rise 2.3 degrees Celsius 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 degrees Celsius. 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 degrees Celsius over their baseline equivalents and by more than 3 degrees Celsius over their baseline equivalents.

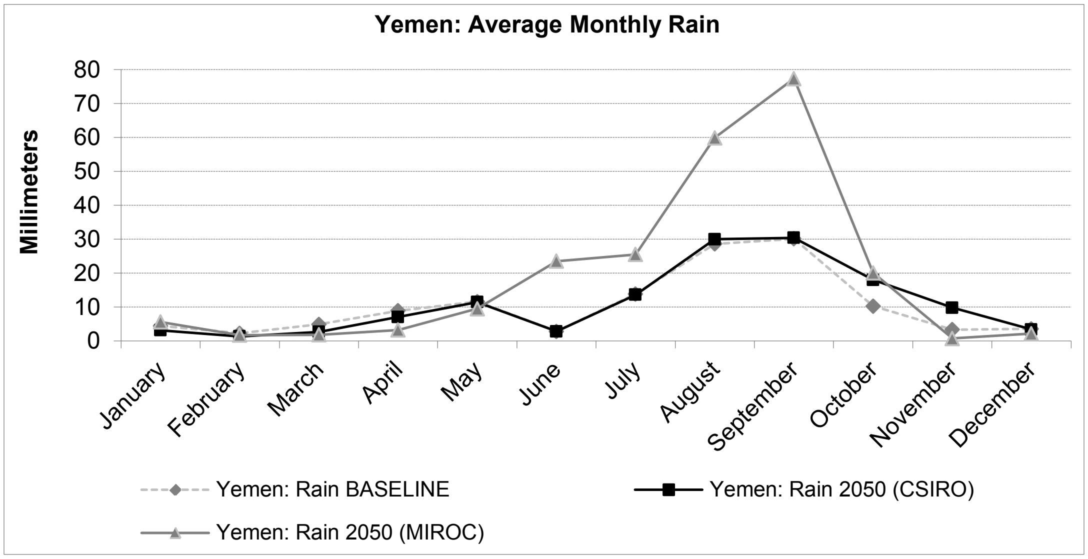
Figure 3.4—Average monthly temperature in Yemen (degrees Celsius)



Source: Authors' calculations based on Jones et al (2010).

Variation in average monthly rainfall across Yemen, as predicted by the CSIRO and MIROC GCM scenarios, is significant only for the latter scenario. As Figure 3.5 shows, average monthly rainfall (in millimeters) of the CSIRO scenario roughly follows the baseline. However, the MIROC scenario predicts an *increase* in rainfall[8] from June to October across Yemen. From October to December, rainfall under the MIROC scenario is below that predicted under the baseline. This pattern of variation (or lack thereof for the CSIRO scenario) is consistent across all of Yemen's regions with the exception of the Upper Highlands, where the rainfall predictions under the CSIRO scenario are significantly lower than their baseline equivalents.[9]

Figure 3.5—Average monthly rainfall (millimeters)



Source: Authors' calculations based on Jones et al (2010).

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[8] As previously described, variations in average monthly rainfall are compared with the equivalent baseline estimates.

[9] See Tables C.1–C.11.

Changes in rainfall and temperature are the main drivers of yield changes: all else was kept the same for the simulations. Yield changes over time due to climate change are projected to vary strongly across major grains as well as AEZs. Table 3.5 shows the results from the DSSAT crop model by AEZ. Driven mainly by the diverging rainfall patterns, projected yield changes for sorghum and millet differ substantially between the MIROC and CSIRO scenarios. Clearly, in an arid region, having more abundant water could greatly increase yield potentials. Accordingly, average sorghum and millet yields increase substantially under the MIROC scenario, whereas under the CSIRO scenario they evolve less favorably, and even decline by 0.6 percent per year in the Desert Zone.

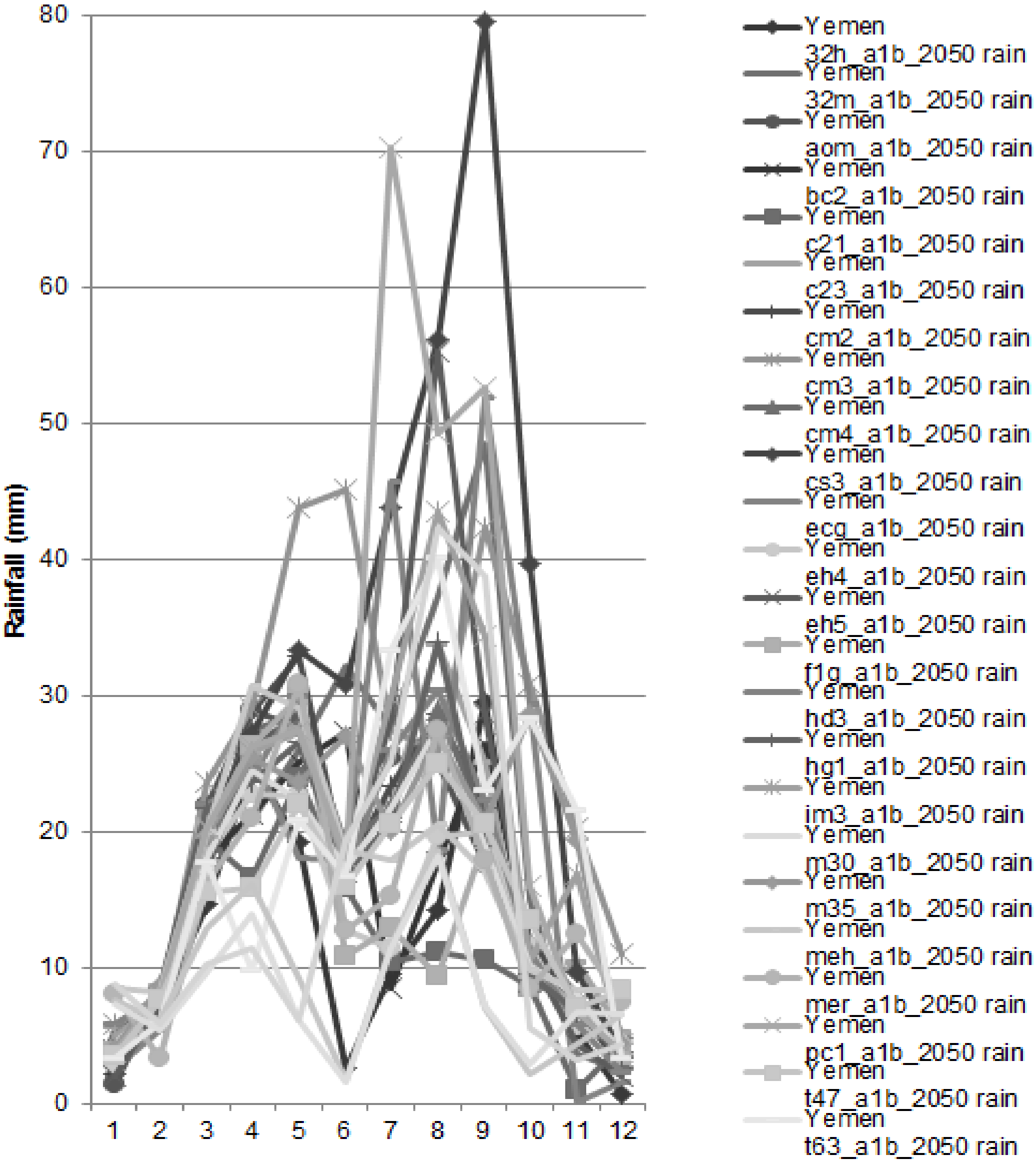
Table 3.5—Average annual yield changes for selected crops, 2000–2050

	Maize		Millet		Sorghum		Wheat	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
				MIROC (% yield changes)				
Yemen	0.1	1.4	2.6	4.0	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	0.0	1.7	2.6	3.3	2.1	2.4	-0.4	0.3
Red Sea and Tihama	-0.2	-0.5	1.7	4.0	3.5	4.0	-0.9	-1.0
Arabian Sea	-0.1	0.2	1.8	4.0	4.0	4.0	-0.2	-0.3
Internal Plateau	-0.1	0.7	4.0	4.0	4.0	4.0	-0.1	1.6
Desert	-0.1	-0.4	1.5	4.0	2.9	4.0	-0.1	-0.8
				CSIRO (% yield changes)				
Yemen	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	0.8	0.8	-0.2	-0.1
Lower Highlands	-0.1	-0.1	-0.1	0.0	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	-0.7	0.3	0.8	0.0	0.2	-0.1	-0.4
Desert	0.0	-0.5	-0.3	-0.9	-0.5	-0.8	-0.1	-0.6

Source: Authors' calculation based on DSSAT.

Given these strong yield results under the MIROC scenario, an important question that arises is how unexpected such a large increase in precipitation is for climate projections in the case of Yemen. We compared the monthly rainfall projections for the FutureClim downscalings (those used for the crop modeling) with downscalings using an alternate methodology (Tabor and Williams 2010) that has datasets available at the same spatial resolution as FutureClim for all of the major GCMs. We found that the summertime increase in precipitation is found in most of the other GCM projections and as such does not appear to be a unique artifact (Figure 3.6).

Figure 3.6—Projected monthly rainfall by 2050 under alternative GCMs for Yemen

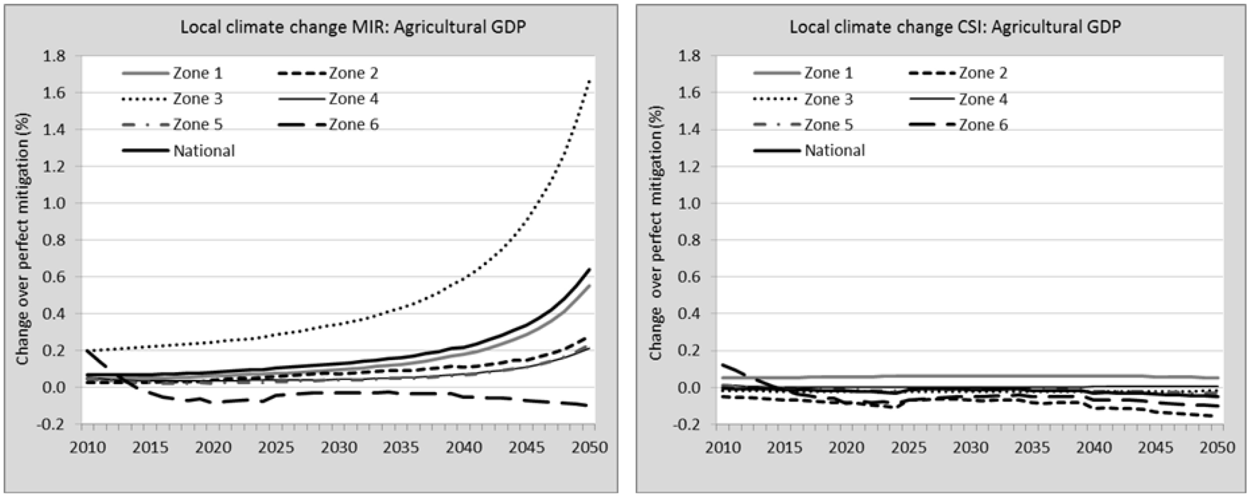


Source: Author's representation based on Tabor and Williams (2010).

Note: Data are available at http://ccr.aos.wisc.edu/climate_modeling/ipcc/futclimateinfo.html. Please note that the downscaling method (and baselines) of Tabor and Williams are not exactly the same as those used as inputs for the DSSAT modeling (for comparison: corresponding results for Tabor and Williams (dashed lines). The baseline used for DSSAT modeling is the heavy black line. The two models used for DSSAT are the heavy solid lines. All the others are based on Tabor and Williams.

Results of the DCGE model show that the local effects of climate change depend to a large extent on the adopted scenario. 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 3.7). Changes in the agricultural GDP growth rate compared with perfect mitigation range between 0.05 and 0.6 percent, whereas average annual economy-wide growth rises by 0.01 percent. Among the regions, zone 3 benefits most from local climate change. This is because in this zone 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. As a result, agricultural GDP hardly changes versus the perfect mitigation scenario.

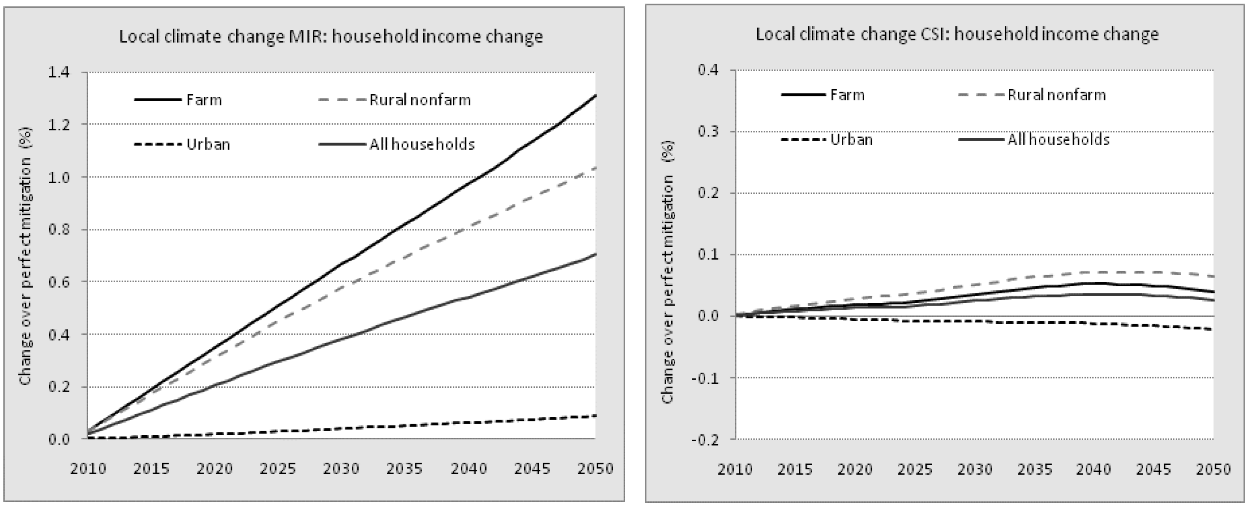
Figure 3.7—Impacts of local changes on agricultural GDP, 2010–2050



Source: Yemen DCGE Model.

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 3.8). Those households are affected through 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 3.8—Impacts of local changes on household incomes, 2010–2050



Source: Yemen DCGE Model.

Combined Climate Change Impacts

Considering the global and local effects of climate change jointly shows that the effects cancel each other out at the macro level. Economic growth does on average not differ from the case of perfect mitigation. Whereas the share of agriculture in the economy falls as part of the general economic transformation process (Table 3.6), 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 3.6—Structural change under climate change scenarios (% of GDP)

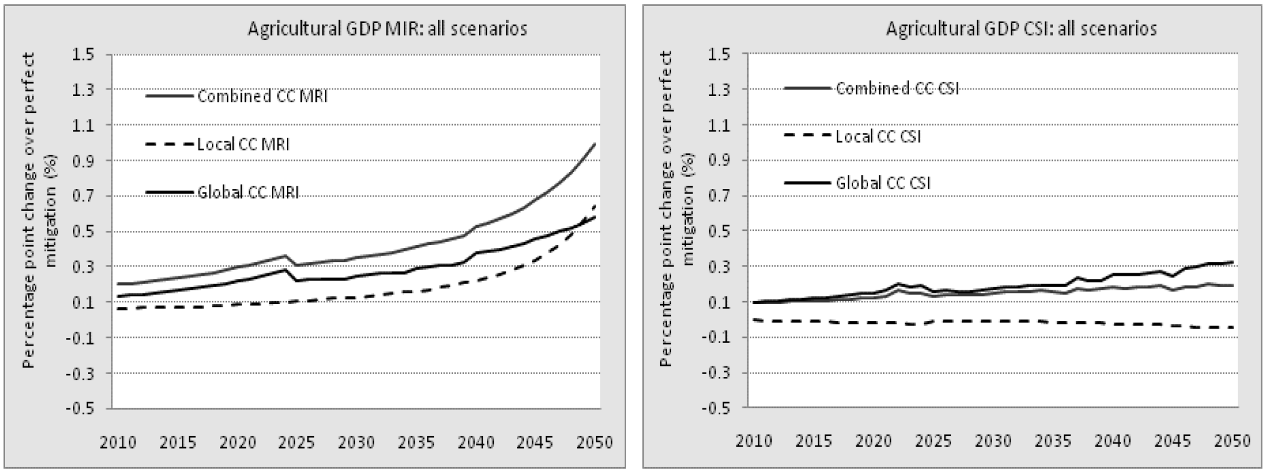
		MIROC		CSIRO	
	Initial	**2030**	**2050**	**2030**	**2050**
Perfect Mitigation					
Agriculture	8.4	6.0	4.6	6.0	4.6
Industry	38.5	39.3	39.3	39.3	39.3
Services	53.1	54.7	56.1	54.7	56.1
Global					
Agriculture	8.4	6.2	5.1	6.1	4.9
Industry	38.5	39.2	39.0	39.3	39.1
Services	53.1	54.6	55.9	54.6	56.0
Local					
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 3.9). 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 Yemen's exports of agricultural crops. This latter effect is amplified when global climate change is factored in and globally higher crop prices provide a boost to the agricultural sector and improve agricultural export performance, thus leading to faster growth of the agricultural sector (versus perfect mitigation). In contrast, due to less optimistic yield predictions, 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.

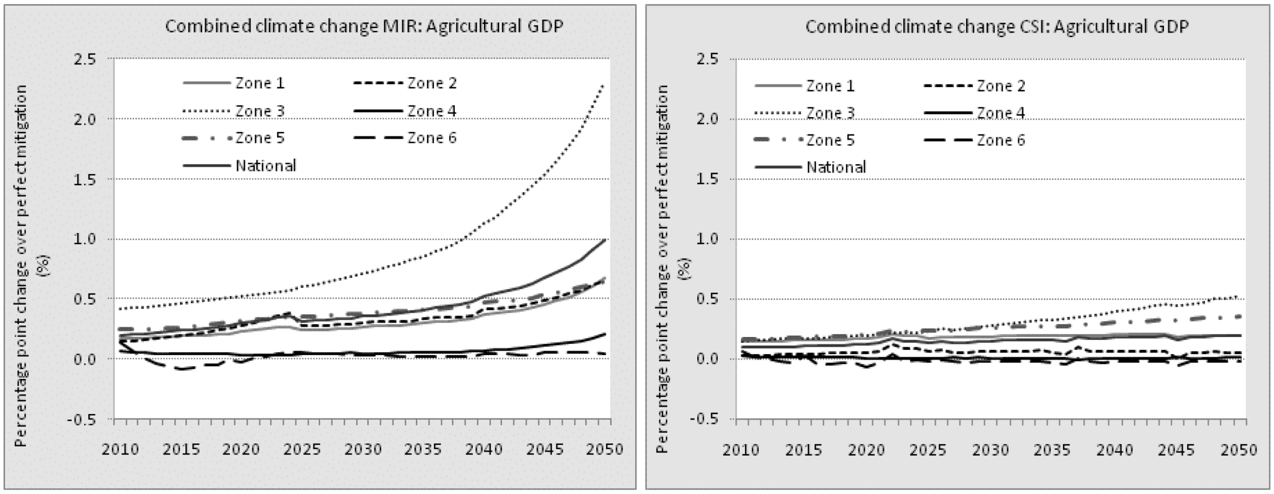
The combined effects of global and local climate change turn out to be favorable for agricultural production in all economically important zones (Figure 3.9b), but again much less so under the CSIRO scenario than under the MIROC scenario. In zone 3, the positive impacts of local and global climate change 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 compared with perfect 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 agricultural value-added, agricultural GDP is hardly affected by the combined effects of climate change.

Figure 3.9a—Impacts of local, global, and combined changes on agricultural GDP, 2010–2050



Source: Yemen DCGE Model.

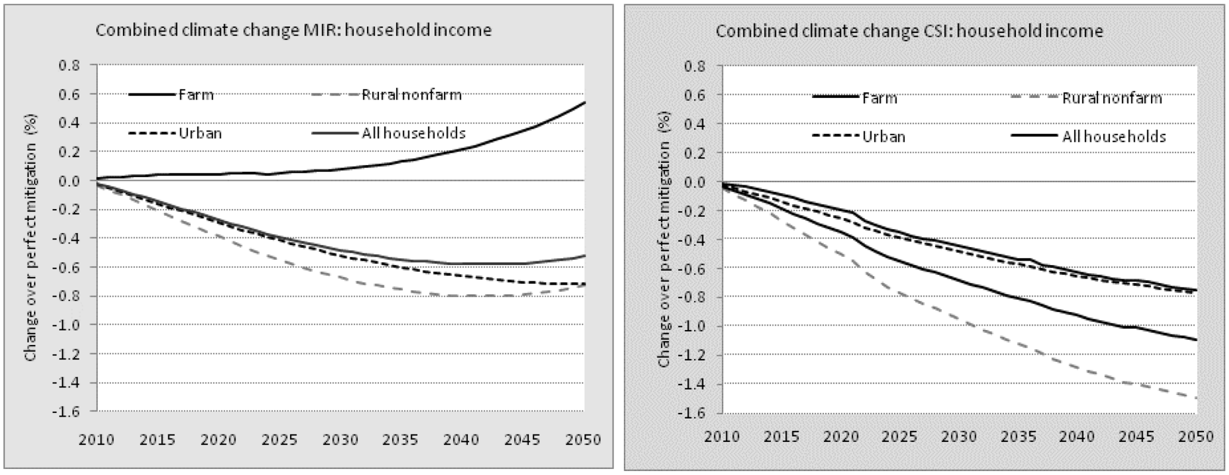
Figure 3.9b—Impacts of combined local and global changes on agroecological zones, 2010–2050



Source: Yemen DCGE Model.

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 predictions, but incomes for rural nonfarm households and urban households fall (Figure 3.10). 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.

Figure 3.10—Impacts of combined local and global changes on household incomes



Source: Yemen DCGE Model.

Changes in real incomes not only differ between household groups but also exhibit considerable variation 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 3.7). 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 3.7—Distributional impacts, local and global climate change, and world price changes

Household group		Population	Per capita income (thousand YER)	Average annual change, 2010–2050 (%)				
			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	2,669,219.1	242	-0.5	-0.5 - -0.4	0.0	-0.4	-1.0 - -0.9
	2	1,203,688	161	-0.6	-0.6 - -0.5	0.1 - 0.0	-0.5	-1.1
	3	774,200	177	-0.3	-0.4	0.1 - 0.0	-0.3 - -0.4	-0.6 - -0.7
	4	1,157,983	170	-0.3	-0.6 - -0.5	0.0	-0.5	-0.8
	5	302,989	159	-0.8	-0.9 - -0.8	0.0	-0.8	-1.6
	6	41,809	137	-0.8	-0.6 - -0.5	0.0	-0.7 - -0.6	-1.4 - -1.3
Rural nonfarm	1	1,946,108.60	152	-1.8	-1.2 - -0.9	0.1 - 0.0	-1.1 - -1.0	-2.9 - -2.8
	2	5,836,100.10	118	-1.8	-1.2 - -0.9	0.9 - 0.1	-0.3 - -0.9	-2.1 - -2.6
	3	1,616,577.60	133	-1.0	-0.9 - -0.8	0.6 - 0.0	-0.3 - -0.8	-1.3 - -1.8
	4	320,780.39	100	-0.6	-0.9 - -0.8	0.0	-0.8	-1.5 - -1.4
	5	999,507.30	127	-1.1	-1.1 - -0.9	0.0	-1.1 - -1.0	-2.2 - -2.1
	6	174,556.80	105	-1.3	-1.0 - -0.8	0.0	-1.0 - -0.9	-2.3 - -2.2

Table 3.7—Continued

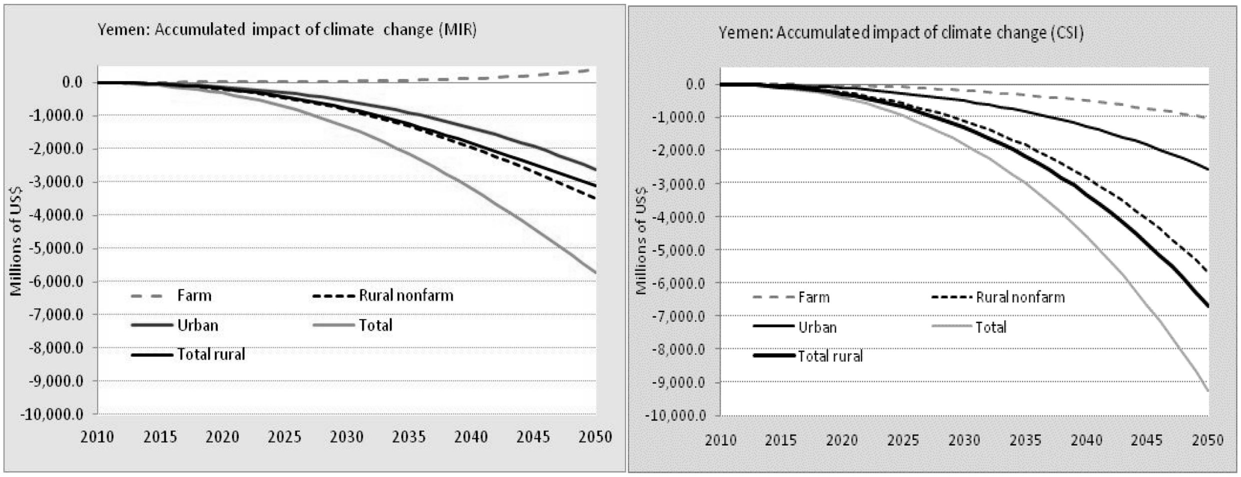
Household group		Population	Per capita income (thousand YER)	Average annual change, 2010–2050 (%)				
			2009	Perfect mitigation	Global climate change[a]	Local climate change[a]	Combined climate change[a]	Combined climate change plus world price changes[a]
Rural farm	1	1,601,351.00	147	-1.8	-0.6 - -0.4	0.0 - -0.1	-0.5	-2.4
	2	2,544,788.70	90	-2.0	-0.6 - -0.4	1.2 - 0.1	0.6 - -0.3	-1.4 - -2.4
	3	737,258.54	108	-1.0	-0.0 - -0.1	1.6 - 0.2	1.6 - 0.1	0.6 - -0.9
	4	134,267.62	111	-0.9	-0.7	0.0	-0.7	-1.6
	5	208,785.15	105	-1.0	-0.4	0.0 - -0.1	-0.4 - -0.5	-1.5 - -1.6
	6	189,341.65	87	-1.5	-1.1 - -0.9	0.0 - -0.1	-1.2 - -1.0	-2.7 - -2.5

Source: Yemen DCGE Model.

Notes: [a] The first number in the cell indicates the MIROC result; the second number indicates the CSIRO result.

The long-term implications of climate change (local and global) lead to a total reduction of household welfare of 1,161.2 or 1,873.6 billion Yemeni rials (YER)(US$5.7 or US$9.2 billion[10]) by 2050 under MIROC or CSIRO conditions, respectively (Figure 3.11). These reductions in welfare accumulate over time. In 2020, household incomes are projected to be 63.8 or 82.0 billion YER ($314.4 or $404.2 million) lower versus a perfect mitigation scenario, whereas those losses increase to 269.6 or 366.8 billion YER ($1.3 or $1.8 billion) by 2030. Rural households suffer more from climate change than urban households. Rural households' incomes by 2050 are 630.1 or 1,353.7 billion YER($3.1 or $6.7 billion) lower compared with urban households with lower incomes of 531.1 or 519.9 billion YER ($2.6 billion or $2.5 billion). 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 711.0 or 1,147.7 billion YER ($3.5 or $5.7 billion) as a consequence of climate change by 2050.

Figure 3.11—Impacts of combined local and global changes on household incomes



Source: Yemen DCGE Model.

Climate change also raises the number of hungry people in Yemen. By 2050, between 80,000 and 270,000 people could go hungry due to climate change (Figure 3.12). 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.

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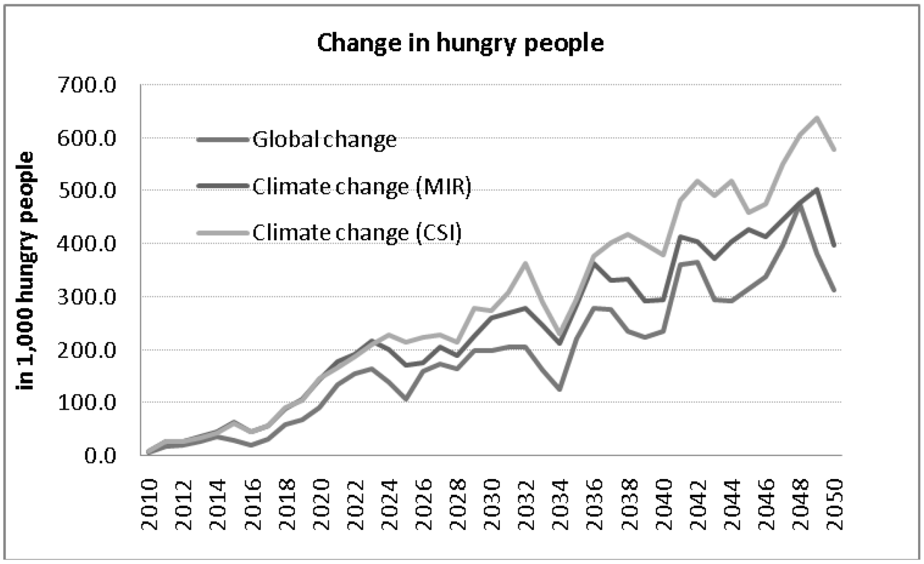
[10] All dollars are U.S. dollars.

Figure 3.12—Impact of climate change on food security



Source: Yemen Combined DCGE and Nutrition Model.

Rural households are harder hit than urban households, and among the rural households the nonfarm households suffer most (Table 3.8). 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.

Table 3.8—Impact of climate change on food security

	Change in hungry people (in 1,000s)		
	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: Yemen Combined DCGE and Nutrition Model.

4. ECONOMIC IMPACTS OF FLOODS IN YEMEN

Yemen is a disaster-prone country that faces a number of natural hazards every year with floods constituting the most important and recurring form of disaster in the country.[11] Whereas regular flooding has traditionally been beneficial for agricultural practices 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. The damages done by floods tend to be exacerbated by an ongoing desertification process and land degradation. In addition, several GCMs predict higher rainfall levels for Yemen, thus potentially increasing the frequency and severity of floods in the future.

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. 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 losses and the impacts on hunger are less well understood.

Quantifying the impacts of flooding is important for designing appropriate mitigation strategies. This may become even more important in the future given that global 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, which is why computable general equilibrium models have become an increasingly popular tool for disaster impact assessments (Pauw et al. 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 above 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 economywide 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 (Table 4.1). This approach allows for looking beyond the reductions in regional agricultural production and also for isolating the impacts on the broader economy and households. In the following, we first provide a short description of past floods in Yemen, then introduce the DCGE simulation design by analyzing crop and livestock changes during and after the October 2008 flood, and finally present model results.

According to the Emergency Events Database of the Centre for Research on the Epidemiology of Disasters (CRED, 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 population in high-risk areas has led to an increased exposure to adverse natural events.

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[11] 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.

Table 4.1—Human toll and damages due to floods and flash floods, 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	NA
	March	Flood	3	Tihama Valley, Hodeidah		3,000	NA
1999		Flood		Socotra archipelago		19,750	NA
2002	August	Flood	1	Hodeidah, Taiz, Hadramout	28	700	NA
	July	Flood	2	Raima	13		NA
	July	Flood	2	Salafiyah	10		NA
	April	Flood		Salafiyah, Hadramout	2		NA
2003	June	Flood	3	Haija, Taiz	15		NA
2005	August	Flash flood	1		12	721	NA
	April	Flash flood	3	Sanaa, Hodeidah	10		NA
2006	April	Flash flood	2	Dhamar, Hodeidah, Manakha	25	320	NA
	February	Flash flood	3	Dhamar, Maabar	5	2,000	NA
2007	August	Flood			50		NA
	Mach	Flash flood	3	Hadramout, Ibb	36	618	NA
	January	Flood	3	Raima, Dhamar	7	2,000	NA
2008	October	Flash flood	2	Hadramout, Al-Mahara	75	25,000	1,235

Source: GY/WB/UNISDR/IFRCC (2009).

Floods are the most important 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 through 19 floods or flash floods. CRED's International Disaster Database (www.emdat.be/) ranked floods as the top four natural disasters in Yemen since 1990 with regard to economic damages. Floods also rank prominently with regard to killed persons (eight of the top 10 are floods) and affected people (nine of the top 10 are floods).

The following impact assessment quantifies the agricultural, economywide, 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 to 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. Moreover, the storm damaged boats and fishing equipment along the coastal line 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 (GY/WB/UNISDR/IFRCC 2009).

Table 4.2 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-run 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, reflecting that it takes time until replanted trees start bearing fruit and young animals produce meat and milk.

Table 4.2—Changes in cropland, number of animals, and fishery yields during and after Hadramout flash flood by agroecological zone

	Base year stocks	Damages	Losses			
	2007	2009	2010	2011	2012	2013
	Yemen		Internal Plateau (Zone 5)			
Cropped area (acres)	1,480,000	-81.6	7.7	56.1	24.0	22.6
Sheep and goats (head)	17,003,000	-3.4	-1.6	-1.0	6.2	0.0
Cattle (head)	1,495,000	-1.4	1.0	-0.2	0.2	0.4
Camel (head)	366,000	-6.3	4.8	-0.6	0.6	0.0
			Arabian Sea Coast (Zone 4)			
Cropped area (acres)		-39.3	3.7	27.0	11.5	10.9
Sheep and goats (head)		-0.8	0.6	-0.8	1.0	0.0
Cattle (head)		-1.6	1.3	-1.6	2.1	0.0
Camel (head)		-3.2	2.8	-3.4	4.4	0.0
Fish (real value-added)		-6.7	5.7	-7.0	9.1	0.0

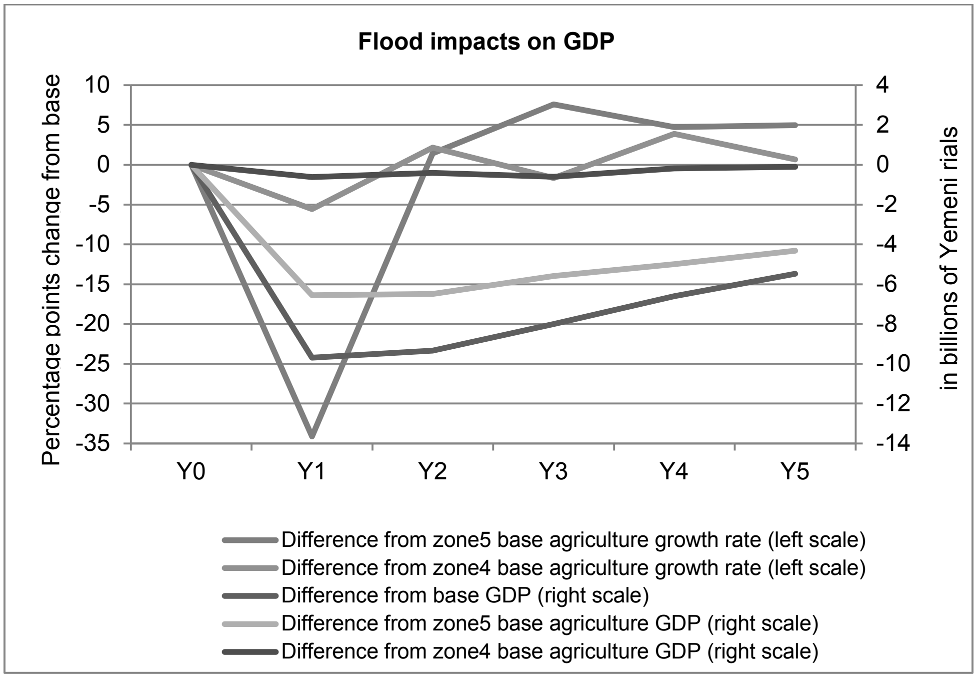
Source: Authors' calculations based on GY/WB/UNISDR/IFRCC (2009).

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 (Tables 3.1 and 3.2). 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. 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 6.6 and 4.3 billion YER annually ($33 and $22 million) during and in the aftermath of the flood; the losses are much lower in zone 4's agriculture (between 0.6 and 0.1 billion YER). 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 10 and 6 billion YER, driven by general equilibrium repercussions resulting from losses of incomes in affected zones and higher prices.

Figure 4.1 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. 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.

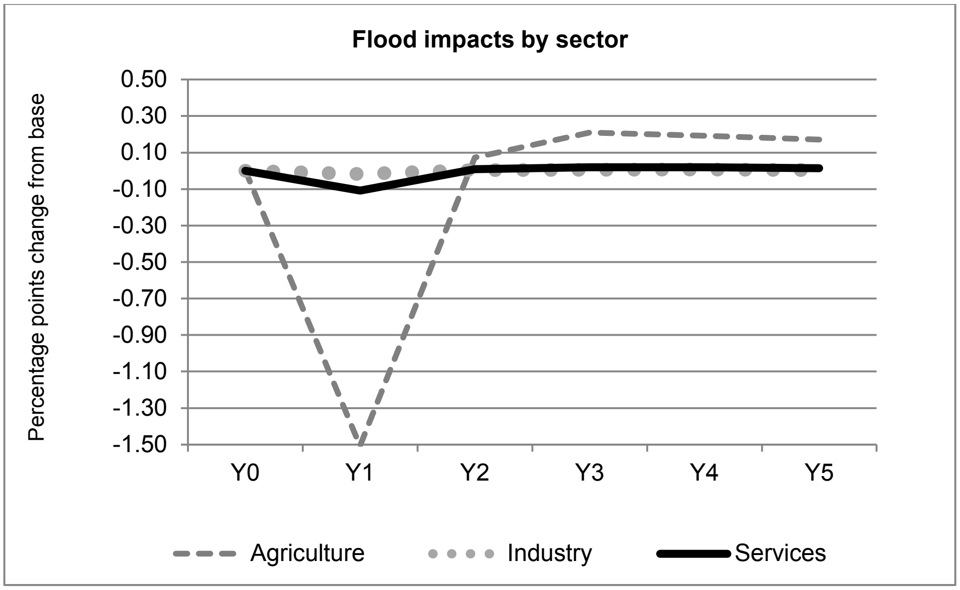
Figure 4.1—Loss in regional agricultural and overall GDP from flood



Source: Yemen DCGE Model.

Agriculture is the sector hardest hit by flood, whereas the industrial and the service sectors are relatively more resilient (Figure 4.2). 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 so lead to a contraction in 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 economywide 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.

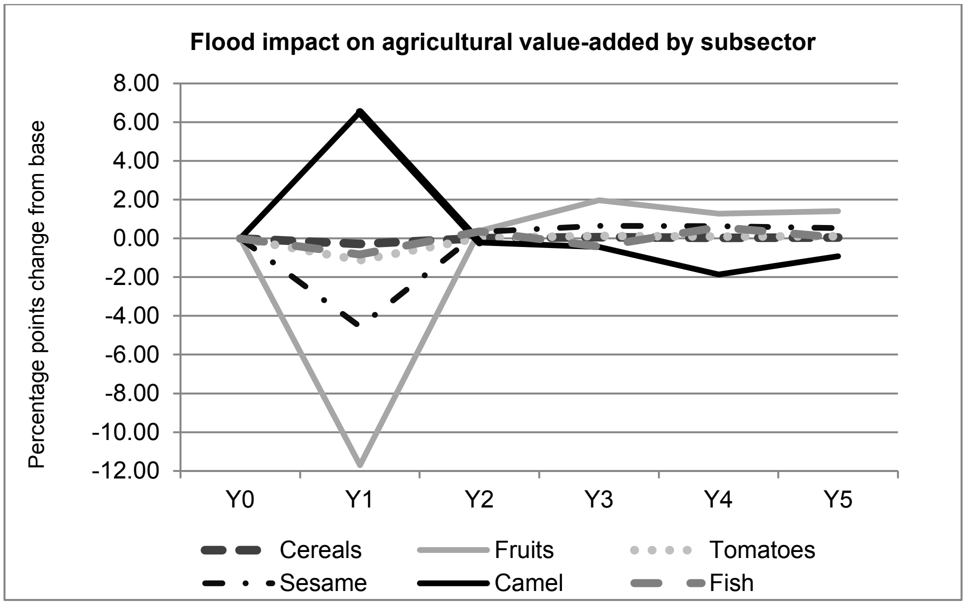
Figure 4.2—Flood impacts on GDP by sector



Source: Yemen DCGE Model.

Within agricultural subsectors, fruits are the hardest hit by the flood, followed by sesame and tomatoes (Figure 4.3). 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)—and 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 value-added 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; 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. Yet this result has to be interpreted cautiously as the model assumes high factor substitution elasticities between, for example, camel stocks and unskilled labor

Figure 4.3—Loss in agricultural GDP from flood by subsector

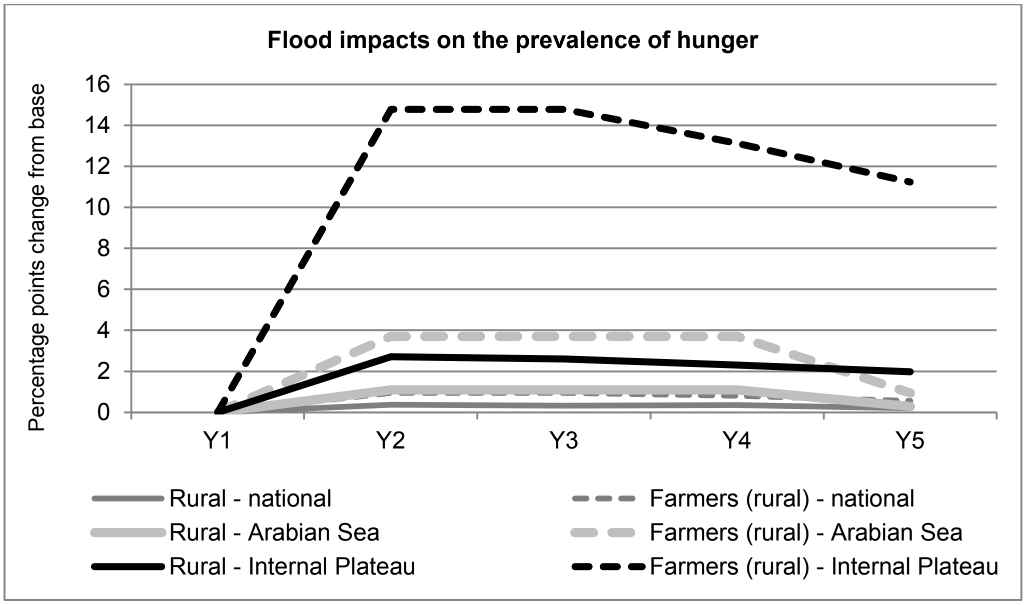


Source: Yemen DCGE Model.

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 4.4). Yet, on the local level, the consequences are severe, especially in the areas that are directly affected by the flood. The rural population and especially farmers in the Internal Plateau zone are hardest hit and, to a 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 households in the Internal Plateau remains high and declines 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 so that the hunger prevalence almost returns to its pre-flood 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 required 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 extend over several years. The negative medium-term impacts on household income and food insecurity can be minimized if farmers can replace the destroyed fruit trees with modern varieties of seedlings for fruit trees that start bearing fruit sooner than the traditional varieties. Nonetheless, investments for reconstruction in the areas damaged by the flood may also create income earning opportunities and generate a development push, which, however, may be of overall limited benefit to the poor farming population in the short and medium term.

Figure 4.4—Percentage change in the prevalence of hunger due to the floods



Source: Yemen DCGE Model and microsimulation model.

5. SUMMARY AND PROPOSED ACTIONS FOR ADAPTATION

This paper has assessed the impacts of climate change on Yemen's economy, agriculture, and households from both a global and local perspective. Global climate change's major impact channel is through changing world food prices, especially since Yemen is a net importer of many food commodities. Local climate change manifests itself through long-term yield changes. Even under perfect climate change mitigation, world market prices for food are projected to increase, posing food security challenges especially for poor households in a net food-importing country. Climate change results in additional world market price increases. The direction of predicted yield changes is less clear cut. Yields for wheat and maize are expected to fall in most of Yemen's AEZs under both climate scenarios. Yields for sorghum and millet are expected to rise in some zones and fall in others under the CSIRO scenario, whereas they are expected to rise considerably across all zones under the MIROC scenario as a result of higher predicted rainfall.

Our results suggest that climate-change-induced higher global prices for food will slightly lower Yemen's overall GDP growth, raise agricultural GDP, and decrease real household incomes. Effects on agricultural GDP vary by AEZ depending on production structure. Whereas producers in zone 3 benefit disproportionately from rises in prices for a range of commodities such as fruits and vegetables, agricultural GDP in zone 4 does not change at all. Real incomes decline in all household groups. Rural nonfarm households are hit hardest as they tend to be net food consumers with high food budget shares. Farm households also experience real income losses given that many of them are net buyers of food.

Local impacts of climate change are different for the two climate scenarios. Under the MIROC scenario, agricultural GDP is somewhat higher than under perfect mitigation. Rural incomes rise due to higher yields and lower prices for sorghum and millet, whereas urban households are largely unaffected because they hardly consume those commodities. Again, producers in zone 3 are the main beneficiaries because in that zone sorghum and millet account for a larger share of agricultural value-added than in any other zone. Under the CSIRO scenario, positive and negative yield changes cancel each other out. As a result, agricultural GDP and incomes for all three household groups hardly change compared with perfect mitigation.

The long-term implications of climate change (local and global) lead to a total reduction of household welfare of 1,161.2 or 1,873.6 billion YER ($5.7 or $9.2 billion) by 2050 under MIROC or CSIRO conditions, respectively. Those reductions in welfare accumulate over time. In 2020, household incomes are projected to be 63.8 or 82.0 billion YER ($314.4 or $404.2 million) lower compared with a perfect mitigation scenario, and those losses increase to 269.6 or 366.8 billion YER ($1.3 or $1.8 billion) by 2030. Rural households suffer more from climate change than urban households. By 2050, rural household incomes are 630.1 or 1,353.7 billion YER ($3.1 or $6.7 billion) lower versus those of urban households, which are 531.1 or 519.9 billion YER ($2.6 to $2.6 billion) lower. 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 711.0 or 1,147.7 billion YER ($3.5 or $5.7 billion) as a consequence of climate change by 2050.

In addition to the longer-term climate change effects, 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. Estimates put the total cumulated real income loss over the period 2008–2012 at 180 percent of preflood regional agricultural value-added. 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 spiked 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 by more than 1 percent due to the flood.

Given that global climate change is likely to become the main driver of household income losses and rising food insecurity, successful global climate negotiations that help mitigate the upward pressure on world food prices are crucial for Yemen's future development. As concerns domestic policy, farm households could over time increasingly benefit from the predicted price increases if more of them had better access to markets and efficient supply chains. However, the National Food Security Strategy acknowledges that the potential for accelerated agricultural growth is constrained by Yemen's severe scarcity of water and arable land, but at the same time it outlines several options for raising agricultural productivity and food security among farm households. Those include investments in water-saving technologies, incentives that encourage the use of more water-efficient crops, and investments to promote agricultural alternatives such as coffee.

The bulk of the adaptation to climate change would, however, have to come from the nonagricultural sector. Policymakers can facilitate private-sector-led growth in various ways, such as through improved access to credit and a more investment-friendly tax regime. Since rural nonfarm households are hardest hit by rising food prices while already exhibiting the highest initial levels of food insecurity, investments that generate rural nonfarm employment in sectors such as food processing and tourism should in particular be encouraged, such as by investing in rural infrastructure. Better opportunities for private investors in rural areas would have to be complemented by transfers aimed at the most food-insecure households.

The main challenge arising from climate variability is that the projected increase in rainfall may raise the risk of floods in the future, which can have devastating effects as the recent Hadramout flood forcefully illustrates. Dealing with recurrent floods requires a comprehensive disaster risk management strategy.[12] Such a strategy would have to consist of a broad set of measures, including the provision of effective short-run emergency assistance for those who suffer the most severe damage, longer-term investments in risk reduction such as the establishment of flood protection systems and the upgrading of roads, and institutional capacity building to ensure that plans are implemented in a coordinated way.

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[12] For a detailed outline of a disaster risk management strategy, see the joint assessment of the 2008 floods by the Government of Yemen, the World Bank, the United Nations International Strategy for Disaster Reduction, and the International Federation for the Red Crescent and Cross (2009).

APPENDIX A: SUPPLEMENTARY TABLES

Table A.1—Mathematical presentation of the Dynamic Computable General Equilibrium Model—core model equations

Production function	$Q_{ct} = \alpha_{ct} \cdot \prod_f F_{fct}^{\delta fc}$		(1)
Factor payments	$W_{ft} \cdot \sum_c F_{fct} = \sum_c \delta_{fc} \cdot P_{ct} \cdot Q_{ct}$		(2)
Import supply	$P_{ct} \le E_t \cdot W_c^m \perp M_{ct} \ge 0$		(3)
Export demand	$P_{ct} \ge E_t \cdot W_c^e \perp X_{ct} \ge 0$		(4)
Household income	$Y_{ht} = \sum_{fc} \theta_{hf} \cdot W_{ft} \cdot F_{fct} + r_h \cdot E_t$		(5)
Consumption demand	$P_{ct} \cdot D_{hct} = \beta_{hc} \cdot \left(1 - v_h\right) \cdot Y_{ht}$		(6)
Investment demand	$P_{ct} \cdot I_{ct} = \rho_c \cdot \left(\sum_h v_h \cdot Y_{ht} + E_t b\right)$		(7)
Current account balance	$w_c^m \cdot M_{ct} = w_c^e \cdot X_{ct} + \sum_h r_h + b$		(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	$s_{ft} = s_{t-1} \cdot \left(1 + \varphi_f\right)$	*f* is land and labor	(11)
Capital accumulation	$s_{ft} = s_{t-1} \cdot \left(1 - \eta\right) + \sum_c \dfrac{P_{ct-1} \cdot I_{ct-1}}{k}$	*f* is capital	(12)
Technical change	$\alpha_{ct} = \alpha_{ct-1} \cdot \left(1 + y_c\right)$		(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/foreign currency units)
F	Factor demand quantity
I	Investment demand quantity
M	Import supply quantity
P	Commodity price
Q	Output quantity
W	Average factor return
X	Export demand quantity
Y	Total household income

Exogenous variables	
b	Foreign savings balance (foreign currency units)
r	Foreign remittances
s	Total factor supply
w	World import and export prices
Exogenous parameters	
α	Production shift parameter (factor productivity)
β	Household average budget share
γ	Hicks neutral rate of technical change
δ	Factor input share parameter
η	Capital depreciation rate
θ	Household share of factor income
κ	Base price per unit of capital stock
ρ	Investment commodity expenditure share
υ	Household marginal propensity to save
φ	Land and labor supply growth rate

Source: Authors' compilation.

Table A.2—Social Accounting Matrix (SAM) disaggregation

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
Potatos	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: Authors' compilation.

Table A.3—Macro Social Accounting Matrix (SAM)

	Activities	Commodities	Factors	Households	Government	Rest of world	Sav-inv.	Inst. tax	Import tariffs	Ind. tax	Total
Activities		7856.6									7856.6
Commodities	2767.5			3201.1	854.1	1414.9	1377.9				9615.5
Factors	5089.1										5089.1
Households			5089.1		-812.0	104.0					4381.1
Government						213.4		204.6	44.4	-279.4	183.0
Rest of world		1993.9									1993.9
Sav-inv.				975.4	140.9	261.6					1377.9
Inst. tax				204.6							204.6
Import tariffs		44.4									44.4
Ind. tax		-279.4									-279.4
Total	7856.6	9615.5	5089.1	4381.1	183.0	1993.9	1377.9	204.6	44.4	-279.4	

Source: Authors' compilation.

Table A.4—Income elasticities estimated for the Dynamic Computable General Equilibrium Model

	Sorghum	Maize	Millet	Wheat	Barley	Other grains	Fruits	Potatos	Vege tables
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: Authors' compilation.

Table A.5—Determinants of per capita calorie consumption

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: Authors’ compilation.

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

APPENDIX B: IMPACT AND SAM CROP ACTIVITY MAPPING

Table B.1—IMPACT and SAM Crop Activity Mapping

IMPACT crops	DCGE model traded agricultural 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: IFPRI IMPACT and Authors' compilation.

Notes: IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade; SAM = Social Accounting Matrix; DCGE = Dynamic Computable General Equilibrium.

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.

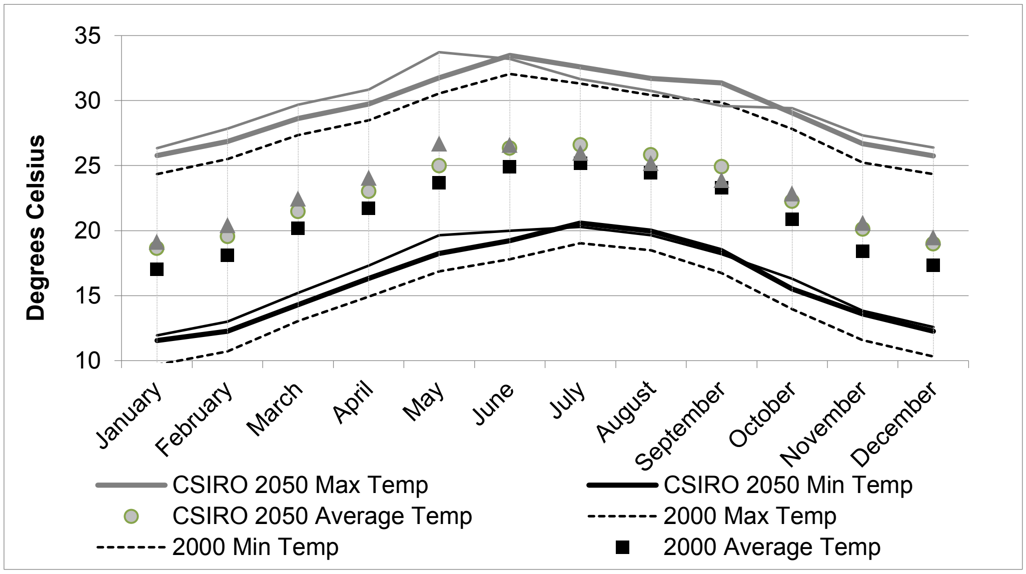
Cattle: Figures for cattle were assumed to follow projections of beef

Chicken: The projections for poultry represented projections for chicken.

Given that not all of 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.

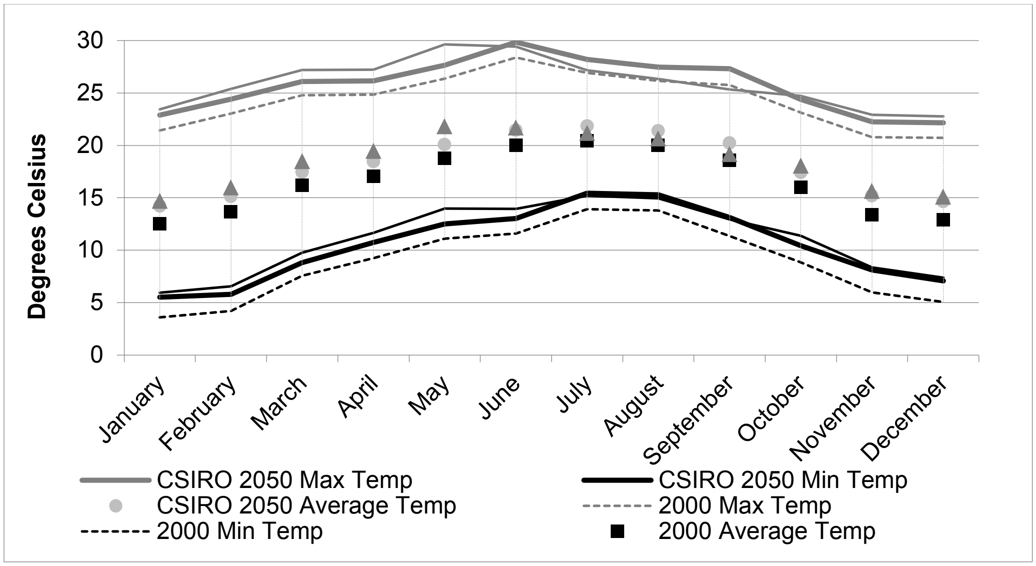
APPENDIX C: TEMPERATURE AND RAINFALL CHANGES BY AGROECOLOGICAL ZONE

Figure C.1—Lower Highlands: Monthly temperature highs and lows



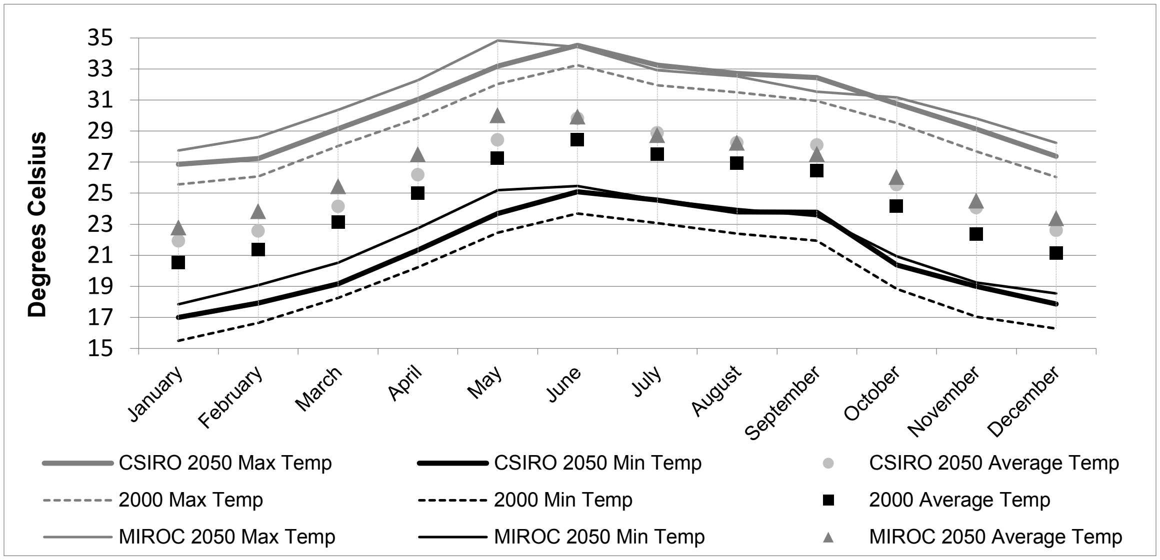
Source: Authors' calculations based on Jones et al (2010).

Figure C.2—Upper Highlands: Temperature highs and lows



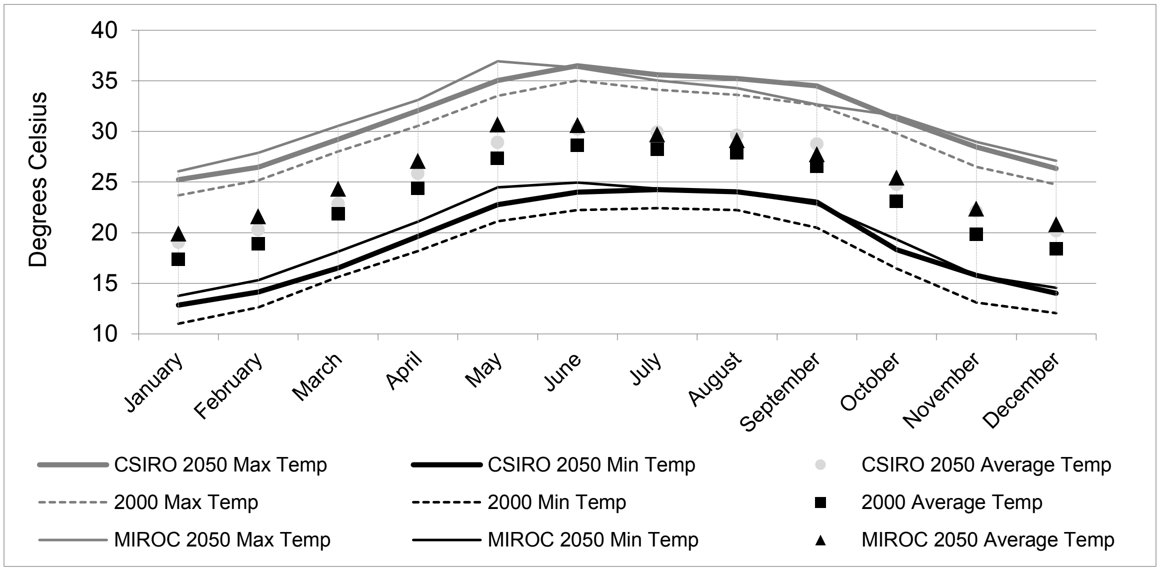
Source: Authors' calculations based on Jones et al (2010).

Figure C.3—Arabian Sea: Temperature highs and lows



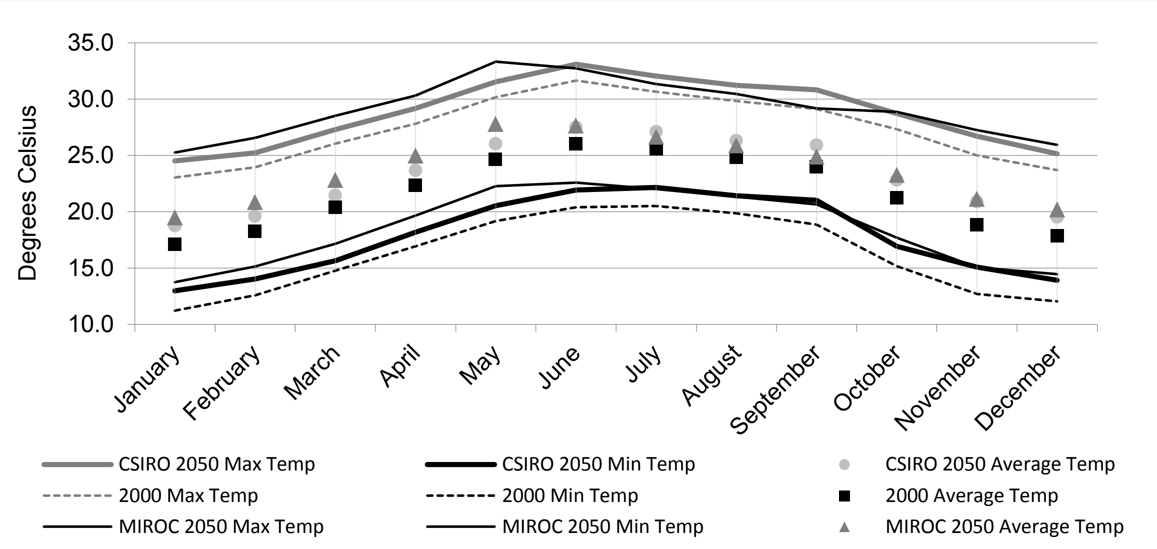
Source: Authors' calculations based on Jones et al (2010).

Figure C.4—Desert: Temperature highs and lows



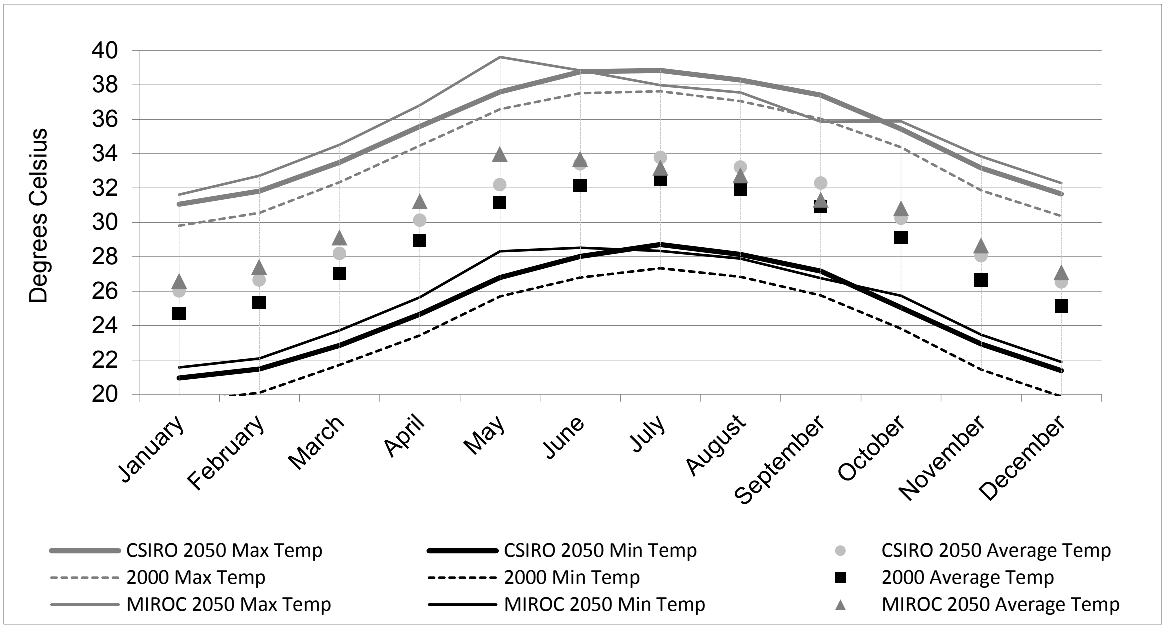
Source: Authors' calculations based on Jones et al (2010).

Figure C.5—Internal Plateau: Temperature highs and lows



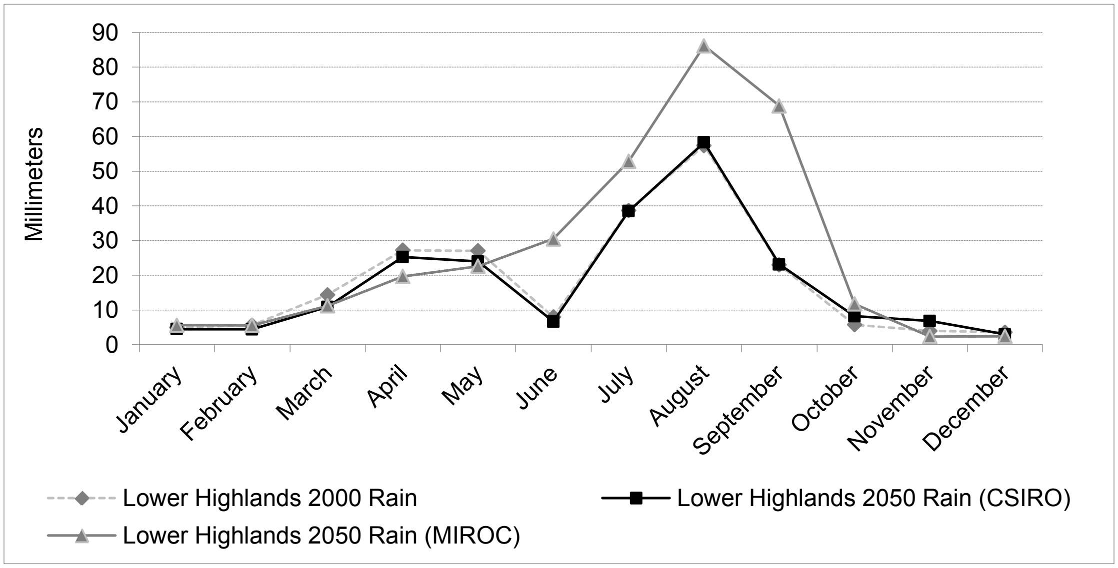
Source: Authors' calculations based on Jones et al (2010).

Figure C.6—Red Sea and Tihama: Temperature highs and lows



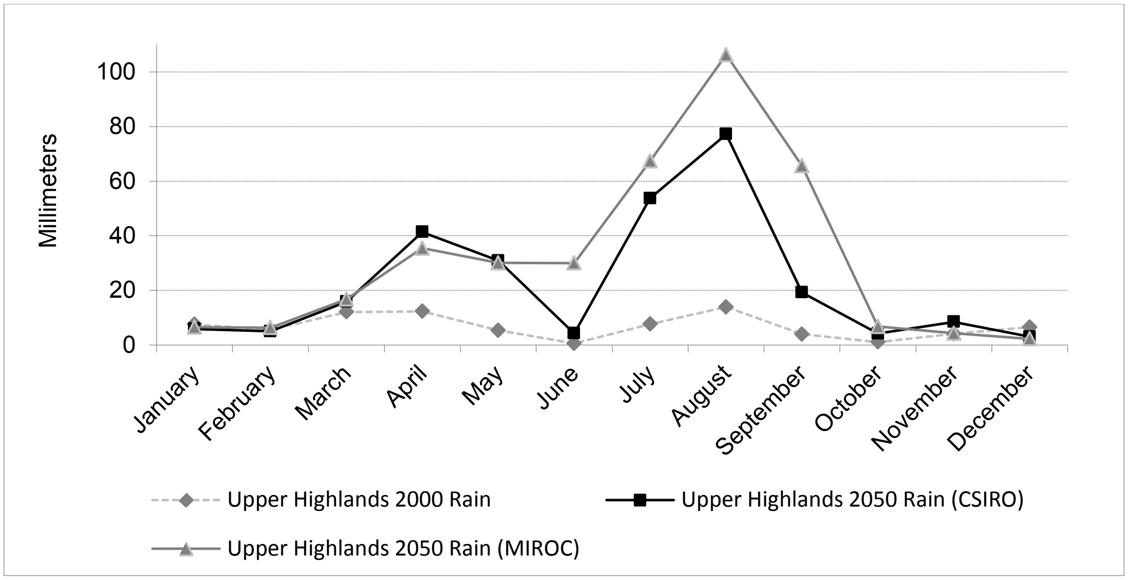
Source: Authors' calculations based on Jones et al (2010).

Figure C.7—Lower Highlands: Average monthly rain



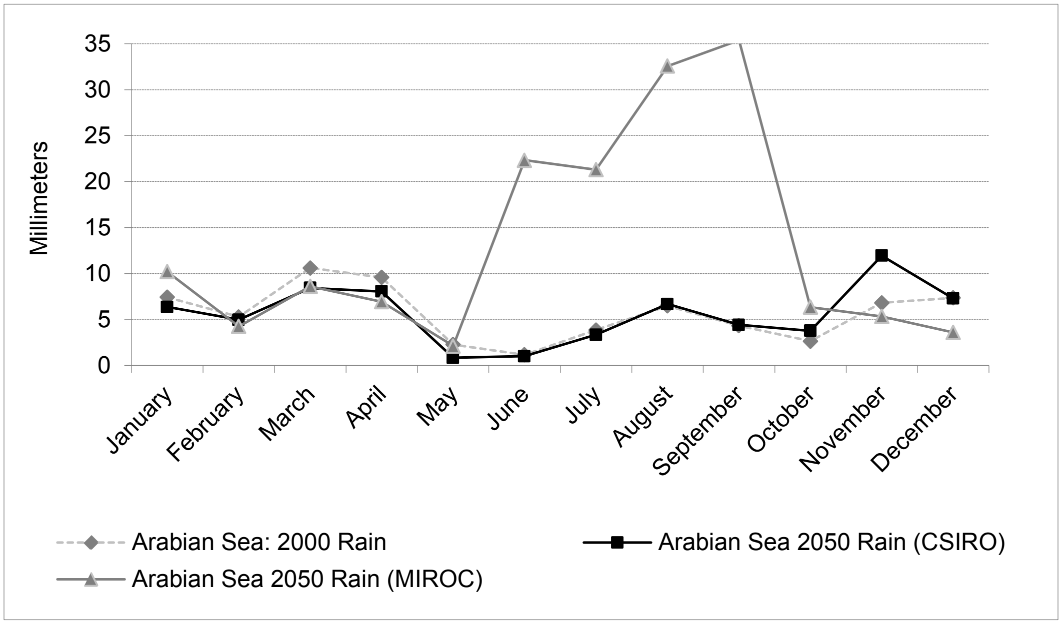
Source: Authors' calculations based on Jones et al (2010).

Figure C.8—Upper Highlands: Average monthly rain



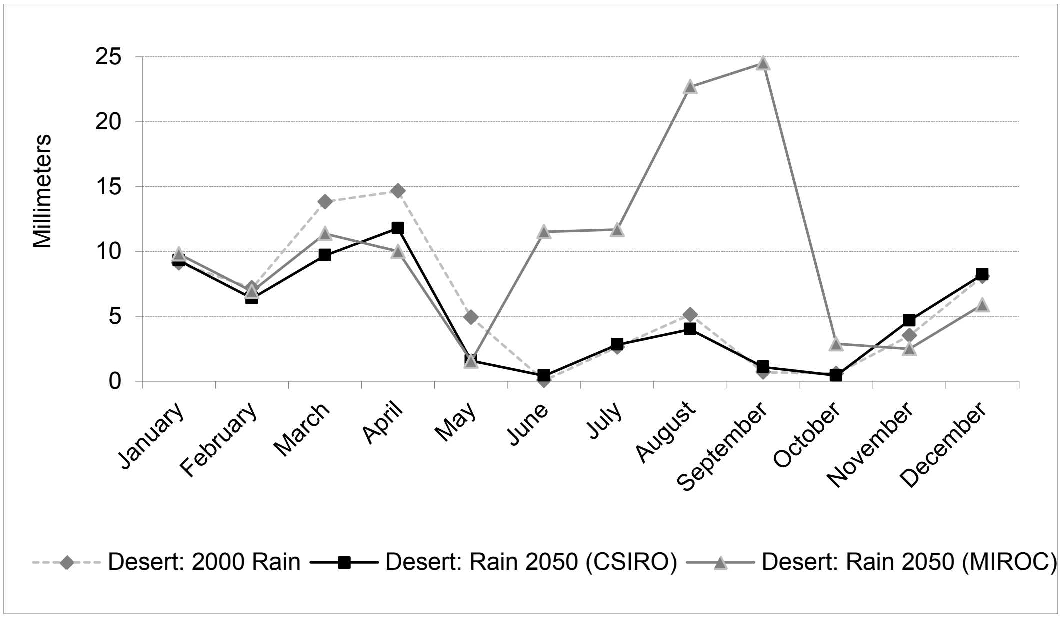
Source: Authors' calculations based on Jones et al (2010).

Figure C.9—Arabian Sea: Average monthly rain



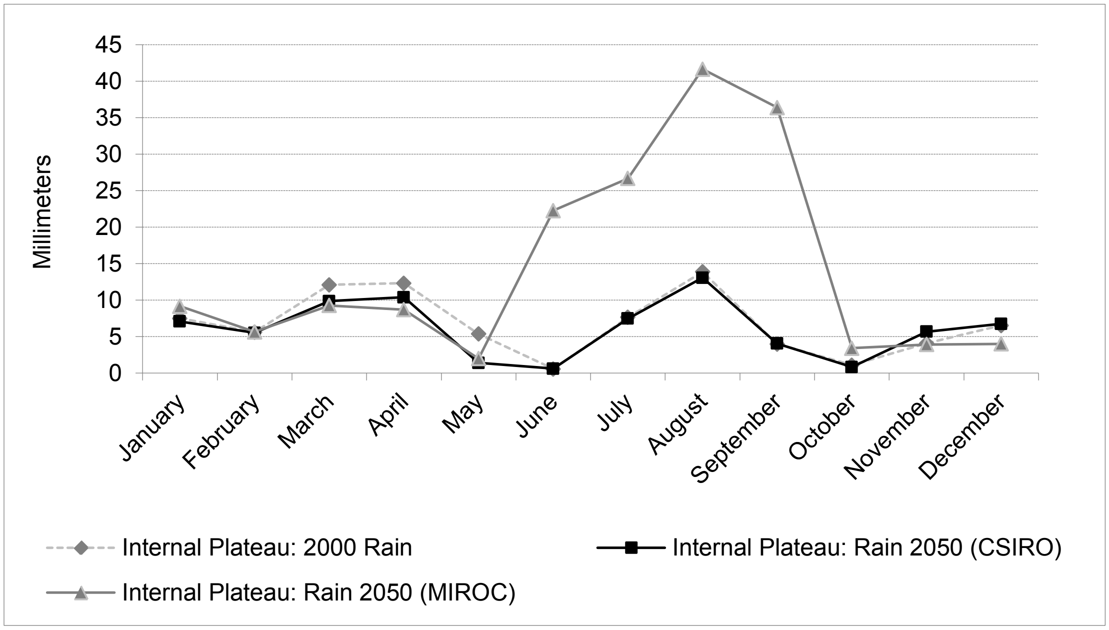
Source: Authors' calculations based on Jones et al (2010).

Figure C.10—Desert: Average monthly rain



Source: Authors' calculations based on Jones et al (2010).

Figure C.11—Internal Plateau: Average monthly rain



Source: Authors' calculations based on Jones et al (2010).

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