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Agriculture, Incomes, and Gender in Latin America by 2050

**An Assessment of Climate Change Impacts and
Household Resilience for Brazil, Mexico, and Peru**

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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ABSTRACT

This report has been prepared in response to growing concerns about the impacts of climate change on Latin American economies, agriculture, and people. Findings suggest that because of the climate change impacts on agricultural production (yield change) and international food prices, unless proper mitigation measures are implemented, by 2050 Brazil and Mexico may face accumulated economic losses between US\$ 272.7 billion and US\$ 550.6 billion and between US\$ 91.0 billion and US\$ 194.7, respectively. Peru, with a different productive structure, may face both economic gain and loss (a gain of US\$11.0 billion against a loss of US\$ 43.3 billion). At the household level, by 2050 Brazilian households may lose 4.3–28.8 percent of one year’s income, and Mexican households may lose 8.0–18.6 percent. The gender analysis suggests that male-headed households may be more vulnerable (less resilient) to climate change than female-headed households, as female-headed households tend to have slightly higher per capita income and higher levels of income diversification than their male counterparts in Brazil, Mexico, and Peru.

Keywords: economics, agriculture, climate change, food prices, Brazil, Mexico, Peru

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1. INTRODUCTION

Climate change affects countries through multiple channels and sectors. The most climate-sensitive sector is agriculture (Mendelsohn and Dinar 2009). This study addresses the economywide and household-level impacts, focusing primarily on those originating in the agricultural sector. It distinguishes itself from previous climate change studies addressing impacts in Latin America and the Caribbean (LAC) in three ways. First, it addresses not only the local impacts of changing crop yields due to climate change but also the global impacts from changing crop yields in the rest of the world, for example, due to drought, as these will affect agricultural commodity prices for local importers and exporters alike. Second, it takes into account the indirect effects that these two local and global effects on agriculture will have on the rest of the economy through factor reallocation, the cost of intermediate inputs, and final consumption. Third, this study includes a gender-differentiated analysis, which has previously been largely absent in the climate change impact literature.

The trend toward urbanization in LAC as elsewhere means that fewer people are living off and producing food on the land. Hence, climate change is affecting fewer households directly through agricultural income change and more households through the indirect effects of food prices. Overall in LAC, 15.9 percent of the labor force is directly employed in agriculture, but there is large variation throughout the region: 15.3 percent, 13.4 percent, and 25.0 percent work in agriculture in Brazil, Mexico, and Peru, respectively.¹ High nutritious yields are needed to feed an estimated global population of 9 billion people in 2050, and climate change could be treating crop yields.^{2,3} This paper focuses on impact estimates based on the first moment or mean state of the climate through temperature and precipitation.^{4,5}

The objective of this study is to analyze the impacts of climate change with a special focus on agriculture in Brazil, Mexico, and Peru. These three countries together cover more than half of LAC's total population. The time period covered is the next four decades, to 2050. The paper addresses four specific types of impacts, namely, (1) direct impacts from increased world prices of agricultural products due to global climate change, (2) direct impacts of local yield changes due to local changes in temperatures and precipitation, (3) indirect impacts following from these two direct impacts as the economies adjust to the direct impacts, and (4) direct and indirect impacts on gender. The paper applies four climate models to illustrate the variability of results dependent on the selected model and allows for autonomous adaption.

The paper is organized in six sections. Section 2 presents the modeling suite. Sections 3, 4, and 5 show the findings on the economic impacts of climate change in Brazil, Mexico, and Peru, respectively. Section 6 presents conclusions.

¹ See Social Indicators of Development, World Bank (<http://data.worldbank.org/indicator/SL.AGR.EMPL.ZS>.) The most recent year for this data series is 2011.

² See esa.un.org/wpp.

³ See <http://www.nature.com/nclimate/journal/v4/n7/full/nclimate2300.html>.

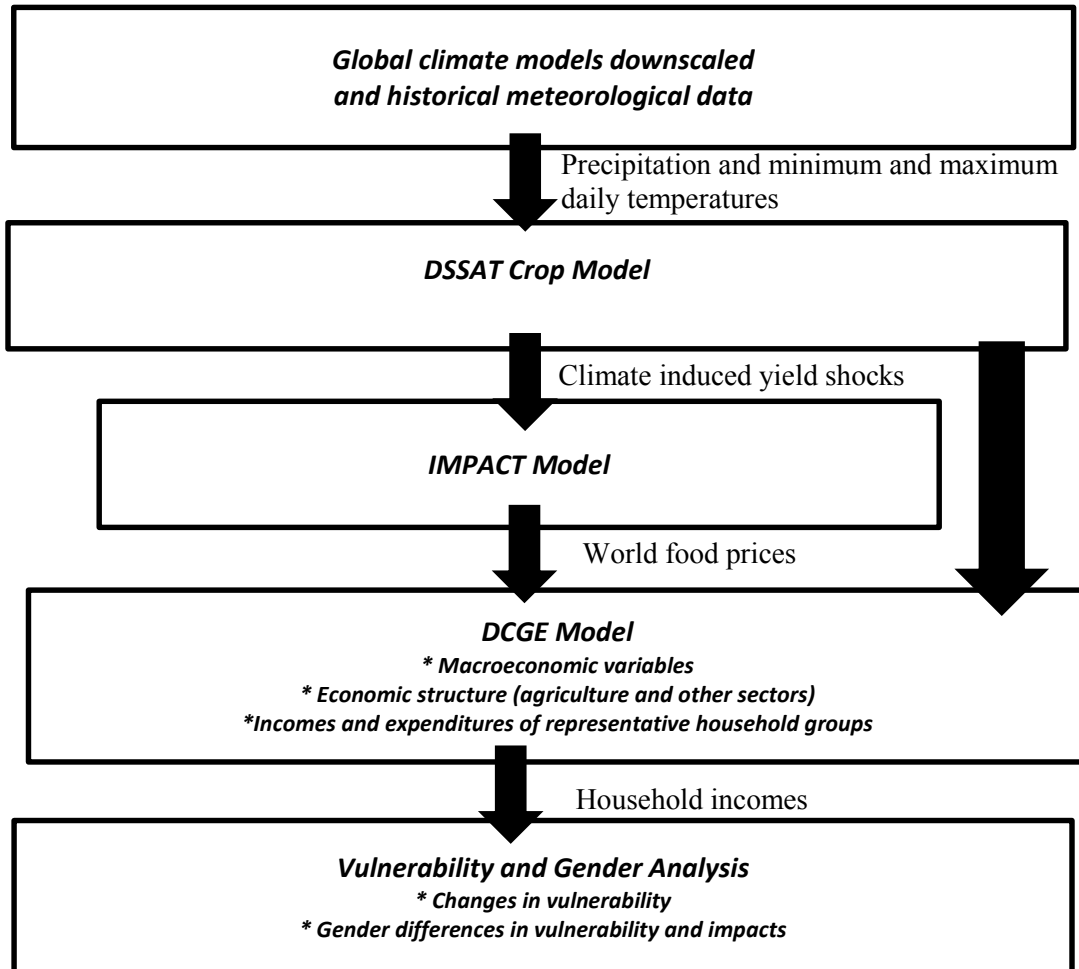
⁴ Climate uncertainty and variability (second moment) related to extreme events and the effects on crop yields is still not well understood. Evidence suggests that very hot days can affect and have an important role in determining crop yields (Rötter et al. 2011.) Crops can fail due to changes in the frequency and interaction of adverse weather events, including heat spells (Trnka et al. 2014).

⁵ Increased concentrations of atmospheric carbon dioxide can present challenges for crops. The direct effect through photosynthesis on staple crops is positive for wheat, rice, soy, and others. Parry et al. (2004) estimate that climate-driven yield losses and fertilization-driven yield gains may be pretty similar in magnitude. However, new research finds that the positive crop yield impacts are partly counterbalanced by lower nutritional value under enhanced carbon dioxide conditions; see www.nature.com/nclimate/journal/v4/n7/full/nclimate.

2. MODELING SUITE

The major components of the modeling framework employed in this study are the downscaling and debiasing of global climate scenarios, a crop model, a global agricultural economy model, and countrywide economic models. As shown in Figure 2.1, the downscaled global climate model scenarios feed precipitation and minimum and maximum daily temperatures into the Decision Support System for Agrotechnology Transfer (DSSAT), which in turn generates changes in yields for both rainfed and irrigated crops in the three economies under analysis. Yield changes are communicated from DSSAT to both International Food Policy Research Institute's (IFPRI's) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) and to countrywide dynamic computable general equilibrium (DCGE) models. Changes in world food prices derived from IMPACT are communicated to the DCGE model to assess the impacts of climate change on the economic structure and consumption of representative household groups.

Figure 2.1 Schematic overview of the modeling suite



Source: Authors' elaboration.

Note: DSSAT = Decision Support System for Agrotechnology Transfer; IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade; DCGE = dynamic computable general equilibrium.

An Overview of Recent Climatic Changes in Brazil, Mexico, and Peru

Knowledge about climate change in LAC has increased significantly in the past 5–10 years as climate observations have become more accessible (Office of Evaluation and Oversight 2014). At least three specific studies have analyzed past temperature and precipitation trends in the three countries analyzed. Andersen, Román, and Verner (2010) analyzed climate data⁶ from May 1948 to March 2008 for 34 high-quality meteorological stations in Brazil and found that of these, 31 stations show significant warming, 3 show no significant change, and none show significant cooling. The authors found that the North region is warming about twice as fast as the South region and the Northeast and Centerwest regions are warming at intermediate rates. In contrast to the results for temperature, the authors found no clear tendencies with respect to precipitation.

Using the same data source, Andersen and Verner (2010) analyzed the data from 21 high-quality stations in Mexico during the same period and found more mixed results. Out of the 21 stations, 12 showed a significant positive trend for temperature, 3 showed a significant negative trend, and the remaining 6 showed no significant trend (using a 95 percent confidence level). Since individual stations are subject to idiosyncratic variations, it is necessary to average the results from several stations to get reliable trends for a region. The authors found indications that the Central Zone of Mexico is warming about three times faster than the Coastal Zones. A trend analysis reveals no systematic changes in rainfall during the 1948–2008 period as all stations except 1 showed no significant trend in monthly precipitation anomalies.

Finally, for the case of Peru, Andersen, Suco, and Verner (2009) analyzed similar data for 24 high-quality stations, finding that 15 of these show a significant warming trend, typically by 0.2 to 0.3° Celsius (C) per decade, 4 show a significant negative trend of between –0.1 and –0.2 °C per decade, and 5 show no significant trend. The authors found that it was not possible to establish any systematic differences between regions. They also concluded that there have been no systematic trends in precipitation in Peru during the past six decades.

As we will see in the following section, the ambiguous results about past trends in precipitation carry over to the projections about future changes in precipitation.

Overview of Climate Change Scenarios

For this study, five climate change scenarios⁷ were used to simulate potential effects of climate change by 2050. The perfect mitigation scenario follows historical patterns with regard to temperature and precipitation and their subsequent effects on crop yields. This scenario serves as a counterfactual to allow us to isolate the effects of climate change on agricultural systems. The four additional future climates were drawn from results running Representative Concentration Pathway (RCP) 8.5 in four Earth System Models (ESMs),⁸ which was used in the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report, the Inter-Sectoral Impact Model Intercomparison Project, and the Agriculture Model Intercomparison and Improvement Project. RCP 8.5 was selected as it was the concentration pathway that represented the most extreme case of radiative forcing (8.5 watts per square meter by 2100),⁹ thus providing us with the most extreme effects of potential greenhouse gas buildup in the atmosphere and sufficient data needed to run the crop models (see section below). The four ESMs used are the following:

- GFDL-ESM2M—designed and maintained by the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory (GFDL) (<http://www.gfdl.noaa.gov/earth-system-model>)

⁶ The data come from the Monthly Climatic Data for the World database collected by the National Climatic Data Center in the United States.

⁷ For the purpose of this study we consider one emissions scenario run with four global circulation models climate change scenarios.

⁸ Earth System Models are often referred to as General Circulation Models.

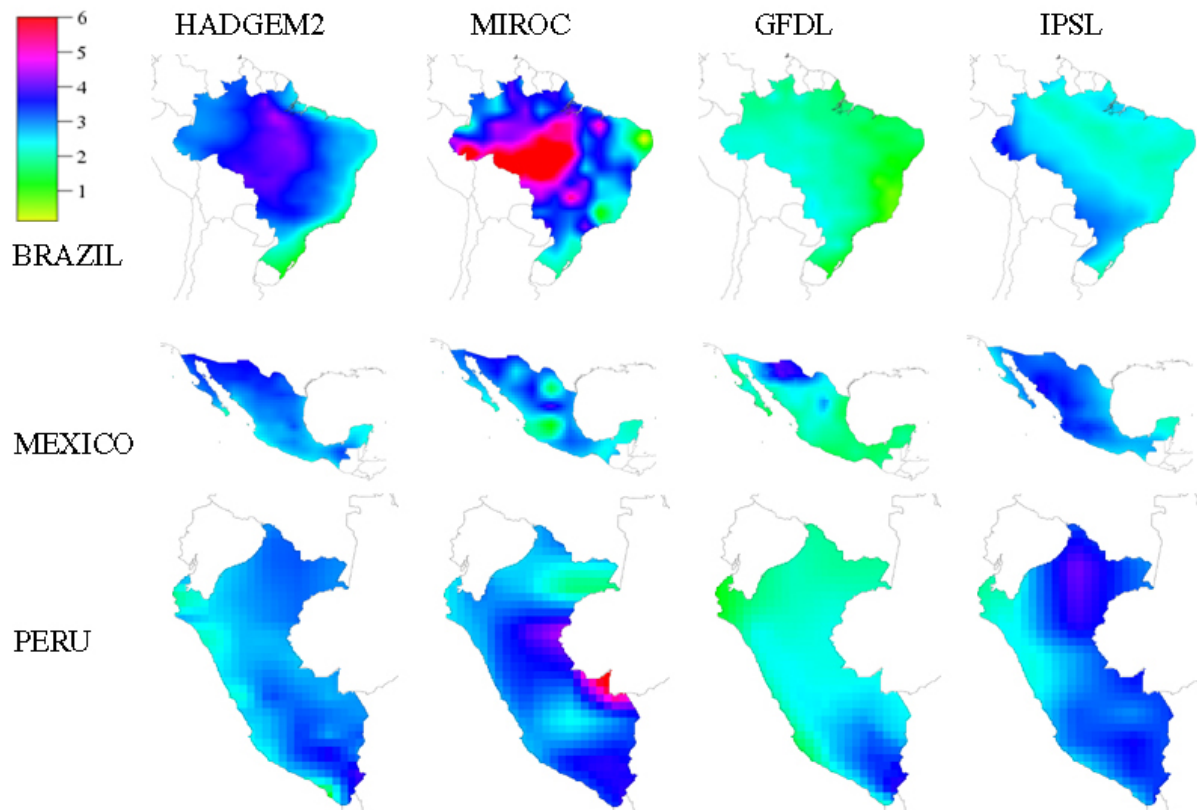
⁹ This scenario is equivalent to reaching atmospheric carbon dioxide concentrations of 630 parts per million by 2050 and 1,230 parts per million by 2100 (compared to 400 parts per million currently).

- HADGEM2-ES—the Hadley Centre’s Global Environment Model, version 2 (<http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem2>)
- IPSL-CM5A-LR—the Institut Pierre Simon Laplace’s ESM (<http://icmc.ipsl.fr/index.php/icmc-models/icmc-ipsl-cm5>)
- MIROC-ESM—Model for Interdisciplinary Research on Climate, developed by the University of Tokyo, NIES (National Institute for Environmental Studies), and JAMSTEC (Japan Agency for Marine-Earth Science and Technology) (<http://www.geosci-model-dev-discuss.net/4/1063/2011/gmdd-4-1063-2011.pdf>)

The figures below show how average annual maximum temperatures and total annual precipitation are projected to change between time slices 1991–2010 and 2041–2060 for the four downscaled ESMs used in this project.

From Figure 2.2 we can see that the climate scenarios in general project higher temperature increases in the interior of each country and lower increases along the coast. MIROC is generally the most extreme climate scenario, with temperature increases of up to 6 °C in the Amazon basin during the next 50 years. In contrast, the GFDL scenario projects much more modest temperature increases, typically of 1–2 °C during 50 years.

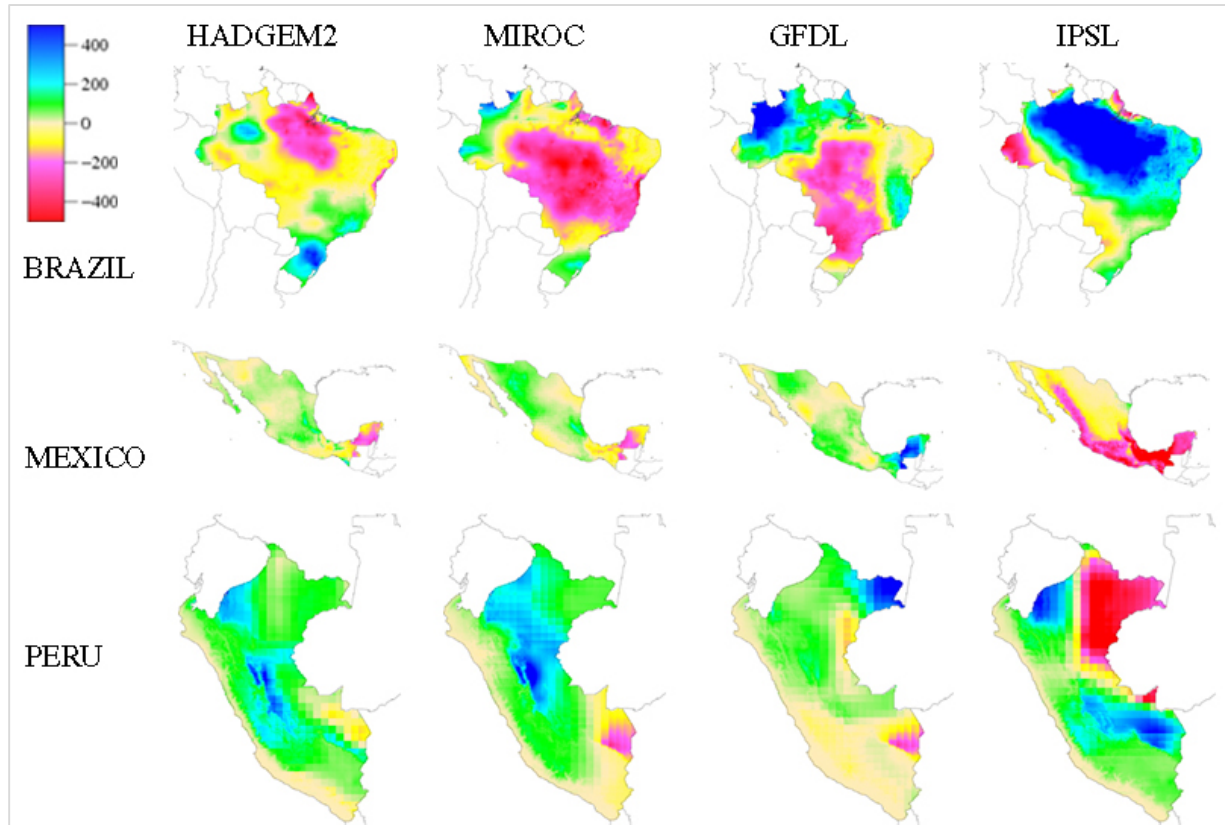
Figure 2.2 Projected changes in average annual maximum temperatures (in degrees Celsius) in Brazil, Mexico, and Peru according to four downscaled climate scenarios (2041–2060 minus 1991–2010)



Source: Authors’ elaboration.

While all scenarios project temperature increases, although of quite different magnitudes for the same extreme RCP, there is much less agreement about precipitation changes. Figure 2.3 shows, for example, that MIROC projects severe drying in central Brazil (the soybean-producing region) while IPSL projects a substantial increase in precipitation in the same region. In contrast, IPSL projects severe drying of southern Mexico, while GFDL projects a much wetter climate for the same region.

Figure 2.3 Projected changes in total annual precipitation (millimeters per year) in Brazil, Mexico, and Peru according to four climate scenarios (2041–2060 minus 1991–2010)



Source: Authors' elaboration.

IPSL seems to be an outlier in terms of precipitation, although it looks intermediate in terms of temperature increases. By simulating the impacts of all four climate scenarios, we will get a good idea of the uncertainty surrounding the results, even within the same RCP scenario.

For the modeling of impacts of climate change on crop yields, we use not only these average tendencies but also the intra-annual changes projected in each scenario.

DSSAT Crop Model

Location-specific effects on crop productivity can be projected using process-based crop simulation models. In turn, the crop models are driven by weather, consistent with conditions indicated by the ESMs, completing the connections between climate conditions at one end and economic outcomes at the other.

Crop models require a basic set of weather information to adequately represent how the plants grow and respond to their changing environment. The crop models employed here are from the DSSAT family and work on daily high temperature, low temperature, rainfall, and shortwave solar radiation reaching ground level. While ESMs per se are relatively plentiful, not all of these quantities are readily available. Temperature data typically are the easiest to find and are thought to be the most reliable.

However, for agriculture, precipitation (and to a lesser extent, sunshine) is really where the game is played for climate change purposes. As a result, the choice of future climate circumstances is constrained by pragmatic concerns of data availability and usability.

The data employed were drawn from four ESMS working under RCP 8.5 conditions as described in the section above: HADGEM2, MIROC, GFDL, and IPSL.

The ESM outputs were obtained and processed by colleagues at the Potsdam Climate Institute to a ½-arc-degree spatial resolution and further aggregated temporally to monthly averages by colleagues at Columbia University.¹⁰ A delta-method approach adjusted the values by putting the changes between the baseline period and future periods on a common baseline. Daily weather realizations were generated by the Simulation of Meteorological variables (SIMMETEO) random weather generator based on the adjusted monthly averages.¹¹ Finally, the crop models within DSSAT used the daily weather as inputs to determine yields under the various conditions.

The crop models generated gridded maps of yields. Each crop was modeled for both rainfed and irrigated conditions under perfect mitigation as well as the four future climate situations, meaning $2 \times (1 + 4) = 10$ maps of yields per crop. The economic models, of course, work at regional levels of some sort depending on the particular application. To make the different scales work together, the pixel-level yields were aggregated within the appropriate regional boundaries. An area-weighted average was employed by using maps of physical area allocations by crop from the Spatial Production Allocation Model as the weighting factors.¹² More detailed discussions of the aggregation process and its implications can be found in Mueller and Robertson (2014) and Robertson et al. (2013). The economic models took these regional yields and used them to adjust the evolution of productivity through time within their frameworks.

The tables below summarize the projected changes in crop yields for the major crops in each of the subregions in the three countries analyzed. These simulations do not include the beneficial effect of carbon dioxide fertilization on crop yields.

One of Brazil's most important agricultural products is soybeans, contributing about 22 percent and 16 percent to regional agricultural GDP in the Central Tropical Subhumid and Southern Humid regions, respectively. According to the DSSAT model soybean production in these regions would be adversely affected in all climate scenarios, but especially so in the wet IPSL scenario (Table 2.1).

¹⁰ See Jones et al. (2003) and Hoogenboom et al. (2012).

¹¹ See Geng, Penning de Vries, and Supit (1986) and Geng et al. (1988).

¹² See You et al. (2006) and You et al. (2014).

Table 2.1 Projected annual crop yield changes for Brazil (percentage per year), 2000–2050

Region	Maize, cassava, and sugarcane	Rice	Soybeans and cotton	Wheat
<i>Climate scenario: GFDL</i>				
Brazil	-0.39	-0.14	-0.27	-0.28
Central tropical subhumid	-0.41	0.04	-0.36	-0.28
Eastern semiarid	-0.34	-0.21	-0.20	-0.43
Northern tropical humid	-0.37	-0.25	-0.20	-0.07
Southern humid	-0.21	-0.31	0.06	0.00
<i>Climate scenario: HADGEM2</i>				
Brazil	-0.46	-0.26	-0.31	-0.56
Central tropical subhumid	-0.33	-0.20	-0.26	-0.56
Eastern semiarid	-0.50	-0.27	-0.32	-0.88
Northern tropical humid	-0.64	-0.30	-0.35	-0.52
Southern humid	-0.74	-0.40	-0.22	0.00
<i>Climate scenario: IPSL</i>				
Brazil	-0.57	-0.22	-0.40	-0.36
Central tropical subhumid	-0.63	-0.10	-0.59	-0.36
Eastern semiarid	-0.35	-0.33	-0.24	-0.50
Northern tropical humid	-0.54	-0.28	-0.27	-0.51
Southern humid	-0.61	-0.36	0.15	0.00
<i>Climate scenario: MIROC</i>				
Brazil	-0.45	-0.17	-0.32	-0.51
Central tropical subhumid	-0.31	0.00	-0.11	-0.51
Eastern semiarid	-0.47	-0.22	-0.35	-1.11
Northern tropical humid	-0.67	-0.28	-0.47	-0.46
Southern humid	-0.65	-0.36	-0.15	0.00

Source: Authors' calculations based on Decision Support System for Agrotechnology Transfer (2014).

In Mexico, maize is the main agricultural product in the West Arid, Central High Arid, and Southern Humid regions, contributing between 14 and 22 percent of regional agricultural GDP. However, maize yields are affected very differently across regions in three of the four climate scenarios. Only for the very dry IPSL scenario do we see substantial drops in maize yields in all parts of Mexico (Table 2.2).

Table 2.2 Projected annual crop yield changes for Mexico (percentage per year), 2000–2050

Region	Maize and sugarcane	Potatoes	Sorghum	Beans and alfalfa	Wheat
<i>Climate scenario: GFDL</i>					
Mexico	-0.22	-0.10	0.01	-0.37	-0.04
West Arid	-0.58	-0.41	-0.09	-0.06	0.18
North and East Arid	-0.04	0.11	0.11	-0.46	0.12
Central High Arid	-0.02	0.08	-0.01	-0.28	-0.24
Southern Humid	-0.45	-0.13	-0.23	-0.29	-0.40
<i>Climate scenario: HADGEM2</i>					
Mexico	-0.33	0.08	-0.23	-0.37	-0.16
West Arid	-0.71	-0.02	-0.30	-0.38	0.08
North and East Arid	-0.55	0.14	-0.30	-0.37	0.10
Central High Arid	0.02	0.17	-0.10	-0.36	-0.39
Southern Humid	-0.73	-0.03	-0.37	-0.38	-0.38
<i>Climate scenario: IPSL</i>					
Mexico	-0.59	-0.32	-0.09	-0.46	-0.07
West Arid	-0.78	-0.94	-0.30	-0.12	0.19
North and East Arid	-0.44	-0.07	0.30	-0.55	0.21
Central High Arid	-0.38	-0.02	-0.30	-0.36	-0.33
Southern Humid	-0.87	-0.08	-0.59	-0.38	-0.30
<i>Climate scenario: MIROC</i>					
Mexico	-0.32	-0.12	-0.22	-0.33	-0.04
West Arid	-0.60	-0.47	-0.20	-0.17	0.15
North and East Arid	-0.17	0.01	-0.38	-0.33	0.12
Central High Arid	-0.01	0.10	-0.03	-0.33	-0.22
Southern Humid	-0.73	-0.09	-0.37	-0.37	-0.33

Source: Authors' calculations based on Decision Support System for Agrotechnology Transfer (2014).

In Peru, potatoes contribute more than 10 percent to agricultural GDP in the Highlands, and here all models predict very substantial increases in yields due to higher temperatures and more precipitation (Table 2.3).

Table 2.3 Projected annual crop yield changes for Peru (percentage per year), 2000–2050

Region	Maize	Potatoes and root crops	Cotton	Cereals
<i>Climate scenario: GFDL</i>				
Peru	-0.18	0.61	-0.12	-0.03
Coastal	-0.41	0.65	-0.12	-0.16
Interior	0.01	0.53	-0.01	0.08
<i>Climate scenario: HADGEM2</i>				
Peru	-0.27	1.03	-0.16	-0.05
Coastal	-0.58	1.15	-0.17	-0.21
Interior	-0.02	0.75	0.00	0.10
<i>Climate scenario: IPSL</i>				
Peru	-0.25	1.03	-0.12	-0.06
Coastal	-0.52	1.17	-0.12	-0.20
Interior	-0.02	0.70	-0.18	0.05
<i>Climate scenario: MIROC</i>				
Peru	-0.25	1.10	-0.13	-0.01
Coastal	-0.50	1.27	-0.14	-0.15
Interior	-0.05	0.71	-0.10	0.10

Source: Authors' calculations based on Decision Support System for Agrotechnology Transfer (2014).

The yield changes modeled for all of these countries are within the diverse range of effects seen across the globe. For example, the annual effect on soybeans ranges between about -0.5 and +0.3 percent, with the whole world average coming in around -0.2 percent, which makes Brazil, at about -0.3 percent per year, slightly harder hit. Across the world, the maize situation ranges between -0.8 percent and no change, with -0.5 percent for a typical worldwide value, meaning that Mexico's roughly -0.3 percent per year is on the better side of typical. Potatoes range between about -0.6 and +0.2 percent and the global picture at about -0.2 percent per year, putting Peru's +1.0 percent at the very high end of benefitting from the changing climate. Overall, the modeled responses for these three countries are not outliers in the global context, although they do reflect the diversity of circumstances found on our planet.

The IMPACT Global Agricultural Economy Model

The country-level DCGE models need guidance as to the world prices at national borders. The world prices can be determined using a global model of agriculture, in this case IMPACT.

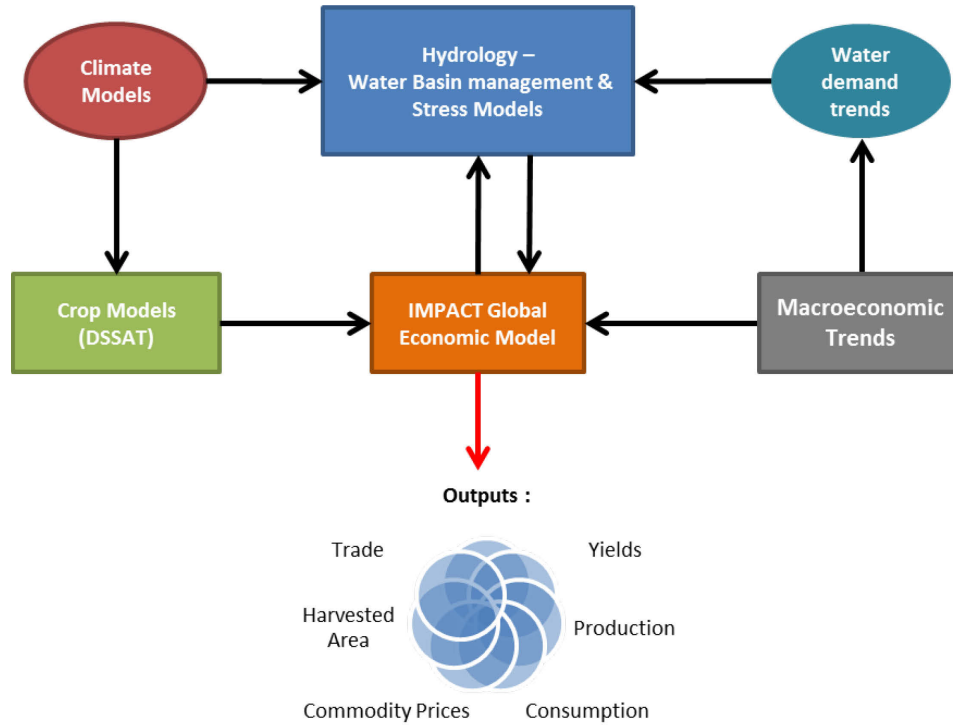
IMPACT was developed at IFPRI in the early 1990s as a partial equilibrium computer simulation model focused on global agriculture. Over time this trade model has been expanded to answer a growing set of ex ante research questions, such as the effects of climate change and water availability on agriculture and food security globally. To respond to this growing demand, IMPACT has been redesigned as a modular network of linked economic, water, and crop models. At the core of this network are the original partial equilibrium trade model and a suite of water models.

The trade model is a system of equations offering a methodology for analyzing baseline and alternative scenarios for global food demand, supply, trade, income, and population. IMPACT simulates agricultural markets in 159 geopolitical regions (Brazil, Egypt, France, and so forth). Within each region supply, demand, and prices for agricultural commodities are determined, with all regions linked through trade. World agricultural commodity prices are determined annually at levels that clear international markets. To simulate the effects of climate change and the availability of water a more disaggregated level is required. IMPACT uses the food production unit, which is the intersection of the 159 geopolitical regions with 126 hydrological basins, giving 320 subnational units and allowing for the modeling of water basin management and its effects on agriculture. IMPACT simulates 62 agricultural commodity

markets, which represents the majority of food and cash crops. For more information about the IMPACT model, please see Rosegrant and IMPACT Development Team (2012).

Figure 2.4 describes the links between the different models that constitute the IMPACT system of models. All models except the climate models and their subsequent bias correction are run by IFPRI.

Figure 2.4 The IMPACT system of models



Source: Authors.

Note: IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade; DSSAT = Decision Support System for Agrotechnology

The five climate futures were run against the same socioeconomic scenario, which was drawn from IPCC’s Fifth Assessment Report. The socioeconomic scenario was defined as Shared Socioeconomic Pathway Number 2, which is characterized by economic development that more or less follows historical trends and medium population growth projection. This socioeconomic scenario is analogous to, although not exactly the same as, IPCC’s 4 Assessment Report (AR4) Medium-Medium socioeconomic scenario. Table 2.4 summarizes the GDP and population growth rate assumptions that define Shared Socioeconomic Pathway Number 2.

Table 2.4 Summary of GDP, population, and GDP per capita assumptions for Shared Socioeconomic Pathway Number 2, by region

Region	GDP (billions of US dollars ppp)			Population (millions)			Per capita GDP (US dollars per person)		
	2010	2050	Annual growth (%)	2010	2050	Annual growth (%)	2010	2050	Annual growth (%)
Africa and Middle East	6,255	32,593	3.4	1,321	2,508	1.3	4,737	12,996	2.0
East Asia, Southeast Asia, and Oceania	19,277	80,411	2.9	2,216	2,337	0.1	8,699	34,408	2.8
South Asia	4,420	32,574	4.1	1,598	2,296	0.7	2,767	14,184	3.3
Former Soviet Union	2,855	8,984	2.3	279	277	0.0	10,234	32,402	2.3
Europe	14,629	27,784	1.3	537	577	0.1	27,228	48,146	1.1
Latin America and Caribbean	5,899	19,278	2.4	590	746	0.5	10,007	25,852	1.9
North America	14,289	29,929	1.5	344	450	0.5	41,490	66,526	0.9
World	67,624	231,553	2.5	6,884	9,191	0.6	9,823	25,192	1.9

Source: Authors' compilation.

Note: GDP = gross domestic product; ppp = purchasing power parity.

In general, during the next 40 years, prices of major agricultural products are projected to increase due to the increased demand brought about by a larger and richer world population. In addition to these increases, climate change is expected to cause changes in world prices due to changes in supply. The price indexes in Figure 2.5 show how world prices for key products are expected to develop under different climate scenarios and a perfect mitigation scenario according to the IMPACT model.

Figure 2.5 Global food price scenarios, price indexes, 2005 = 100 (2010–2050)

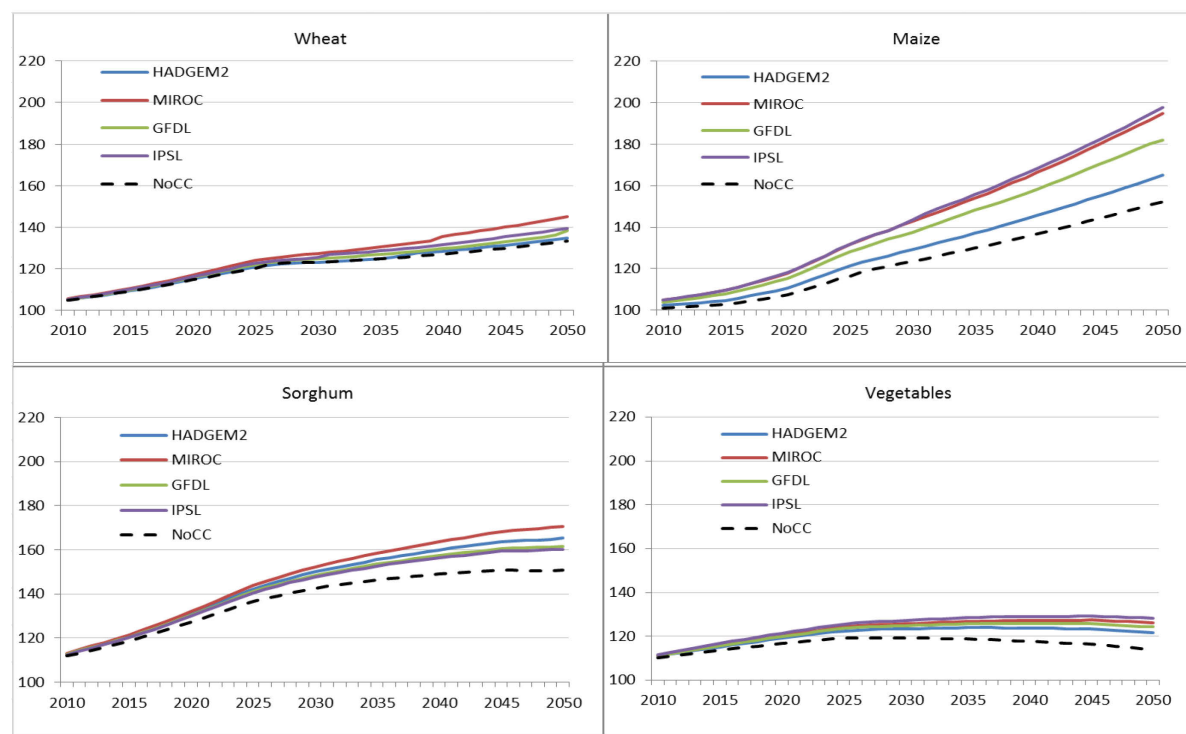
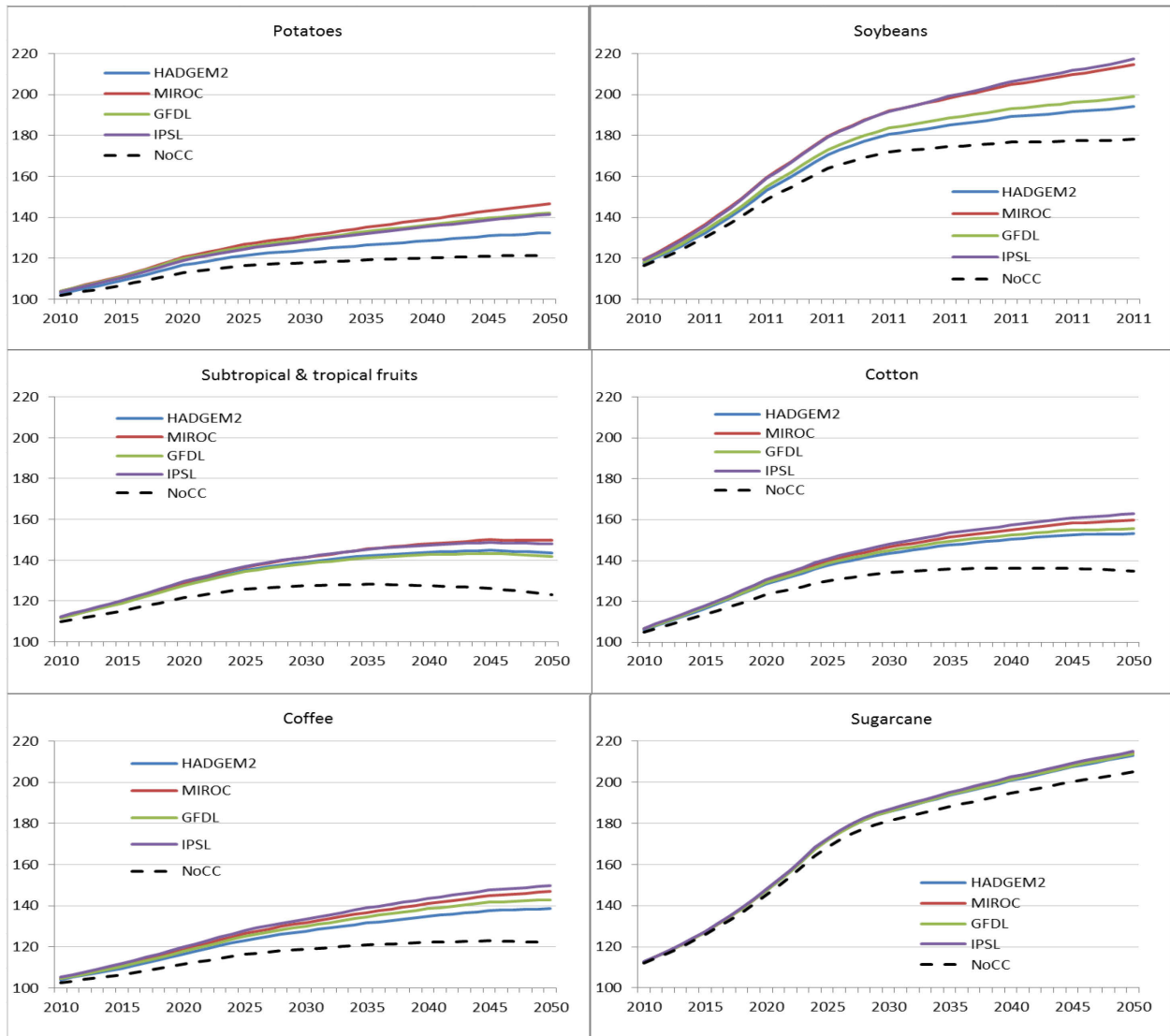


Figure 2.5 Continued



Source: International Food Policy Research Institute’s International Model for Policy Analysis of Agricultural Commodities and Trade (2014).

Note: NoCC = no climate change (or perfect mitigation).

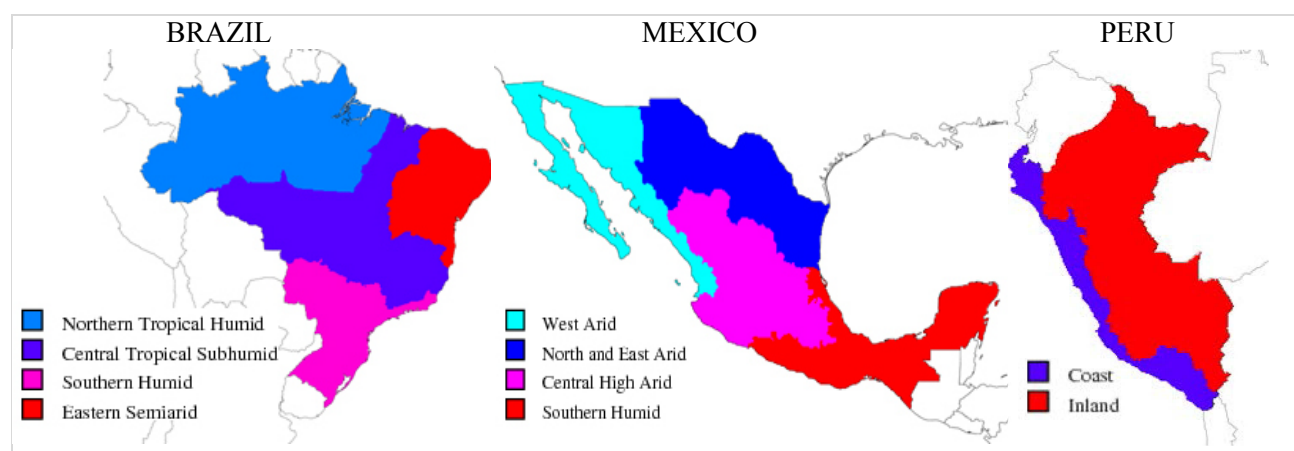
For all crops except sorghum, the HADGEM2 climate scenario produces the lowest price changes compared to the perfect mitigation scenario. In contrast, the IPSL and MIROC climate scenarios typically produce price increases that are about two times larger than those for HADGEM2, while the GFDL climate scenario produces intermediate results for all crops. Finally, world market prices for maize and soybeans are most affected by global climate change.

DCGE Models

Climate change affects world prices and local agricultural production, with diverse implications for the three economies analyzed. Moreover, spatial variation in local climate change impacts within countries means that such effects can vary across subnational regions. We therefore develop economywide models with different agroecological zones (AEZs) (Figure 2.6 and Table 2.5) to capture the major linkages between climate change, production, and households. The recursively DCGE models used in this report

are constructed to be consistent with neoclassical general equilibrium theory. An early version of this DCGE model can be found in Thurlow (2004). Recent applications investigating climate change impacts include Syria, Tunisia, and Yemen (see Verner and Breisinger 2013; Breisinger et al. 2013; Wiebelt et al. 2013; Breisinger et al. 2014). A summary of the main equations can be found in the Appendix.

Figure 2.6 Agroecological zones of Brazil, Mexico, and Peru



Source: Authors' elaboration.

Table 2.5 Country model characteristics

Country	Sectors and commodities	Agroecological zones (AEZs)	Factors	Households
Brazil	37 sectors, 19 nonagriculture, 18 agriculture, all differentiated by 4 AEZs	4 AEZs: Northern Tropical Humid (4.1% of total agricultural GDP), Central Tropical Subhumid (34.3%), Southern Humid (47.5%), Eastern Semi-arid (14.1%)	10 labor types by wage level, capital; mobile across AEZs; 4 land by AEZ	40 household types by AEZ and income deciles
Mexico	39 sectors, 20 nonagriculture, 19 agriculture differentiated by 4 AEZs	4 AEZs: West Arid (36.2%), North and East Arid (18.6%), Central High Arid (21.8%), Southern Humid (23.4%)	6 labor types by skill category and male/female, capital; mobile across AEZs; 4 land by AEZ	80 household types by AEZ, gender, and income deciles
Peru	36 sectors, 21 nonagriculture, 15 agriculture, all differentiated by 2 AEZs	2 AEZs: Coast (31.8%) and Inland (68.2%)	3 labor types by skill category, capital; 2 land by AEZ; all factors immobile across AEZs	4 household types, rural and urban by AEZ

Source: Country social accounting matrixes (2014).

Producers in the model are price takers in output and input markets and maximize profits using constant returns to scale technologies. Primary factor demands are derived from constant elasticity of substitution value-added functions, while intermediate input demand by commodity group is determined by a Leontief fixed-coefficient technology. The decision of producers between production for domestic and foreign markets is governed by constant elasticity of transformation functions that distinguish between exported and domestic goods in each traded commodity group to capture any quality-related differences between the two products. The export price is determined by the world price times the

exchange rate adjusted for any taxes and subsidies. Under the small-country assumption, each country faces perfectly elastic world demand curves for its exports at fixed world prices. The revenue-maximizing equilibrium ratio of exports to domestic goods in any traded commodity group is determined by the endogenous interaction of the relative prices for these two commodity types. On the demand side, imported and domestic goods are treated as imperfect substitutes in both final and intermediate demand under a constant elasticity of substitution Armington specification. In line with the small-country assumption, each country faces an infinitely elastic world supply at fixed world prices. The equilibrium ratio of imports to domestic goods is determined by the cost-minimizing decisions of domestic agents based on the relative tax-inclusive prices of imports and domestic goods.

The model distinguishes between various institutions, including enterprises, the government, and different household groups. Households and enterprises receive income in payment for the producers' use of their factors of production. Institutions pay direct taxes and save according to their respective marginal saving propensities. Enterprises pay their remaining incomes to households in the form of dividends. Households use their incomes to consume commodities according to fixed budget shares as derived from a Cobb-Douglas utility function. The government receives revenue from activity taxes, sales taxes, direct taxes, and import tariffs and then makes transfers to households, enterprises, and the rest of the world. The government also purchases commodities (actually remuneration for the provision of public goods) in the form of government consumption expenditures, and the remaining income of the government is saved (with recurrent budget deficits representing negative savings). All savings from households, enterprises, government, and the rest of the world (foreign savings) are collected in a savings pool from which investment is financed.

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

There are several labor and capital categories in the model, differentiated according to country-specific characteristics (Table 2.5). All types of labor are assumed to be fully employed and mobile across sectors. Capital is assumed to be sector specific within periods but mobile over time. New capital from past investment is allocated to sectors according to profit rate differentials under a "putty-clay" specification. This means that once capital stocks have been invested it is difficult to transfer them to other uses. In agriculture cultivated land in each AEZ is assumed to be mobile and can be reallocated across crops in response to shocks. Thus, changes in crop production could be the result of changes in yields, intensification, and changes in land use patterns. In the Peruvian model, all factors, including labor types and capital, are intersectorally mobile but interregionally immobile (Table 2.5).

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

The DCGE models for Brazil, Mexico, and Peru are specifically built to capture the economic and distributional effects of climate change in these three Latin American countries. Since global and local climate change affects different crops differently, the model captures both the sectoral and the spatial heterogeneity of crop production and its linkages to other sectors such as food processing, manufacturing, and services.

The Brazilian DCGE model includes 37 production activities and commodities, 15 factors of production, and 10 household types, where all production activities and households are specific to each AEZ. Thus, the Brazilian DCGE model includes a maximum of 148 production activities¹³ and 40 household types. The 18 agricultural production activities are split into cereals (3), export crops (2), other crops (6), livestock (5), and forestry and fishing (2). Other production sectors and commodities included in the Brazilian DCGE model are industry (14) and services (5).¹⁴

The Mexican DCGE model includes 39 production activities (20 nonagriculture and 19 agriculture) and commodities, 11 factors of production, and 20 household types, where only agricultural activities and households are specific to each AEZ. Thus, the Mexican DCGE model includes a maximum of 93 production activities and 80 household types. The 18 agricultural production activities are split into cereals (3), vegetables (5), fruits and nuts (3), other crops (4), livestock (3), and forestry and fishing (1). Other production sectors included in the Mexican DCGE model are industry (9) and services (11).¹⁵

The Peruvian DCGE model includes 36 production activities (21 nonagriculture and 15 agriculture) and commodities, 5 factors of production, and 2 household types, where all activities, factors, and households are specific to each AEZ. Thus, the Peruvian DCGE model includes a maximum of 72 production activities; 6 types of labor; 2 types of capital and land, respectively; and 4 household types. The 15 agricultural production activities are split into cereals (2), vegetables (2: potatoes and root crops), export crops (5), cotton (1), sugarcane (1), livestock (2), and forestry and fishing (2). Other production sectors included in the Peruvian DCGE model are industry (15) and services (6).¹⁶

All three models run from 2010 to 2050 and are recursive dynamic; that is, the dynamics occur between 2010 and 2050 in each year. Investments are savings driven, and savings grow proportionally to households' income. In the baseline scenario, as well as in all other scenarios, we assume that the nominal exchange rate is fixed and serves as the numeraire. The government budget is flexible, which means that the government can adjust to changes in revenues and spending by increasing or decreasing the budget deficit. Government consumption—which is exogenous—is assumed to grow annually at average growth rates observed during the past ten years (Brazil: 3.1 percent, Mexico: 2.5 percent, Peru: 7.0 percent). These trends would maintain government expenditure's share in total GDP basically constant for the three countries. Data on past government expenditure trends for the three countries were obtained from the Economic Commission for Latin America and the Caribbean's website (http://estadisticas.cepal.org/cepalstat/WEB_CEPALSTAT/estadisticasIndicadores.asp?idioma=e). The workforce is expected to grow in each country at the same rate as the population grows, according to United Nations (2010). Labor supply is thus assumed to be exogenous in the models, and labor is fully mobile across sectors.

Capital is assumed to be sector specific within periods but mobile over time. New capital from past investment is allocated to sectors according to profit rate differentials under a putty-clay specification. This means that once capital stocks have been invested it is difficult to transfer them to other uses. Available land is fixed for all AEZs in each country, which means that total current cultivated land cannot be expanded in the future. This assumption reflects the scarcity and partly captures the limited growth potential of the agricultural sector due to water and other constraints. Yet land can be reallocated between crops in response to changes in relative prices.

Annual total factor productivity (TFP) growth changes in all nonagricultural and agricultural sectors from 2009 to 2050 complete the set of values for the exogenous variables. TFP for nonagricultural sectors is assumed to grow at 0.7 percent and 0.6 percent annually in Brazil and Mexico, and TFP for the

¹³ Wheat, tobacco, coffee, and cotton are not produced in the Northern Tropical Humid region; wheat is not produced in the Eastern Semiarid region; tobacco is not produced in the Central Tropical Subhumid region.

¹⁴ For a detailed list of production activities and commodities, factors of production, household types, and other accounts of the social accounting matrix (SAM), see Bento de Souza (2014) and the accompanying SAM.

¹⁵ For a detailed list of production activities and commodities, factors of production, household types, and other accounts of the SAM, see Jemio et al. (2014) and the accompanying SAM.

¹⁶ For a detailed list of production activities and commodities, factors of production, household types, and other accounts of the SAM, see Morley, Nin-Pratt, and Thurlow (2008) and the accompanying SAM.

agricultural sectors is assumed to grow at annual rates of 0.5 percent in both countries. This two-speed TFP growth in agricultural and nonagricultural sectors reflects the expected structural change under a business-as-usual scenario that is observed in all successfully transforming countries (Breisinger and Diao 2008). For Peru, we assumed identical TFP growth rates for agriculture and nonagriculture of 2.5 percent. Together with exogenous labor growth and endogenous capital stock growth, these TFP growth rates produce average GDP growth rates as observed during the past ten years in Brazil, Mexico, and Peru.

The country DCGE models capture autonomous adaptation to climate change. Yield changes from the DSSAT model enter the production functions of the DCGE models. These crop-specific and AEZ-specific changes in productivity change the returns to factors and alter output prices. For example, farm households can decide to employ their factors of production, such as labor, for nonfarm activities instead of growing crops and raising livestock. In response to changes in output prices, producers can substitute certain factors and inputs to react to changing relative costs of inputs. Or imported food can replace locally grown food when relative prices of locally grown food increase (and vice versa). A set of several elasticities guides these changes. The main elasticities include the substitution elasticity between primary inputs in the value-added production function, which determine the ease with which, for example, capital can be substituted by labor inputs; the trade substitution and transformation elasticities between domestically produced and imported and exported goods; and the income elasticity in the demand functions, which is assumed to be 1.0. For the factor substitution elasticity we choose 3.0 for all pairs of primary factors in all production sectors in all three countries, which implies high adjustment flexibility in production; the elasticity of transformation between supply to the domestic market and supply to foreign markets is 4.0, and the substitution elasticity in domestic demand between imported and domestically produced goods is 6.0 for all goods and services in Mexico and Peru, while we assume much lower transformation and substitution elasticities of 0.5 and 2.0 for Brazil. These elasticities reflect the real economic adjustments to international price shocks in a large country, where domestic supply and demand are largely directed toward domestic markets and price signals received by producers and consumers are dominated by local production costs. Thus, when suppliers and buyers face price shocks they may be slow to identify new sources of demand and supply, especially if products in question are differentiated. Low export-output shares and low import-absorption shares, together with low trade elasticities, also imply that the domestic price system is much more insulated from world market price changes and therefore less affected from global climate change than in the other two—more trade oriented—countries.

The country models include 4 representative household groups for Peru, 40 for Brazil, and 80 for Mexico. The household groups are first separated regionally by AEZs and then, within each AEZ, into urban and rural households in Peru and into male- and female-headed households in Mexico. We then split household groups in each AEZ in Brazil and Mexico into income deciles. This differentiation of household groups allows us to capture the distinctive patterns of income generation and consumption and the distributional impacts of climate change in each of the three countries.

A more detailed description of the essential features of the DCGE model and a discussion about how structural features and crucial parameters affect the direct and indirect effects of world market price changes and agricultural yield changes on resource allocation as well as functional and socioeconomic income distribution is given in Wiebelt et al. (2015) for the case of Tunisia.

Gender and Resilience

At first glance, climate change and all its associated effects, such as temperature increases, changes in rainfall, sea level increase, and glacier retreat, may not affect women and men differently. However, there are complex and dynamic links between gender relations and climate change (Terry 2009). The literature generally finds that rural women in developing countries are among the most vulnerable groups (for example, Lambrou and Piana 2006) because they often are responsible for the most climate-sensitive activities, such as agriculture, water collection, and fuelwood collection (Byrne and Baden 1995; Denton 2009). Moreover, there are generally gendered differences in access to water, land, and resources (Sachs

1996; UN Women Watch 2009). One of the reasons women are left with the more climate-sensitive activities is gendered differences in labor market access (Buechler 2009) and mobility (UN Women Watch 2009).

Research on mobility and migration patterns suggests that in times of disaster and stress, such as those that might arise from climate change, men tend to migrate while women and girls stay behind. The resulting increased work burdens, specifically related to agriculture, may make it difficult for them to continue their existing income-generating activities, let alone take up additional opportunities (Denton 2009).

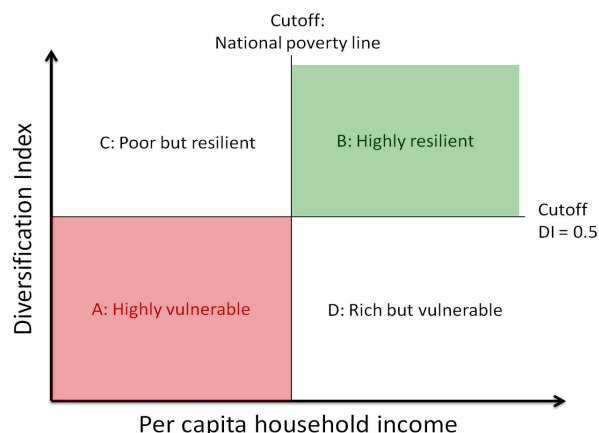
The fact that women and girls are often responsible for most of the unpaid care tasks around the household also means their lives are directly affected by the changes brought about by climate change. They often have to walk farther to find increasingly scarce food, fuel, and water as well as care for family members who are susceptible to the health risks linked to climate change. For example, climate change is expected to cause more extreme precipitation patterns, with more droughts and more floods (IPCC 2013), and in both cases it is typically women who have to work harder to obtain water during droughts and deal with the mess and increased disease burden caused by floods (Denton 2009). As a result, women and girls find themselves with less time for education, income-generating activities, and participation in community decisionmaking processes, further entrenching unequal gender relations (Skinner 2011). There also may be gendered differences in spending patterns. Households that spend a large share of their income on food may be particularly vulnerable to food price increases brought about by climate change (Food and Agriculture Organization of the United Nations 2011).

However, gender roles and relations are highly context specific and therefore must be studied and addressed in local contexts (Verner 2012).

To complement the simulations by a direct vulnerability analysis of household survey data from the three countries, we use the vulnerability indicators proposed by a recent Inter-American Development Bank study (Andersen et al. 2014). This paper argues that although vulnerability is a very complex concept, it can be quantified and analyzed usefully at the household level using just two main indicators: (1) per capita household income and (2) household income diversification. The most vulnerable households are those that simultaneously have low levels of income and low levels of diversification because any shock could threaten their entire income base. In contrast, households with high and well-diversified incomes will be much better able to withstand any adverse shock.

Andersen and Cardona (2013) develop a simple typology of vulnerability based on these two indicators. A household that has a per capita income below the national poverty line and a Diversification Index (DI) less than 0.5 is classified as highly vulnerable, while a household that has a per capita income above the poverty line and a DI greater than 0.5 is classified as highly resilient (Figure 2.7).

Figure 2.7 The four main vulnerability types in Andersen and Cardona (2013)



Source: Andersen and Cardona (2013).

Note: DI = Diversification Index.

Andersen and Cardona (2013) argue that diversification is the opposite of income concentration, so a simple and logical way of constructing a DI is simply 1 minus the widely used Herfindahl-Hirschman Index of Concentration:

$$DI = 1 - \sum_{i=1}^N p_i^2 \quad (1)$$

where N is the total number of income sources and p_i represents the income proportion of the i th income source. The value of the index is 0 when there is complete specialization (100 percent of total household income comes from one source only) and approaches 1 as the number of income sources increases and no single source dominates household incomes.

The advantage of using the DI instead of just the number of livelihood sources is that it is not very sensitive to the grouping of small income sources together with bigger ones. For example, if a household had three sources, contributing 90 percent, 9 percent, and 1 percent, respectively, the DI would be 0.1818. If we lump together the last two sources, the index changes only marginally to 0.1800. This is a reduction of less than 1 percent in the index, whereas the reduction in number of livelihood sources would be 33 percent. This property of robustness to alternative classifications is important as we will necessarily have to make some assumptions about how to classify and group different income sources together (Andersen and Cardona 2013). In principle, one should define “sources” in such a way that there is very low correlation across states of nature. Thus, if both the husband and the wife are engaged in subsistence agriculture, that would count as only one income source because adverse climatic or market conditions would affect both in a very similar way. If they also had some cattle, that would count as an additional income source, as cattle and agricultural productivity are not strongly correlated. Indeed, cattle are often used as a self-insurance mechanism in Latin America. In practice, the exact classification of sources will depend on the amount of detail available in the household surveys of each country. Thus, while the index can be compared across groups within the same country, it is more difficult to compare across countries.

Since these two indicators can be calculated for every household in each of the countries analyzed, we can compare the probability of falling into the highly vulnerable corner for any group of interest, including female- and male-headed households.

The methodology, however, does not permit the analysis of intrahousehold gender differences in vulnerability. This is a potential weakness, as there may very well be intrahousehold differences that the household-level analysis cannot capture (Institute for Advanced Development Studies 2014). There are multiple gender-specific vulnerabilities related to differing familial and community obligations and life cycle events (for example, childbirth, childcare, lower social status, lower access to and control over assets, and mobility constraints), and these shape opportunities for men, women, and children to build resilience and constrain the coping strategies they employ to manage risk (Holmes and Jones 2013).

Intertemporal Discount Factor and Reporting of Results

To summarize the results of annual climate change impacts during the next 40 years, we calculate the net present value (NPV) of the impacts and compare them to the NPV of the relevant variable in the perfect mitigation scenario. This will give us an average measure of impact during the 40 years, but the impacts will typically be smaller than average in the beginning of the period, when climate has not yet changed much, and larger than average by the end, when the full climate changes illustrated in Figures 2.2 and 2.3 have occurred.

To avoid automatically disregarding the larger effects that occur toward the end of the period analyzed, we apply a very low intertemporal discount rate of 0.5 percent. However, our results are not sensitive to the choice of discount rate, since we always compare to a relevant variable that has been summarized using the same discount rate.

Three indicators are used to assess the impacts of climate change on total GDP, agricultural GDP, and households’ welfare. The three indicators are the following:

Accumulated Absolute Value of Losses

Indicator 1 was calculated following three steps. First, simulation outputs of the model present figures for all three variables expressed in constant-value local currency for all scenarios. These figures were converted into constant-value US dollars by dividing the whole series by the exchange rate in the base year. Second, aggregated values of the variables were calculated for each of the scenarios by adding up the string of values of the variable for the whole time horizon of the simulation. Finally, the indicator was calculated as the deviations of the aggregated values for each of the scenarios from that corresponding to the no climate change scenario.

$$I_1 = \sum VJ_i - \sum Vncc_i,$$

where

I_1 = indicator 1,

VJ_i = value of variable V in climate change scenario j and in year i, and

$Vncc_i$ = value of variable V in no climate change scenario and in year i.

Percentage of Accumulated GDP in No Climate Change Scenario

Indicator 2 was calculated by dividing indicator I_1 by the aggregated string of values of the variable in the no climate change scenario:

$$I_2 = (\sum V_i - \sum Vncc_i) / \sum Vncc_i.$$

Percentage of GDP in Base Year

Indicator 3 was calculated by dividing indicator I_1 by the value of the variable in the base year (2009).

$$I_2 = (\sum V_i - \sum Vncc_i) / V_{BY},$$

where

V_{BY} = value of the variable in the base year.

It is important to keep in mind several caveats of these indicators to avoid potential misinterpretations:

1. Indicator 1 does not provide a clear idea of the size of the impacts, since we cannot tell by just looking at this indicator whether the impacts are large or small. It is always important to compare it with reference to the value of another known variable. This shortcoming can be solved by expressing this indicator in per capita terms. The positive aspect of this indicator is that its meaning can be easily understood.
2. Indicator 2 does provide a reference to assess whether the effects are large or small, which is the aggregate value of the variable in the no climate change scenario. Actually, this indicator can be expressed as a percentage. This indicator provides a more precise idea of the size of the effects because it compares an aggregated string of values of impacts over the long term with an aggregated string of values of the variable over the same time horizon. However, it can be more difficult to understand since it is hard to visualize the size of the economy in the longer term.
3. Indicator 3, like indicator 2, provides a reference to assess the magnitude of the impacts. However, this indicator tends to provide an artificially enlarged magnitude of the impacts since it compares an aggregated string of values of impacts over the long term with the value of the variable in one single year. However, the indicator is much easier to interpret since the present magnitude of the variable is much easier to visualize.

Tables A.5 through A.7 provide an overview of results for each country and each indicator. Throughout most of the country sections in the main text, we discuss the results using indicator 2, whereas the executive summary refers to all indicators to give the readers broad perspective on the projected magnitude of impacts.

3. SOCIOECONOMIC IMPACTS OF CLIMATE CHANGE IN BRAZIL

Brazil is one of the world's largest producers of agricultural products and can therefore expect important impacts from both global price changes and local yield changes. Previous studies on the impacts of climate change on agriculture in Brazil have found potentially severe impacts, with farms losing on average 23 percent of their land values by 2060 in the worst climate scenario (Seo and Mendelsohn 2008). Seo and Mendelsohn's (2008) study on the economic costs and opportunities of climate change in Brazil estimates that except for sugarcane, all crops are supposed to be affected by a reduction in low-risk production areas, especially soybeans (-34 to -30 percent), maize (-15 percent), and coffee (-18 to -17 percent). Crop yields would fall in particular for staple crops in the North East region (Margulis and Burle Schmidt Dubeux 2011).

However, although absolute agricultural production is large in Brazil, agriculture contributes only about 5.5 percent to total GDP (Table 3.1), so the effect on the overall economy is still bound to be relatively small. Moreover, most of Brazil's production and consumption of agricultural goods is directed toward domestic markets. Impacts of global price changes will therefore be concentrated on a few export-oriented agricultural subsectors (such as soybeans, coffee, and maize) and import-substituting subsectors (wheat), together making up 30 percent of agricultural value-added, while all other agricultural sectors largely produce for the domestic market and therefore are not directly affected by world market price changes. Finally, Brazil is by far the world's largest producer and exporter of coffee and just passed the United States as the leading soy-producing and -exporting country. This implies that the country has some power on world markets; these two agricultural commodities and domestic production costs are more insulated from production costs of foreign competitors than in other countries and for other agricultural goods in Brazil.¹⁷

Since Brazil is located in the tropics and spans the equator, the climate is already hotter than ideal for almost all crops, so as indicated in Table 2.1 further increases are expected to have a negative effect on crop yields almost everywhere. Again the direct impact is concentrated on a few agricultural subsectors making up 40 percent of agricultural value-added. Yet other agricultural subsectors and forestry compete with directly affected subsectors for agricultural land as well as other primary and secondary inputs and therefore are affected indirectly. In addition, nonagricultural sectors also compete with agriculture for labor, capital, and intermediate inputs and therefore are also affected indirectly.

In this section we will first analyze the effects of changes in global agricultural prices due to global climate change, and subsequently we will analyze the effects of changes in crop yields due to local climate change. After presenting the combined effect of the two types of impacts, we will present a gender-differentiated analysis of vulnerability.

¹⁷ We therefore assume much lower export transformation and import substitution elasticities in Brazil (0.5 and 2.0) than in Mexico and Peru (4.0 and 6.0). As a result, both the transmission of world market price changes into domestic price changes and the restructuring of supply and demand toward exports and imports are much lower.

Table 3.1 Brazil: Agricultural value-added by region and agricultural trade orientation, 2008

Agricultural goods	NORTHERN TROPICAL		CENTRAL TROPICAL		SOUTHERN HUMID		EASTERN SEMIARID		All regions					
	Billions of reais	%	Billions of reais	%	Billions of reais	%	Billions of reais	%	Billions of reais	%	EXPshr	EXP-OUTshr	IMPshr	IMP-DEMshr
Maize	0.18	3.23	4.27	9.06	6.55	10.05	0.93	4.80	11.93	8.69	0.59	10.44	0.07	1.56
Wheat			0.08	0.17	1.74	2.67			1.82	1.33	0.08	10.56	1.00	61.58
Rice	0.18	3.23	0.85	1.80	3.01	4.62	0.19	0.98	4.23	3.08				
Soybeans	0.09	1.62	10.10	21.43	10.49	16.10	1.39	7.18	22.07	16.08	3.83	38.46		
Cassava	0.55	9.87	0.72	1.53	0.76	1.17	0.57	2.94	2.60	1.89				
Tobacco					2.78	4.27	0.05	0.26	2.83	2.06	0.02	1.72		
Citrus fruits	0.03	0.54	0.28	0.59	2.94	4.51	0.26	1.34	3.51	2.56	0.03	1.95		
Cotton			1.55	3.29	0.16	0.25	0.79	4.08	2.50	1.82				
Coffee			4.63	9.82	0.84	1.29	0.34	1.76	5.81	4.23	1.61	64.47		
Sugarcane	0.06	1.08	1.82	3.86	6.67	10.24	1.52	7.85	10.07	7.34				
Other crops	1.04	18.67	5.52	11.71	8.45	12.97	6.68	34.50	21.69	15.81	0.36	3.57	0.50	5.81
Live cattle	1.48	26.57	7.72	16.38	5.87	9.01	2.14	11.05	17.21	12.54	0.20	2.21		
Poultry	0.21	3.77	1.13	2.40	4.83	7.41	1.07	5.53	7.24	5.28				
Live milk cattle	0.27	4.85	4.29	9.10	3.25	4.99	1.21	6.25	9.02	6.57				
Pigs	0.12	2.15	0.88	1.87	1.62	2.49	0.39	2.01	3.01	2.19				
Eggs	0.10	1.80	0.89	1.89	1.53	2.35	0.63	3.25	3.15	2.30	0.04	1.77		
Forestry	0.84	15.08	2.14	4.54	2.97	4.56	0.69	3.56	6.64	4.84	0.05	1.67	0.31	10.22
Fishery	0.42	7.54	0.27	0.57	0.69	1.06	0.51	2.63	1.89	1.38	0.01	1.00	0.06	6.46
Total	5.57	100.00	47.14	100.00	65.15	100.00	19.36	100.00	137.22	100.00				
%	4.06		34.35		47.48		14.11		100.00					

Source: Social accounting matrix for Brazil (2014).

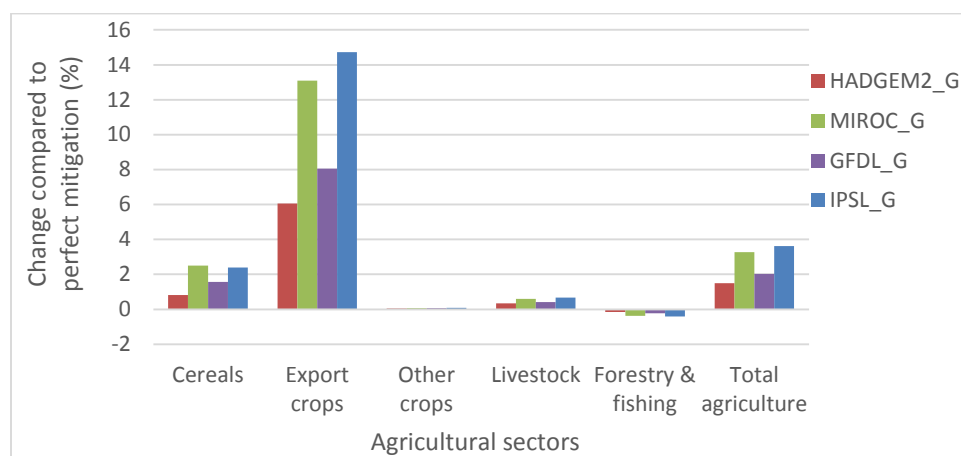
Notes: EXPshr = Commodity share of total export revenues; EXP-OUTshr = Share of exports in commodity demand; IMPshr = Commodity share of total import expenditures; IMP-DEMshr = Share of imports in commodity supply; GDP = gross domestic product. Goods with EXP-OUTshr or IMP-DEMshr of less than 1 percent are treated as nonexport or nonimport goods. Values in red are directly affected by world market price changes. Values highlighted in gray are directly affected by yield changes. Total GDP at factor cost = 2.5 trillion reais. Agriculture's share of GDP = 5.5%.

Impacts of Global Agricultural Commodity Price Changes on the Brazilian Economy and Households

Brazil's demand for agricultural goods is strongly biased toward domestic markets, with imported goods making up just 3.6 percent of total absorption of agricultural goods and 1.9 percent of the total import bill (Table 3.1). Wheat is the only agricultural commodity with a sizeable import intensity of 62 percent, yet the world market price of wheat is not very much affected by global climate change (Figure 2.5). Thus, the impact of global climate change in Brazil is felt largely on the supply side of agricultural markets. Although overall agricultural export intensity is rather low, with only 10 percent of domestic agricultural production being exported, producers of maize, wheat, soybeans, and coffee, which contribute 30 percent to total agricultural value-added, all export a sizeable share of their production, ranging from 10 percent for maize and wheat to 39 percent and 65 percent for soybeans and coffee.

Improvement of agricultural international terms of trade caused by increasing global prices for these commodities, which result from global climate change (Figure 2.5), would have a favorable effect on agricultural GDP in Brazil driven by export expansion (Figure 3.1), especially in the Central Tropical Subhumid region that has specialized in large-scale soybean, coffee, and maize production (Figure 3.2).

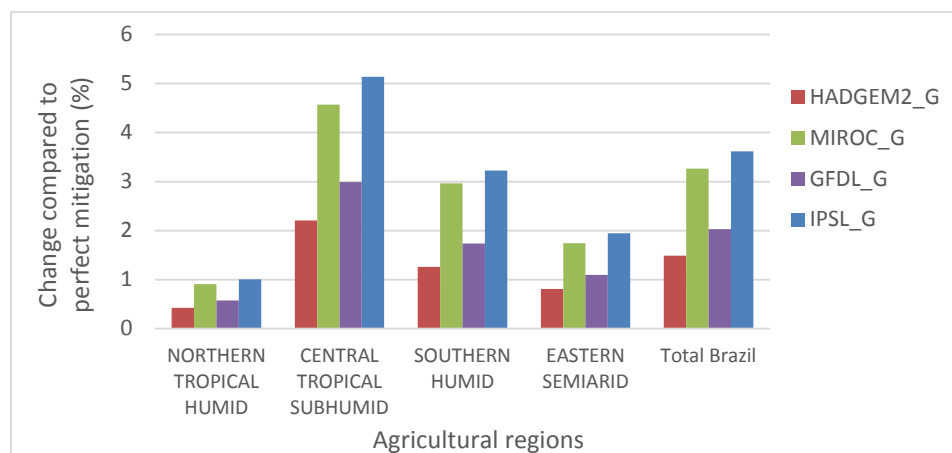
Figure 3.1 Impacts of global agricultural price changes on the net present value of agricultural gross domestic product in Brazil, by product group



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: _G = Global scenario.

Figure 3.2 Impacts of global agricultural price changes on the net present value of agricultural gross domestic product in Brazil, by region



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

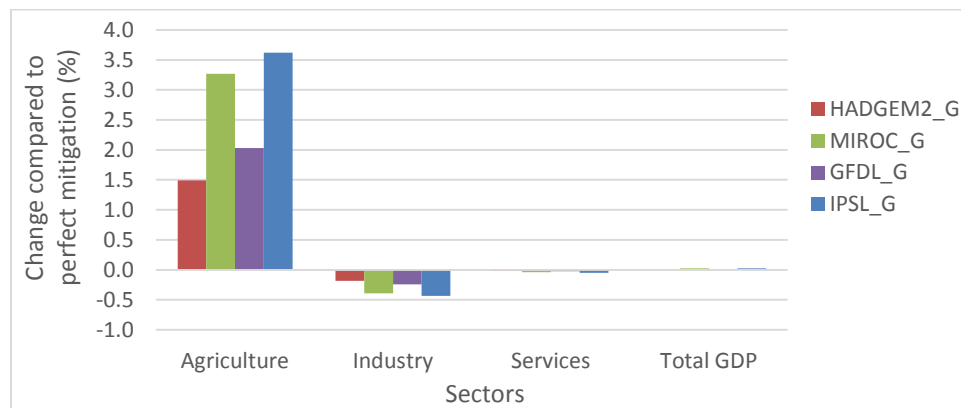
Note: _G = Global scenario.

In contrast, the Northern Tropical Humid region, with its production of cassava, other crops, live cattle, and wood for domestic markets and wood processing, is largely unaffected by global price changes. Finally, agricultural production in the Eastern Semiarid region benefits from higher world market prices for maize and soybeans.

Overall, the NPV of agricultural GDP in Brazil would be expected to increase by 1.5 to 3.6 percent compared to a perfect mitigation scenario due to world price changes, depending on the climate scenario (Figures 3.1 and 3.2).

This advantage for the agricultural sector, however, turns into a disadvantage for other sectors, including some agricultural subsectors, since several of these—especially the industrial sector—use agricultural inputs and will suffer from inputs’ being more expensive. Cost push as a result of backward linkages is most pronounced in food processing, where intermediate input costs make up more than 80 percent of total production costs. In addition, since the export-oriented agricultural sector will become relatively more profitable due to higher output prices, this sector will attract more investment, labor, and capital at the expense of the remaining sectors. Finally, the strong expansion of soybeans and coffee production will attract land from other agricultural uses, especially the forestry sector, thereby leading to increased deforestation (Figure 3.1). Since the agricultural sector is very small compared to the nonagricultural sectors, the increase of agricultural real income of about 2.5 percent on average across the four climate scenarios is outweighed by average real income losses of 0.3 percent in industry, leaving overall real GDP practically unaffected by global climate change (Figure 3.3).¹⁸

Figure 3.3 Impacts of global agricultural price changes on the net present value of gross domestic product in Brazil, by sector



Source: Authors’ elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: _G = Global scenario.

While real GDP is unaffected by global climate change and increasing world market prices for agricultural goods, the terms-of-trade improvement leads to higher domestic producer prices and higher wages, profits, and land rental rates, thereby raising domestic factor incomes and absorption including household consumption.

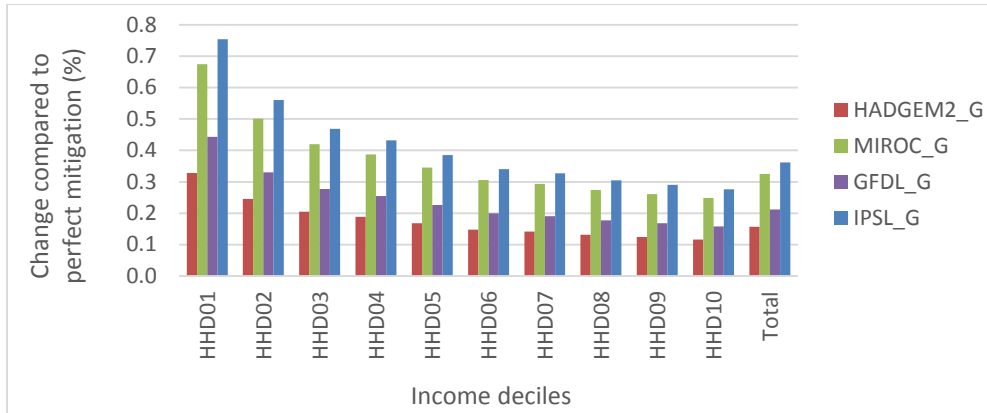
The positive terms-of-trade effect and the resulting increases in wages, profits, and land rentals translate into a small improvement of welfare for all households—from the poorest to the richest (Figure 3.4).¹⁹ The total increase in household welfare amounts to 0.15 to 0.36 percent, depending on the climate change scenario, and is larger for the poorest households (the two lowest-income deciles; Figure 3.4), which receive a larger than average share of their functional income from the relatively scarce factor,

¹⁸ Clearly, the full employment assumption underlying the dynamic computable general equilibrium simulations in this report does not allow any significant changes in real gross domestic product as a result of world market price changes. Such changes could only result from, for example, efficiency gains if resources are reallocated from sectors with high domestic resource costs to sectors with low domestic resource costs. Yet efficiency gains and losses are negligible.

¹⁹ Changes in household welfare are measured by changes in households’ equivalent variation, which is a welfare measure that controls for changes in prices.

land, and the supply of low skilled labor, which are both used relatively intensively in the export-oriented agricultural sectors.

Figure 3.4 Impacts of global agricultural price changes on household welfare in Brazil, by income deciles



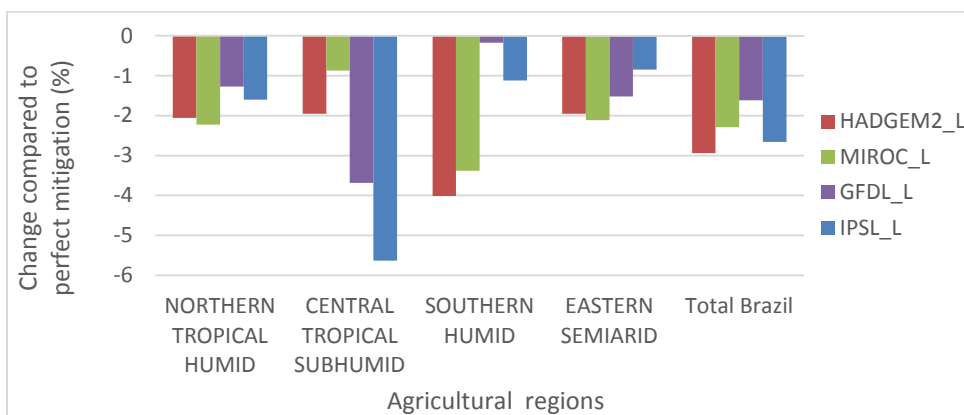
Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: HHD01 to HHD10 = First to tenth income decile; _G = Global scenario.

Impacts of Local Crop Yield Changes on the Brazilian Economy and Households

While the primary impact of changes in world market prices is limited to the exported part of domestic production of a few agricultural goods in Brazil, changes in local crop yields affect both more goods (Table 3.1) and total production of these goods. As shown in Table 2.1, the impacts of climate change on Brazilian crop yields are expected to be overwhelmingly negative. This will imply reductions in agricultural GDP in all regions, but especially in the Central Tropical Subhumid region specializing in large-scale soybean, coffee, and maize production. In this region, the negative effect is on the order of 1 to 6 percent. In contrast, crops that are affected by local climate change make up a small share of agricultural production in the Northern Tropical Humid region. Moreover, cassava—which makes up 50 percent of affected crops in this region—is a pure nontradable. Thus, output losses in cassava production resulting from lower yields are almost compensated for by increasing prices. Overall, the fall in agricultural GDP due to the local yield changes is on the order of 1.5 percent in the GFDL scenario to 3.0 percent in the HADGEM2 scenario (Figure 3.5).

Figure 3.5 Impacts of local yield changes on the net present value of agricultural gross domestic product in Brazil, by region

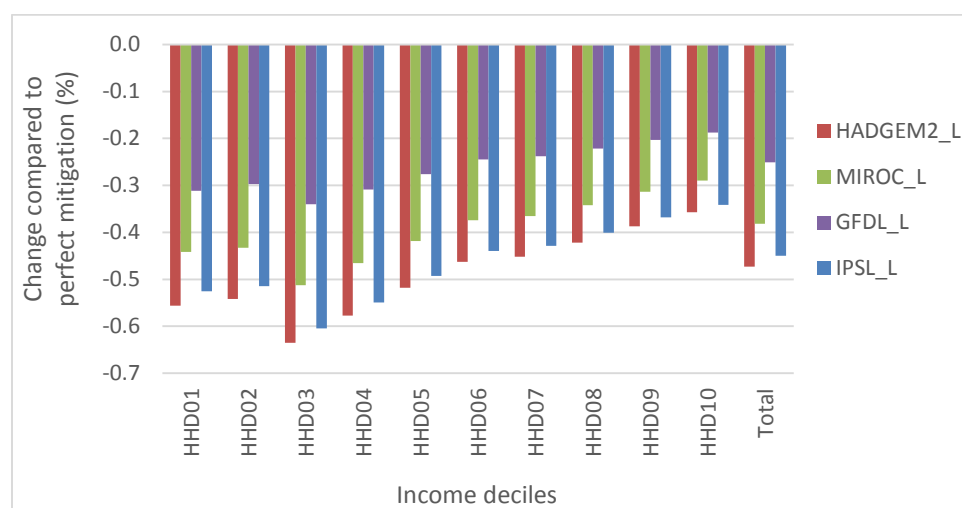


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: _L = Local scenario.

All households, both net producers and net consumers across all regions, suffer from the reduction in agricultural yields due to local climate change, but the poorer deciles suffer relatively more than the richer deciles (Figure 3.6). Again, poorer households are more affected—now from local climate change—because these receive a larger share of their functional income from land rents, which will fall more strongly than profit and wage rates since land is exclusively used in agriculture (and forestry), while labor and capital are also used in other sectors that are not directly affected by local climate change. On the other hand, income losses in rice, cassava, and sugarcane production resulting from lower yields are partly compensated for by higher domestic prices for these nontradable goods. Yet these agricultural commodities make up a low share of total agricultural production. On average during the 40-year simulation period, the size of the drop in household welfare due to this effect is between 0.25 percent and 0.50 percent.

Figure 3.6 Impacts of local yield changes on household welfare in Brazil



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

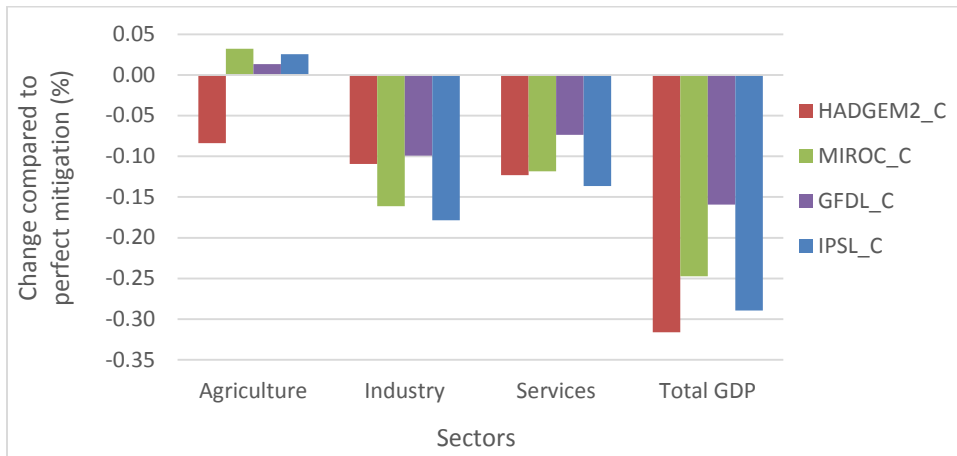
Notes: HHD01 to HHD10 = First to tenth income decile; _L = Local scenario.

Combined Impacts of Global and Local Climate Change on the Brazilian Economy

Considering the global and local effects of climate change jointly shows that (1) local effects dominate global effects and (2) indirect effects on other sectors dominate direct effects on agriculture.

Although macroeconomic growth on average does not differ much from the case of perfect mitigation, the sectoral contribution to growth is slightly changed in favor of agriculture due to the global effects of climate change, which render the production of various agricultural commodities more profitable in three out of the four climate change scenarios. The exception is the HADGEM2 scenario, where the combination of lower world market increases and higher yield losses hampers agricultural growth. Yet the indirect impact on nonagriculture of climate change is even worse, thus still favoring agriculture at least relatively (Figure 3.7).

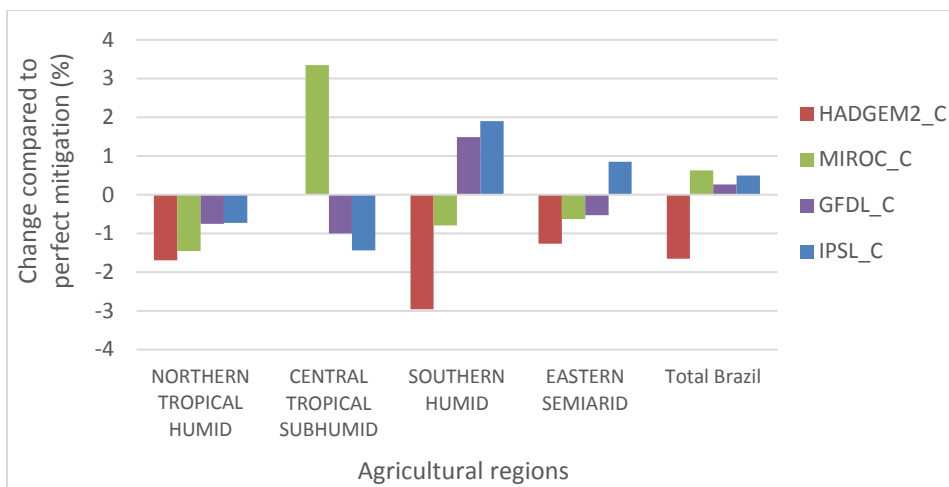
Figure 3.7 Combined impacts of climate change on the net present value of sectoral and total gross domestic product in Brazil



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).
 Note: _C = Combined scenario.

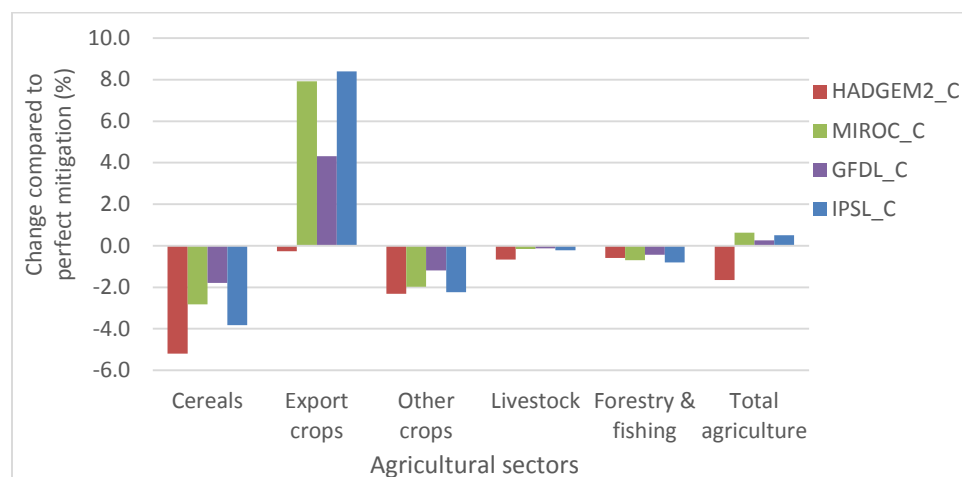
Results for the agricultural sector differ noticeably between climate scenarios, across both regions and agricultural products (Figures 3.8 and 3.9). Agricultural output rises under the combined MIROC, GFDL, and IPSL scenarios with increasing speed over time (not shown in the figures) but falls in the HADGEM2 scenario. As shown in the previous section, the impacts of local climate change in isolation have negative implications for agricultural production. The overall fall in yields due to the local impacts of climate change translates into higher domestic agricultural prices and a rise in imports. Higher domestic prices weaken competitiveness on the world market and thus also affect Brazil's exports of agricultural crops. This latter effect is more than compensated for when global climate change is factored in and globally higher prices provide a boost to the agricultural sector and improve agricultural export performance, thus leading to faster growth of the agricultural sector (versus perfect mitigation). In contrast, due to less optimistic world price projections, agricultural growth in the HADGEM2 scenario is slightly lower than in the perfect mitigation scenario when both local and global climate change effects are taken into account.

Figure 3.8 Combined impacts of climate change on the net present value of agricultural gross domestic product in Brazil, by region



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).
 Note: _C = Combined scenario.

Figure 3.9 Combined impacts of climate change on the net present value of agricultural gross domestic product in Brazil, by product group

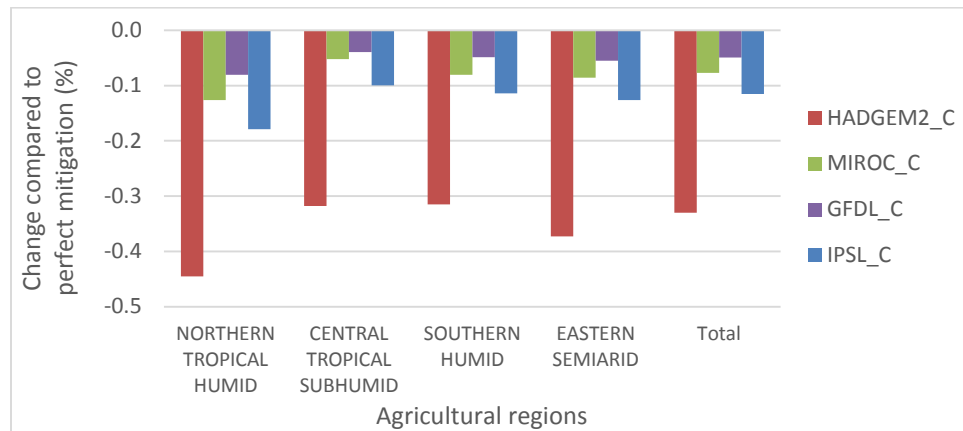


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).
 Note: _C = Combined scenario.

The combined effects of global and local climate change turn out to be favorable for export crops only (Figure 3.9), but again only for the IPSL, MIROC, and GFDL scenarios, not for the HADGEM2 scenario and less so under the GFDL scenario than under the IPSL and MIROC scenarios. For the two biggest agricultural regions—Central Tropical Subhumid and Southern Humid—the positive impacts of global climate change and the negative impacts of local climate change add up to a real income gain of between 1.7 percent in the Southern Humid region under GFDL conditions and 3.3 percent in the Central Tropical Subhumid region under MIROC conditions. In any case, the combined effects of climate change in Brazil are dominated by a significant improvement in international terms of trade for soybeans and coffee, which increase domestic absorption, improve overall household welfare (see below), and may lead to a reduction of poverty but at the same time lead to strong specialization and regional concentration in agriculture and a loss of international competitiveness of the industrial sector, that is, Dutch disease.

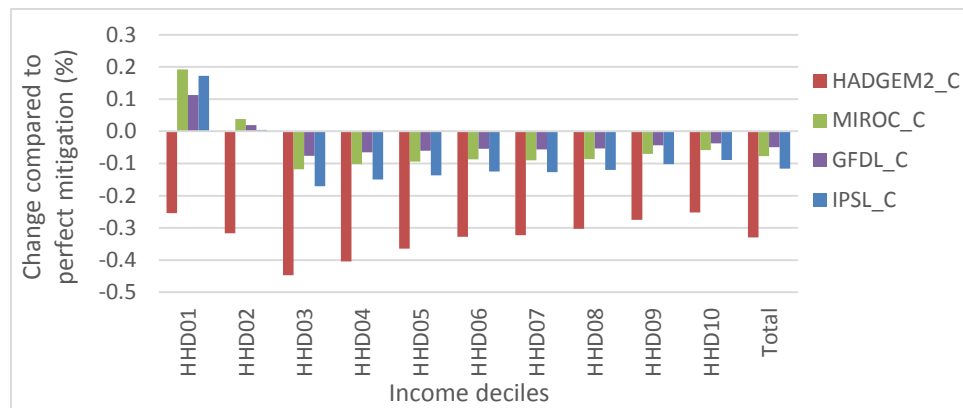
The combined effect on household welfare is typically negative but very small for all regions and income deciles, except for the HADGEM2 scenario wherein the combined effect is dominated by impacts of local climate change, that is, decreasing yields, lower producer prices, lower factor income, and higher consumer prices (Figures 3.10 and 3.11). The latter is most strongly felt in the Northern Tropical Humid and the Eastern Semiarid regions, which either do not or only partially benefit from terms-of-trade improvements in agriculture. As a consequence, their welfare falls by up to 0.4 percent.

Figure 3.10 Combined impacts on household welfare in Brazil, by region



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).
 Note: _C = Combined scenario.

Figure 3.11 Combined impacts on household welfare in Brazil, by income deciles



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).
 Note: HHD01 to HHD10 = First to tenth income decile; _C = Combined scenario.

Only households that belong to the lowest income decile may benefit under the other climate scenarios, while the second lowest income decile is almost unaffected. As shown in the previous sections, these two household groups are slightly more affected by the negative impacts of local climate change than the average household but benefit significantly more from global climate change. The reason is that impacts of improving terms of trade and lower agricultural yields on wages and profit rates almost compensate for each other, while the increase in land rents is felt in the agricultural income and income of the poorest household decile.

In all climate scenarios, higher world market prices for wheat (Table 2.1) do not have a significant impact on the consumer price, since wheat makes up a tiny portion of consumption expenditures. Wheat price changes affect prices for processed food, but here again overall expenditures on processed food make up only 11 percent of overall private consumption. Moreover, the poorest households are net producers of wheat and therefore benefit from slightly higher prices for wheat. Thus, the impact of combined climate change on household welfare is felt mostly on the income side, where improving terms of trade lead to higher remuneration of all factors, particularly land rents and wages for lower-skilled labor, while lower yields lead to falling factor remuneration. Since the positive impacts of global price increases due to climate change dominate the negative impacts of local yield changes, especially in the MIROC and IPSL climate scenarios, welfare is improving for the lowest-income deciles, which earn a larger share of their income from land use and the supply of low-skilled labor.

Vulnerability and Gender Differences in Brazil

With more than a third of all households being female headed, Brazil has an unusually large female headship rate compared to other countries in Latin America. This is particularly pronounced in the urban areas of Brazil, where this share reaches 38 percent; in rural areas it is only 18 percent (Table 3.2). Combined with Brazil's very high urbanization rate of 85 percent, this means that only 2.6 percent of all households consist of female-headed households in rural areas, the group that is often of concern when discussing gender and climate change (for example, Rivero Reyes 2002; Lambrou and Piana 2006; Denton 2009).

Table 3.2 Brazil: Distribution of households by gender and location (percentage of all households)

Type of household	Brazil, 2008		
	Rural	Urban	Total
Male headed	12.0	53.2	65.2
Female headed	2.6	32.1	34.8
Total	14.7	85.3	100.0

Source: Authors' elaboration based on national household survey data.

In urban areas, where 92 percent of all female-headed households reside, female-headed households have per capita incomes that are on average 8 percent lower than those of male-headed households. However, in rural areas, female-headed households have slightly higher levels of per capita income (Table 3.3).

Table 3.3 Brazil: Per capita household income, by household type (reais per month per person)

Type of household	Brazil, 2008		
	Rural	Urban	Total
Male headed	378	883	790
Female headed	409	812	782
Total	384	856	787

Source: Authors' elaboration based on national household survey data.

In both rural and urban areas, the incomes of female-headed households are significantly more diversified than those of male-headed households (Table 3.4). There are a number of reasons for this. First, female-headed households tend to have more complex compositions and often include several income earners, whereas male-headed households include a large share of traditional families, where the man is the only breadwinner. Second, female heads are on average several years older than male heads, which means that they have had more time to build up the human, physical, and social capital necessary to create a diversified income base and at the same time are less likely to have small children, who limit income-earning options, especially for women. Third, since women tend to earn less than men with equivalent skills in equivalent jobs, women may find it necessary to complement their main income with alternative incomes.

Table 3.4 Brazil: Household Income Diversification Index, by household type

Type of household	Brazil, 2008		
	Rural	Urban	Total
Male headed	0.406	0.455	0.446
Female headed	0.461	0.479	0.478
Total	0.416	0.464	0.457

Source: Authors' elaboration based on national household survey data.

If we define all households with per capita incomes under the national poverty line in Brazil and DIs less than 0.5 as highly vulnerable, then we can calculate the share of each household type that falls into the highly vulnerable corner of Figure 2.7. The results are shown in Table 3.5. On average, female-headed households in urban areas are more likely to be vulnerable than male-headed households, but the opposite is true in rural areas, where female-headed households are substantially less likely to be vulnerable, because not only do they have higher levels of income but their incomes are more diversified than those of male-headed households in rural areas. In total, female-headed households in Brazil tend to be slightly less vulnerable than male-headed households.

Table 3.5 Brazil: Probability of being highly vulnerable, by household type (percentage)

Type of household	Brazil, 2008		
	Rural	Urban	Total
Male headed	22.6	8.5	11.1
Female headed	17.6	9.5	10.1
Total	21.7	8.9	10.7

Source: Authors' elaboration based on national household survey data.

It is worth highlighting that rural households are two to three times more likely to be vulnerable than urban households in Brazil. This is mainly due to the much lower incomes but also to the slightly lower level of income diversification.

In an equivalent manner, we can calculate the shares of each household group that fall into the highly resilient group (those that simultaneously have incomes above the national poverty line and DIs greater than 0.5). Table 3.6 shows that in both rural and urban areas, female-headed households are significantly more likely to be highly resilient than male-headed households, with the difference being particularly large in rural areas.

Table 3.6 Brazil: Probability of being highly resilient, by household type (percentage)

Type of household	Brazil, 2008		
	Rural	Urban	Total
Male headed	25.7	43.8	40.5
Female headed	38.9	46.7	46.1
Total	28.0	44.9	42.4

Source: Authors' elaboration based on national household survey data.

The finding that female-headed households in general are less vulnerable and more resilient than male-headed households means that female-headed households should be better able to absorb the adverse shocks of climate change in the form of both decreasing yields and increasing prices of agricultural products.²⁰

²⁰ These findings refer to the current situation in Brazil as calculated from basic household data.

4. SOCIOECONOMIC IMPACTS OF CLIMATE CHANGE IN MEXICO

Three out of four climate scenarios used in this study project substantial reductions in precipitation in the southern part of Mexico. This is a region that has historically demonstrated high vulnerability to precipitation changes (Johnson 2011). The Mayan collapse, for example, has been shown through sediment cores from Lake Chichancanab to coincide with the driest period of the late Holocene epoch (Hodell, Curtis, and Brenner 1995). Research by Haug et al. (2003) indicates that the area previously had experienced a period of wetter climate and high population growth, which was then followed by an extended severe drought period, thus suggesting that the population had grown to a point that could be sustained only during periods of favorable climates but exceeded carrying capacities during periods of adverse climatic conditions.

Studies of contemporary Mexico, however, suggest that Mexico is no longer so vulnerable to climate change. An influential study published in 2009 by the government of Mexico finds that in the worst-case scenario the accumulated impacts of climate change during the rest of the century amount to 44 percent of current GDP for one year (assuming a very low 0.5 percent discount rate) (Galindo 2009).²¹ Since accumulated GDP for the rest of the century is some 625 times larger than current GDP, under the GDP growth assumptions made in the study, the implication is that the average effect during the rest of the century is less than 0.1 percent per year. This is one or two orders of magnitude less than what Stern (2006) finds is the average impact across the world.

Andersen and Verner (2010) use municipality-level data to estimate the general relationships between climate, income, and child mortality in Mexico but find that climate plays only a very minor role in explaining the large differences in income levels and child mortality rates observed in Mexico. Compared with the results from applying identical methodologies in several other countries, including Peru and Brazil, the authors conclude that Mexico appears to be considerably less vulnerable to expected future climate change than do other countries in Latin America.

Studies focusing only on the impacts on agriculture usually find a larger impact than economywide studies. Lopez-Feldman (2013), for example, applies a Ricardian-type regression analysis to 1,567 agricultural households in Mexico to estimate the relationship between climate variables and agricultural incomes. He finds that climate change would cause a decrease of 11–15 percent in the incomes of the agricultural households surveyed.

In this section we will focus mainly on the impacts on the agricultural sector, but, in contrast to Lopez-Feldman (2013), we also will analyze the indirect effects on the other sectors and household groups. In addition, the yield and price changes will occur gradually over time, rather than instantaneously, and since we are using a general equilibrium model, where agents are assumed to optimize, there automatically will be a large degree of autonomous adaptation or reallocation in response to the climate change impacts.

Table 4.1 shows that agricultural GDP accounts for only 3.1 percent of total GDP in Mexico and that the most important agricultural products are maize, vegetables, cattle, and a group of products called “other agriculture.” In terms of imports, wheat, sorghum, and fruits are important, and the price increases of these products would be expected to adversely affect Mexico.

²¹ It should be noted that Estrada, Tol, and Gay-Garcia (2011) strongly criticize the methodologies applied in Galindo (2009) and warn against using the results for policy recommendations.

Table 4.1 Mexico: Agricultural value-added by region and agricultural trade orientation, 2008

Agricultural goods	WEST ARID		NORTH AND EAST ARID		CENTRAL HIGH ARID		SOUTHERN HUMID		All regions					
	Billions of pesos	%	Billions of pesos	%	Billions of pesos	%	Billions of pesos	%	Billions of pesos	%	EXPshr	EXP-OUTshr	IMPshr	IMP-DEMshr
Maize	11.08	17.62	4.02	5.26	26.66	21.64	11.39	14.28	53.15	14.58	0.01	0.45	0.78	27.68
Wheat	7.92	12.59	0.72	0.94	4.13	3.35	0.04	0.05	12.81	3.51	0.13	25.71	0.40	46.22
Sorghum	2.49	3.96	5.66	7.41	5.57	4.52	0.63	0.79	14.35	3.94	0.00		0.20	27.71
Beans	1.97	3.13	0.67	0.88	4.50	3.65	1.19	1.49	8.33	2.29	0.01	3.10	0.20	39.19
Tomato	5.12	8.14	0.71	0.93	3.71	3.01	0.86	1.08	10.40	2.85	0.34	81.12	0.02	3.81
Avocado	0.10	0.16	0.00	0.00	8.43	6.84	0.10	0.13	8.63	2.37	0.23	65.60		
Chili	2.54	4.04	1.68	2.20	3.00	2.44	0.57	0.71	7.79	2.14	0.17	55.82		
Potato	2.70	4.29	1.05	1.37	1.41	1.14	0.28	0.35	5.44	1.49	0.04	16.76	0.01	5.77
Banana	0.11	0.17	0.00	0.00	0.75	0.61	3.98	4.99	4.84	1.33	0.01	5.15		
Nuts	0.39	0.62	2.81	3.68	0.37	0.30	0.18	0.23	3.75	1.03	0.03	18.16	0.10	38.90
Apple	0.00	0.00	2.38	3.12	0.42	0.34	0.10	0.13	2.90	0.80	0.00		0.11	47.55
Sugarcane	1.51	2.40	0.84	1.10	5.09	4.13	7.63	9.56	15.07	4.13				
Pasture	0.62	0.99	1.21	1.58	3.64	2.96	5.90	7.40	11.37	3.12	0.00			
Alfalfa	1.21	1.92	1.50	1.96	4.58	3.72	0.05	0.06	7.34	2.01	0.00			
Other agriculture	14.89	23.68	5.79	7.58	36.40	29.55	19.23	24.10	76.31	20.93	0.97	30.45	1.29	30.56
Cattle	5.13	8.16	16.59	21.72	7.86	6.38	14.06	17.62	43.64	11.97	0.09	3.00	0.04	1.63
Poultry	2.81	4.47	21.35	27.95	2.19	1.78	8.57	10.74	34.92	9.58	0.00		0.01	0.30
Other livestock	2.30	3.66	9.40	12.31	4.46	3.62	5.02	6.29	21.18	5.81	0.00	0.07	0.02	1.93
Forestry, fishing and hunting									22.30	6.12	0.18	18.03		
Total	62.89	100.00	76.38	100.00	123.17	100.00	79.78	100.00	364.52	100.00	2.20	12.40	3.18	16.30
%	17.25		20.95		33.79		21.89		100.00					

Source: Social accounting matrix for Mexico (2014).

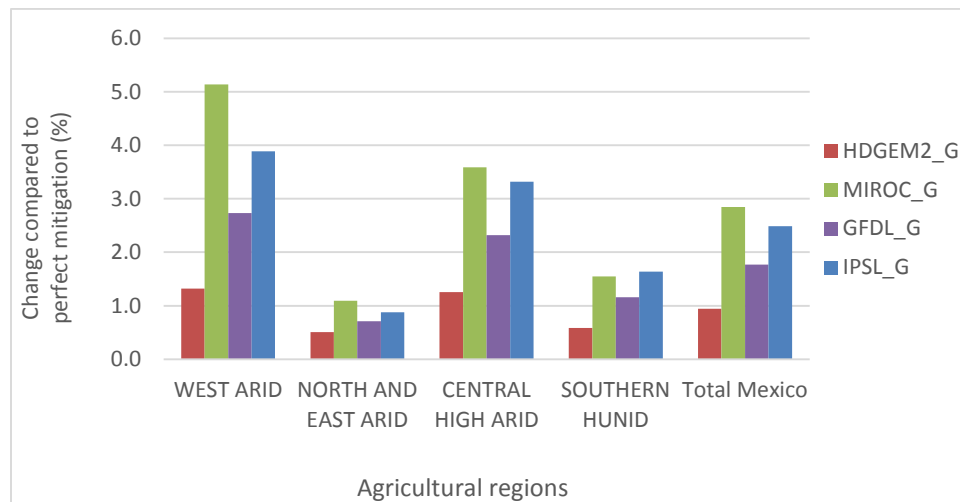
Notes: EXPshr = Commodity share of total export revenues; EXP-OUTshr = Share of exports in commodity demand; IMPshr = Commodity share of total import expenditures; IMP-DEMshr = Share of imports in commodity supply; GDP = gross domestic product. Goods with EXP-OUTshr or IMP-DEMshr of less than 1 percent are treated as nonexport or nonimport goods. Values in red are directly affected by world market price changes. Values highlighted in gray are directly affected by yield changes. Total GDP at factor cost = 11.9 trillion pesos. Agriculture's share of GDP = 3.1%.

Impacts of Global Agricultural Commodity Price Changes on the Mexican Economy and Households

According to Figure 2.5, the main goods produced by Mexico’s agricultural sector will be affected by price increases due to climate change. Higher prices are expected to have a positive impact on agricultural GDP since they will boost the sector’s profitability, attracting more production factors, including labor, capital, and land, from nonagricultural sectors and to agricultural sectors.

However, the positive effects of higher prices on agricultural GDP will not have a similar impact on all of Mexico’s agricultural regions. The regions with the greatest agricultural GDP increases are the West Arid and Central High Arid regions (Figure 4.1), where crops with higher price increases due to climate change, such as maize and wheat, have a significant share of regional agricultural GDP. According to the results from the DCGE model simulations, the NPV of agricultural GDP in these two regions would be between 3 and 9 percent larger in the scenario with increased world prices due to climate change than in the perfect mitigation scenario.

Figure 4.1 Impacts of global agricultural price changes on the net present value of agricultural gross domestic product in Mexico, by region

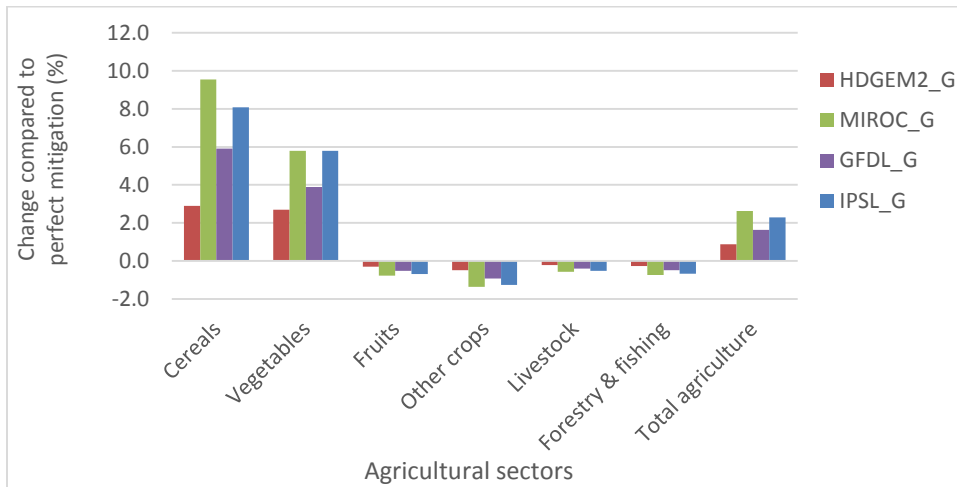


Source: Authors’ elaboration based on dynamic computable general equilibrium simulation results.
 Note: _G = Global scenario.

The North and East Arid region would see the lowest GDP increases due to global agricultural price increases because the agricultural sector in this region specializes in cattle ranching, which is not directly affected by increasing prices due to global climate change. Cattle ranching makes up more than 60 percent of the region’s agricultural GDP.

A crop-by-crop analysis confirms that the agricultural sectors with larger price increases exhibit higher GDP growth. In the case of Mexico, the production of cereals, including maize, wheat, and sorghum, presents GDP gains between 2.9 percent in the HADGEM2 scenario and 9.5 percent in the MIROC scenario in NPV terms when compared to the perfect mitigation scenario. Likewise, the production of vegetables, including beans, tomatoes, avocados, chili, and potatoes, presents GDP gains between 2.7 percent in the HADGEM2 scenario and 5.8 percent in the MIROC and IPSL scenarios. Conversely, agricultural sectors with smaller or no expected price increases, such as fruits, livestock, and forestry, present GDP drops when compared to the sectoral GDP in the perfect mitigation scenario. Again, the higher profitability of those agricultural sectors with higher price increases tends to attract more production factors away from the other sectors, such as fruits, livestock, forestry, and fishing and hunting (Figure 4.2).

Figure 4.2 Impacts of global agricultural price changes on the net present value of agricultural gross domestic product in Mexico, by product group

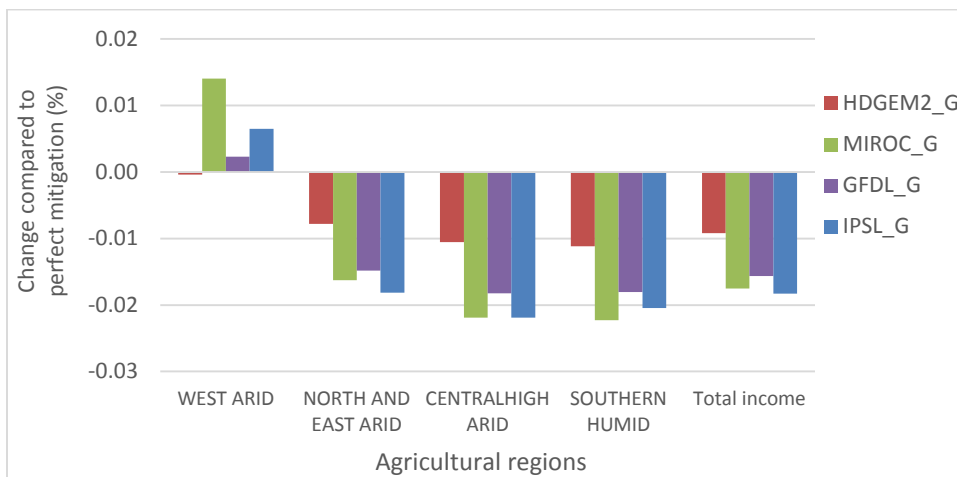


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: _G = Global scenario.

While the effect of global price increases on agriculture in Mexico is slightly positive, the effect on all the remaining sectors and the economy at large is slightly negative. This is due to a factor reallocation away from industry and services toward the slightly more profitable agricultural sector. However, the overall effect amounts to less than 0.02 percent.

These tiny effects are also reflected in the impacts on household welfare. Figure 4.3 shows that the negative effects at less than 0.02 percent are basically irrelevant.

Figure 4.3 The impacts of global agricultural price changes on the net present value of household welfare in Mexico, by region



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: _G = Global scenario.

Figure 4.4 shows the gender-differentiated impacts of global price increases, and although female-headed households see slightly larger adverse impacts than do male-headed households, the differences, at far less than one-tenth of a percentage point, are irrelevant for all practical purposes.

Figure 4.4 The impacts of global agricultural price changes on the net present value of household welfare in Mexico, by gender of the head of household



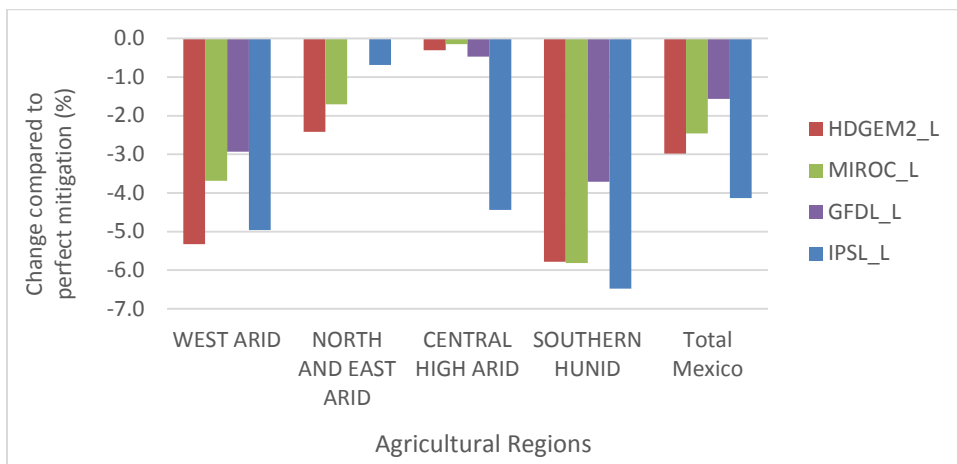
Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: _G = Global scenario.

Similarly, the results suggest that the poorest deciles are adversely affected by the increases in global agricultural prices while the richer deciles benefit, but the differences between the poorest and the richest deciles are less than one-tenth of 1 percent.

Impacts of Local Crop Yield Changes on the Mexican Economy and Households

Climate change is expected to have varied impacts on yields for the different crops produced by the Mexican agriculture sector (Table 2.2). Climate change is expected to have a negative effect on yields in all regions for maize, which is the country's main agricultural product, whereas results are mixed for other crops of less importance. Due to the dominance of maize, the overall effect of yield changes on agricultural GDP is negative, varying between -1.6 percent of agricultural GDP in the GFDL scenario and -4.1 percent in the IPSL scenario. These values represent deviations from the NPV of agricultural GDP in the perfect mitigation scenario (Figure 4.5).

Figure 4.5 The impacts of local yield changes on the net present value of agricultural gross domestic product in Mexico, by region

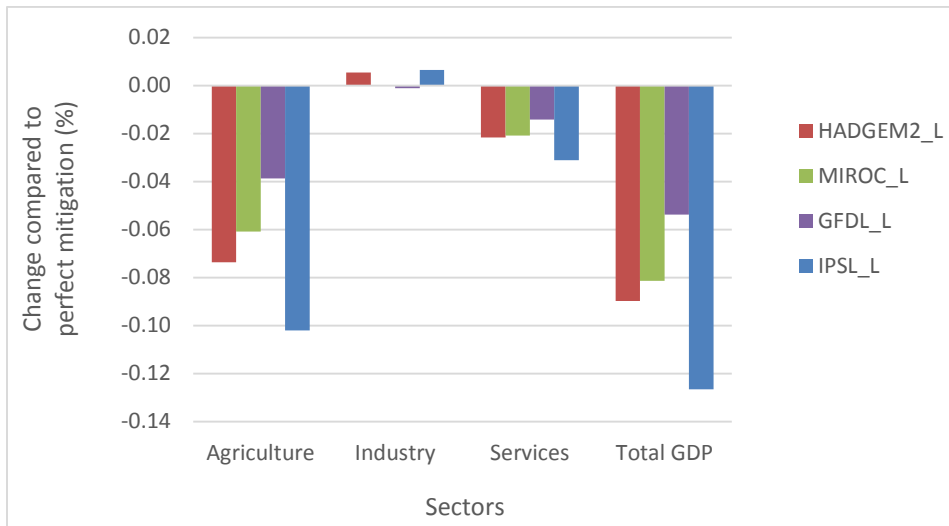


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: _L = Local scenario.

Agricultural GDP in the West Arid and Southern Humid regions exhibits the largest drops due to yield changes. Agricultural GDP drops in the Southern Humid region range from -3.7 percent in the GFDL scenario to -6.5 percent in the IPSL scenario. Again, the larger negative effects that climate change has on the yields of crops produced in this region explain these reductions. Agricultural GDP in the North and East Arid regions is less affected by yield changes, due to the significant share of cattle ranching in the region's agricultural output.

The transmission mechanism of yield changes into the economy involves a reallocation of productive factors across sectors. The reduced profitability in the Mexican agricultural sector due to negative yield changes for the main crops brings about a reallocation of production factors, that is, labor and capital, to the other sectors of the economy. Factor reallocation, however, does not compensate for the initial drop in agricultural GDP. While industrial GDP slightly increases after reallocation, service-sector GDP decreases. The net effect is a reduction in total GDP ranging from -0.05 to -0.13 percent, depending on the climate scenario (Figure 4.6).

Figure 4.6 The impacts of local yield changes on the net present value of total gross domestic product in Mexico, by sector



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.

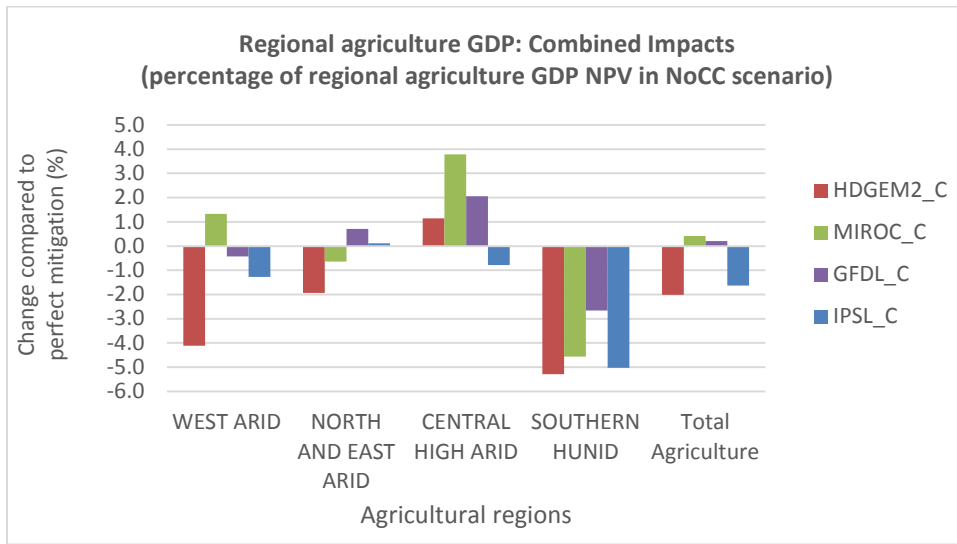
Note: GDP = gross domestic product; _L = Local scenario.

Unlike the effects of global price changes on households' incomes, the effects of yield changes are more evenly distributed across the various household categories in Mexico. These effects tend to be small, about -0.1 to -0.2 percent, due to the reduced share of agriculture in total households' incomes, and they are practically identical across region, gender, and income decile.

Combined Impacts of Global and Local Climate Change on the Mexican Economy

When combining the small impacts of global price changes and the small impacts of local yield changes, we obtain small and ambiguous total effects (Figure 4.7) The combined shocks of price and yield changes unambiguously reduce agricultural GDP in the Southern Humid region for all climate change scenarios, but in all other regions the results are ambiguous.

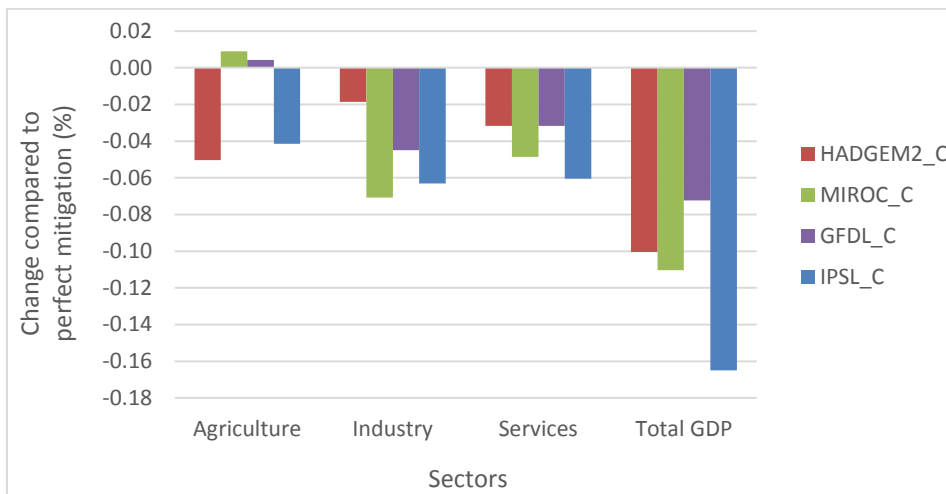
Figure 4.7 The combined impacts of global price changes and local yield changes on the net present value of agricultural gross domestic product in Mexico, by region



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: _C = Combined scenario.

Although impacts on agricultural GDP are ambiguous, the combined effects of price and yield changes on nonagricultural and total GDP are unambiguously negative in all scenarios, though very small (Figure 4.8).

Figure 4.8 The combined impacts of global price changes and local yield changes on the net present value of total gross domestic product in Mexico, by sector

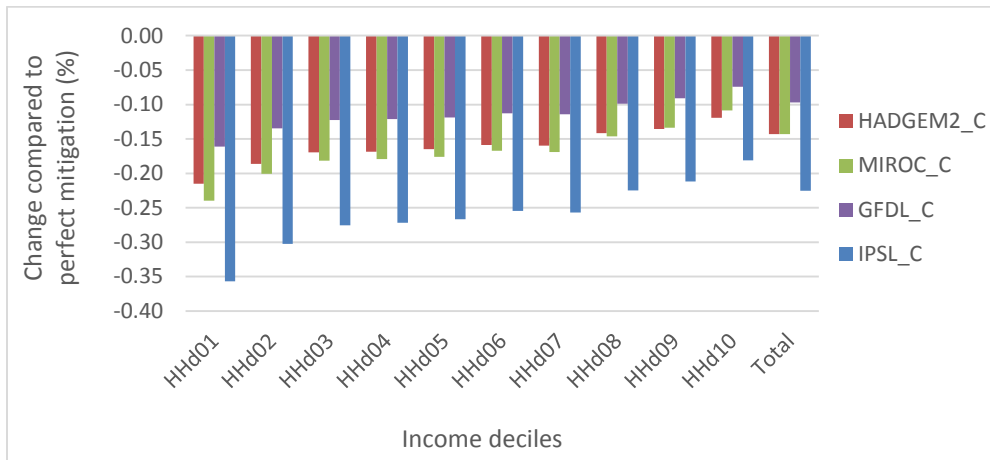


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: _C = Combined scenario.

The combined effects of price and yield changes on households' incomes tend to be similar across the different household categories analyzed in this study (that is, region of location, gender of household head, and income decile). Invariably, all household categories experience welfare losses in all climate change scenarios when compared to the perfect mitigation scenario. Figure 4.9 shows the effects on household incomes for different households grouped according to income deciles. Incomes of

households belonging to the poorest segments tend to be more negatively affected than incomes of households belonging to the richest segments. This is because poorer households' incomes tend to depend to a larger extent on nonskilled labor incomes, while the richest households' incomes depend on skilled labor and capital (profits) incomes. A relatively larger share of nonskilled workers is employed in those agricultural activities, which suffer more from the drop in yields than from the increase in global agricultural prices.

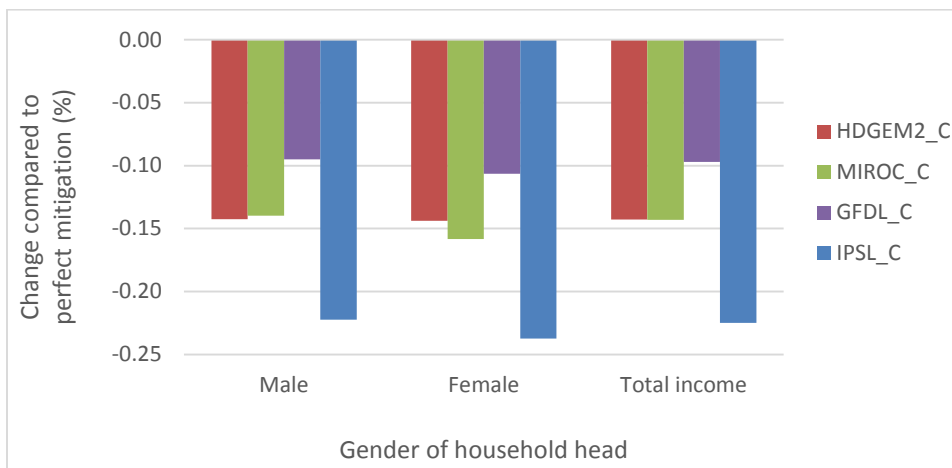
Figure 4.9 The combined impacts of global price changes and local yield changes on the net present value of household welfare, by income deciles



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: HHD01 to HHD10 = First to tenth income decile; _C = Combined scenario.

There are no significant differences in the combined impacts of climate change on Mexico's households with male heads vis-à-vis households with female heads. Figure 4.10 shows that female-headed households appear to be slightly more affected than male-headed households. The most plausible explanation is that female-headed households tend to depend more heavily than their male-headed counterparts on incomes generated in nonagricultural activities or in agriculture activities not so adversely affected by climate change.

Figure 4.10 The combined impacts of global price changes and local yield changes on the net present value of household welfare, by household head's gender



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results.
 Note: _C = Combined scenario.

Vulnerability and Gender Differences in Mexico

About 25 percent of all households in Mexico are female headed, both in rural and in urban areas. Table 4.2 shows the distribution of all households in Mexico by the gender of the head and the location.

Table 4.2 Mexico: Distribution of households by gender and location (percentage of all households)

Type of household	Mexico, 2008		
	Rural	Urban	Total
Male headed	29.0	45.4	74.5
Female headed	10.5	15.0	25.5
Total	39.5	60.5	100.0

Source: Authors' elaboration based on national household survey data.

Per capita incomes in rural areas are less than half those in urban areas, whereas the differences by gender of the head of the household are minor. The biggest difference is found in rural areas, where female headed households on average have per capita income levels 7 percent lower than those of male headed households (Table 4.3).

Table 4.3 Mexico: Per capita household income, by household type (pesos per month per person)

Type of household	Mexico, 2008		
	Rural	Urban	Total
Male headed	1,973	4,246	3,411
Female headed	1,839	4,172	3,455
Total	1,944	4,227	3,422

Source: Authors' elaboration based on national household survey data.

In urban areas, female headed households are significantly more diversified than male headed households, whereas in rural areas they tend to be slightly less diversified, although the difference is not statistically significant (Table 4.4).

Table 4.4 Mexico: Household Income Diversification Index, by household type

Type of household	Mexico, 2008		
	Rural	Urban	Total
Male headed	0.488	0.406	0.436
Female headed	0.479	0.433	0.447
Total	0.486	0.413	0.439

Source: Authors' elaboration based on national household survey data.

This implies that female headed households in urban areas is the least vulnerable group, while female headed households in rural areas is the most vulnerable group (Table 4.5).

Table 4.5 Mexico: Probability of being highly vulnerable, by household type (percentage)

Type of household	Mexico, 2008		
	Rural	Urban	Total
Male headed	28.1	20.6	23.4
Female headed	32.4	18.0	22.4
Total	29.0	19.9	23.1

Source: Authors' elaboration based on national household survey data (2014).

Female headed households in urban areas is also the group that is most likely to be resilient, while male headed households in rural areas is the least resilient group (Table 4.6).

Table 4.6 Mexico: Probability of being highly resilient, by household type (percentage)

Type of household	Mexico, 2008		
	Rural	Urban	Total
Male headed	19.0	31.9	27.2
Female headed	19.3	34.4	29.8
Total	19.1	32.6	27.8

Source: Authors' elaboration based on national household survey data (2014).

Overall, female headed households are slightly less vulnerable and slightly more resilient than male headed households, implying that they should better be able to absorb the adverse shocks of climate change in the form of both decreasing yields and increasing prices of agricultural products. However, when disaggregating by area, we find that female headed households in rural areas is the most vulnerable group. Andersen, Verner, and Wiebelt (2014) include further disaggregation by household types, and find that female headed single-career households in rural areas is the most vulnerable sub-group of all, with a 44.4 percent probability of being highly vulnerable. Thus, while female headed households are not systematically more vulnerable than male headed households, some certainly are.

5. ECONOMIC IMPACTS OF CLIMATE CHANGE IN PERU

According to research carried out by the Tyndall Centre of Climate Change in the United Kingdom, Peru is one of the most vulnerable countries in the world to climate change. When the Mega El Niño of 1997–1998 occurred, cities along the Peruvian coast experienced temperature increases of 6°C more than normal in just a few months, while the impact in most other places in the Americas was limited to a couple of degrees or less. The El Niño event also dramatically altered precipitation patterns in Peru, causing extensive damage. Flooding affected 120,000 homes and destroyed 50 bridges, hundreds of kilometers of paved roads, and 50,000 hectares of crops. The unusually warm water off the coast caused fish to migrate to colder, more nutritious waters, causing sharp reductions (about 74 percent) in the Peruvian fish harvest, which in turn adversely affected the manufacturing chain dependent on fish as a raw material. An excess number of cases of diarrhea were registered, as were outbreaks of malaria, cholera, and dengue fever. Due to the breakdown of infrastructure, prices in some places rose by 20–100 percent due to lack of supply of basic goods. Exports were also adversely affected. Total losses were estimated at close to \$1 billion (Andersen, Suxo, and Verner 2009).

While several studies have analyzed the impacts of extreme events and climate variability at specific sites in Peru (for example, Lagos and Buizer 1992; Checkley et al. 2000; Rivero Reyes 2002; Casimiro, Silvestre, and Pulache 2010), very few studies have analyzed the impacts of long-run climate change for the whole country. One of them is Andersen, Suxo, and Verner (2009), which uses district-level data to estimate the general relationship between climate, income, and life expectancy in Peru. The analysis finds that both incomes and life expectancy show hump-shaped relationships, with optimal average annual temperatures around 18–20°C. These estimated relationships were then used to simulate the likely effects of both past (1958–2008) and future (2008–2058) climate change in each of the districts in Peru. At the aggregate level, future climate change in Peru was estimated to cause a small reduction in average life expectancy of about 0.2 years. This average, however, hides much larger losses in the already hot areas as well as substantial gains in currently cold areas. Similarly, the average impact on incomes is a modest reduction of 2.3 percent, with some districts experiencing losses of up to 20 percent and others gains of up to 13 percent. Future climate change was estimated to cause an increase in poverty (all other things equal) but to have no significant effect on the distribution of incomes.

While Andersen, Suxo, and Verner (2009) use a purely statistical approach to assess overall impacts of climate change in Peru, a study by Met Office (n.d.) provides a useful review of climate change and impacts in Peru based on a review of the literature, almost all of which is global, but with implications for Peru. The study indicated that a majority of global circulation models project a warmer and wetter climate for Peru and that most crop models project that this would have a favorable effect on crop yields in most of the country. It also notices that water stress is a major problem in Peru and that most studies indicate that climate change would either alleviate some of the stress or at least maintain the status quo. Finally, the studies reviewed indicate that problems of flooding could become worse with climate change and that a sea level rise of 1 meter would affect 47 percent of the coastal population in Peru and 46 percent of coastal GDP.

In this section we will analyze first the effects of higher international prices of agricultural commodities due to climate change and then the effect of climate change–induced local yield changes. For both channels of impacts, it is important to understand the structure of the Peruvian agricultural sector, which is summarized in Table 5.1. In general, the agricultural sector contributes only 7.8 percent of the country’s GDP. Within the agricultural sector, it is vegetables and fruits that contribute most to both agricultural GDP and agricultural exports. Coffee and other cash crops also have high export shares. In contrast, the import dependency is relatively high for other cereals (including wheat), cotton, and maize.

Table 5.1 Agricultural value added by region and agricultural commodity, Peru, 2008

Agricultural goods	COAST		INLAND		All regions					
	Billions of nuevos soles	%	Billions of nuevos soles	%	Billions of nuevos soles	%	EXPshr	EXP-OUTshr	IMPshr	IMP-DEMshr
Maize	0.22	4.97	0.59	6.17	0.81	5.79	0.04	1.41	1.08	19.47
Other cereals	0.30	6.70	0.51	5.30	0.81	5.75			2.47	38.30
Potatoes	0.12	2.75	1.07	11.24	1.20	8.54				
Root crops	0.04	0.82	0.35	3.62	0.38	2.73				
Fruits	0.42	9.38	1.46	15.24	1.87	13.38	0.83	7.81	0.23	3.31
Vegetables	1.19	26.75	1.99	20.83	3.18	22.71	1.53	9.39	0.17	1.62
Cotton	0.08	1.90	0.04	0.39	0.12	0.87			0.44	35.94
Coffee	0.04	0.90	0.40	4.18	0.44	3.14	0.75	28.20		
Sugarcane	0.45	10.21	0.46	4.78	0.91	6.50	0.20	3.03	0.53	7.96
Other cash crops	0.32	7.07	0.67	7.01	0.99	7.03	0.56	14.76	0.25	4.28
Cattle	0.13	2.94	0.84	8.81	0.97	6.95				
Poultry	0.37	8.21	0.22	2.26	0.58	4.15				
Other livestock	0.03	0.67	0.24	2.48	0.27	1.91				
Forestry	0.02	0.48	0.22	2.25	0.24	1.69				
Fishing	0.72	16.25	0.52	5.43	1.24	8.87	1.53	25.54	0.19	2.62
Total	4.46	100.00	9.56	100.00	14.01	100.00	5.44	6.90	5.36	7.23
%	31.79		68.21		100.00					

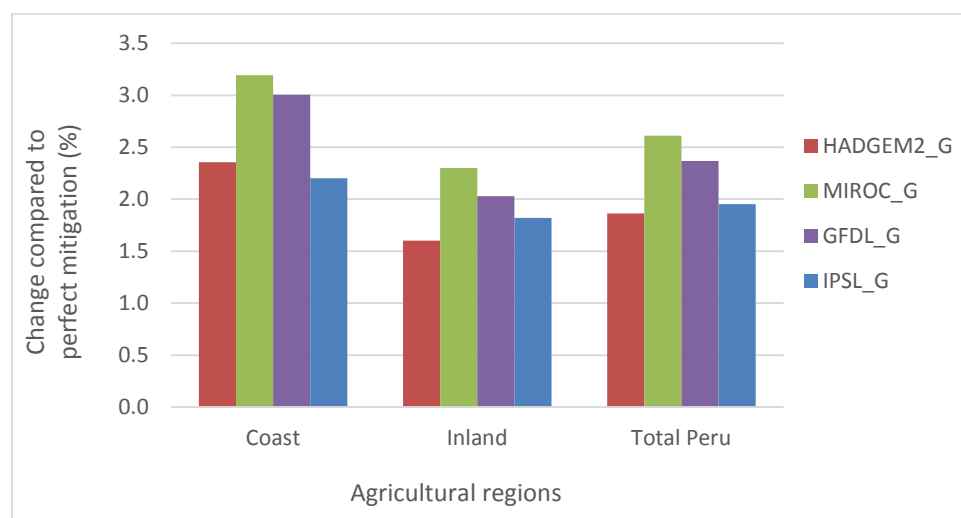
Source: Social accounting matrix for Peru (2014).

Notes: EXPshr = Commodity share of total export revenues; EXP-OUTshr = Share of exports in commodity demand; IMPshr = Commodity share of total import expenditures; IMP-DEMshr = Share of imports in commodity supply; GDP = gross domestic product. Goods with EXP-OUTshr or IMP-DEMshr of less than 1 percent are treated as nonexport or nonimport goods. Values in red are directly affected by world market price changes. Values highlighted in gray are directly affected by yield changes. Total GDP at factor cost = 179.6 billions of nuevos soles. Agriculture's share of GDP = 7.8%.

Impacts of Global Agricultural Commodity Price Changes on the Peruvian Economy and Households

As shown in Figure 2.5, world prices for many agricultural commodities are projected to increase due to climate change. These price increases will have both positive and negative effects on the Peruvian economy. In all climate scenarios, and in both the coastal and inland regions, the NPV of agricultural GDP would increase by around 2 percent due to the increase in global prices (Figure 5.1).

Figure 5.1 Impacts of global agricultural price changes on the net present value of agricultural gross domestic product in Peru, by region



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

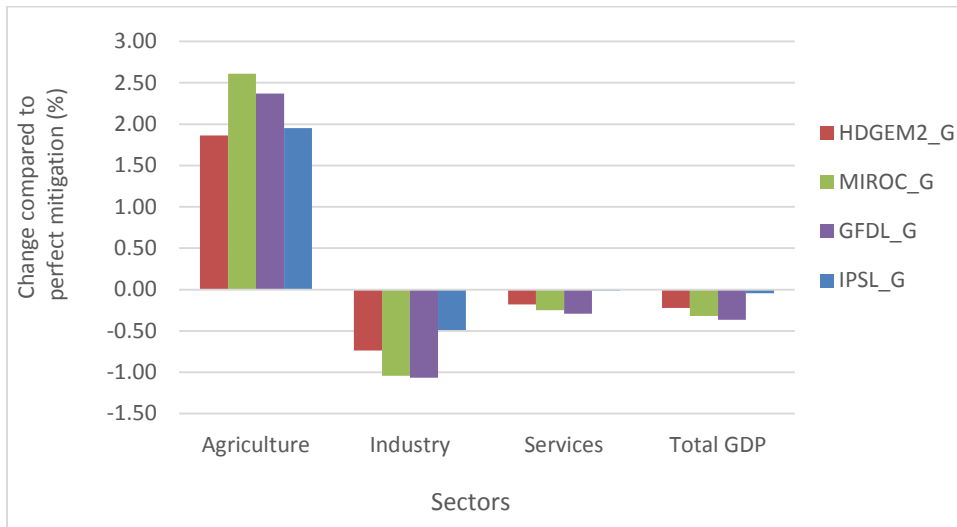
Note: _G = Global scenario.

Impacts on agricultural GDP vary by region depending on the region's production structure. In general, regions that produce more of the commodities that experience the largest world market price increases relative to other commodities (Figure 2.6) would benefit the most. Producers in the coastal area benefit particularly from rising prices for vegetables, sugarcane, and cotton and thus benefit slightly more than inland farmers in percentage terms. In absolute terms, however, inland farmers clearly benefit most given that two-thirds of agricultural value-added is produced in this region (Table 5.1).

A crop-by-crop analysis shows that the rise in agricultural GDP in Peru due to global price changes is driven by export expansion of coffee, fruits, vegetables, and other cash crops and import substitution of cotton, sugarcane, and cereals, while potatoes and root crops, livestock, and forestry reduce their production. Thus, cereals and export crop producers, landowners, and suppliers of unskilled labor used intensively in these sectors would be the main beneficiaries of global price increases, while capital owners and suppliers of skilled and semiskilled labor would realize income losses due to global price increases.

As in Brazil, the advantage for the agricultural sector turns into a disadvantage for the other sectors since the other sectors, especially the industrial sector, use agricultural inputs and will suffer from cost pressure. Since the nonagricultural sectors are about ten times larger than the agricultural sector in Peru, the modest reductions in GDP in the nonagricultural sectors outweigh the larger improvements in the agricultural sector, leading to an overall decrease in GDP due to global price changes of between 0.09 and 0.24 percent (Figure 5.2).

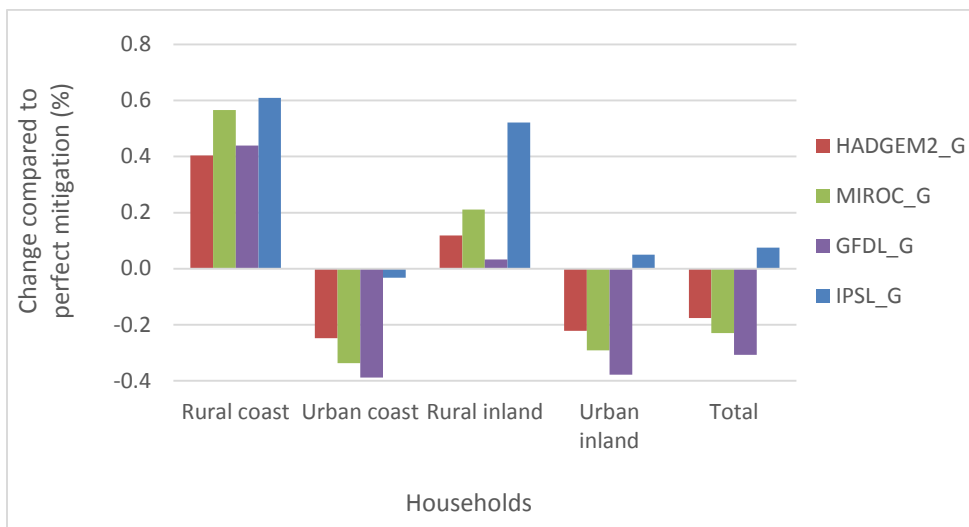
Figure 5.2 Impacts of global agricultural price changes on the net present value of sectoral gross domestic product in Peru, by sector



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).
 Note: GDP = gross domestic product; _G = Global scenario.

The positive effect on agricultural GDP and the negative effect on nonagricultural GDP, together with increasing consumer prices, translate into an increase in welfare for rural households of 0.12–0.54 percent and a decrease for urban households of 0.01–0.39 percent (Figure 5.3). Consistent with changes in agricultural output, the effect on rural household welfare is less pronounced under the HADGEM2 and GFDL scenarios than under the MIROC and IPSL scenarios. Welfare of urban households is reduced by increasing world food prices in all climate scenarios.

Figure 5.3 Impacts of global agricultural price changes on the welfare of Peruvian households, by location

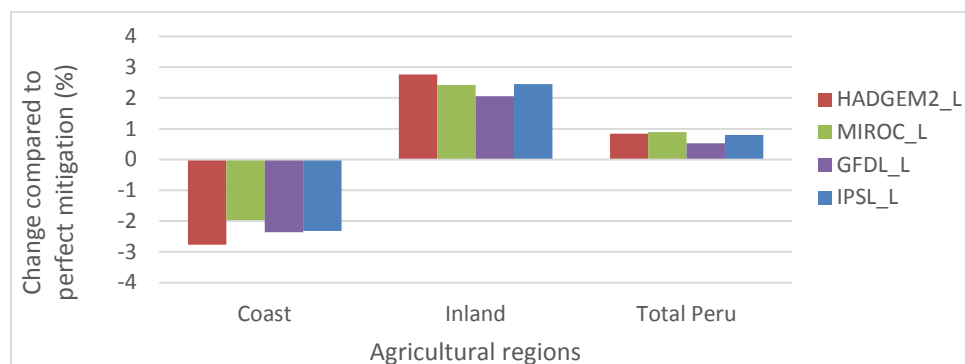


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).
 Note: _G = Global scenario.

Impacts of Local Crop Yield Changes on the Peruvian Economy and Households

As explained previously, climate change is expected to adversely affect the yields of most crops, but potatoes in Peru are a notable exception (Table 2.3). Potatoes are grown mainly in the Highlands of Peru, so these yield improvements would cause inland agricultural GDP to increase by 2.1–2.8 percent according to our simulations. In contrast, the deterioration of yields for the crops grown in the coastal regions would cause agricultural GDP in the coastal region to decrease by a slightly higher magnitude. The total effect for agricultural GDP in all of Peru is a slight increase of 0.5–0.9 percent (Figure 5.4).

Figure 5.4 Impacts of local yield changes on agricultural gross domestic product in Peru, by region

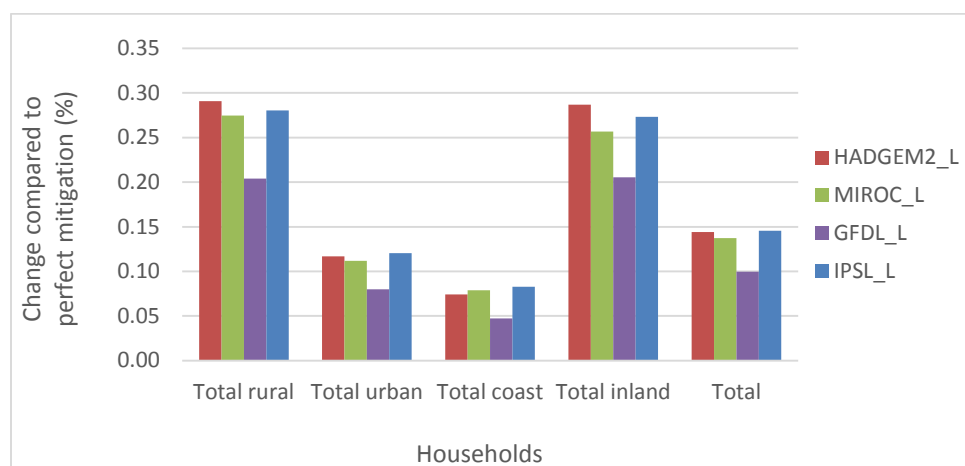


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: _L = Local scenario.

Rural households evidently benefit from the increase in crop yields and agricultural GDP. But urban households also benefit (Figure 5.5). This is because the increase in yields of nontraded agricultural goods, like potatoes and root crops, causes an increase in production, which causes a drop in local agricultural prices, which benefits urban consumers. On the other hand, reductions of yields and domestic production of internationally traded agricultural goods, like cereals, fruits, and vegetables, do not lead to dramatically increasing domestic prices because import competition provides an upper bound on domestic price changes. Thus, on average, all Peruvian households benefit from the changes in yields brought about by local climate change, but the effect is very small, amounting to only about 0.1 percent on average over all climate scenarios during the 40-year simulation period.

Figure 5.5 Impacts of local yield changes on household welfare in Peru



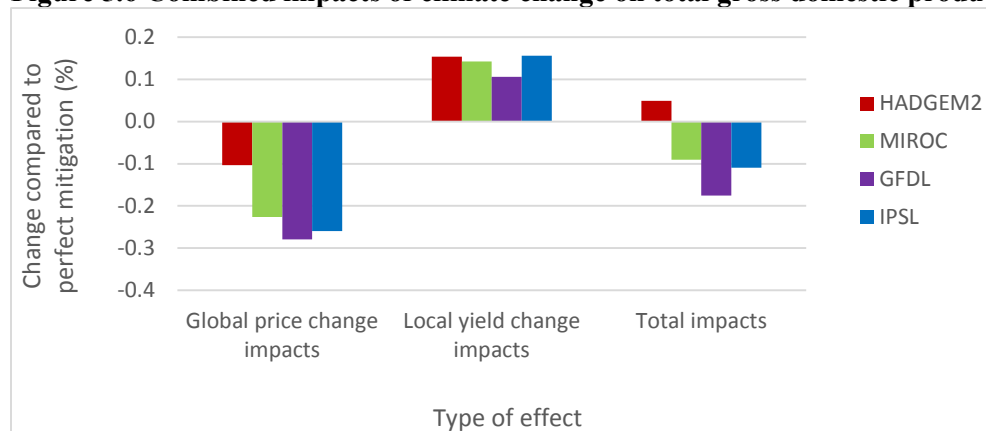
Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: _L = Local scenario.

Combined Impacts of Global and Local Climate Change on the Peruvian Economy

The combined impacts of global price changes and local yield changes sums up to a small negative impact on the Peruvian economy in three out of four climate scenarios (Figure 5.6).

Figure 5.6 Combined impacts of climate change on total gross domestic product in Peru

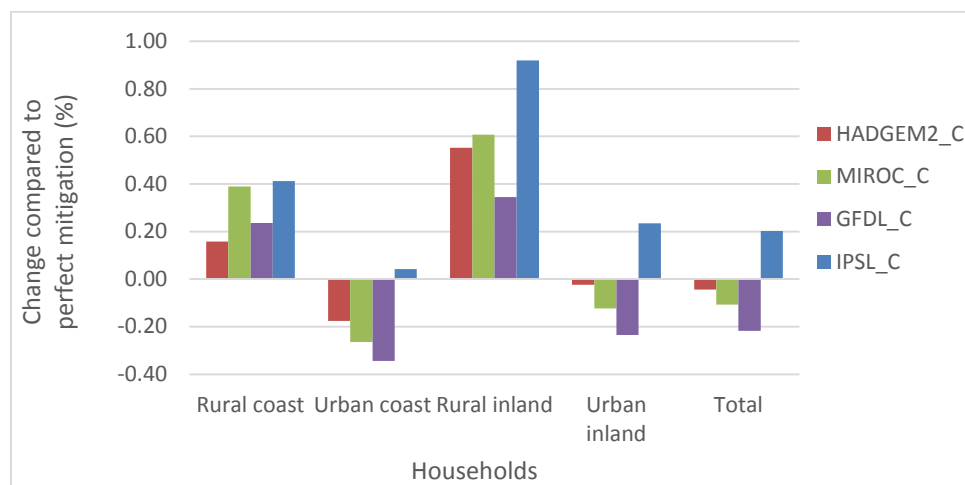


Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

The average effect is on the order of -0.10 percent of GDP during the 40-year period analyzed, but obviously the impacts are smaller in the beginning of the simulation period and larger by the end.

The combined effect on household welfare is positive for rural households (about 0.5 percent on average during the whole period) but practically zero for urban households and for all households in Peru (Figure 5.7).

Figure 5.7 Combined impacts of climate change on household welfare in Peru, by household type



Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: _C = Combined scenario.

Vulnerability and Gender Differences in Peru

At only 19 percent, Peru has the lowest female headship rate of the three countries analyzed. This rate is even lower in rural Peru at only 14 percent (Table 5.2).

Table 5.2 Peru: Distribution of households by gender and location (percentage of all households)

Type of household	Peru, 2008		
	Rural	Urban	Total
Male headed	40.2	40.7	80.9
Female headed	6.8	12.3	19.1
Total	47.0	53.0	100.0

Source: Authors' elaboration based on national household survey data (2014).

In both rural and urban areas, female-headed households have lower per capita income levels than male-headed households. The difference is 14 percent in rural areas and 7 percent in urban areas. Nevertheless, due to the higher share of female-headed households in urban areas, combined with the much higher incomes in urban areas, female- and male-headed households on average end up with practically the same levels of income (Table 5.3).

Table 5.3 Peru: Per capita household income, by household type (nuevos soles per month per person)

Type of household	Peru, 2008		
	Rural	Urban	Total
Male headed	330	820	567
Female headed	285	764	568
Total	322	805	568

Source: Authors' elaboration based on national household survey data (2014).

While female-headed households tend to have lower incomes, these tend to be more diversified, although this is due to urban differences only (Table 5.4).

Table 5.4 Peru: Household Income Diversification Index, by household type

Type of household	Peru, 2008		
	Rural	Urban	Total
Male headed	0.462	0.418	0.441
Female headed	0.459	0.477	0.470
Total	0.461	0.433	0.447

Source: Authors' elaboration based on national household survey data (2014).

Combining the results on income levels and diversification levels, we find that female-headed households in urban areas are the least vulnerable and female-headed households in rural areas are the most vulnerable (Table 5.5).

Table 5.5 Peru: Probability of being highly vulnerable, by household type (percentage)

Type of household	Peru, 2008		
	Rural	Urban	Total
Male headed	25.48	11.82	18.86
Female headed	26.24	8.64	15.82
Total	25.62	11.00	18.18

Source: Authors' elaboration based on national household survey data (2014).

In both rural and urban areas, female-headed households are more likely to be highly resilient than male-headed households, with the difference being particularly large in urban areas (Table 5.6).

Table 5.6 Peru: Probability of being highly resilient, by household type (percentage)

Type of household	Peru, 2008		
	Rural	Urban	Total
Male headed	26.7	41.8	34.0
Female headed	27.5	50.6	41.2
Total	26.9	44.1	35.6

Source: Authors' elaboration based on national household survey data (2014).

The finding that female-headed households in general are less vulnerable and more resilient than male-headed households means that they should better be able to absorb the adverse shocks of climate change. However, the climate change shocks that are foreseen by the modeling suite applied in this paper are relatively small, so this resilience will probably be of more use against all other types of shocks that might happen, including extreme climate events, accidents, unemployment, health problems, divorce, economic crises, conflict, and pests).

6. CONCLUSIONS AND PROPOSED ACTIONS FOR ADAPTATION

This report has analyzed the impacts of climate change in Brazil, Mexico, and Peru, focusing on three specific types of impacts: (1) the direct impacts from increased world prices of agricultural products due to global climate change, (2) the direct impacts of local yield changes due to local changes in temperatures and precipitation, and (3) the indirect impacts following from these two direct impacts as the economies adjust to the direct impacts.

Four climate scenarios were used to illustrate the variability of results. All of them were run with the most extreme RCPs used in IPCC's Fifth Assessment Report (+8.5 watts per square meter by 2100), so they all represent the high end of likely impacts. In addition, all the simulations ignore the potentially positive impacts of carbon dioxide fertilization on crop yields, which has been shown in other studies to potentially change substantial negative yield impacts to slightly positive yield impacts (for example, Ludena and Mejia 2012). But this has yet to be sufficiently well represented in crop models. However, with time, given current and potential future emissions levels, the chosen scenarios might well represent a likely future. Moreover, as climate change scenarios do not adequately reflect growing climate variability and our main focus is the impacts on agriculture, our results most likely underestimate a true worst-case climate change scenario. All other caveats relating to economy, climate, and crop projections out to 2050 apply.

Despite this, we find quite modest effects of climate change through these three channels. In general, the large increases in the global prices of agricultural products caused by climate change tend to benefit agricultural producers but harm the rest of the economy. Since the agricultural sectors make up less than 10 percent of total GDP in all three countries analyzed, the negative effect on the rest of the economy tends to dominate the positive effects on the agricultural sector. In contrast, negative crop yield changes due to climate change tend to harm both agricultural producers and agricultural consumers. However, other productive sectors might benefit slightly as the lower profitability of agriculture means that productive factors, such as labor and capital, instead shift toward industry and services. In total, the combined impacts estimated amount to less than 1 percent of household incomes during the next 40 years.

The report also made an effort to assess differences in climate change impacts by gender. However, as the results from the computable general equilibrium analysis were small for either gender, we decided to apply a supplementary analysis of vulnerability by the gender of the head of households. In the three countries analyzed, the female headship ratio was significantly lower in rural areas compared to urban areas. In addition, we found that female-headed households tended to have slightly higher per capita incomes and substantially higher levels of income diversification than male-headed households in the three countries, implying that they would be less vulnerable to any type of shock, climatic or otherwise, than male-headed households.²²

Apart from these general tendencies, there are some country-specific effects that are worth mentioning:

First, although agriculture's contribution to overall GDP is low in all three countries—ranging from 3.1 percent in Mexico to more than 5.5 percent in Brazil to 7.8 percent in Peru—trade orientation varies considerably across the three countries, with Brazil being a large net exporter of agricultural commodities and Mexico a large net importer, while Peru's agricultural export and import intensities are quite similar. As a result, the immediate impact of climate change—improving agricultural terms of trade and lower yields—is almost exclusively felt on the supply side in Brazil, changing factor income, absorption, and household welfare, while it is not much felt in Mexico and Peru, where positive supply-side effects are compensated for by negative demand-side effects. Second, with Brazil's relatively strong insulation from world markets, higher costs for agricultural commodities lead to cost push in processing sectors. Third, the accelerated specialization in land-intensive production and export of soybeans, coffee,

²² These findings come directly from the input data and are thus not the result of any model assumptions. It is important to note that this household-level analysis may ignore important intrahousehold gender differences concerning the impacts of climate change.

and maize resulting from high world market prices may—if there are no safeguard mechanisms in place—result in accelerated deforestation. Fourth, on the positive side, since these sectors heavily use unskilled labor, the expansion of soybeans, coffee, and maize production will contribute to a slight reduction in poverty in Brazil.

Given the relatively small impacts of climate change estimated through these channels and a certain degree of uncertainty associated with them, many kinds of policies should be able to counter the adverse effects. These policies include investments in education, technology, and public infrastructure, particularly infrastructure to support efficient agricultural trade and supply chains. These are no-regrets policies that should be pursued in any case. As for gender and climate change, linking gender and climate change should go beyond demonstrating the vulnerability of women and men and their need for focused and tailor-made capacity development. Climate change policy should seek to integrate women's concerns but without insulating such issues from the wider discourses about the overall environmental constraints faced by everyone (Denton 2009). In fact, results from this study suggest that women may be less vulnerable than men, and it will be important to look at women as a source for solutions for improving resilience, also for male-headed households.

APPENDIX: SUPPLEMENTARY TABLES

Table A.1 Mathematical presentation of the dynamic computable general equilibrium mode: Core model equations

Type of equation	Equation	Number
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	$s_{ft} = s_{t-1} \cdot (1 + \varphi_f)$	(11)
Capital accumulation	$s_{ft} = s_{t-1} \cdot (1 - \eta) + \sum_c \frac{P_{ct-1} \cdot I_{ct-1}}{k}$	(12)
Technical change	$\alpha_{ct} = \alpha_{ct-1} \cdot (1 + y_c)$	(13)

Note:

Subscripts

c Commodities or economic sectors

f Factor groups (land, labor, and capital)

h Household groups

t Time periods

Endogenous variables

D Household consumption demand quantity

E Exchange (local/foreign currency units)

F Factor demand quantity

I Investment demand quantity

M Import supply quantity

P Commodity price

Q Output quantity

W Average factor return

X Export demand quantity

Y Total household income

Exogenous variables

b Foreign savings balance (foreign currency units)

r Foreign remittances

s Total factor supply

w World import and export prices

Exogenous parameters

α Production shift parameter (factor productivity)

β Household average budget share

γ Hicks neutral rate of technical change

δ Factor input share parameter

η Capital depreciation rate

θ Household share of factor income

κ Base price per unit of capital stock

ρ Investment commodity expenditure share

u Household marginal propensity to save

φ Land and labor supply growth rate

Source: Authors' compilation.

Table A.2 Brazil: Economic structure in the base year (2008) (percent)

Sectors/Commodities	Value-		Labor value-		Export share	Export intensity	Import share	Import intensity
	added share	Production share	added share	Consumption share				
Maize	0.5	0.4	0.4	0.1	0.6	10.4	0.1	1.5
Wheat	0.1	0.1	0.1	0.0	0.1	10.2	1.0	60.2
Rice	0.2	0.1	0.1	0.0				
Soybeans	0.9	0.7	0.7	0.0	3.9	38.4		
Cassava	0.1	0.1	0.1	0.1				
Tobacco	0.1	0.1	0.1	0.0	0.0	1.6		
Citrus Fruits	0.1	0.1	0.1	0.1	0.0	1.9		
Cotton	0.1	0.1	0.1	0.0				
Coffee	0.2	0.2	0.2	0.0	1.7	63.7		
Sugarcane	0.4	0.3	0.3	0.0				
Other crops	0.9	0.7	0.7	1.8	0.4	3.6	0.5	5.8
Live cattle	0.7	0.7	0.6	0.0	0.2	2.2		
Poultry	0.3	0.3	0.2	0.1				
Live milk cattle	0.4	0.3	0.3	0.3				
Pigs	0.1	0.1	0.1	0.0				
Eggs	0.1	0.1	0.1	0.2	0.0	1.7		
Forestry	0.3	0.2	0.2	0.1	0.1	1.6	0.3	11.1
Fishery	0.1	0.1	0.1	0.1	0.0	1.1	0.1	6.1
Mining	3.2	3.2	1.2	0.0	14.4	33.5	11.5	31.3
Food processing	2.6	6.9	2.9	11.9	13.3	14.3	2.2	3.2
Textiles	0.2	0.3	0.3	0.0	0.5	11.6	0.7	19.4
Other clothes	2.2	2.6	2.6	4.7	3.5	9.9	1.5	5.9
Wood	0.3	0.4	0.3	0.0	1.1	19.8	0.1	2.1
Paper	0.4	0.7	0.4	0.5	0.8	7.8	0.7	8.5
Fuel	0.8	3.5	0.5	3.0	4.7	10.1	6.2	14.4
Chemicals	1.9	4.0	1.6	4.1	4.1	7.4	15.7	26.9
Non metallic minerals	0.6	0.9	0.7	0.1	0.8	6.5	0.6	6.0
Metals	2.5	4.0	1.9	0.2	9.8	18.0	5.6	13.1
Machinery	3.9	8.7	4.7	7.3	17.8	15.2	32.2	28.1
Other manufacturing	1.4	2.2	1.5	3.1	2.7	9.1	3.2	12.8
Construction	4.9	4.6	4.8	0.0				
Electricity, gas, and sewerage	3.2	3.2	1.4	3.6			0.7	1.8
Trade	12.5	8.6	13.5	9.9	6.7	5.7		
Hotels and meals	1.8	2.0	2.0	5.4	2.7	10.2	3.6	14.6
Transports	5.1	5.1	5.9	6.0	2.9	4.2	2.1	3.5
Other services	32.0	23.5	26.5	37.3	7.2	2.3	11.4	4.0
Public services	14.8	10.7	23.0	0.0				
Total	100.0	100.0	100.0	100.0	100.0	7.4	100.0	8.6
Total agriculture	5.5	4.9	4.4	2.8	6.9	10.4	1.9	3.6
Total non-agriculture	94.5	95.1	95.6	97.2	93.1	7.2	98.1	8.9

Source: Authors' compilation based on the Brazilian social accounting matrix (2014).

Table A.3 Mexico: Economic structure in the base year (2008) (percent)

Sectors/Commodities	Value-	Labor value-			Export share	Export intensity	Import share	Import intensity
	added share	Production share	added share	Consumption share				
Maize	0.5	0.4	0.4	0.2	0.1	5.2	1.5	41.7
Wheat	0.1	0.1	0.1	0.0	0.0	5.0	0.3	41.9
Sorghum	0.1	0.1	0.1	0.0	0.0	5.0	0.4	41.8
Beans	0.1	0.1	0.1	0.0	0.0	5.7	0.2	42.2
Tomato	0.1	0.1	0.1	0.1	0.2	55.9	0.0	11.6
Avocado	0.1	0.1	0.1	0.1	0.2	55.6	0.0	11.7
Chili	0.1	0.1	0.0	0.1	0.2	56.0	0.0	11.8
Potato	0.1	0.0	0.0	0.0	0.1	55.9	0.0	11.7
Banana	0.0	0.0	0.0	0.1	0.1	31.0	0.1	44.1
Nuts	0.0	0.0	0.0	0.1	0.1	31.4	0.1	44.2
Apples	0.0	0.0	0.0	0.1	0.0	31.4	0.1	44.4
Sugarcane	0.1	0.1	0.1	0.0	0.0	2.3	0.0	4.4
Pastures	0.1	0.1	0.1	0.0	0.0	2.3	0.0	4.4
Alfalfa	0.1	0.1	0.1	0.0	0.0	2.2	0.0	4.4
Other agriculture	0.6	0.5	0.5	0.4	0.9	27.4	0.3	13.7
Cattle	0.4	0.5	0.3	0.0	0.1	3.0	0.1	1.9
Poultry	0.3	0.4	0.2	0.3				
Other livestock	0.2	0.2	0.2	0.2	0.0	2.2	0.0	3.3
Forestry, timber, fishing, hunting	0.2	0.2	0.1	0.1	0.1	5.5	0.0	2.9
Hydrocarbons	7.5	4.6	4.4	0.0	13.5	45.5		
Mining	1.4	1.3	1.3	0.0	1.1	13.3	0.9	11.4
Electricity, water, and gas	2.1	2.3	1.8	2.0	0.2	1.5		
Construction	8.9	9.3	11.1	0.0				
Food processing	4.6	6.8	3.6	15.2	2.6	6.0	4.5	10.9
Textiles and leather products	0.9	1.3	0.9	2.0	2.5	30.9	3.1	38.0
Paper and wood	0.6	1.1	0.6	0.6	0.7	10.2	2.9	33.7
Chemicals and oil refinery	4.2	9.7	3.6	8.9	7.3	11.7	23.3	31.9
Metalic products, machinery, equipment	6.3	14.5	6.0	7.1	59.7	64.5	60.7	67.1
Commerce, transport, and storage	21.2	17.2	18.9	24.4	9.5	8.7		
Communication	2.7	2.4	2.4	4.0				
Financial services	3.2	2.9	3.2	4.6	0.7	4.0	0.9	5.5
Renting of dwellings	12.4	7.8	7.0	16.7				
Services to firms	6.4	4.6	8.2	1.0			0.5	1.7
Education	4.0	2.6	7.9	1.6				
Health services	2.1	1.8	3.6	1.6				
Communal and social services	0.5	0.4	0.4	0.9				
Restaurants and hotels	2.3	1.9	2.1	4.3				
Other private services	2.1	1.7	2.5	3.5			0.1	0.6
Public services	3.8	3.2	8.2	0.0				
Total	100.0	100.0	100.0	100.0	100.0	15.6	100.0	17.0
Total agriculture	3.1	2.8	2.5	1.7	2.2	11.9	3.2	18.2
Total non-agriculture	96.9	97.2	97.5	98.3	97.8	15.8	96.8	17.0

Source: Authors' compilation based on the Mexican social accounting matrix (2014).

Table A.4 Peru: Economic structure in the base year (2002) (percent)

Sectors/Commodities	Value-		Labor value-		Export share	Export intensity	Import share	Import intensity
	added share	Production share	added share	Consumption share				
Maize	0.5	0.3	0.4	1.0	0.0	1.4	1.1	19.5
Other cereals	0.5	0.3	0.4	0.7			2.5	38.3
Potatoes	0.7	0.6	0.3	1.5				
Root crops	0.2	0.2	0.1	0.5				
Fruits	1.1	0.8	0.6	2.0	0.8	7.8	0.2	3.3
Vegetables	1.8	1.3	1.1	3.1	1.5	9.4	0.2	1.6
Cotton	0.1	0.1	0.0	0.0			0.4	35.9
Coffee	0.3	0.2	0.1	0.1	0.8	28.2		
Sugarcane	0.5	0.7	0.6	0.9	0.2	3.0	0.5	8.0
Other cash crops	0.6	0.4	0.3	1.0	0.6	14.8	0.3	4.3
Cattle	0.6	0.6	0.5	0.7				
Poultry	0.3	0.4	0.3	0.7				
Other livestock	0.2	0.3	0.1	0.3				
Forestry	0.1	0.1	0.1	0.3				
Fisheries	0.7	0.6	0.7	1.3	1.5	25.5	0.2	2.6
Mining	4.7	4.6	2.9	0.0	32.7	69.9	4.6	27.3
Food processing	5.7	8.8	5.8	17.1	12.0	14.3	5.0	6.4
Textiles	0.9	1.7	1.4	0.4	1.6	9.6	2.0	13.4
Clothing	1.3	1.8	1.7	2.8	5.9	35.2	1.6	11.5
Wood products	0.4	0.8	0.6	1.6	1.1	12.7	0.3	3.1
Paper products	1.0	1.4	0.6	1.4	0.7	4.8	2.9	19.4
Chemicals	2.9	4.3	1.9	8.2	6.1	14.9	18.3	33.5
Non-metallic minerals	1.3	1.7	1.4	0.4	0.5	2.8	1.1	7.2
Ferrous metals	0.4	0.6	0.3	0.0	0.6	10.2	4.8	49.9
Non-ferrous metals	0.6	2.2	0.4	0.0	15.3	67.3	0.6	8.1
Metal products	0.6	0.8	0.4	0.0	0.0	0.6	0.8	10.4
Machinery and equipment	0.9	1.6	0.7	3.8	1.0	7.0	26.5	64.8
Other manufacturing	0.1	0.2	0.1	0.1	0.3	20.7	1.9	44.8
Construction	7.4	8.3	11.2	0.5				
Water and electricity	2.1	1.6	1.6	1.5				
Retail and wholesale trade	17.5	13.4	19.4	0.0	4.5	3.5		
Hotels and catering	4.4	4.6	4.5	9.8	3.9	8.8	3.8	9.1
Transport and communication	8.4	9.1	7.8	10.2	6.5	7.4	9.1	10.7
Business services	14.8	12.2	9.9	5.9	1.4	1.2	9.2	7.8
Other private services	10.6	9.0	8.4	22.3	0.5	0.6	2.3	2.7
Government services	6.1	4.7	13.1	0.0				
Total	100.0	100.0	100.0	100.0	100.0	10.0	100.0	10.9
Total agriculture	7.9	6.8	5.7	14.1	5.4	6.9	5.4	7.2
Total non-agriculture	92.1	93.2	94.3	85.9	94.6	10.2	94.6	11.3

Source: Authors' compilation based on the Peruvian social accounting matrix (2014).

Table A.5 Brazil: Overview results

Climate change scenarios	Accumulated absolute gains (+) and losses (-) (billions of constant 2009 US dollars)	As percentage of accumulated NoCC values	As percentage of base year values
Gross Domestic Product (GDP)			
HADGEM2_C	-550.6	-0.4	-32.3
MIROC_C	-440.0	-0.3	-25.8
GFDL_C	-272.7	-0.2	-16.0
IPSL_C	-519.9	-0.3	-30.5
Agriculture GDP			
HADGEM2_C	-106.4	-1.7	-138.1
MIROC_C	41.9	0.7	54.3
GFDL_C	17.5	0.3	22.7
IPSL_C	33.6	0.5	43.6
Households' welfare			
HADGEM2_C	-304.0	-0.3	-28.8
MIROC_C	-71.3	-0.1	-6.8
GFDL_C	-45.4	-0.1	-4.3
IPSL_C	-106.3	-0.1	-10.1

Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: NoCC = no climate change (or perfect mitigation); _C = Combined scenario.

Table A.6 Mexico: Overview results

Climate change scenarios	Accumulated absolute gains (+) and losses (-) (billions of constant 2009 US dollars)	As percentage of accumulated NoCC values	As percentage of base year values
Gross Domestic Product (GDP)			
HADGEM2_C	-113.4	-0.1	-10.0
MIROC_C	-139.8	-0.1	-12.3
GFDL_C	-91.0	-0.1	-8.0
IPSL_C	-194.7	-0.2	-17.2
Agriculture GDP			
HADGEM2_C	-49.1	-2.0	-147.2
MIROC_C	9.1	0.4	27.2
GFDL_C	4.3	0.2	13.0
IPSL_C	-40.4	-1.6	-121.1
Households' welfare			
HADGEM2_C	-89.6	-0.1	-11.8
MIROC_C	-89.6	-0.1	-11.8
GFDL_C	-60.8	-0.1	-8.0
IPSL_C	-141.2	-0.2	-18.6

Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: NoCC = no climate change (or perfect mitigation); _C = Combined scenario.

Table A.7 Peru: Overview results

Climate change scenarios	Accumulated absolute gains (+) and losses (-) (billions of constant 2009 US dollars)	As percentage of accumulated NoCC values	As percentage of base year values
Gross Domestic Product (GDP)			
HADGEM2_C	-16.4	-0.1	-22.5
MIROC_C	-32.2	-0.3	-44.3
GFDL_C	-43.3	-0.4	-59.6
IPSL_C	11.0	0.1	15.1
Agriculture GDP			
HADGEM2_C	16.7	2.7	329.7
MIROC_C	21.9	3.5	431.7
GFDL_C	18.0	2.9	354.7
IPSL_C	16.9	2.7	333.1
Households' welfare			
HADGEM2_C	-4.1	0.0	-7.8
MIROC_C	-9.5	-0.1	-18.2
GFDL_C	-18.8	-0.2	-36.1
IPSL_C	16.7	0.2	32.1

Source: Authors' elaboration based on dynamic computable general equilibrium simulation results (2014).

Note: NoCC = no climate change (or perfect mitigation); _C = Combined scenario.

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