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Global and Local Economic Impacts of Climate Change in Syria and Options for Adaptation

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ABSTRACT

There is broad consensus among scientists that climate change is altering weather patterns around the world. However, economists are only beginning to develop tools that allow for the quantification of such weather changes on countries' economies and people. This paper presents a modeling suite that links the downscaling of global climate models, crop modeling, global economic modeling, and subnational-level computable equilibrium modeling. Important to note is that this approach allows for decomposing the potential global *and* local economic effects on countries, including various economic sectors and different household groups. We apply this modeling suite to Syria, a relevant case study given the country's location in a region that is consistently projected to be among those hit hardest by climate change.

Despite a certain degree of endogenous adaptation, *local* impacts of climate change (through declining yields) are likely to affect Syria beyond the agricultural sector and farmers and also reduce economy-wide growth and incomes of urban households in the long term. The overall effects of *global* climate change (through higher food prices) are also negative, but some farmers can reap the benefit of higher prices. Combining local and global climate change scenarios shows welfare losses across all rural and urban household groups of between 1.6 – 2.8 percent annually, whereas the poorest household groups are the hardest hit. Finally, while there is some evidence that droughts may become more frequent in the future, it is clear that even without an increase in frequency, drought impacts will continue to put a significant burden on Syria's economy and people.

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 and 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 countries and people to climate change.

Keywords: Syria, Middle East and North Africa, climate change, drought, poverty, development, growth

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1. INTRODUCTION

Climate change and variability affects countries' economies and households through a variety of channels. Rising temperatures and changes in rainfall patterns affect agricultural yields of both rainfed and irrigated crops. The unchecked rise of sea levels leads to loss of land, landscape, and infrastructure. A higher frequency of droughts will change hydropower production, and an increase in floods can significantly increase the need for public investment in physical infrastructure (Stern 2006; World Bank 2007; Garnaut 2008; Yu et al. 2009). These sector-level impacts will in turn affect other sectors and thus economic growth and household incomes.

Depending on countries' natural conditions and economic structure, climate change affects countries differently. For example, countries that depend on rainfed agriculture, such as many in sub-Saharan Africa, are more vulnerable to an increase in climate variability, with projected large losses in their national output (Thurlow 2009). Countries with large delta regions, such as Vietnam, are projected to be hardest hit by rising sea levels, with strong implications for food security and the rural poor (Yu et al. 2010). Countries that are already experiencing water stress, especially those in the Middle East and North Africa, are likely to experience additional declines in agricultural yields, resulting in negative effects on rural incomes and food security (Breisinger et al. 2010). Climate change may also exacerbate climate variability and reduce agricultural production and incomes in countries that depend on annual floods such as Bangladesh or in drought-prone countries such as many in the Middle East (Yu et al. 2009, Breisinger et al. 2010).

Adding up these country level effects from climate change is likely to have impacts on the global economy, through changes in global supply, trade flows and commodity prices. Depending on the net import or export position of countries and the net producing and consuming status of households of specific commodities affected, countries and households are likely to be affected differently by climate change. Nelson et al. (2009, 2010) project that global food prices will increase as a consequence of continued high global population growth, changing food consumption patterns, and climate change. Furthermore, continued high economic growth rates in emerging economies are likely to increase future energy costs (IEA 2010). In addition to rising energy demand, climate change mitigation policies may significantly raise energy costs, with potentially strong economic implications for developing countries (DOE 2010). For example, the Energy Information Administration (EIA) projects that oil prices may rise to US$200 a barrel under its high-price scenario. Taking higher food and energy prices into consideration is therefore important for any climate change impact assessment at the country level.

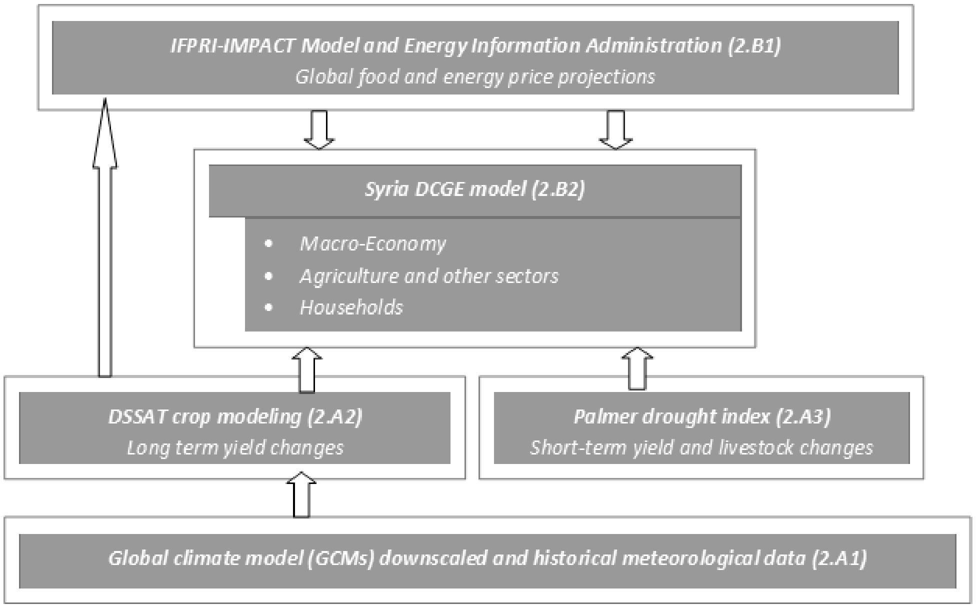
Yet, despite the potentially significant impacts on world commodity price changes from climate change induced, existing country-level economic impact assessments have largely neglected this global dimension. To address this gap in the literature, this report assesses both the local and global economic impacts of climate change in the Syrian Arab Republic. Syria is an important case study given the country's location in a region that is consistently projected to be amongst the hardest hit by climate change. In addition, both global and local impacts matter for Syria's future development, given its status as a net food- and energy-importing country for many commodities.

The remainder of the paper is structured as follows: Section 2 presents the modeling suite (analytical framework) of the study and describes each of its components. Section 3 presents the results of the climate change impact assessment, and Section 4 analyzes the effects of droughts. Section 5 concludes with recommendations for the Syrian government climate change adaptation.

2. MODELING SUITE

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

Figure 2.1—Modeling suite



Source: Author's creation.

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

Biophysical Impacts

Downscaling of GCMs

Jones et al. (2009) used GCM simulations available from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset. This dataset contains model output from 22 of the GCMs used for the Fourth Assessment Report of the

Intergovernmental Panel on Climate Change (IPCC) and for a range of scenarios, including the three Special Report Emissions Scenarios (SRES) used in the IPCC's Fourth Assessment Report, AR4: A2, one family of scenarios, is a high-greenhouse-gas-emission scenario; A1B, a subset of the A1 family of scenarios, is one of medium emissions; and B1, the fourth family of scenarios, is one with low emissions. Model output data are not available for all combinations of the GCM and emissions scenarios, at least not the basic core variables for many crop and pasture models such as precipitation, maximum daily temperature, and minimum air temperature. This, in turn, severely restricted the choice of GCMs. From the CMIP3 dataset, Jones et al. (2009) used three GCMs— Centreb National de Recherches Météorologiques Coupled Model Version 3 (CNRMCM3), The Commonwealth Scientific and Industrial Research Organisation Mark 3.0 (CSIRO-Mk3.0), and MIROC 3.2[1] (medium resolution)—and obtained maximum and minimum temperature data for the ECHam5[2] model from another source (the Climate and Environmental Retrieval and Archive – CERA - database at DKRZ) for the three SRES scenarios. This restricts our choice of GCMs with sufficient data for crop modeling, and we chose to focus on the MIROC A1B. Comparisons between precipitation and daily minimum and maximum temperature projections for 2050 from 12 climate scenarios (four models, each with three emissions scenarios) show that MIROC A1B projects lower rainfall and higher temperature than most of the other 11 scenarios. Therefore, results from this report should be interpreted as high-range impact scenarios.[3]

Data for GCM deviations for five time slices were obtained for the above-mentioned GCM and scenario combinations as follows[4]: 1991–2010 (denoted as 2000), 2021–2040 (denoted as 2030), 2041–2060 (denoted as 2050), 2061–2080 (denoted as 2070), and 2081–2100 (denoted as 2090) for average monthly precipitation, and maximum (tmax) and minimum (tmin) temperatures. Processing this data resulted in different calculated mean monthly climatic conditions climatologies for each time slice and for each variable from the original transient daily GCM time series. The mean monthly fields were then interpolated from the original resolution of each GCM to 0.5 degrees latitude–longitude using conservative remapping (which preserves the global averages). We then calculated monthly climate anomalies (absolute changes) for monthly rainfall, mean daily maximum temperature, and mean daily minimum temperature, for each time slice relative to the baseline climatology (1961–1990). The point of origin was designated as 1975, being the midpoint of the 30-year baseline. In the current case, we made a preliminary investigation of the functional forms of the projections using cluster analysis. All pixels from each of the four models for scenario A1B were clustered for precipitation, tmax, and tmin using the values of the five time periods as clustering variants. Fourth-order polynomial fits were made for all models at all scenarios, and another set was made for the average of the four models. The gridded anomalies were then downscaled to a higher resolution, and daily weather data were generated that are characteristic, to some extent, of the future climates produced using a stochastic daily weather generator.

In general, ground-based observations of meteorological records from national meteorological agencies of the country under investigation (in this case, Syria) are preferable to a global dataset in analyzing subnational crop water use and crop productivity; however, those data are not adequately available for this study. From the Global Historical Climatology Network (GHCN) and National Climatic Data Center (NCDC) global databases, long-term daily meteorological data, including precipitation data and data required to compute crop water requirement, are available for only seven weather stations in Syria. Weather station–based statistical downscaling models can downscale precipitation, maximum and minimum daily temperature for future climate change scenarios to those seven stations by taking into account historical meteorological records. However, these seven stations may not sufficiently represent spatial climate variations in the agroecological zones. Various data tests also uncover potential consistency issues with these data. For example, we estimated dew point temperature with daily minimum

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[1] MIROC3.2 is the Model for Interdisciplinary Research on Climate developed at the Center for Climate System Research, University of Tokyo.

[2] ECHAM5 model is the 5th generation of the ECHAM general circulation model developed at the Max Planck Institute for Meteorology, Germany.

[3] For a comparison of precipitation and temperature values under different GCM scenarios, refer to Appendix J.

[4] According to standard climate change analysis, historical periods are typically compared to periods in the future.

temperature in downscaled climate change scenarios. However, historical records from global weather station datasets suggest that the correlation between these two variables is not very strong, indicating that estimating dew point temperature based on minimum temperature may not be appropriate for Syria. Finally, given that the weather station–based records also come from a global dataset rather than from local authorities (which would be ideal), we decided to use Jones et al. (2009) pixel-level global data, which were also used in global climate change analysis in the IMPACT model.

Crop Yield Simulation

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

DSSAT requires detailed daily climate data, not all of which are readily available, so various approximation techniques were developed. To simulate today's climate, we use the Worldclim current conditions dataset,[5] which is representative of 1950–2000 and reports monthly average minimum and maximum temperatures and monthly average precipitation. Site-specific daily weather data are generated stochastically using the SIMMETEO software. At each location, 30 iterations were run and the mean of the yield values were used to represent the effect of the climate variables. The climate data are derived from downscaled GCM projections that provide monthly precipitation, average minimum temperatures, and average maximum temperatures for each location. Companion downscaling techniques provide the monthly average number of rainy days and the average incident shortwave solar radiation flux. For a detailed discussion of specific model inputs, see Appendix C.

The crop yield changes from DSSAT at the pixel level are aggregated to match Syria's agroecological zones (Figure 2.2). Yield changes for six crops under two production systems (irrigated and rainfed) were combined at the agroecological zone level from the baseline dataset and two climate change scenarios (CSIRO A1B and MIROC A1B) at 30 arc-minute grid cells spatial resolution (see Appendix G). In all cases, we assume that the values all climate variables change linearly between 2000 and 2050. This assumption eliminates any random extreme events such as droughts or high rainfall periods and also assumes that the forcing effects of GHG emissions proceed linearly; that is, we do not see a gradual increase in climate change. The effect of this assumption is to underestimate negative effects from climate variability. To address this limitation, we analyze the impacts of the most relevant climate variability event—droughts—in a separate section.

Drought Analysis

Like many other countries in the Middle East and North Africa, Syria experiences periodic droughts as part of its climatic system. Yet, these extreme weather events usually have long-term consequences on people and their assets. Low levels of rainfall, especially when persisting for several months or even years, are one of the major characteristics of droughts. However, the time and space variations in rainfall

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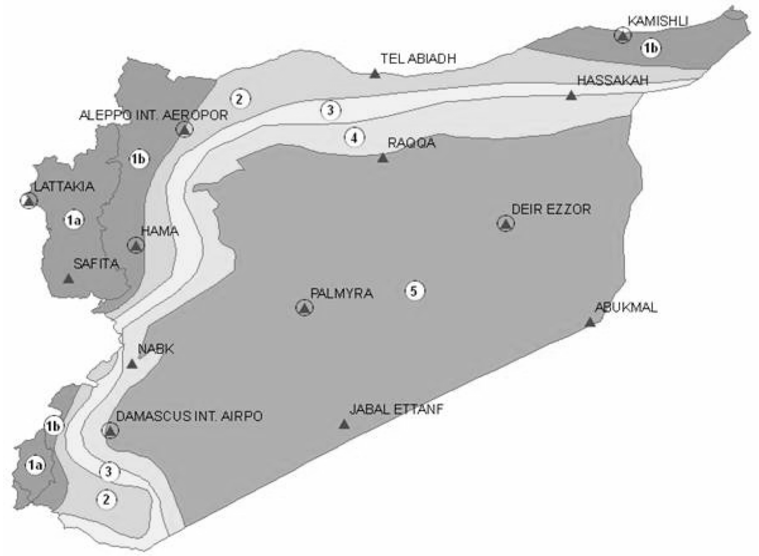
[5] The Worldclim current conditions dataset is available at www.worldclim.org.

often make it difficult to assess and compare the severity of droughts spatially, which is important both for drought monitoring and for drafting drought impact mitigation and adaptation policies.

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

To analyze the severity and frequency of drought events, we divide Syria into five agroecological zones that are mainly defined according to rainfall quantities. An agroecological zone is a land unit defined by major climate indicators measured over the length of the moisture availability period. In Syria, the climate, terrain, and soil characteristics of its five major agroecological zones (Figure 2.2) also largely define the farming systems. As described by FAO (2010), zone 1 receives annual average rainfall of more than 350 mm. It makes up 14.5 percent of Syria's land area and consists of two subzones, with the first receiving more than 600 mm of rainfall annually and where the yields of rainfed crops are certain for all the years. Zone 2 receives 250–350 mm of precipitation annually. The main crops in zone 2 are wheat, barley, and summer crops. This zone makes up 13.3 percent of the country's land area. Zone 3 receives 250 mm of precipitation annually, with a 50 percent chance in any year that rainfall is no less than this amount, thus ensuring production in one to two years out of every three. This zone mainly grows grain crops, but legumes are also grown here. Zone 3 makes up 7.1 percent of Syria's total area. Zone 4 is a marginal zone, receiving 200–250 mm of precipitation annually. Only barley can be grown in this zone, and it can be used as permanent pastures. Zone 4 makes up 9.9 percent of the total land area. Zone 5 is the steppe lands that make up 54.7 percent of the country's total area and receives less than 200 mm precipitation annually (UNDP and GEF, 2010). The land in zone 5 is not suitable for rainfed cultivation.

Figure 2.2—Agroecological zones in Syria



Source: IFPRI based on LANDSCAN.

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

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

Economic Impacts

Global Impacts: IFPRI IMPACT Model

The challenge of modeling climate change effects arises in the wide-ranging nature of processes involved in the working of markets, ecosystems, and human behavior. The analytical framework used in this report integrates various modeling components that range from the macro to the micro and from processes that are driven by economics to those that are essentially biophysical in nature. This section draws on Nelson et al. (2009) and gives an overview of the model, data, and assumption; more technical details can be found in Appendix Table H.7 , Rosegrant et al. (2001), and Nelson et al. (2009, 2010).

The IMPACT model is a partial equilibrium agricultural model with 32 crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes and meals, sugar, and fruits and vegetables. IMPACT has 115 country (or in a few cases country-aggregate) regions, and within each region supply, demand, and prices for agricultural commodities are determined. Large countries are further divided into major river basins, and these divisions are called *food production units* (FPUs). 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 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 ISPAM dataset of crop location and management techniques (You and Wood 2006). These results are then aggregated and fed into the IMPACT model. For future climate, we use the fourth assessment report A2 that runs using the CSIRO A1B and B1 and MIROC A1B and B1 models. For more information on the downscaling methodology, please refer to Appendix B. At one time the A2 scenario was considered an extreme scenario, although recent findings suggest that it may not be. 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 GHG emissions proceed linearly; that is, we do not see a gradual increase in climate change. The effect of this assumption is to underestimate negative effects from climate variability.

Local Impacts: Syria DCGE Model

Climate change affects world prices and local agricultural production with implications for the Syrian 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 Syria with five agroecological zones (Figure 2.2) 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 theoretical background and the analytical framework of DCGE models have been well documented in Dervis et al. (1982), and the detailed mathematical presentation of a static CGE model is described in Lofgren et al. (2002). The recursive dynamic version is based on this standard CGE model with the incorporation of a series of dynamic factors. The early version of this DCGE model can be found in Thurlow (2004), and its recent applications include Breisinger et al. (2009). A summary of the main equations can be found in Table E.4.

The DCGE model is specifically built to capture the economic, distributional, and poverty effects of climate change and droughts in Syria. Given the importance of agriculture, 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 23 production activities, 19 commodities, 9 factors of production, and 20 household types. The 17 agricultural production activities are split into livestock (4), fish (1), and crop production activities (12), where all crop production activities are specific to each agroecological zone. In addition, wheat and barley production activities are divided into irrigated and nonirrigated production systems.[6] Major data sources for the underlying social accounting matrix (SAM) include a 2007 macro SAM developed by the National Development Planning Commission (Appendix Table E.1), the Household Income and Expenditure Survey (HIES 2006/07), and the National Agricultural Policy Center's (NAPC's) comprehensive dataset on agricultural production, trade, and inputs. Specifically, the NAPC database is used to build a new agricultural supply use table based on crop budgets by agroecological zone. These data sources have been complemented with information from FAOSTAT (FAO 2010).

The model runs from 2007 to 2050 and is recursive dynamic; that is, the dynamics occur between 2007 and 2050 in each year. Investments are savings-driven, and savings grow proportionally to household incomes. 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 Syrian workforce is expected to grow at the same rate as the population grows, following an average long-term trend of 1.5 percent growth as projected by the UN (UN 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 into government and private sector. Accordingly, different wage rates for labor are 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 report. 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 Syria and thus partly captures the limited growth potential of the agricultural sector due to water constraints. Agriculture accounts for 90 percent of total water usage in Syria and for an estimated water deficit of nearly 5 billion cubic meters per year by 2025; therefore, addressing the severe water constraint becomes imperative for Syria'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 2007 to 2050 complete the set of values for the exogenous variables. TFP growth for nonagricultural sectors is assumed to be 1 percent annually, and TFP for the agricultural sectors is assumed to grow at annual rates of 0.5 percent. These different rates of

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[6] For a detailed list of production activities and commodities, factors of production, household types, and other accounts of the 2007 SAM, see Table E.1. The disaggregated SAM with agricultural and spatial detail is based on an aggregate 2007 SAM of Syria's State Planning Commission (SPC 2007).

TFP growth in the agricultural and nonagricultural sectors reflect the expected structural change under a business-as-usual scenario that is observed in all successfully transforming countries (Breisinger and Diao 2008). Under this baseline scenario, the share of the agricultural sector in Syria declines from an initial 17 percent of GDP to 9 percent of GDP by 2050.

The model captures some autonomous adaptation to climate change and droughts. Yield changes from the DSSAT model are introduced in the production function of the CGE model. These crop-specific and agroecological zone–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). *It is thus important to note that the model results should be interpreted as an optimistic scenario, in which the policy and economic environment allows for and supports climate change adaptation.* A set of several elasticities guide these 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, users of fuel can substitute this fuel for other 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, determines how consumers react to higher prices. We estimated the income elasticity for Syria from a semilog inverse function suggested by King and Byerlee (1978) and based on the data from HIES (Appendix F). 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 20 representative household groups for distributional and poverty effects. The household groups are first separated by rural or urban location. We then split urban into metropolitan and town households and rural into farm and nonfarm households. Each of these household types is further split by their respective expenditure quintile to capture the distinctive patterns of income and consumption and the distributional impacts of climate change. The DCGE model also links to a microsimulation model, which allows for the endogenous estimation of drought impacts on poverty reduction.[7] All HIES sample households are included in the microsimulation model, and their total expenditures and expenditures on each commodity or commodity group are linked to each of the 20 representative households included in the DCGE model according to their rural or urban location and income quintiles. The linkages between the DCGE and microsimulation models allow for the analysis of the micro impact of changes in the representative households' consumption induced by changes in their income and changes in market prices and other factors. The endogenous changes derived from the DCGE model for the 20 representative households are used to recalculate consumption expenditure of their corresponding households in the survey dataset. New levels of total consumption expenditures are recalculated based on individual household budgets; and the new poverty rates for each region, rural and urban, and the national total are obtained by comparing expenditure levels (in real terms) with the official poverty line defined for HIES.

We use the DCGE model and design four sets of scenarios. The first set of scenarios captures the global impacts of climate change, while the second set of scenarios assesses the local impacts of climate change. The third set combines the two to assess the joint effects, and the fourth considers the impacts of drought (Table 2.1). Within the first set of scenarios, we design three scenarios: Scenario 1A changes the world food prices consistent with IMPACT model results under no climate change, or perfect mitigation. Scenario 1B explores climate change–related price effects under MIROC A1B, with the assumption that no climate change impacts are felt locally in Syria (see Figure 3.2 for price changes). Scenario 1C is a scenario to test the sensitivity of results to potential global energy price increases (see Appendix A).

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[7] We conduct poverty analysis only for drought impact and focus on distributional impacts for the climate change effects. This is because given the long-term horizon of 40 years, poverty even in the baseline scenario will be close to zero, which prohibits any meaningful comparison with the climate change scenario.

Scenario 2 imposes the yield changes from the DSSAT model on a crop-by-crop level and by agroecological zone. The related matching between DSSAT results and CGE production activities is shown in Appendix G. Results for Scenarios 1B through 3 are reported as a change from the perfect global mitigation scenario to isolate the climate change effects. Results of the drought scenario are presented relative to the baseline.

Table 2.1—Climate change and drought scenarios

Scenarios	Change in model	Input
Baseline	See text	See text
Global impacts of climate change		
Scenario 1A	Perfect mitigation, compared to base	IMPACT, MIROC A1 B
Scenario 1B	Climate change, compared to perfect mitigation	IMPACT, MIROC A1 B
Scenario 1C	Energy price sensitivity analysis, compared to 1B	IMPACT, MIR B1 and EIA
Local impacts		
Scenario 2	Crop yield changes	DSSAT MIROC A1 B
Joint impacts		
Scenario 3	1B and 2	IMPACT and DSSAT, MIROC A1 B
Drought impacts		
Scenario 4	Crop yields and livestock production	Palmer index and historical data

Source: Authors.

3. ECONOMIC IMPACTS OF CLIMATE CHANGE IN SYRIA

Syria is in the process of substantial economic reform to accelerate growth and transform its economy. In fact, significant progress in these areas has been made during the past five years, supported by extensive reforms in the fields of trade, taxes, subsidies, foreign direct investment, and the development of non-oil industries. Economic growth averaged more than 5 percent during the period 2004–2008, and the incidence of poverty declined to about 12 percent in 2006–2007.

Yet, climate change may threaten Syria's progress in development and pose a significant burden on economic growth and household incomes, especially those of the poor. The major channels through which the Syrian economy is likely to be affected most are through the global impacts as a result of changing global commodity prices and the local impacts on agricultural production; the increase in sea level and floods may play a lesser role (NAPC, pers. comm.). Important determinates of future water availability are likely to include more than climate change. Particularly, there is uncertainty related to levels of future water allocation and river flows, which will depend on a comprehensive water strategy that addresses not only national water sources and uses but also regional water-sharing agreements with neighboring countries. Agriculture uses about 90 percent of all water, of which 47 percent is surface water that Syria shares with its neighbors, mainly from the Tigris, Euphrates, and Orontes Rivers (World Bank 2010). Although we acknowledge the importance of a comprehensive water strategy, including potential river flow futures goes beyond the scope of this paper.

Structure of the Syrian Economy

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

Agricultural and related processing contributes about 19 percent to GDP, about half of which is produced in agroecological zone 1. Livestock alone makes up close to 6 percent of GDP, dominated by sheep production (3.1 percent). Vegetables and fruits contribute 2.5 percent and 3.0 percent to GDP, respectively, followed by cereals, with 3.3 percent (Table 3.1). Nonirrigated cereals production is mostly concentrated in agroecological zones 1 and 2, as are water-intensive crops such as fruits and vegetables (Table 3.2). In terms of their contributions to GDP, zone 2 is the second largest contributor, followed by zones 5, 3, and 4.

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

Table 3.1—Structure of the Syrian economy by sector, 2007

	GDP	Private consumption	Import intensity	Export intensity
Wheat	2.8	0.1	7.9	1.1
Barley	0.4		42.1	87.1
Other cereals	0.1	1.1	72.9	0.7
Fruits	3.0	8.3	1.5	5.1
Vegetables	2.5	6.5	1.8	30.4
Olives	1.0	0.5	0.0	42.8
Cotton	1.1			
Other crops	0.6	1.0	19.4	14.0
Sheep	3.1	5.1	0.1	0.5
Cattle	1.8	4.3	0.2	0.1
Camels	0.1	0.0		
Poultry	0.7	3.6	0.1	
Fish	0.2	0.5		
Food processing	1.5	20.4	12.9	16.9
Manufacturing	12.9	13.1	77.2	80.3
Mining	24.5		87.9	42.9
Energy and water	6.2	4.8		
Public services	11.7	0.8		
Private services	25.7	29.7	17.8	45.8
Total	100	100	28.2	34.8

Source: DCGE model.
Note: Import intensities are calculated as shares of total domestic consumption (final and intermediate). Export intensities are the ratios of exports to domestic production.

Table 3.2—Agricultural value added, by zone and crop, 2007 (share)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Total
Wheat	7.1	6.0	1.2	1.7	3.2	19.2
Durum	4.3	2.5	0.4	0.5	1.3	9.0
Irrigated	2.7	1.9	0.4	0.5	1.3	6.8
Non-irrigated	1.6	0.6				2.1
Soft	2.8	3.5	0.8	1.2	2.0	10.3
Irrigated	1.6	2.3	0.7	1.2	2.0	7.7
Non-irrigated	1.2	1.2	0.1			2.6
Barley	0.3	1.6	0.7	0.3	0.2	3.1
Irrigated		0.1	0.0	0.1	0.2	0.3
Non-irrigated	0.3	1.6	0.7	0.3		2.8
Other cereals	0.0	0.1	0.1	0.2	0.6	1.0
Fruits	17.9	4.3	1.8	0.7	0.9	25.6
Vegetables	12.5	6.8	1.6	2.1	5.3	28.3
Olives	4.9	1.9	0.4	0.3	0.5	7.9
Cotton	2.8	3.2	0.8	1.1	2.1	10.2
Other crops	2.7	1.1	0.2	0.2	0.4	4.7
Total	48.3	25.0	6.9	6.6	13.2	

Source: D CGE model.

Another dimension of development, especially in times of crisis like droughts, is food security, which can be defined as a situation of all people having access to food[8]. According to this definition, food security mainly depends on a country's ability to import food or produce food or both (macro level), and on households' ability to produce food or buy food or both (micro level). Macro-level food security can

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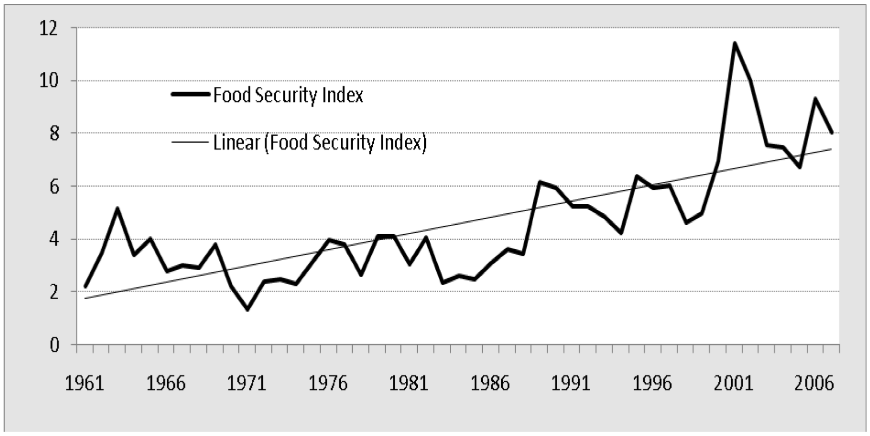
[8] The most widely accepted definition of food security is the one adopted by the 1996 World Food Summit (WFS): "Food security, at the individual, household, national, regional and global levels [is achieved] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996).

be measured as the ratio of total exports to food imports; therefore, food security by definition does not equal food self-sufficiency—a fact of particular relevance for the Middle East and North Africa (MENA) region (Diaz Bonilla et al. 2002; Yu, You, and Fan 2009; Breisinger et al. 2010). The rationale for using this measure is that exports generate foreign exchange earnings and incomes, which generally help financing food imports and food purchases at household levels. In fact, a country can be food secure if it exports enough goods and services to finance food imports. However, this does not necessarily imply that all households, in all regions and income brackets, have access to sufficient food at all times.

Syria's food security index has climbed steadily from 1961 to 2007 (Figure 3.1), yet food security remains much lower than in neighboring Turkey and the international average (Breisinger et al. 2008). The index is likely to have worsened during the 2008 global food crisis, but before the crisis it had been steadily increasing. This increase was mainly due to Syria's increase in total merchandise exports relative to its food imports, rising from an index of 2.2 in 1961 to 8.0 in 2007. This experience in Syria, in addition to that in neighboring Turkey, confirms that contrary to the often held position that food security only depends on improving agricultural production, it can also be improved by increasing total exports (incl. non-agricultural goods and services). Turkey's food security index has averaged around 30 since the 1990s, indicating that the country uses only about 4 percent of its export earnings to import food. Turkey's high levels of food security have been supported by a strong export performance.

Figure 3.1—Food security in Syria, 1961–2007



Source: Authors' calculations based on FAOSTAT.

Turkey's strong performance in food security can, among others, be explained by sound macroeconomic policies that have fostered environment for strong growth (IMF, 2005; IMF, 2010). Its average annual GDP growth rate came at 8 percent from 2000 to 2005. During that period too, it registered the lowest inflation figures in over a generation, steadied and appreciated its lira, reduced its domestic debt, and maintained on average a steady annual increase in its agricultural value added by an average of 2 percent (IMF 2005).[9] Thus, continuing policies of economic diversification and improving competitiveness will be important contributor to improve food security in Syria also.

A major determinant of food security at the household level is household income. Dividing households according to their location, occupation, and income quintiles allows for the analysis of income and distributional effects of climate change. The top 20 percent of households earn about 40 percent of all household incomes (as reported in HIES 2006/07), and the bottom quintile earns about 13 percent of all incomes. Broadly in line with the estimate of agricultural GDP, farm households earn about 21 percent of all household incomes However, within farm households are large discrepancies. Farmers in the top

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[9] Despite substantial macroeconomic improvements, Turkey still maintains some vulnerabilities such as a high unemployment rate (at 10 percent), dollarization of its economy, high public debt figures, a growing capital account, and decreasing exports (IMF 2010).

quintile account for 44 percent of all income earned by farm households, but those in the bottom quintile, only 13 percent. As expected, skill levels of labor are strongly related to household income levels (Table 3.3). Poor households earn most of their income from unskilled labor, and households in higher income quintiles rely more on skilled labor and capital earnings.

Table 3.3—Structure of household income sources (by type and quintile), 2007

	Labor		Capital	Land	Livestock	Total
	Skilled	***Unskilled***				
City 1	3.3	70.0	26.7			100.0
2	6.8	61.2	32.1			100.0
3	13.2	59.3	27.5			100.0
4	19.9	40.8	39.3			100.0
5	11.3	13.1	75.6			100.0
Town 1	3.7	63.6	27.4	4.6	0.8	100.0
2	6.6	70.8	17.1	4.7	0.8	100.0
3	7.2	61.5	25.4	5.0	0.8	100.0
4	10.1	45.7	39.3	4.1	0.8	100.0
5	8.3	22.4	65.4	3.1	0.7	100.0
Rural nonfarm 1	2.0	55.4	42.6			100.0
2	4.2	46.5	49.3			100.0
3	6.3	50.8	42.8			100.0
4	6.2	44.8	49.0			100.0
5	5.1	25.6	69.4			100.0
Rural farm 1	0.9	35.1	21.7	35.3	7.0	100.0
2	1.8	34.1	21.0	36.7	6.4	100.0
3	2.1	36.8	19.3	36.2	5.5	100.0
4	3.0	39.4	13.8	37.7	6.1	100.0
5	1.4	12.8	71.1	12.8	2.0	100.0

Source: DCGE model.

It is against these structural characteristics of the Syrian 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 3.2 reports the effects of the climate change scenarios on world food prices (CSIRO A1B and MIROC A1B). It also reports the price effects with no climate change (perfect mitigation). With no climate change, world prices for the most important agricultural crops—rice, wheat, maize, and soybeans —will increase between 2000 and 2050, driven by population and income growth and biofuels demand. Even with no climate change, the price of rice would rise by 62 percent, maize by 63 percent, soybeans by 72 percent, and wheat by 39 percent. Climate change would result in additional price increases of: 32 to 37 percent for rice, 52 to 55 percent for maize, 11 to 14 percent for soybeans, and 94 to 111 percent for wheat (Nelson 2009).[10] One of the assumptions of IMPACT is that the second generation (cellulosic) biofuels will phase in from 2025 on and replace food feedstock-based biofuels. The reduction in demand for food crops the slower price increase after 2025. Livestock are not

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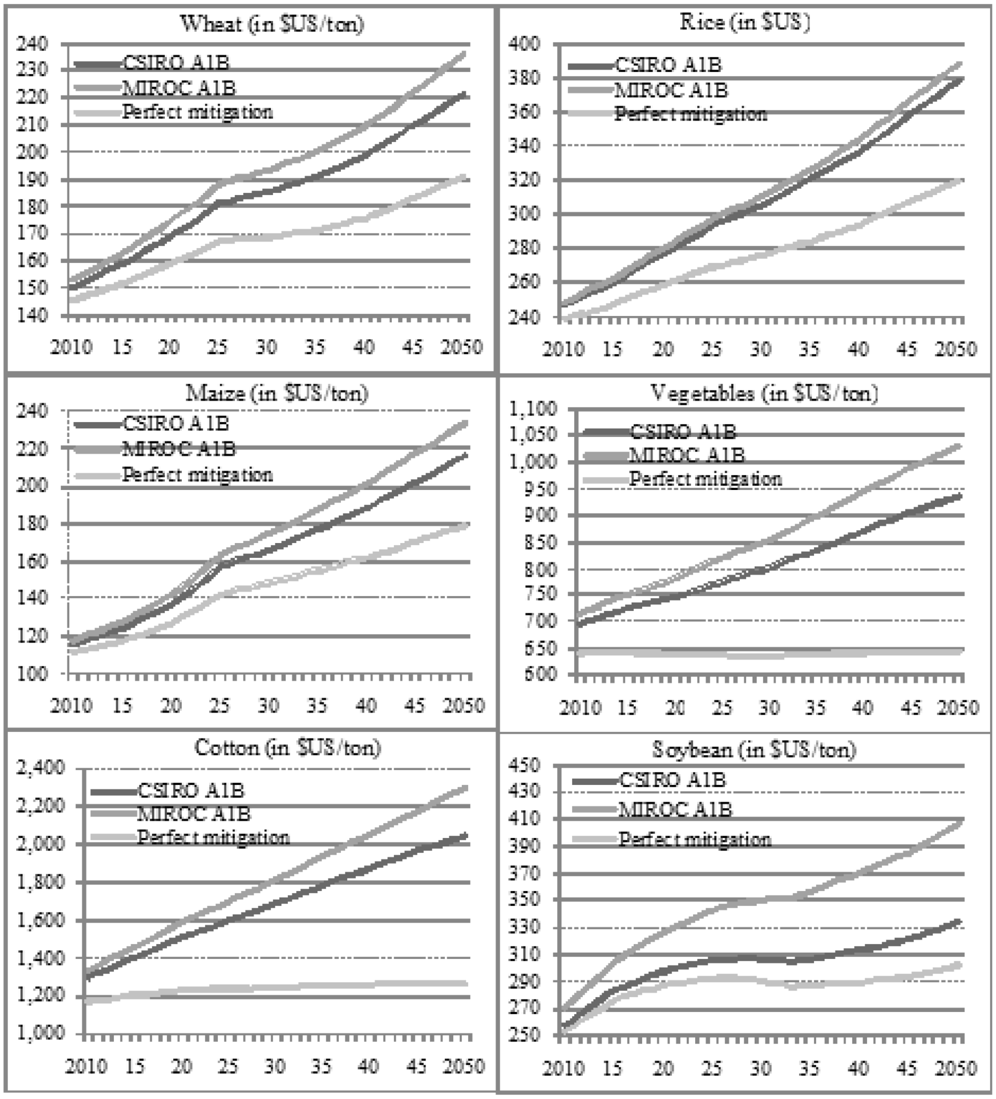
[10] In addition to various CGMs, Nelson et al. (2009) also include low, medium, and high assumptions on population and GDP percent growth. For this study, we use the medium-level assumptions.

directly affected by climate change in the IMPACT model; however, the effects of higher feed prices caused by climate change pass through to livestock, resulting in higher meat prices.

Figure 3.2—Global food price scenarios



Source: IFPRI IMPACT model.

Climate change–related global food price increases benefit the agricultural sector in Syria through higher prices but lead to overall negative effects on the economy as a whole. The annual average agricultural growth rate is between 0.2 and 0.4 percent higher compared with the perfect mitigation scenario, but exhibits a declining trend over time (Figure 3.3).[11] The positive effect on agricultural growth GDP cannot outweigh the negative effect on other sectors, which reduces the overall annual growth rate by 0.01–0.02 percent between 2010 and 2050, relative to the case of perfect global mitigation (Appendix Table H.7). This slower growth is mainly explained by an increase in the real exchange rate and higher costs for factors employed in the agricultural sector.

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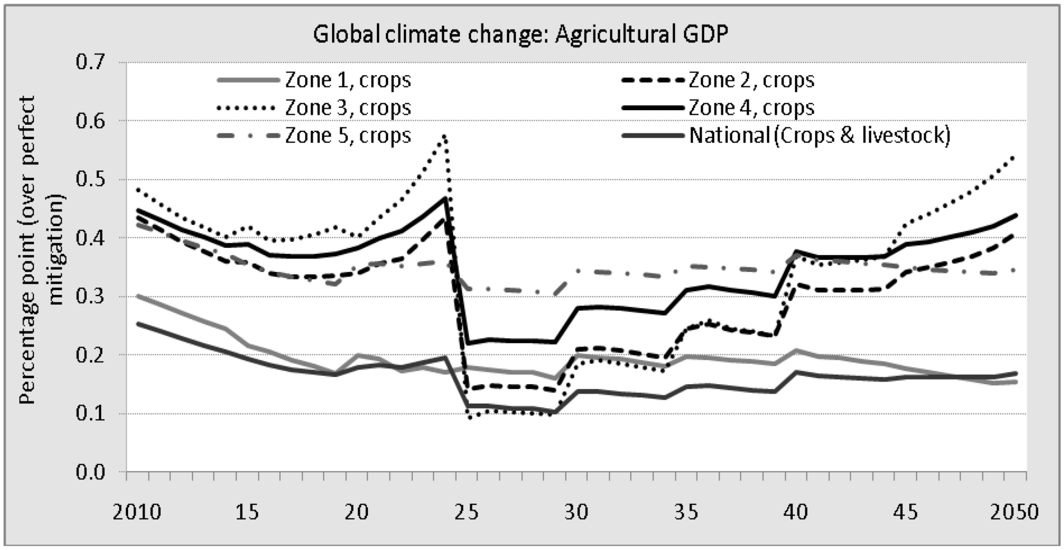
[11] In the DCGE model it was not possible to separate livestock by agroecological zones. Therefore, totals in the graphs refer to total GDP, while the zone-level results exclude livestock.

Figure 3.3—Impacts of global changes on agricultural GDP, 2010–2050



Source: DCGE model.

Impacts on crop GDP growth vary by agroecological zone depending on the zone's production structure. In general, the zones that grow more crops that experience the largest world market price increases relative to other crops benefit the most (Figure 3.3). Agricultural growth in zones 1–5 ranges between 0.1 and 0.5 percent above the perfect mitigation scenario during the entire period. Benefits to the agricultural sector accrue in two phases, a 0.1-0.6 percentage point growth rate acceleration compared to perfect mitigation until 2025, followed by a steady increase in agricultural output in most zones from 2025-2050.[12] The sudden change in agricultural GDP around the year 2025 underlines the importance of considering global effects on domestic agriculture. While the drop does not strongly effect the overall impact, it does show that the projected change in global biofuel policies and the expected slowing of food price rises have repercussion on the country and sector levels. Zone 5, for example, stays within the range of 0.4 to 0.3 percent higher compared with the baseline, while the zone 1 values do not rise beyond 0.3 percent higher. The relatively low additional growth in zone 1 is explained by its high share of fruit and vegetable production (Figure 3.3), for which world market prices rise relatively less than prices of other crops. However, in absolute terms, zone 1 gains the most, given that about 50 percent of agricultural value added is produced in this zone.

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

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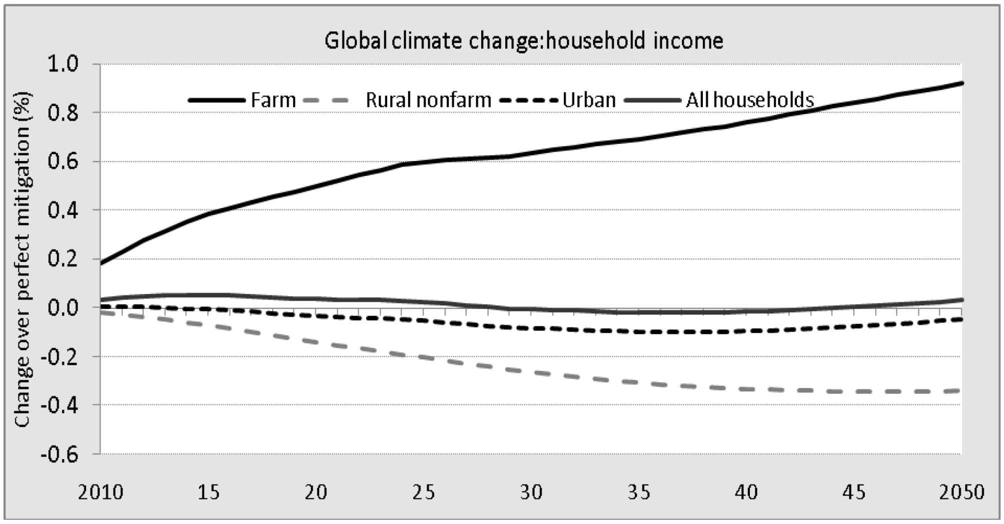
[12] As discussed in 3.18, the change in world market prices due to projected changes in biofuels policies has repercussions on the country level. A slower increase in global food prices leads to a slower increase in producer prices in Syria and thus slower agricultural growth.

Figure 3.4—Household-level impacts



Source: DCGE model.

Results of an energy sensitivity analysis show that a potential increase in global energy prices (due to climate change or other factors) will exacerbate negative economic impacts (Figure A.2). This is because Syria is currently and is likely to remain a net energy-importing country and thus, assuming no major technological breakthroughs to substitute oil, higher oil prices will raise production costs (fertilizer, transport), lowering competitiveness and real incomes. Higher oil prices raise production costs (fertilizer, transport etc.) reducing profits and welfare by significantly adding to the expenditures of Syria's households.

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

Local Impacts of Climate Change

Yields in all agroecological zones are projected to decrease over time due to climate change, albeit at different levels. Table 3.4 shows the results from the DSSAT crop model explained in Section 2 for the crops for which sufficient information was available by agroecological zones. Results indicate that yields of rainfed crops in general are hit the hardest and decline between 29 and 57 percent from 2010 to 2050 compared with rates in perfect mitigation. A combination of lower rainfall and higher temperatures, in addition to changes in solar radiation, the physical and chemical characteristics of soil, and levels of fertilizer applications, explain these lower yields.

Table 3.4—Yield changes for selected crops

Yield Change	Annual Yield Change (kg)	MIROC Average Annual Yield Change (%)	Yield Change (2000–2050, %)
	Zone 1		
Wheat irrigated	–9.7	–0.8	–37.8
Wheat rainfed	–3.6	–0.6	–28.9
Maize irrigated	–0.8	0.0	–0.9
Potatoes irrigated	–14.3	–0.8	–27.3
	Zone 2		
Wheat irrigated	–4.4	–0.4	–19.7
Wheat rainfed	–3.3	–0.5	–23.5
Maize irrigated	–8.5	–0.1	–7.2
Potatoes irrigated	–9.0	–0.9	–22.7
	Zone 3		
Wheat irrigated	–2.9	–0.3	–12.6
Wheat rainfed	–7.4	–0.9	–46.4
Maize irrigated	–5.9	–0.1	–5.1
Potatoes irrigated	–14.6	–0.6	–17.7
	Zone 4		
Wheat irrigated	–3.3	–0.3	–14.4
Wheat rainfed	–6.7	–1.1	–57.2
Maize irrigated	–4.9	–0.1	–5.0
Potatoes irrigated	–29.6	–0.9	–40.0
	Zone 5		
Wheat irrigated	0.0	0.0	–0.2
Maize irrigated	–5.4	–0.1	–5.9
Potatoes irrigated	–17.1	–0.8	–29.9

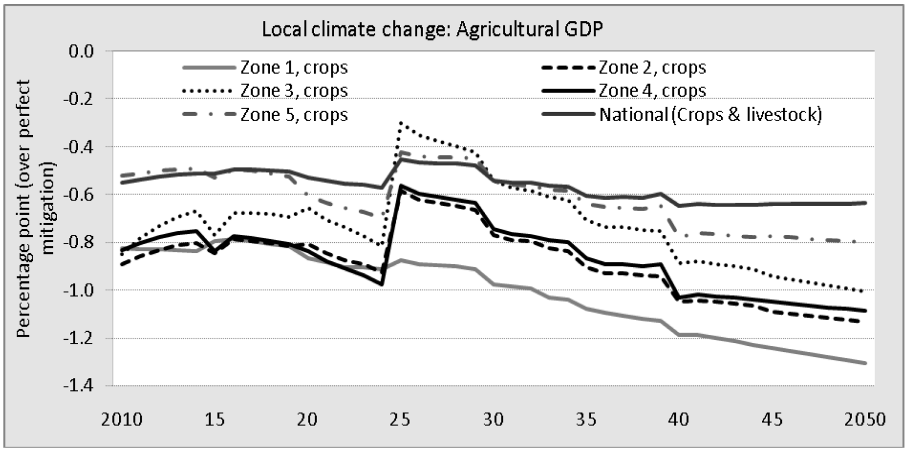
Source: Authors' calculations based on DSSAT.

However, yields for irrigated crops are also projected to significantly fall in all zones, mainly due to higher temperatures. The largest annual yield reductions for irrigated wheat occur in zones 1 and 2, which are the two most productive zones for agriculture in Syria. Reductions in annual maize yields have been stable at 0.1 percent across all the agroecological zones. Potato yields have shown the largest yield reductions across all zones relative to wheat and maize. The following paragraphs analyze how the decline in yields for different crops affects agricultural GDP, the economy as a whole, and households.

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

Across the five agroecological zones, crop GDP shows a long-term declining trend; however, the magnitude of change for each of the five zones differs depending on their crop mix (Figure 3.5). When climate change is only local, the largest and steepest declines in crop GDP are in zone 1, which accounts for half of agricultural production in Syria. The least affected zone on the other hand is zone 5, as it contributes only 13 percent to crop activity in Syria. Thus, zones 1 and 2 are most affected by local climate change, both in relative and in absolute terms.

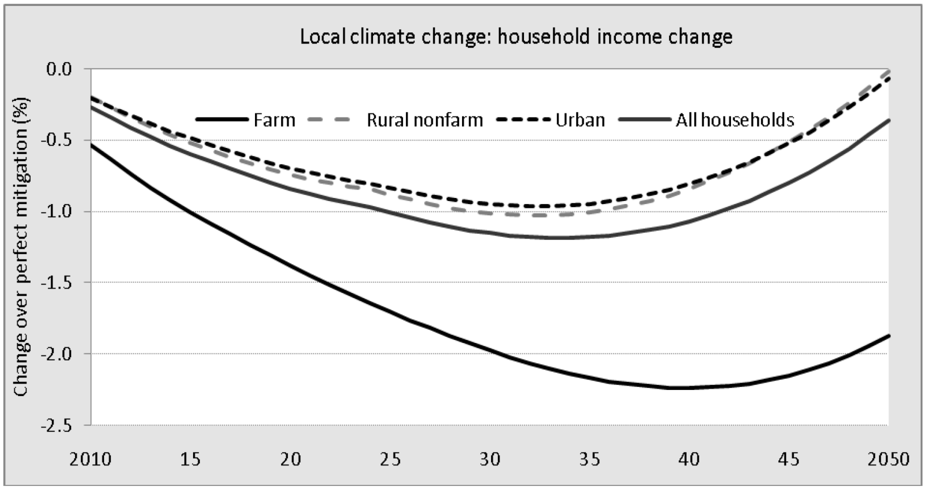
Figure 3.5—Impacts of local changes on agricultural GDP, 2010–2050



Source: DCGE model.

Local climate change reduces welfare for all household groups, but households adapt to climate change over time. The hardest hit households are the farm households, whose annual income is between 0.5 and 2.2 percent lower than that in perfect mitigation (Figure 3.6). They are impacted through two major channels: The loss of income from lower yields cannot be compensated by higher prices they receive for their products. Agricultural price increases are also modest because the loss in domestic output is substituted by imports. Factor income for the rural nonfarm households also falls, as their income-generating potential is tied to the rural sector, and with the overall decrease in wages, they too lose income. Compared with the rural households, urban households suffer the least because they earn most of their income (via highly skilled labor and capital) and therefore are less affected than the low-skilled labor and landowners in the rural areas (Table 3.5). All households adapt to climate change by shifting their production factors to sectors of production that are less affected by climate change, both within and outside of agriculture.

Figure 3.6—Household income change



Source: DCGE model.

Table 3.5—Distributional impacts, local and global climate change

	Average Household Income (Thousand SYP)	Per Capita Income (Thousand SYP)	Average Annual Change, 2010–2050 (%)		
Households by Quintiles	2007	2007	Global Climate Change	Local Climate Change	Combined Climate Change
Urban 1	199	28	0.1	–1.3	–2.3
2	222	37	0.1	–1.1	–2.0
3	236	44	0.1	–1.1	–1.9
4	294	63	0.0	–0.8	–1.7
5	563	160	–0.3	–0.1	–1.3
Rural Nonfarm 1	209	27	–0.2	–1.2	–2.8
2	277	40	–0.2	–0.9	–2.4
3	262	44	–0.2	–0.9	–2.3
4	337	62	–0.2	–0.8	–2.3
5	510	116	–0.3	–0.3	–1.7
Rural Farm 1	293	36	1.1	–2.8	–2.3
2	337	45	1.2	–2.7	–2.0
3	379	55	1.2	–2.6	–2.0
4	369	66	1.3	–2.9	–2.1
5	1,050	204	0.0	–0.7	–1.8

Source: DCGE model.

The poorest in both rural and urban household groups are the ones that suffer the most from local climate change. The poorest quintiles (lowest 20 percent) in all groups earn an average of between 1.2 and 2.8 percent less per year than under perfect mitigation, compared with a lower decline of between 1.3 and 1.8 percent for the richest household groups (Table 3.5). The poorest among the farm households group are the hardest hit among all groups, with an average annual income loss of 2.8 percent compared with perfect mitigation. Specifically, given that rural farm households have an initial income of 293,000 Syrian pounds (SYP) per year, these households would lose an average of about 8,000 SYP of income due to climate change (a 2.8 percent decline). While this decline may seem small at first glance, it is important to bear in mind that these annual losses accumulate over 40 years. In addition, as mentioned above, simulation results reflect a more optimistic scenario, in people can freely adapt to a changing climate by switching crop patterns and moving out of agriculture and into other sectors of the economy.

Combined Climate Change Impacts

Considering the global and local effects of climate change jointly shows that the two compound each other. Economic growth is on average 0.05 percentage points lower each year compared with perfect mitigation between 2010 and 2030 (Appendix Table H.7). However, as in the case of local climate change only, the economy adapts to climate change over time but never reaches the levels of the perfect mitigation scenario. Climate change speeds up structural change in the economy, where the share of agriculture declines to 8.3 percent in 2050, compared with 9.5 percent under perfect mitigation (Table 3.6). Consequently, the industrial and services sectors gain in relative importance, moving from 45 and 37 percent of GDP, respectively, to 47 and 46 percent, respectively, by the end of the period.

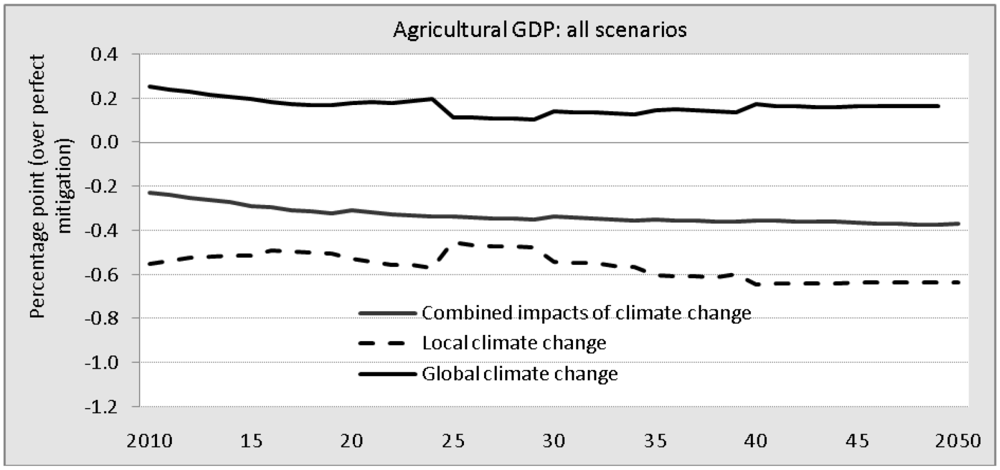
Table 3.6—Structural change under climate change scenarios (% of GDP)

	Initial	2030	2050
Perfect Mitigation	100.0	100.0	100.0
Agriculture	17.3	11.7	9.0
Industry	45.2	45.1	44.8
Services	37.5	43.2	46.2
Global	100.0	100.0	100.0
Agriculture	17.3	12.5	10.2
Industry	45.2	44.5	43.9
Services	37.5	42.9	45.9
Local	100.0	100.0	100.0
Agriculture	17.3	10.6	7.3
Industry	45.2	45.8	46.1
Services	37.5	43.6	46.6
Combined	100.0	100.0	100.0
Agriculture	17.3	11.3	8.3
Industry	45.2	45.3	45.3
Services	37.5	43.3	46.4

Source: DCGE model.

Agricultural output declines under the combined climate change scenario with increasing speed over time. As shown previously, the impact of global climate change in isolation has positive implications on agricultural production; however, when the negative impacts on agricultural GDP from local climate change are factored in, over time, the agricultural growth rate is between 0.2 and 0.4 percentage points lower each year than under perfect mitigation. The overall reduction in yields due to the local impacts of climate change translates into higher domestic agricultural prices and also in increase in imports. Higher domestic prices reduce competiveness on the world market and thus also affect Syria's exports of agricultural crops. However, this latter effect is reduced when global climate change is factored in and globally higher crop prices provide a boost to the agricultural sector and improve agricultural export performance, leading to faster growth of the agricultural sector (compared with perfect mitigation). Given these two opposite impacts, under combined climate effects, agricultural GDP declines to 0.4 to 0.6 percentage points below perfect mitigation outcomes over the entire period (Figure 3.7). The decline accelerates over time, indicating that if no climate change mitigation action is taken, agriculture is likely to continue to suffer after 2050.

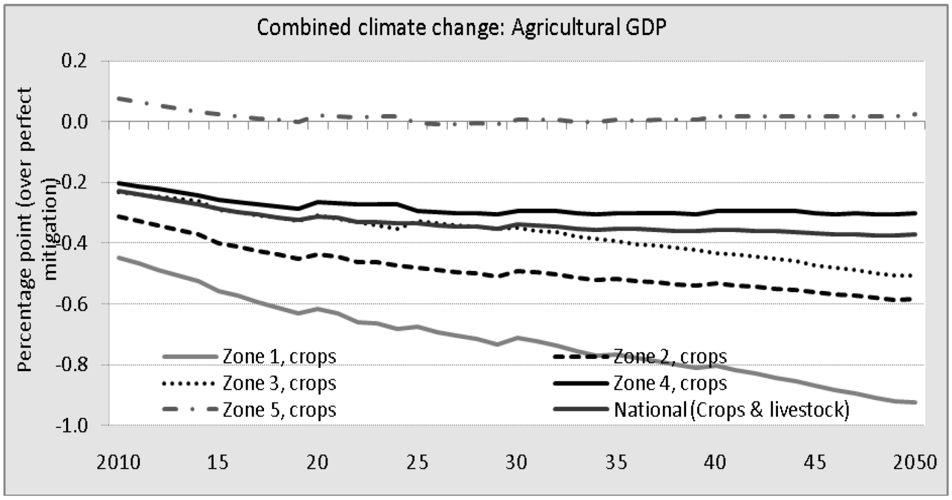
Figure 3.7—Impacts of global changes on agricultural GDP, 2010–2050



Source: DCGE model.

The combined effect of global and local climate change has detrimental effects on agricultural GDP across all zones, with the largest declines occurring in zones 1 and 2, which together account for three-quarters of agricultural production in Syria (Figure 3.8). Despite the positive impacts that global climate change may provide to the Syrian agricultural sector due to the increased price of agricultural produce, the reduced local agricultural yields hurts output in all zones. GDP growth rates are between 0.2 and 0.9 percentage points lower across zones compared with perfect mitigation, with the sharpest declines in zones 1 and 2. Zone 5 is the least affected in terms of reduction in crop output, largely because of the absence of rainfed agriculture. If factoring in potential impacts on livestock (which was not possible in this report), zone 5 is likely to suffer losses in agricultural output, too.

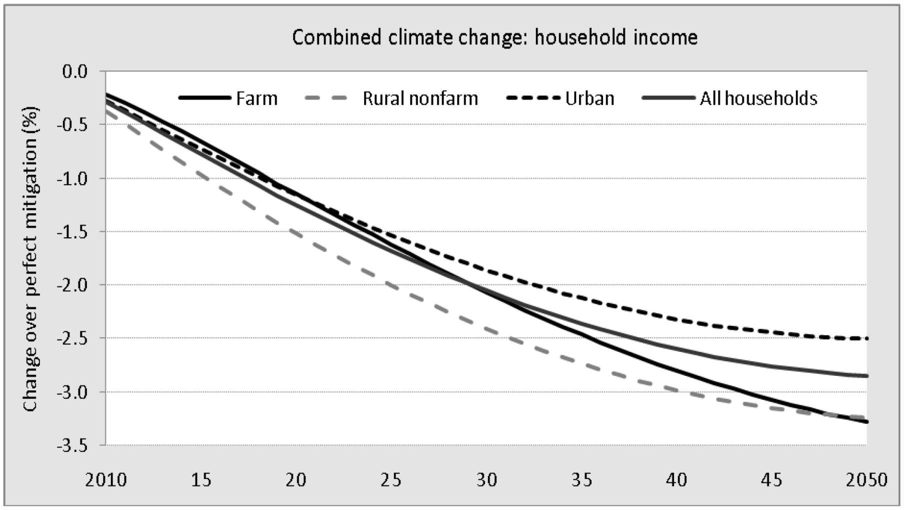
Figure 3.8—Impacts of combined local and global changes on agricultural GDP, 2010–2050



Source: DCGE model.

Taking the global and local impacts of climate change together leads to sharp declines in household welfare. The magnitude of these combined losses is far greater than when climate change was confined to the local arena. Mainly, two effects account for this scenario: an income effect and a price effect on household expenditure. For the former, despite the fact that under a global climate change scenario farmers benefit from the higher agricultural prices, when local yields decline due to local climate change, farmers are unable to increase their production and thus fail to benefit from this income potential. Additionally, agricultural prices are higher and households have to increase their consumption of imported goods, and therefore households end up paying more for their food basket than they did when climate change impacts were only local. Real income of rural farmers decreases by up to 3.2 percent compared with perfect mitigation (Figure 3.9). As for rural nonfarm households, their real income falls by up to 3.2 percent over the baseline by 2050 as a result of being net food consumers who have to contend with their rising expenditure on food. Again, the welfare reductions, compared with perfect mitigation, are far greater than when climate variability was local.

Figure 3.9—Household income change, local and global climate change



Source: DCGE model.

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

These results suggest that climate change will negatively affect the economy and households, despite optimistic assumptions about the capabilities of households to adapt to climate change in the long run. It is also important to note that specific household groups such as Bedouins and specific sub-regions of Syria, such as Badia are likely to be hit harder than the aggregate picture shown here suggests. In addition, the model may underestimate the emerging water scarcity and related negative effects on agriculture. Furthermore, this section discussed the long term effects of climate change and did not include climate variability (droughts). The impacts of droughts are likely to compound the negative long term effects and are analyzed in the following section.

4. ECONOMIC IMPACTS OF DROUGHTS IN SYRIA

Drought Characteristics

Syria frequently suffers from droughts, causing negative implications for the economy and people. In general, droughts affect a country through a variety of channels. Low rainfall leads to crop yield reduction or, in extreme cases, to complete loss of the harvest, especially for rainfed agriculture. Droughts also affect the livestock sector, especially animals that rely on pastures for feed. Not only the frequency of droughts but also the length of the dry period matters, where prolonged periods of low rainfall tend to exacerbate the impacts. In addition to these direct effects on the agricultural sector and farm households, indirect effects of droughts are likely to affect other sectors of the economy and nonfarm households.

Experience from the 2007–2009 droughts confirms that the impacts of climate variability reach beyond the agricultural sector and the rural poor in Syria. Narratives suggest that the recent droughts have been especially damaging for small-scale farmers and herders, while affecting nonfarm households through higher prices and thus reductions in real incomes.[13] In addition, reductions in wheat yields have made Syria a net wheat importer over the past three years, with macroeconomic implications on the balance of payments and concerns about macro-level food security. Although these general directions of drought impacts in Syria are well known, the potential size of drought impacts in terms of GDP lost and changes in poverty are not as well understood.

Quantifying the impacts of drought is important to incorporate appropriate responses into development strategies. This may become even more important in the future, given that global climate change may increase the severity and frequency of extreme weather events (Salinger 2005). However, conducting drought impact assessments is complicated by the complex nature of the impacts and the availability of data. Isolating drought effects can be challenging, and if data are incomplete, it may not always be possible to assess the direct and indirect effects, which is why computable general equilibrium (CGE) models have become an increasingly popular tool for disaster impact assessments (Pauw et al. 2010). Within the CGE literature, the most common analyses are ex ante, to assess the impacts of hypothetical events (for example, Boyd and Ibarraran 2009), and ex post, to evaluate the impacts of historical events (for example, Horridge, Madden, and Wittwer 2005).

This drought impact assessment uses the CGE model presented in Section 2 to assess the potential impacts of future droughts in Syria. We use an ex post approach by using the data from a historical drought event in Syria and, more specifically, the changes in yields and losses in livestock that occurred during 1999–2001. This approach allows us to look beyond the reductions in agricultural production and also isolate the impacts on the broader economy and households. This chapter reviews major meteorological characteristics in Syria relevant for plant growth and identifies major drought events by agroecological zone using the Palmer index and then introduces the CGE simulation design by analyzing historical crop and livestock data and present model results.

Droughts in Syria have occurred frequently during the past 50 years. Throughout the fifty years, from 1961 to 2009, Syria suffered through [close to] a quarter century's worth of drought, a figure quite significant in that it makes up slightly over 40% of this period in Syria's history. On average, the drought periods lasted close to four and a half years each time; however, the drought years of the 1970s were especially notable because they affected four out of the five agricultural zones in Syria and lasted for 10 consecutive years. Following these droughts, the intensity and frequency of the drought periods varied across Syria and its different agroecological zones.

From an agricultural perspective, a drought's spatial extent can prove as important as its severity measure, and disaster risk management is especially challenging when droughts occur in different zones at the same time. The more the spread of drought occurrences across the zones at once, the more serious the implications may be on the country's food security and economic stability in general. Food self-sufficiency is not a necessary condition for food security; however, a longer-lasting nationwide drought

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[13] Based on interviews from a fieldtrip in April 2010.

occurrence would severely impact not only rural livelihoods and the agricultural sector but all livelihoods and the consequent implications on poverty. Dwindling foreign currency earnings become scarce with harsh implications for food security.

Over the past half century, nearly 40 percent of the time drought occurred in zones 2, 3, and 4 (Table). The probability of a drought was only slightly lower in zones 1 and 5. In zone 5, however, multiyear droughts are more frequent, which can be more harmful because water storage (for example, in reservoirs, soil, and aquifers) and food storage may likely be depleted before a prolonged drought terminates, forcing herders to reduce their animal stocks. It is also worth noting that the average length of a drought is extremely long in zone 4. The International Disaster Database of the Center for Research on Epidemiology of Disasters (CRED 2009) ranked the droughts in 1999 and 2008 among the top 10 natural disasters in Syria since 1990.

Normal weather conditions (that is, with a Palmer Z index between –1.5 and 1.5) were simultaneously observed across all five agroecological zones only during the 1960s and to some extent the 1980s. However, other than the sixties and eighties, normal weather only occurred simultaneously in two to three zones, indicating that Syria is prone to extreme weather events especially during the past 20 years.

Moderately wet conditions, with a Palmer Z index of greater than 1.5 and less than 3, are very rare in Syria and have only once been experienced by all five zones simultaneously, in 1969 and in 1988. As for very wet events - a Palmer Z index of greater than 3 - the data does not show a single year when all five agro ecological zones witnessed such a phenomenon. The frequency and length of droughts varies significantly by agroecological zone. Zones 1, 2, 3, and 4 have witnessed longer drought periods ranging from four to nine and a half years (Table 4.1). Zone 5, on the other hand, has witnessed the most frequent occurrences of drought during this 50-year period. And overall, except for zone 1 and to a lesser extent zone 5, droughts have become more frequent and have lasted longer in Syria from 1970 onward.

Table 4.1—Drought characteristics, 1961–2009

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

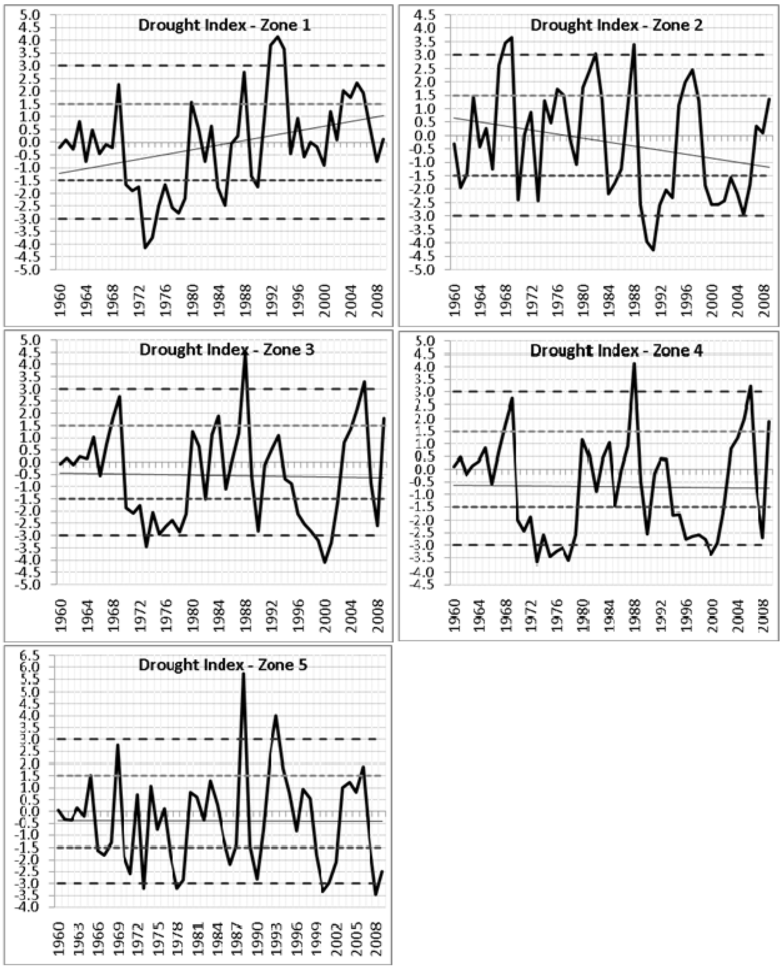
Source: Authors' calculations.

Droughts have become more frequent during the past twenty years in zone 2, yet no clear evidence indicates that droughts have become more frequent in other zones (Figure 4.1). This seems to contradict the general perception of people suffering from droughts, especially Bedouins and farmers. One possible explanation is that the *impacts* of droughts may have become more severe due to higher population densities and groundwater depletion. For example, the farm animal population has increased along with the citizenry population. As a consequence, less pasture is available for herders and their animals to migrate to during droughts, with devastating consequences for the survival of their animals. Therefore, even for the same severity of drought, the socioeconomic consequences can be much greater than that in the past.

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

Droughts recurrently affect all zones, and thus economic activities and the people living in these zones. Appendix Table H.8 shows that the northern region of Syria has the highest population density among zones 1 through 4. Zone 1 extends from Syria's southwestern border of Lebanon to its northwestern coastline along the Mediterranean Sea and to its northeastern border of Turkey. The population density in zone 1 is highest along the coast of the Mediterranean Sea within and around the city of Latakia in zone 1 and to a lesser extent along the border of Lebanon and around the city of Kamishli along the Turkish border. Within zone 2, the population density is slightly lower (still within the same northwestern region) and appears as clusters around the cities of Aleppo and Hama.[14] Furthermore, there is a notable clustering in zone 2 along the Lebanese border in the southwestern portion of Syria. Zone 3 (like zone 2) extends from the southern tip of Syria to its northeastern-most tip. In this zone, the highest population density is in the southern part of Syria around the capital, Damascus, which is located within both zones 3 and 4.borders, however, whose population density also extends to the neighboring zone (3). Zone 5 makes up the majority of Syria's surface area; however, it has the lowest population density of all five agro ecological zones. The highest population density in zone 5 is along the route that links the cities of Raqqa, Deir Ezzor, and Abu Kamal.

Figure 4.1—Drought index, 1960–2009



Source: IFPRI 2010 and authors' calculations.

Historical Drought Impacts on Agriculture

We use an ex ante approach to assess the impact of droughts on agriculture, the economy, and poverty and focus on the 1999–2001 drought for this impact assessment. The 1999–2001 drought lasted three

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[14] Aleppo and Hama are on the border of zones 1 and 2 but are considered more into zone 2 than 1.

years, consistent with the average drought period during the past 50 years, and it affected four out of five agroecological zones, thus making it a nationwide event (Figure 4.1 and Table 4.1). We also choose this drought for practical reasons because crop data are available for the whole drought period and by agroecological zone from the Syrian Agricultural Database (SADB), which is not the case for the years before 1985 and for the most recent drought of 2008–2010. In essence, we thus use an average historical event and assess what impact it would have if a similar event would recur in the future.

We use historic data for changes in crop yields and livestock numbers (goats, sheep, cattle, camels) to implement the drought shocks in the dynamic CGE (DCGE) model, and we assume that the changes in yields and livestock numbers are entirely caused by the drought event. For the three years following 1998, Table shows the severe impact of this drought that affected Syria on three of its strategic crops: wheat, barley, and cotton. The most common theme that the figures below show are sharp decreases in yields in the initial years of drought and then slow recovery. The most adversely affected zones were zones 4 and 5, and consequently, crops grown in those zones fared the worst, especially wheat and barley. The yields for cotton were also volatile every year from 1998 to 2001, albeit not as much as the yields of barley and wheat.

The 1999–2001 droughts led to severe yield reductions and in some zones even to complete crop failure. For example, yields for irrigated wheat plummeted from between 3.1 and 3.8 tons per hectare in the pre-drought year of 1998 to 2.7 to 3.1 tons per hectare in 1999, and between 0.8 and 2.3 tons per hectare to 1.0 tons per hectare and complete crop failure in 1999 for non-irrigated wheat across all zones. Barley was also hard hit, yet to a lesser extent than wheat, with reductions between 13 and 47 percent between 1998 and 1999. In the second drought year, yields continued to fall in most zones, yet yields started to recover in zones 1 and 3. The annual yields for cotton were also volatile from 1998 to 2001, albeit not as much as the yields of barley and wheat.

Both rainfed crops and irrigated crops are hard hit by droughts. While the impact of droughts on rainfed crops is straightforward, the impact on irrigated yields is more modest and depends on how droughts may affect groundwater levels, river flows, or both. Table 4.2 also indicates that there is a difference among crops. While yields for irrigated wheat and barley drop sharply in 1999 and 2000, cotton yields appears to be largely unaffected by rainfall variations. For both irrigated and rainfed crops, yields quickly rebound when the drought is over.

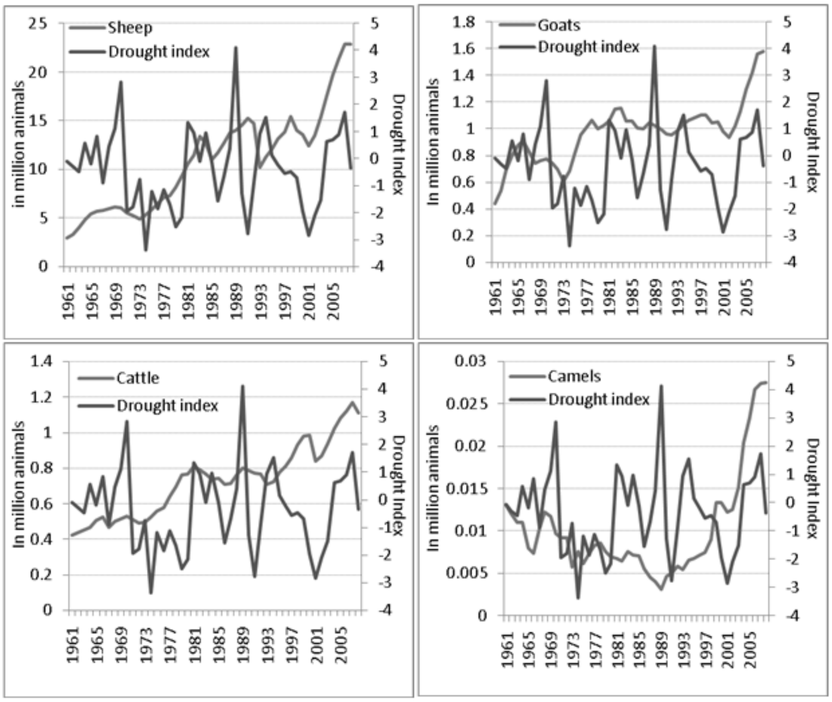
Table 4.2—Yield variability during 1999–2001 drought

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

Source: SADB, 2008.

Livestock made up more than 5 percent of Syrian gross domestic product (GDP) and about 30 percent of agricultural GDP in 2007; thus, drought-related reductions in number of livestock are expected to have economy-wide implications. Sheep and goats make up the largest share of GDP (3.2 percent), followed by cattle (1.5 percent), camels (0.1 percent), and poultry (0.6 percent). The CGE model reflects this structure and includes these livestock categories as separate production activities. The relative reduction in livestock production is based on the reduction of livestock numbers observed during 1999–2001, which are then translated into reduction of livestock-specific capital and (TFP) (Table 4.3).

Figure 4.2—Number of livestock, 1961–2009



Source: Syrian Agricultural Database (SADB) 2008 and authors' calculations.
Note: The drought index is a simple average of agroecological zones 1 and 5.

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

Table 4.3—Changes in the number of animals during 1999–2001 drought

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

Source: Authors' calculations based on SADB 2008.

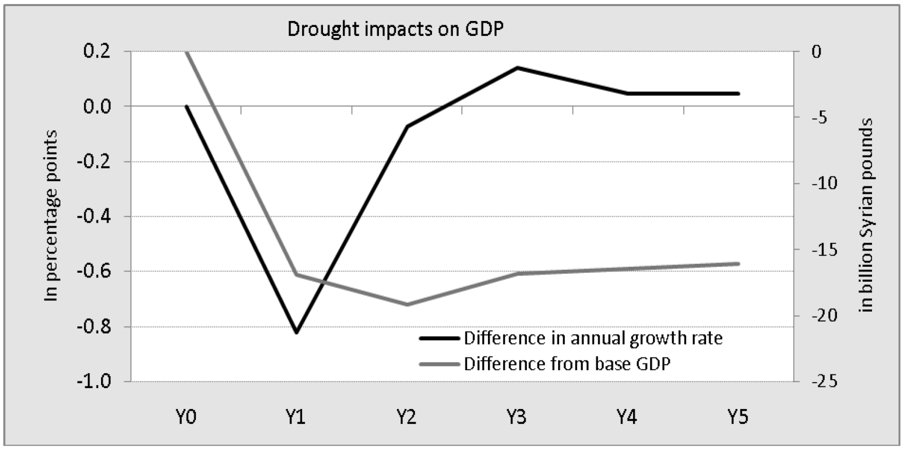
The effect on livestock during the drought episode 1999-2011 has varied and the severity of the impact was disproportionate among the different livestock raised in Syria (Table). The production of camels, vis-à-vis other livestock, has shown the least volatility during these drought years, confirming the conventional wisdom that camels are most water stress resistant due to their ability to store large amounts of water. However, especially sheep herds and goats suffered big losses during 1999–2001, from –3.3 percent to –9.0 percent annually (Table). Cattle were less affected, which can be explained by the fact that a large number of cattle may rely on feed rather than pasture.

Drought Impacts on the Economy, Food Security, and Poverty

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

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

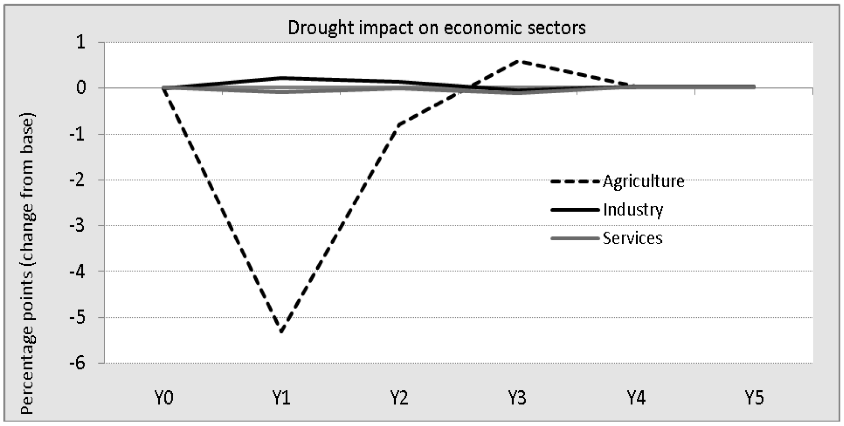
Figure 4.3—Loss in GDP from drought



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

Agriculture is the sector hardest hit by drought, whereas the industry and service sectors are relatively more resilient (Figure 4.4). The loss in yields and animals cannot be compensated by the resulting higher prices of agricultural commodities and so leads to a sharp contraction in agricultural GDP growth. In the initial year of drought, the service sector also contracts due to a decrease in aggregate demand. However, model results suggest that industrial sectors may benefit from drought, albeit to a low extent. This can be explained mainly by changes in factor rents. Droughts lead people to migrate out of agricultural activities to seek jobs in other sectors. This lowers the economy-wide wage rates, especially for low-skilled labor. The industrial and service sectors, which use this type of labor extensively, benefit from the lower labor costs and so become more competitive.

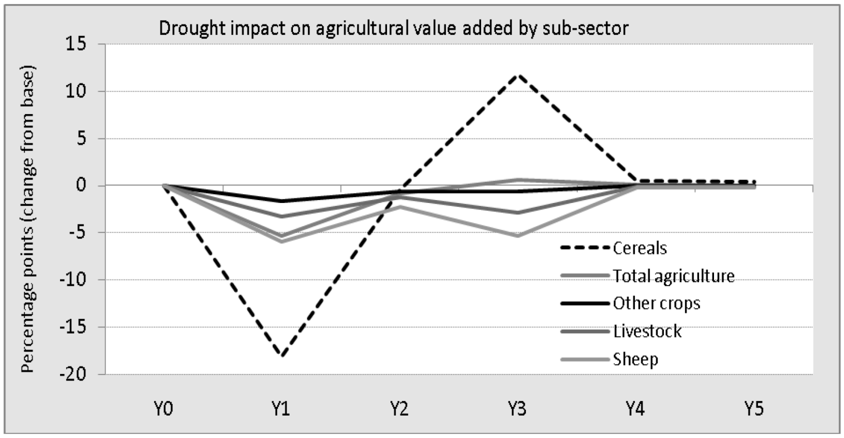
Figure 4.4—Drought impacts by sector



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

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

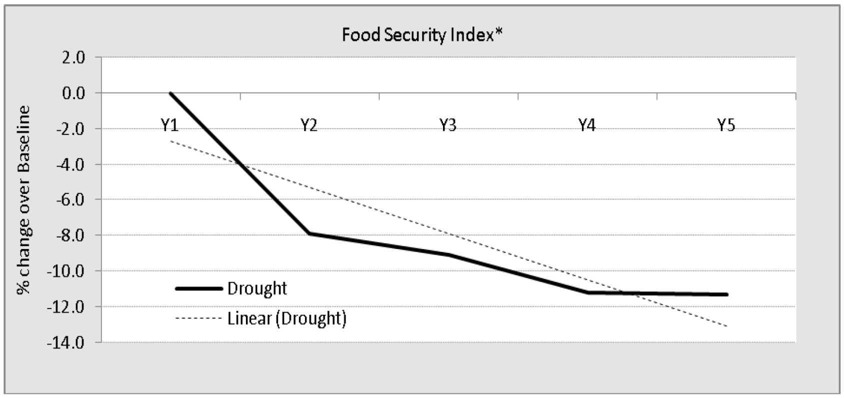
Figure 4.5—Loss in agricultural GDP from drought by subsector



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

Macro-level food security is a serious concern during drought, as the reduction in food production requires a sharp increase in food imports. At the same time, exports show little change and thus the food security index follows a decreasing trend under drought conditions. Household-level food security is also likely to declines, especially among the poorest household groups, an issue that we capture with changes in poverty levels. (Figure 4.6).

Figure 4.6—Food security index



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

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

Table 4.4—Poverty impact of drought (percentage point change from baseline)

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

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

Poverty increases the most in rural areas, where drought impacts cause the number of people living below the poverty line to increase by 0.69 percentage points compared with 0.56 in urban areas. Of all groups, the nonfarm sector shows the highest increase in poverty rate. This can be explained by the fact that Bedouins, who are likely to be among the hardest hit, are not considered farmers in the underlying model.[15] However, it is important to note that the most vulnerable household groups, such as the Bedu see much higher increases in poverty that the aggregate results suggest . It is estimated that about 1.5 million Bedouins live in Syria. The livelihood of Bedouin households is mainly from sheepherding and to a lesser extent camelherding.

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

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[15] The household survey did not allow for identifying Bedouin households.

5. CONCLUSIONS AND PROPOSED ACTIONS FOR ADAPTATION

This report has taken a global and local perspective in assessing the impacts of climate change on the Syrian economy, agriculture, and households. The major impact channels of global climate change are through changing world food (and energy) prices, especially because Syria has become a net importer of oil and petroleum products and many food commodities in recent years. The impacts of local climate change are seen through both long-term yield decreases and potentially higher climate variability (droughts).

Even under perfect climate change mitigation, the world market prices for food are projected to increase. For example, the price of rice is projected to rise by 62 percent, maize by 63 percent, soybeans by 72 percent, and wheat by 39 percent, posing food security challenges especially for net food importing countries and poor households. Climate change results in additional world market price increases: 32 to 37 percent for rice, 52 to 55 percent for maize, 94 to 111 percent for wheat, and 11 to 14 percent for soybeans. Energy prices may also rise as a consequence of climate change, yet estimates vary widely, and factors other than climate change are likely to play a major role too. The results of this report suggest that higher global prices for food will lower overall gross domestic product (GDP) growth, decrease real household incomes, and hurt the poorest the most in Syria.

Local impacts of climate change on Syrian agriculture will be seen mainly through declining yields. The yields of most crops across all agroecological zones are projected to decrease over time due to climate change. Irrigated wheat is projected to decline between 0.2 percentage points and 38.8 percent in agroecological zones 1–5, rainfed wheat between 12.6 and 28.9 percent, maize by 0.9 to 5.9 percent, and potatoes between 17.7 and 40.0 percentage points. The agricultural sector suffers from overall long-term declines in yields, yet different agroecological zones are affected differently. Annual agricultural GDP growth is projected to be between 0.3 and 0.4 percent lower due to combined climate change than in a situation without climate change.

Global impacts will be felt by Syria through rising food (and potentially energy) prices. Results of this report suggest that higher global prices for food (and energy) negatively affect most sectors of the economy, except for agriculture, which benefits from higher prices. Real household incomes decline, particularly those of poor rural nonfarm households. Local impacts of climate change hit the agricultural sector particularly hard. Annual agricultural GDP growth is estimated to be 0.6 percent lower on average between 2010 and 2050 compared with a situation of perfect mitigation. Agroecological zones are affected differently; the major production zones, 1 and 2, show the sharpest declines in crop output. Combining local and global climate change effects slows GDP growth in all sectors. Rural households (both farm and nonfarm households) suffer the most from climate change, but urban households are also worse off when compared with the perfect mitigation scenario. Urban households earn on average 1.6 percent less income each year, while rural incomes are 2.0 percent lower.

Droughts in Syria have occurred frequently during the past 50 years. Throughout the fifty years, from 1961 to 2009, Syria suffered through [close to] a quarter century's worth of drought, a figure quite significant in that it makes up slightly over 40 percent of this period in Syria's history. An increase of the frequency and severity of droughts would not only hurt agricultural sector but also the Syrian economy and its poor. Results show that the loss in economic output during drought years may reach as much as 0.8 percentage points of baseline GDP. Food security and the poor are hard hit by droughts. Spiking food imports are the main driver of lower food security. Poverty increases by about 0.6 percent during a drought, and the rural nonfarm poor are hardest hit with poverty rate increases of more than 1.0 percentage points.

Given the strong global *and* local impacts of climate change, a diverse set of policy actions at different levels will be required to mitigate the negative socioeconomic effects. Moreover, global price increases, declining crop yields, and droughts affect different sectors and households differently, which underscores the necessity to consider a variety of mitigation tools, including global and national action plans, investments in agriculture, social protection, and disaster risk management. These adaptation measures are explained in more detail below.

Advancing a Global Action Plan

Richer and more developed nations have contributed most to greenhouse gas (GHG) emissions, which are causing climate change. In addition, more developed countries will be less vulnerable to climate change than developing nations. Hence, the former bear a responsibility to support the latter in finding ways to adapt, whether through finance, technical expertise, or a combination of both. Thus, globally and locally, some measure of redistribution may become inevitable in the near future.

The international community, including individual countries, needs to increase investment in international research and development in the agricultural sector. Research and development should not only emphasize productivity of crops and livestock but also support modified crop varieties and livestock dietary varieties in a climatically changing world. In general, a greater emphasis should be placed on increasing the knowledge pool at the global level.[16] This enhanced international effort should create global public goods and knowledge to help all countries increase agricultural productivity in a changing climate.

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

Reform of the global food system should become a priority to make it more resilient to climate change and other shocks and to make trade freer and better. With the inevitability of increased climate variability, trade is a crucial mitigation and adaptation channel that would allow "…regions of the world with fewer negative effects to supply those with more negative effects" (Nelson et al. 2010). The heterogeneity with which climate change will impact countries, and regions within countries, necessitates that Syria, as other countries, rely increasingly on healthy and open trade relationships to fulfill the increasing demand for food. Syria already acknowledges these crucial ties; it has recently submitted a request to accede to the World Trade Organization that is currently being reviewed by an assigned Working Party (TWN 2010). The result may provide the additional channels necessary to face imminent climate variability.

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

Acknowledging and incorporating global climate change and variability and their appropriate mitigation and adaptation measures into national development targets and policies is crucial for successful adaptation and mitigation. In general, wealthier countries and households are likely to find it easier to adapt to new challenges. Therefore, general policies and investments that foster sustainable growth will also broaden the options for adaptation for governments and citizens. In the case of food security, for example, this report has shown that prices of global food commodities are likely to rise due to general global population and income growth, and compounded by climate change. Turkey and other countries have demonstrated that improved food security can be achieved with broad-based development, specifically by increasing and diversifying nonfood exports and increasing household incomes. Nonfood exports generate much-needed foreign exchange to purchase food commodities on international markets.

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[16] An example of research that is currently inconclusive in its application to the inevitable increase in GHG emissions is carbon dioxide (CO_2) fertilization. Further tests may shed light on how crops may fare in a world with rising CO_2 (The Economist 2010).

Accelerating growth that is export oriented and that benefits all household groups should therefore also be a primary tool for Syria to develop in a changing climate.

Agricultural and Rural Development Policies

Yields of rainfed crops are hit specifically hard by droughts and by the long-term impacts of climate change. Scientific advancement in breeding more drought-resistant varieties will therefore be crucial in the future of rainfed agriculture in Syria. Investing in the development of drought-resistant seeds and encouraging farmers to adopt these seeds may mitigate adverse consequences on rainfed agriculture and safeguard farmers from drought-induced yield losses. Farmers also have different on-farm management techniques to offset the impacts of climate change. On-farm management practices may include shifting the planting date, switching crop varieties or crops, expanding the area of production, and increasing irrigation coverage (Burke and Lobell 2010).

Irrigation efficiency must be improved where economically viable to get "more crop per drop." Irrigated crops are less affected by droughts; however, expanding irrigation is possible only to a limited extent, especially in Syria and all other countries in the MENA region, which have severely constrained water resources. Therefore, increasing irrigation efficiency becomes necessary for the future of irrigated agriculture in Syria. In addition, a system that conserves rainfall and efficiently distributes water in other zones should also be a part of the national plan to further investment in water, an increasingly scarce resource. However, it is important to note that increasing irrigation efficency often increases yields but translates only partly into water savings.

In addition to developing heat- and drought-resistant cultivars that would weather the expected decrease in water availability and increase in temperature, an important part of investment, research, and development in agriculture would also include changes in crop practices – optimum sowing dates, choice of cultivars, planned plant density (Hainoun 2008b), reevaluation and redesigning of irrigation, and water-harvesting practices to sustain a healthy agricultural sector.

In addressing climate variability, it is essential to distinguish between short-term measures and long-term measures. The former improve the resiliency of the agricultural sector, and the latter introduce structural changes that affect the sector's profile for the longer term (Easterling 1996). Some examples of short-term mitigation practices include varying the planting season from year to year as necessary. For instance, some farmers in some parts of Africa and Asia vary the planting season by one or two months from year to year (Burke and Lobell 2010). Longer-term mitigation measures may also vary. For instance, depending on the expected type of the variability in climate, such as precipitation levels or temperature, measures may be taken to change the crop varieties farmers use for planting (Burke and Lobell 2010). If the region is expecting a decrease in precipitation, then using faster-maturing seeds varieties would reduce the time the plant has to withstand lower moisture availability. If precipitation levels are not expected to change but temperatures are expected to increase, then longer-maturing seed varieties may be an appropriate alternative (Burke and Lobell 2010).

Structuring and legislating the livestock sector to highlight its income-generating prominence in the Syrian economy will significantly contribute to different mitigation and adaptation measures. With the expected continuation of climate variability and increased drought occurrences, the livestock sector is one that requires extensive adaptation policies and methodologies to continue contributing to rural livelihoods in Syria. Adaptation methods may be categorized under general climate variability adaptation and more specific livestock sector adaptation. The former includes various targets, from collecting and structuring information and data, to conducting the necessary research, to disseminating findings, and finally to monitoring the impacts. Adaptation methods for the sector may be broadly classified under the following focuses: improve grazing management, improve animal biocapacity, enhance rural livelihoods, improve market access, and increase the studies on climate change and its impact on the Syrian economy (Batima 2006).

Grazing management techniques and practices need to have the conservation of the country's ecosystems as a prime objective. Land used for grazing should be used for one season, after which the herd should be moved to another piece of land and the previously grazed land restored for its next cycle of grazing. Furthermore, grazing times may be modified to avoid hours of extreme weather conditions for the well-being of the animal. Other grazing management techniques include increasing the reliance on cultivated pasture lands, improving pasture yields, and increasing the conservation of pasture water supply. It will be necessary to adopt legislation that will organize the possession of land for pasture to heighten a sense of ownership and thus encourage pasture land development (Batima 2006).

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

To adapt the rural space to a changing climate, the physical, financial, social, and risk-management infrastructure will need improvements to enhance rural livelihoods. These may be achieved by promoting a strong education for rural households and increasing nonfarm income opportunities and relationships through improving market access to major cities in their vicinity. Consequently, these developed and sustainable channels are fundamental to develop and disseminate new technologies, information, and support to herders. One way to help mitigate risks is to assess whether erecting an *index based livestock insurance* (IBLI) (Ayantunde et al. 2010) may provide the herders with the necessary coverage to maintain their livelihoods (see details on index-based insurance, below). Overall, any financial support scheme must not propagate moral hazard or passivity among herders but instead must increase independence and proactiveness as individuals and as herder communities (Seo and Mendelsohn, 2008). All the above methods may help in rural income diversification to mitigate the risks associated with climate variability and its impact on livestock sector productivity.

Social Protection Policies

Even if the severity and frequency of droughts remains constant, the Syrian people are likely to suffer increasingly negative socioeconomic impacts as a result of higher population and livestock density and increasing groundwater depletion. Herders in particular are hit increasingly hard, mainly because of the sharp spike in livestock density and the competition for pasture land. In addition to policies and investments in agriculture and rural areas, social safety nets are essential to provide the necessary channels of outreach and mitigation to the poor and vulnerable, both in times of crisis and under the more benign conditions of product, information, and technical support dissemination.

The poorest of the poor are hardest hit by climate change; thus, improving the targeting of existing safety nets and building new ones is critical to protect the poor. Relying on already existing channels and improving or extending them cuts down on new outreach costs as well as helps integrate national and sectoral policy into an overall objective of poverty mitigation and adaptation and livelihood sustainability. In Syria, there is a necessity for improving and expanding social safety nets. In this process, it is important to know who the vulnerable are, where they are, what they need, how to reach them, and how to receive feedback from them.

Drought management should be combined with social safety nets and long-term development goals. Drought management should become part of the overall economic development planning framework by recognizing the role of social transfers in building economic resilience among communities vulnerable to disasters, and it should be implemented by the relevant Syrian authorities, international agencies, and donors. Such initiatives include direct transfers, cash-for-work programs, community asset building through public works, assistance in undertaking microenterprises, other productive activities, and nutrition and health programs. These initiatives would work at the field level and play a key role in providing immediate relief after disasters as well as assist in recovery and rehabilitation activities. The effectiveness of their roles in past droughts should be evaluated to estimate present and future needs for capacity building, funding, and the possible expansion of their role in disaster management.

Disaster Risk Management Strategies

It is crucial to build a rich and functioning network for risk mitigation of the social and extension services that link farmers to agricultural research as well as the vulnerable population to markets and policymakers. A network of extension services is crucial in outreach to farmers and the agricultural community as a whole in disseminating relevant information, techniques, and cultivars; and such a network guarantees that national policies are implemented down to the individual unit: the farmer. A network also provides a strong link between farmers, scientists, and policymakers to collect information relevant to technological advancements and policymaking. Furthermore, relying on an already existing, strong social safety net allows for outreach and dissemination to the vulnerable in the event of a national disaster, such as an all-encompassing drought.

Index-based weather insurance schemes can be a powerful tool to mitigate the risk to small farmers' livelihoods due to weather variability and consequent crop loss. The most conventional method followed is single insurance policies that cover a single crop for a specific weather failure (Robles 2010; Hill 2010a). However, farmer uptake has been quite low and basis risk has been high. Reasons for low uptake in many countries are that the crop models for these schemes operate under generic assumptions or characteristics that simulate typical cropping practices within favorable environments; as such, they may not be applicable to practices on small farms in developing countries, especially if they face several input constraints and shortages not accounted for in the models (Robles 2010). Furthermore, these weather insurance policies are usually too complex for the average, poorly educated, liquidity-constrained farmer to be comfortable with. To address these challenges, innovative methods of weather insurance schemes have been introduced in some countries (Hill 2010a, 2010b) and could be introduced in Syria as well.[17] One tool is to introduce simple weather securities designed to insure against different weather events for different months or different phases of the crop cycle. The securities are set up against a relevant weather index, such as rainfall, and a range of weather occurrences is chosen. If the weather event falls within that range, then the farmer receives a fixed payment, which the farmer decides upon. The amount paid to the farmer will depend on how severe the weather event occurrence is, based on the weather index. The farmer decides how much to insure for and pays a percentage of that amount for the weather insurance *ticket*. The larger the range of weather incidence chosen, the larger the percentage of the insured amount paid for the ticket (Robles 2010). The impact on farmer welfare may then be measured from their resulting consumption and production decisions.

The advantages of these simple weather security schemes are several. The insurance would be provided through groups to reduce the transaction costs for the insurance company (Martins-Filho et al. 2010), and the company increases coverage on weather variability to small farmers, which translates to less livelihood disturbances and risk. The additional benefit would be to eventually eliminate the need to provide the sometimes distorted subsidies extended to farmers as a risk and income-loss mitigation tool (Robles 2010). These schemes would eventually provide a means to correctly quantify the benefits and drawbacks of weather variability and the accompanying insurance markets for future advancements (Robles 2010). However, there may also be some drawbacks to these schemes. In order to successfully operate, there has to be in place a relevant weather index against which the insurance schemes may be tied to, in order to sustainably provide timely and accurate information. Also, given the reliance on the group insurance structure for these schemes, there needs to be in place, or under construction, strong farmer extension channels for product and information dissemination.

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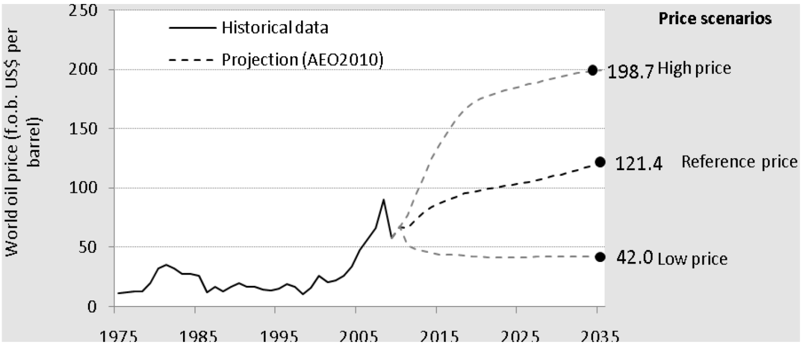
[17] For more information, see Using Simple Weather Securities to Insure Rain-Dependent Farmers in Ethiopia and Smallholder Access to Weather Securities: Demand and Impact on Consumption and Production Decisions at www.ifpri.org/book-744/node/7125 and www.ifpri.org/book-744/node/7124, respectively.

APPENDIX A: ENERGY SENSITIVITY ANALYSIS

Similar to world food prices, world energy prices are projected to increase due to a combination of growth in emerging economies, changing supply, and potentially, climate change. For example, Paltsev and Reilly (2009) estimate that continued high economic growth in East Asia alone may contribute an additional US$25 per barrel to the price of oil by 2025. However, while the strong correlation between economic growth and energy consumption (and thus prices) is well established, the relationship between climate change and energy prices is not straightforward. One reason is the remaining political uncertainty related to climate change mitigation options, which are expected to have strong impacts on prices. To the best of the authors' knowledge, no energy price projections specifically related to climate change are available at the time of writing. Therefore, we choose to draw on the U.S. Energy Information Administration's latest oil price projections and assume that prices from 2011–2035 follow the trend of the reference price scenario starting from the model's base oil price level.

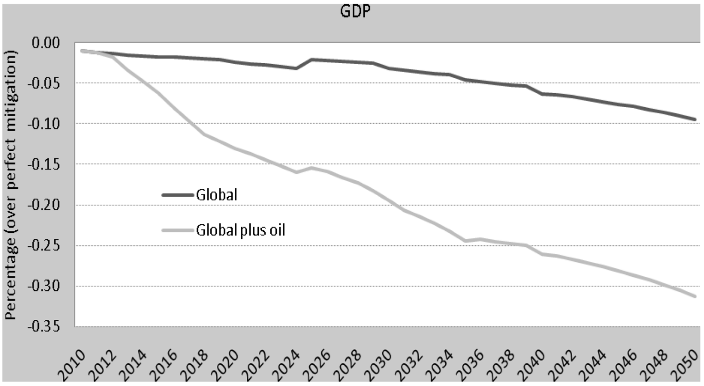
Figure A.1—Global oil prices: Historical and future projections



Source: U.S. Energy Information Administration 2010.

Results of an energy sensitivity analysis show that a potential increase in global energy prices (due to climate change or other factors) will exacerbate negative economic impacts (Figure A.2). This is because Syria is currently and is likely to remain a net energy importing country and thus, assuming no major technological breakthroughs of oil substitutes, higher oil prices will raise production costs (fertilizer transport etc.), lower competitiveness and real incomes. Higher oil prices raise production costs, (fertilizer, transport etc.) reducing profits and welfare as they significantly add to the expenditures of Syria's households.

Figure A.2—Global oil price projections



Source: DCGE model results.

APPENDIX B: DOWNSCALING OF GLOBAL SCENARIOS

Climate change scenarios used in the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) global analysis are from the downscaled global climate model (GCM) scenarios prepared by Jones et al. (2009), who used GCM simulations available from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset. This dataset contains model output from 22 of the GCMs used for the fourth assessment, and for a range of scenarios including the three SRES scenarios used in AR4: A2, a high-GHG (greenhouse gas)-emission scenario; A1B, a medium-emission scenario; and B1, a low-emission scenario. Model output data are not available for all combinations of GCM and emissions scenarios, at least not the basic *core* variables for many crop and pasture models such as precipitation, maximum daily temperature, and minimum air temperature. This severely restricted the choice of GCMs. From the CMIP3 dataset, Jones et al. (2009) used three GCMs—CNRMCM3, CSIRO-Mk3.0, and MIROC 3.2 (medium resolution)—and obtained maximum and minimum temperature data for the ECHam5 model from another source (the CERA database at DKRZ) for the three SRES scenarios. This gave us data for a total of four GCMs and three emissions scenarios.

Data for GCM deviations for five time slices were obtained for the above-mentioned GCM and scenario combinations: 1991–2010 (denoted as 2000), 2021–2040 (denoted as 2030), 2041–2060 (denoted as 2050), 2061–2080 (denoted as 2070), and 2081–2100 (denoted as 2090) for average monthly precipitation and maximum (tmax) and minimum (tmin) temperatures. Processing of these data resulted in calculated mean monthly climatic conditions for each time slice and for each variable from the original transient daily GCM time series. The mean monthly fields were then interpolated from the original resolution of each GCM to 0.5 degrees latitude–longitude using conservative remapping (which preserves the global averages). We then calculated monthly climate anomalies (absolute changes) for monthly rainfall, mean daily maximum temperature, and mean daily minimum temperature, for each time slice relative to the baseline climatic conditions (1961–1990). The point of origin was designated 1975, being the midpoint of the 30-year climate normals.

In the current case, we made a preliminary investigation of the functional forms of the projections using cluster analysis. All pixels from each of the four models for scenario A1B were clustered for precipitation, tmax, and tmin using the values of the five periods as clustering variates. Fourth-order polynomial fits were made for all models at all scenarios and another set was made for the average of the four models. The gridded anomalies were then downscaled to a higher resolution, and daily weather data were generated that are characteristic, to some extent, of the future climatic conditions produced using a stochastic daily weather generator.

APPENDIX C: INPUTS USED FOR DSSAT MODEL

Agronomic Inputs

Six other agronomic inputs are needed: soil characteristics, crop variety, planting dates, carbon dioxide (CO_2) fertilization effects, water availability, and nutrient levels.

Soil Characteristics

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

Crop Variety

DSSAT includes many different varieties of each crop. For the results reported here, we use the maize variety Garst 8808, a winter wheat variety, a large-seeded Virginia runner-type groundnut variety, a maturity group 5 soybean variety, and for rice a recent International Rice Research Institute (IRRI) indica rice variety and a Japonica variety. The rice varieties are assigned by geographic area according to whichever is more commonly cultivated within the region.

Planting Date

Climate change will alter the planting month in some locations, shifting the month in which a crop can be safely planted forward or back. Furthermore, in some locations, crops that can be grown in 2000 may not be grown in 2050, or vice versa as a result of climatic changes over time.

Three sets of calendars have been developed for use with the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)—one for general rainfed crops, one for general irrigated crops, and one for spring wheat. For rainfed crops, we assume that a crop is planted in the first month of a four-month contiguous block when monthly average maximum temperature (tmax) does not exceed 37°C (about 99°F), monthly average minimum temperature (tmin) does not drop below 5°C (about 41°F), and monthly total precipitation is not less than 60 mm. In the tropics, the planting month begins with the rainy season. For irrigated crops, the first choice is the rainfed planting month. When that month is not feasible, a series of special cases is considered for South Asia, Egypt, and the rest of the northern hemisphere. Otherwise, the planting month is based on the dry season.

Spring wheat has a complicated set of rules. In the northern hemisphere, the planting month is based on finding a block of months that are sufficiently warm but not excessively so. If all months qualify, then the month is keyed off the dry season. In the southern hemisphere, spring wheat is usually grown during the meteorological wintertime as a second crop. Hence, the planting month depends not on what is optimal for wheat but on when the primary crop is harvested. Hence, the planting date is based on a shift from the rainfed planting month. Outside of this, the planting month is based on the rainy season.

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

Developing a climate-based growing season algorithm for winter wheat was challenging. Our solution was to treat winter wheat differently than other crops. Rather than using a cropping calendar, we let DSSAT use planting dates throughout the year and choose the date that provides the best yield for each pixel.

Carbon Dioxide Fertilization Effects

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

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

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

Water Availability

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

Nutrient Level

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

APPENDIX D: IMPACT 2009 MODELING FRAMEWORK

Modeling Climate Change in IMPACT

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

Following is the yield equation:

$$YC_{tni} = \beta_{tni} \times (PS_{tni})^{\gamma_{iin}} \times \prod_{k} (PF_{tnk})^{\gamma_{ikn}} \times (1 + gy_{tni}) - \Delta YC_{tni}(WAT_{tni}), \qquad \text{(D.1)}$$

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

Climate change productivity effects are produced by calculating location-specific yields for each of the five crops modeled with DSSAT for the 2000 and 2050 climates as described above and converted to a growth rate that is then used to shift gy_{tni} by a constant amount.

Rainfed crops react to changes in precipitation as modeled in DSSAT. For irrigated crops, water stress from climate change is captured as part of a separate hydrological model, a semidistributed macroscale hydrological model that covers the global land mass (except Antarctica and Greenland). It conducts continuous hydrological simulations at monthly or daily time steps at a spatial resolution of 30 arc-minutes. The hydrological module simulates the rainfall-runoff process, partitioning incoming precipitation into evapotranspiration and runoff that are modulated by soil moisture content. A unique feature of the module is that it uses a probability distribution function of soil water holding capacity within a grid cell to represent spatial heterogeneity of soil properties, enabling the module to deal with subgrid variability of soil. A temperature-reference method is used to judge whether precipitation comes as rain or snow and determines the accumulation or melting of snow in conceptual snow storage. Model parameterization was done to minimize the differences between simulated and observed runoff processes using a genetic algorithm. Effects are modeled for five years at the beginning for each simulation run to minimize any arbitrary assumption of initial conditions. Finally, simulated runoff and evapotranspiration at 30 arc-minute grid cells are aggregated to the 281 FPUs of the IMPACT model.

One of the more challenging aspects has been to deal with spatial aggregation issues. FPUs are large areas. For example, the India Ganges FPU is the entire length of the Ganges River in India. Within an FPU, there can be large variations in climate and agronomic characteristics. A major challenge was to come up with an aggregation scheme to take outputs from the crop modeling process to the IMPACT FPUs. The process we used is as follows: First, within an FPU, choose the appropriate SPAM dataset, with a spatial resolution of 5 arc-minutes (approximately 10 km at the equator) that corresponds to the crop–management combination. The physical area in the SPAM dataset is then used as the weight to find the weighted average yield across the FPU. This is done for each climate scenario (including the no-climate-change scenario). The ratio of the weighted average yield in 2050 to the no-climate-change yield is used to adjust the yield growth rate in equation (D.1) to reflect the effects of climate change.

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

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

Area Supply Function:

$$AC_{tni} = \alpha_{tni} \times (PS_{tni})^{\varepsilon_{iin}} \times \prod_{j \neq i} (PS_{tnj})^{\varepsilon_{ijn}} \times (1 + ga_{tni}) - \Delta AC_{tni}(WAT_{tni}) \tag{D.2}$$

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

APPENDIX E: SUPPLEMENTARY TABLES

Table E.1—Macro Social Accounting Matrix (SAM)

	mact	mcom	mlab	mcap	mlnd	mhhd	mgov	mdtax	mstax	mmtax	ms-i	mrow	mtot
mact		3,714											3,714
mcom	1,462					1,205	248				619	772	4,307
mlab	650												650
mcap	1,553												1,553
mlnd	49												49
mhhd			650	1,141	49		21					10	1,872
mgov				331				197	-262	19		42	327
mdtax						197							197
mstax		-262											-262
mmtax		19											19
ms-i						470	57					93	619
mrow		835		81									916
mtot	3,714	4,307	650	1,553	49	1,872	327	197	-262	19	619	916	

Source: Author's compilation.

Notes: mact: Activities, mcom: Commodities, mlab: Labor, mcap:Capital, mlnd: Land, mhhd: Households, mgov: Government, mdtax: Direct Taxes, mstax, mmtax: Tariffs, ms-i: Savings-Investment, mrow: Rest of the World, mtot: Total.

Table E.2—Income Elasticities Estimated for Dynamic Computable General Equilibrium (DCGE) Model

	Cereal	Fruits	Veggie	Olives	Other crops	Sheep & goat	Cattle	Poultry	Fish	Food process	Manuf	Energy &water	Service
City 1	0.6	1.7	0.8	2.4	0.8	1.4	1.0	0.9	4.1	1.3	1.1	1.3	0.7
City 2	0.6	1.2	0.7	1.5	0.8	1.0	0.8	0.8	1.7	1.2	1.1	1.2	0.9
City 3	0.7	0.9	0.7	1.4	0.9	0.8	0.7	0.7	1.3	1.0	1.1	1.1	1.0
City 4	0.7	0.8	0.6	1.1	1.0	0.7	0.7	0.7	1.2	1.0	1.1	0.8	1.0
City 5	0.6	0.6	0.6	1.2	1.0	0.5	0.6	0.7	0.7	0.8	1.1	0.7	1.1
Town 1	0.5	1.6	0.7	2.5	0.8	1.2	0.8	0.9	2.8	1.3	1.1	1.0	0.8
Town 2	0.5	1.4	0.6	1.7	0.7	0.9	0.8	0.8	1.9	1.2	1.0	1.0	1.0
Town 3	0.5	1.1	0.6	1.9	0.8	0.8	0.8	0.7	2.0	1.1	1.0	1.0	1.2
Town 4	0.5	1.0	0.6	0.9	0.7	0.7	0.8	0.7	1.1	0.9	0.9	0.8	1.3
Town 5	0.5	0.7	0.5	0.4	0.6	0.6	0.7	0.6	0.6	0.6	0.9	0.7	1.6
Rural non farm 1	0.6	1.8	0.7	2.7	0.8	2.0	0.8	0.9	4.6	1.1	1.0	1.0	0.9
Rural non farm 2	0.5	1.5	0.6	2.1	0.7	1.5	0.8	0.7	2.7	1.0	0.9	1.1	1.2
Rural non farm 3	0.5	1.2	0.6	1.4	0.6	1.6	0.7	0.6	1.9	0.9	0.9	1.1	1.4
Rural non farm 4	0.4	1.0	0.5	1.1	0.5	1.3	0.6	0.6	1.7	0.8	0.9	1.0	1.6
Rural non farm 5	0.5	0.8	0.5	1.1	0.4	1.3	0.5	0.5	1.1	0.7	0.9	0.9	1.5
Farm 1	0.7	1.6	0.7	3.6	0.8	1.6	1.0	1.1	8.0	1.1	0.9	1.1	0.9
Farm 2	0.6	1.3	0.7	2.0	0.8	1.3	1.1	0.9	2.5	0.9	0.9	1.0	1.3
Farm 3	0.4	1.2	0.6	2.3	0.6	1.2	0.8	0.7	1.4	0.9	0.9	1.1	1.4
Farm 4	0.4	1.1	0.6	1.1	0.5	1.3	0.9	0.6	2.0	0.8	0.9	1.0	1.6
Farm 5	0.4	0.9	0.5	0.8	0.5	1.4	0.7	0.6	1.0	0.7	0.9	0.9	1.6

Source: Authors' calculations.

Table E.3—Social Accounting Matrix (SAM) disaggregation

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

Source: Author's compilation based on disaggregation results.

Table E.4—Mathematical presentation of Dynamic Computable General Equilibrium (DCGE) 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	$P_{ct} \leq E_t \cdot W_c^m \perp M_{ct} \geq 0$		(3)
Export demand	$P_{ct} \geq E_t \cdot W_c^e \perp X_{ct} \geq 0$		(4)
Household income	$Y_{ht} = \sum_{fc} \theta_{hf} \cdot W_{ft} \cdot F_{fct} + r_h \cdot E_t$		(5)
Consumption demand	$P_{ct} \cdot D_{hct} = \beta_{hc} \cdot (1 - v_h) \cdot Y_{ht}$		(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	$s_{ft} = s_{t-1} \cdot (1 + \varphi_f)$	f is land and labor	(11)
Capital accumulation	$s_{ft} = s_{t-1} \cdot (1 - \eta) + \sum_c \frac{P_{ct-1} \cdot I_{ct-1}}{k}$	f is capital	(12)
Technical change	$\alpha_{ct} = \alpha_{ct-1} \cdot (1 + y_c)$		(13)

Notes:

Subscripts

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

Endogenous variables

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

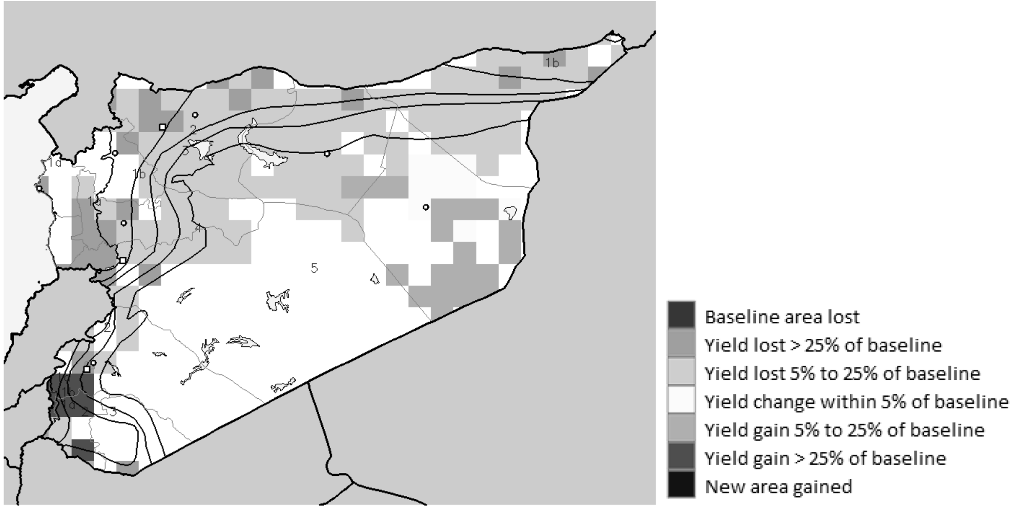
α	Production shift parameter (factor productivity)
β	Household average budget share
γ	Hicks neutral rate of technical change
δ	Factor input share parameter
η	Capital depreciation rate
θ	Household share of factor income
κ	Base price per unit of capital stock
ρ	Investment commodity expenditure share
υ	Household marginal propensity to save
φ	Land and labor supply growth rate

Source: Thurlow, 2004.

APPENDIX F: METHODOLOGY OF AGGREGATION FROM PIXEL DATA TO AGROECOLOGICAL ZONES

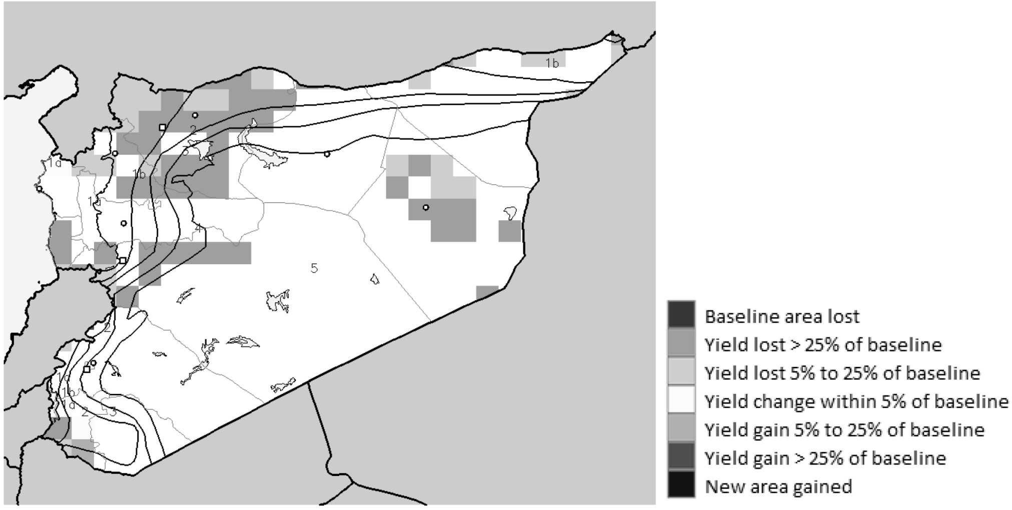
Within a Linux environment, we created a script to aggregate area and production from pixel data to agroecological zones. Yield changes for six crops under two production systems, irrigated and rainfed, were summarized at agroecological zones from a baseline dataset and two climate change scenarios (CSI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

Figure F.1—Yield change for irrigated wheat



Source: IFPRI, DSSAT MIROC A1B.

Figure F.2—Yield change for rainfed wheat



Source: IFPRI, DSSAT MIROC A1B.

APPENDIX G. MAPPING DECISION SUPPORT SYSTEM FOR AGROTECHNOLOGY TRANSFER (DSSAT) AND INTERNATIONAL MODEL FOR POLICY ANALYSIS OF AGRICULTURAL COMMODITIES AND TRADE (IMPACT) CROPS TO THE SOCIAL ACCOUNTING MATRIX (SAM) SECTORS

Table G.1—DSSAT and SAM crop activity mapping

DSSAT Crops	Sector in the Social Accounting Matrix
Durum wheat irrigated	Irrigated durum wheat
Durum wheat rainfed	Rainfed durum wheat
Soft wheat irrigated	Irrigated soft wheat
Soft wheat rainfed	Rainfed soft wheat
Barley rainfed	Barley
Other cereals	Other cereals
Vegetables	Vegetables
Fruit	Fruits
Other crops	Other crops

Source: DSSAT, SPC 2007.

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

Durum and Soft Wheat

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

Barley

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

Other Cereals

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

Vegetables and Fruits

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

Other Crops

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

Table G.2—IMPACT and SAM crop activity mapping

IMPACT Model Crops	DCGE Model Sectors
Wheat	Wheat
Rice and maize	Other cereals
Cotton	Fruits
Cotton	Cotton
Soybeans and other grains	Other crops
Lamb	Sheep and goats
Beef	Cattle
Poultry	Chicken

Source: SPC 2007.

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

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

Fruits: Figures for fruits were those projected for cotton.

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

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

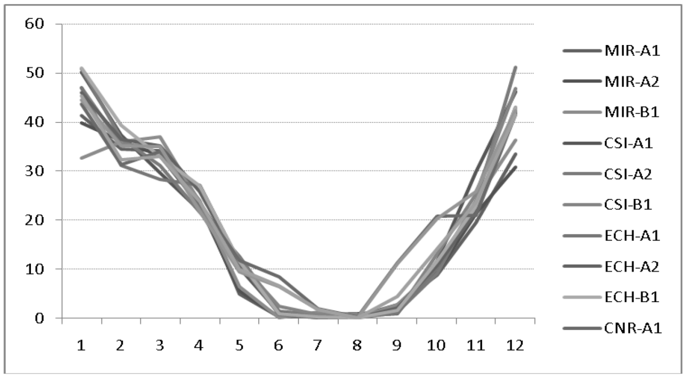
Cattle: Figures for cattle were assumed to follow the projections for beef.

Chicken: The projections for poultry represented projections for chicken.

APPENDIX H: SUPPLEMENTARY FIGURES

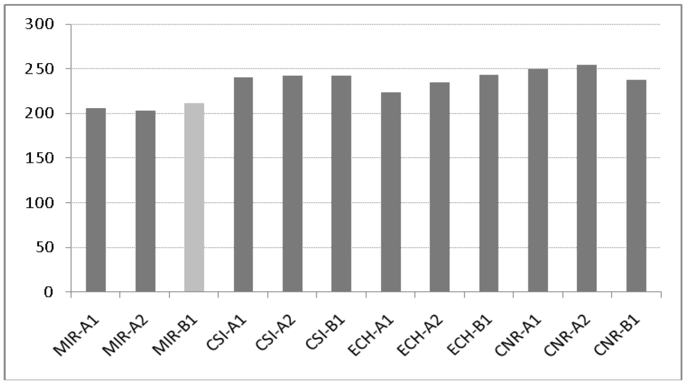
Precipitation

Table H.1—Comparison of mean monthly precipitation by global climate model (GCM)



Source: Authors' calculations based on Jones et al. (2009).

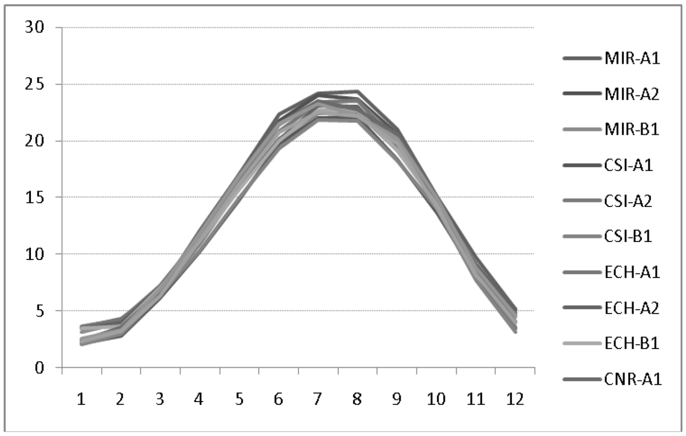
Table H.2—Comparison of mean annual precipitation by GCM



Source: Authors' calculations based on Jones et al. (2009).

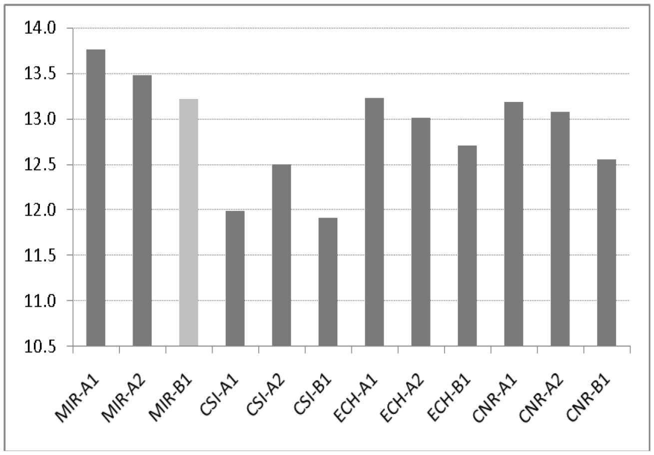
Temperature

Table H.3—Comparison of daily minimum temperature (tmin) averaged to monthly



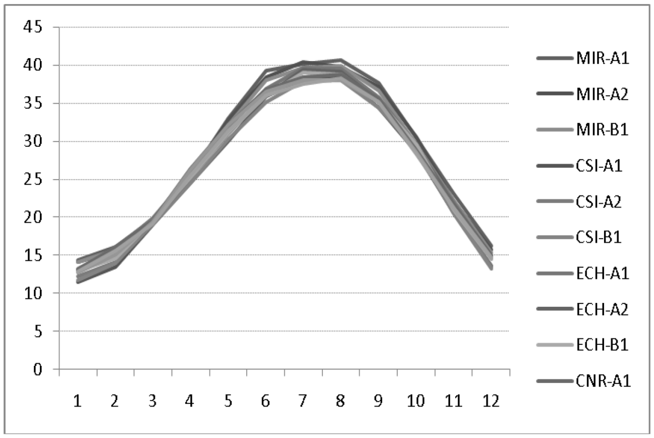
Source: Authors' calculations based on Jones et al. (2009).

Table H.4—Comparison of daily tmin averaged to annual



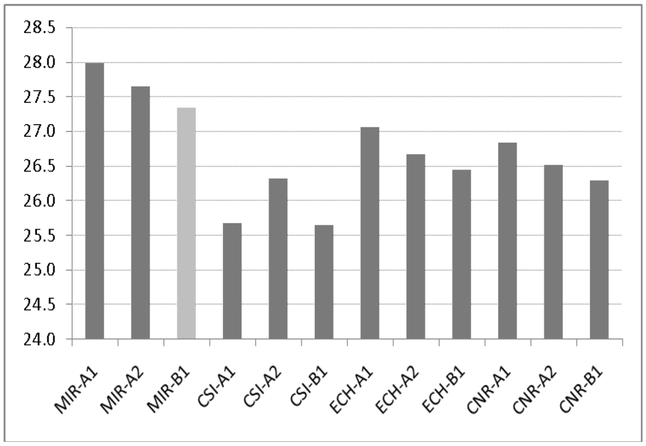
Source: Authors' calculations based on Jones et al. (2009).

Table H.5—Comparison of daily maximum temperature (tmax) averaged to monthly



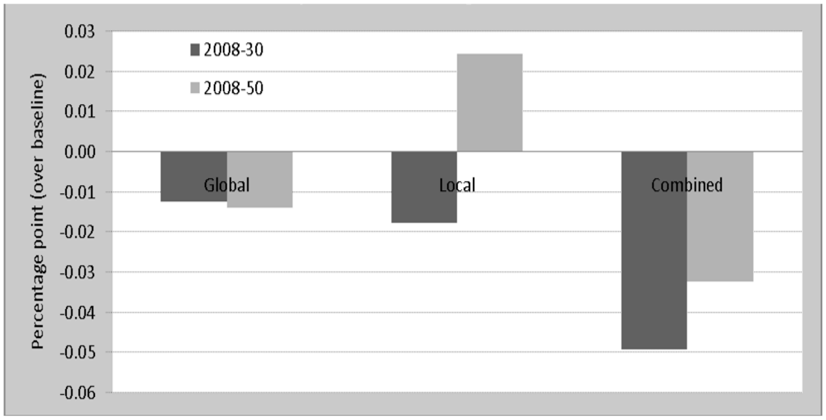
Source: Authors' calculations based on Jones et al. (2009).

Table H.6—Comparison of daily tmax averaged to annual



Source: Authors' calculations based on Jones et al. (2009).

Table .H.7— Impacts of climate change on gross domestic product (GDP)



Source: DCGE model.

Table H 8—Population density in Syria by agroecological zone

Source: IFPRI based on LANDSCAN.

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