IDB WORKING PAPER SERIES Nº IDB-WP-01289

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Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library
Climate change impacts on agriculture in Latin America and the Caribbean: an application of the Integrated Economic-Environmental Modeling (IEEM) Platform / Onil Banerjee, Martín Cicowiez, Ana R. Rios, Cicero Z. de Lima.
p. cm. — (IDB Working Paper Series ; 1289)
Includes bibliographic references.
1. Agriculture-Environmental aspects-Latin America. 2. Climatic changes-Latin America. 3. Crops and climate-Latin America. 4. Environmental economics-Latin America.
I. Banerjee, Onil. II. Cicowiez, Martín. III. Rios, Ana R. IV. Lima, Cicero Z. de. V. Inter-American Development Bank. Environment, Rural
Development and Risk Management Division. VII. Series.
IDB-WP-1289

JEL Codes: C68 Computable General Equilibrium Models; J2 Demand and Supply of Labor; Q1 Agriculture; Q5 Environmental Economics.

Keywords: Integrated Economic-Environmental Modeling (IEEM) Platform; dynamic computable general equilibrium (CGE) model; climate change; agriculture; greenhouse gas emissions.

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Climate Change Impacts on Agriculture in Latin America and the Caribbean: An Application of the Integrated Economic-Environmental Modeling (IEEM) Platform

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Abstract

In this paper, we assess the economy-wide impact of Climate Change (CC) on agriculture and food security in 20 Latin American and the Caribbean (LAC) countries. Specifically, we focus on the following three channels through which CC may affect agricultural and non-agricultural production: (i) agricultural yields; (ii) labor productivity in agriculture, and; (iii) economy-wide labor productivity. We implement the analysis using the Integrated Economic-Environmental Model (IEEM) and databases for 20 LAC available through the OPEN IEEM Platform. Our analysis identifies those countries most affected according to key indicators including Gross Domestic Product (GDP), international commerce, sectoral output, poverty, and emissions. Most countries experience negative impacts on GDP, except for the major soybean producing countries, namely, Brazil, Argentina and Uruguay. We find that CC-induced crop productivity and labor productivity changes affect countries differently. The combined impact, however, indicates that Belize, Nicaragua, Guatemala and Paraguay would fare the worst. Early identification of these hardest hit countries can enable policy makers pre-empting these effects and beginning the design of adaptation strategies early on. In terms of greenhouse gas emissions, only Argentina, Chile and Uruguay would experience small increases in emissions.

1. Introduction

In this paper, we assess the economy-wide impact of Climate Change (CC) on agriculture and food security in 20 Latin American and the Caribbean countries. Specifically, we focus on how CC may impact agricultural and non-agricultural production through changes in agricultural yields, changes in agricultural labor productivity, and changes in cross-sector labor productivity. To do so, we use the Integrated Economic-Environmental Model (IEEM) and databases for the 20 Latin American and Caribbean countries available through the OPEN IEEM Platform. We focus on five crops – maize, soybean, rice, beans, and wheat – which are the most important crops for the LAC region in terms of food security, volume of production and economic value. Based on future climate modeling undertaken in Gourdji et al. (2015) and a comprehensive set of climate impacts on yield estimated in Schiek and Prager (2020), these estimated impacts are implemented in the IEEM framework to understand how the physical and biophysical impacts of CC could affect key economic, social and environmental indicators including Gross Domestic Product, sectoral output, employment and poverty, among other indicators. The section that follows provides a description of the LAC context. Section 2 describes the main channels through which climate change is affecting and is expected to impact food security and agriculture in the LAC region. Section 3 details our methods, an overview of the economic structure of the countries considered and scenario design. Section 4 presents results and analysis and section 5 concludes the paper with a summary of the main findings and policy implications.

1.2. Study Context

The Latin American and Caribbean (LAC) region is comprised of countries that differ greatly in economic and demographic profile and landscape, from the Bahamas and Mexico to Argentina and Chile, the region has a population of 646 million which is highly urbanized (81%). The current regional Gross Domestic Product (GDP) is estimated at US$ 5.719 trillion (2019) with a Gross National Income (GNI) per capita of US$ 8,775 (World Bank 2020). The LAC region is marked with high levels of inequality and despite some progress in the past decade, there have been setbacks since 2015 with the poverty rate reaching 30.1% of the total population (185 million) and extreme poverty reaching 10.7% (66 million) in 2018 (ECLAC 2019). Considering rural and urban areas, the poverty and extreme poverty rates are 1.76 and 2.36 higher in rural areas, thus the reduction of inequality in all its dimensions is one of the region's central challenges.

In 2020, the COVID-19 pandemic imposed unprecedented pressure on LAC's economic development, exacerbating both poverty, and equality. Global economic and social costs of the health crisis have emerged from labor shortages created by restrictions on movements of people, changes in agricultural input costs and food availability, as well loss of income. The LAC agriculture and food markets faced increased relative importance of food in household consumption especially in the poorest and most vulnerable countries in the region (Laborde et al. 2020). These restrictions are affecting the four pillars of food security: availability, access, utilization, and stability.

The international trade restrictions[1] imposed by some countries during this period coupled with the deterioration of many countries' fiscal condition may affect cash transfer programs and the ability to invest in agricultural R&D and food market. These restrictions amplify the importance of availability and stability in food supply- two pillars of global and regional food security. The sharp reduction in economic growth, an expected reduction of 9% in GDP in 2020, will push more 45.4 million people into poverty and 28.5 million to extreme poverty. This represents an increase of 6.9% compared with the previous year, affecting a total of 230.9 million people or 37.3% of the LAC population.

On the other hand, it is well known that CC is reshaping LAC on several fronts, such as agricultural production (Prager et al. 2020), migration (Woetzel et al. 2020), social and political conflicts (ECLAC 2019), biodiversity loss (Boit et al. 2016), deforestation (Prager et al. 2020), and labor productivity changes (Day et al. 2019), all of which are contributing to large economic, environmental and social costs. CC is resulting in both physical and biophysical impacts. The physical impacts include changes in precipitation regimes, increased heat stress and increased high-risk events, such as droughts, aridity and fire (Magrin et al. 2014). In many regions, there is uncertainty in the direction of these changes because of uncertain precipitation projections and differences in hydrological models. A consistent use of data, projection and scenario assumptions across sectoral and regional aspects is crucial to improve the assessment at regional and local scales in LAC (O'Neill et al. 2020). At the same time, biophysical impacts include changes in agricultural

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[1] Argentina, Brazil, Paraguay, Peru, Ecuador, Colombia, Costa Rica, El Salvador, Honduras, and Haiti have some active export/import restrictions on November, 2020 according to ITC Market Access Map, COVID-19 Temporary Trade Measures, www.macmap.org.

yields, livestock and fisheries production (Nelson et al. 2014), as well as the shifting of biomes and ecosystems, and changes in biodiversity (Boit et al. 2016).

There are many challenges for the LAC region in the short and long-run. The reduction of poverty and inequality are crucial to foster sustainable development. In the short term, the global health crisis accentuates these problems by delaying solutions and imposing new challenges, especially those related to food markets and food security. In the long run, all these challenges are exacerbated by CC. It is more critical than ever to improve our understanding of how all these drivers are reshaping the LAC region through the lens of sustainable development and its social, economic and environmental dimensions.

2. Climate Change and Food Security in the LAC Region

The biophysical impacts of climate change are defined by global and regional climate patterns. The climate change literature contains projected changes in temperature and precipitation as well as changes in the likelihood of extreme events such as heat stress, droughts, , as well as tropical cyclones - especially important for the LAC region given its extensive coastline and tropical and subtropical climate (Rosenzweig et al. 2014). From the point of view of agriculture yields, undoubtedly the interaction of climate change effects on temperature, precipitation and CO_2 concentration are the most relevant and determine new levels of agriculture productivity and adaptation in the region (Reyer et al. 2017). At the same time, the LAC region has the greatest potential to increase its cultivated area in the future through the expansion of agricultural intensification technologies, for example (Wu et al. 2018).

The interaction of changes in temperature, precipitation and CO_2 concentrations can lead to dramatic land-use changes in the region. Temperature-sensitive crops may be grown in new locations that previously were not possible (Challinor et al. 2014; Moore et al. 2017). Likewise, new temperature and precipitation regimes may reshape growing degree days (Anandhi 2016) as well as modify the phenology (e.g., growth, flowering and fruit ripening) for several crops (Sherry et al. 2011). Some of the biophysical impacts of climate change can be amplified or mitigated by the management responses of farmers.

The impacts of CC can be observed on both the supply and the demand side of the economy and can be mediated to some degree by international trade. On the demand side, CC can affect consumption patterns, caloric intake, regional or international purchases, as well as the timing of consumption since climate events can postpone or anticipate investments and consumption. On the supply side, production costs are likely to increase due to reduced crop yields, land availability, water scarcity (Fitton et al. 2019), and labor allocation across different activities given the level of exposure to climate effects (Kjellstrom et al. 2016; Heal and Park 2016). Furthermore, international supply chains can be affected since transportation and distribution are critical to maintaining the stability, availability and access of food at both regional and international levels.

The impacts of CC on economic and social outcomes have been the subject of increasing scrutiny and while our understanding of these impacts is increasing, uncertainty remains (Dell, Jones, and Olken 2014; Carleton and Hsiang 2016). Climate impacts in the agricultural sector have been studied particularly closely because of the sector's dependency on climatic stability and its importance in contributing to low-income livelihoods and food security (Rosenzweig et al. 2014; Reyer et al. 2017). Climate impacts on crop yields vary depending on crop type, production systems and the availability of certain technologies such as irrigation and climate-adapted crop varieties, and location. The location factor is particularly relevant for the LAC region given its territorial extent, diversity of ecosystems and microclimates, and soil formations which gives rise to the region's high aptitude for agriculture and the capacity to produce a wide variety of crops.

Recent research has assessed the impact of observed CC on the yields of the top ten globally important crops, namely barley, cassava, maize, oil palm, rapeseed, rice, sorghum, soybean, sugarcane and wheat at high spatial resolution. The results show generally positive impacts in LAC where in Brazil, Argentina, Paraguay and Cuba, consumable food calories increased overall, while declining in the Dominican Republic, Ecuador, Bolivia, Uruguay and Venezuela (Ray et al. 2019).

International trade interacts in important ways with the observed biophysical impacts of changing climates. For example, based on five crops (beans, maize, rice, soybean, and wheat) which are important for LAC economics and food security, Prager et al. (2020) showed that CC lowered the average growth in yields, total area under cultivation and output. These impacts caused trade deficits in several LAC regions, suggesting increased exposure to food insecurity for most countries (Prager et al. 2020).

These economic yield responses are the result of several interactions between agricultural, food market, and economic agents, as well as the biophysical processes of CC, such as the increase in the concentration of CO_2 that benefits crop growth. However, other yield differentials need to be taken into account, such as climate variability and how it affects total factor productivity (Lachaud, Bravo-Ureta, and Ludena 2017). At the same time, (Hertel and de Lima 2020) suggest that a broader view should extend the impact analysis to inputs beyond land, including the consequences of CC for labor productivity, as well as the market for intermediate inputs. Largely overlooked is CC's impact on the rate of total factor productivity growth and the potential for more rapid depreciation of the underlying knowledge capital underpinning this key driver of agricultural output growth.

The livestock sector is economically important especially for Brazil, Mexico, Argentina, Colombia, and Peru. Output from these countries represents 83.8% of total meat production in the LAC region in 2018 (FAO, 2020). Research exploring CC's interactions with the livestock sector, however, is scarce, particularly for non-ruminant animals. As temperature increases, the quantity and quality of feedstock changes (Hristov et al. 2017), and heat stress directly affects livestock and its productivity.

Heat stress in livestock increases mortality rates affecting animal reproduction, and reduces animal intake and milk production in the case of cattle (Johnson 2018; Das et al. 2016). Moreover, changes in humidity and temperature lead to changes in the distribution of pathogens and diseases (Van den Bossche and Coetzer 2008). For low levels of global warming, the literature shows heterogenous results across countries and livestock types. For example, productivity could decrease marginally across Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay and Venezuela for beef cattle, dairy cattle, chicken and pigs (Seo, McCarl, and Mendelsohn 2010). For other livestock such as sheep, productivity could increase by up 20%, given the adaptability of these animals to warmer and drier conditions. In some countries such as Paraguay, beef cattle production might decrease significantly, by 16% to 27%.

3. Methods

3.1 The Integrated Economic-Environmental Modeling Platform

In this paper, we conduct scenario analysis using Integrated Economic-Environmental Modeling (IEEM) Platform (Banerjee et al. 2016; 2019; 2021). IEEM is a Computable General Equilibrium (CGE) model designed for national, subnational as well as regional-level analysis of medium- and long-run development policies to assess their contribution to sustainable economic development. Technically, IEEM is comprised of a set of simultaneous linear and non-linear equations. It is an economy-wide model, providing a comprehensive and consistent view of the economy, including linkages between disaggregated production sectors and the incomes they generate, households, the government and its budget and fiscal policies, and the balance of payments.

IEEM is a powerful framework for analyzing shocks related to CC given that it captures, in an integrated way, household welfare, fiscal issues, and differences between sectors in terms of household preferences, labor intensity, capital accumulation, technological change, and links to international trade and the domestic economy. IEEM is a recursive dynamic framework where in each period, the different agents, specifically, producers, households, government, and the nation in its dealings with the outside world, are subject to budget constraints. Income and expenditure are fully accounted for, and by construction, equal, as they are in real economies.

The decisions of each agent, where producers and households maximize profits and utility, respectively, are made subject to their budget constraints. For example, households set aside part of their income for paying direct taxes and savings, allocating what is left to consumption with a utility-maximizing composition. For the nation, the real exchange rate typically adjusts to ensure that the external accounts are in balance. Other balancing options, including adjustments in foreign reserves or borrowing, but these mechanisms may not be viable in the long run. Wages, rents, and prices play a crucial role by clearing markets for factors and commodities comprised of goods and services. For commodities that are traded internationally (exported and/or imported), domestic prices are influenced by international price developments. For each of the countries modeled in this exercise, the small country assumption is made whereby international markets demand and supply each country’s exports and imports at given world prices.

Over time, production growth is determined by growth in factor employment and changes in total factor productivity (TFP). Growth in capital stocks is endogenous, depending on investment and depreciation. For other factors, the growth in employable stocks is exogenous. For labor and natural resources, with sector-specific factors for natural-resource-based sectors, the projected supplies in each time period are exogenous. For natural resources, they are closely linked to production projections. For labor, the projections reflect the evolution of the population in labor force age and labor force participation rates. The unemployment rate for labor is endogenous. TFP growth is made up of two components, one that responds positively to growth in government infrastructure capital stocks and one that, unless otherwise noted, is exogenous.

3.2 The IEEM Database

For this study, IEEM databases for 20 countries in the LAC region were extracted from the OPEN IEEM Platform, with circa 2015 as the base year[2]. While the LAC region is comprised of 31 countries, IEEM databases and models have only been developed for those countries that have complete and reliable System of National Accounts data (European Commission et al. 2009). The OPEN IEEM Platform is an online resource that provides access to, at the time of writing, 25 IEEM models for the LAC region and beyond, as well as other tools and databases for integrated economic-environmental modeling[3].

The 20 country IEEM databases consist of Social Accounting Matrices (SAM) and complementary data, most importantly, data on factor stocks, elasticities (in production, consumption, and trade), and baseline projections for GDP and other indicators such as population (total and labor force age) and labor unemployment and underemployment rates. Details on the construction of an IEEM database may be found in (Banerjee et al. 2019) Table 2.1 shows the accounts used across all SAMs in this application, which determine the disaggregation of each of the individual IEEM country models.

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[2] The 20 countries modeled are: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, Paraguay, El Salvador and Uruguay.

[3] https://openieem.iadb.org

Table 2.1: disaggregation of IEEM used in this paper.

Category	**Item**
Sectors (activities and commodities) (27)	*Agriculture (6)*
	Oilseeds and cereals; vegetables; fruits; flowers; other crops; livestock
	Other primary (3)
	Forestry; fishing; mining
	Manufacturing (10)
	Food, beverages and tobacco products; textiles; wood and paper; refined pet prod; chemicals, rubber and plast; non-metallic mineral products; metals; machinery and eq; vehicles; other manufacturing
	Other industry (3)
	Electricity and gas; water; construction
	Services (5)
	Trade; transport; hotels and rest; public administ; other services
Factors (6)	Labor
	Capital, private
	Capital, government
	Land
	Fishing resources
	Extractive resources
Institutions (4)*	Households
	Enterprises
	Government
	Rest of the world
Taxes (5)	Tax, social security contributions
	Tax, activities
	Tax, commodities
	Tax, imports
	Tax, income
Distribution margins (3)	Trade and transport margins, domestic
	Trade and transport margins, imports
	Trade and transport margins, exports
Investment (3)	Investment, private
	Investment, government
	Investment, change in inventories

*The institutional capital accounts are for the domestic non-government (i.e. an aggregate of households and enterprises), government, and the rest of the world.

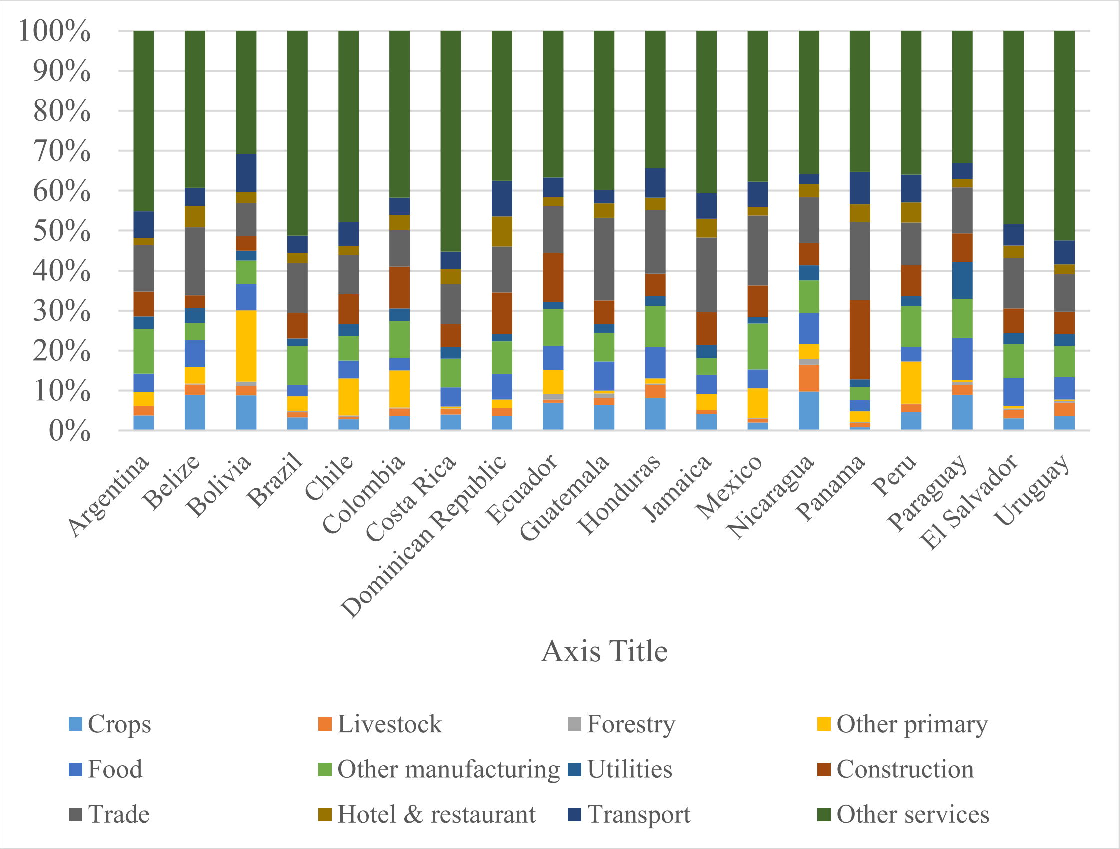
Source: Authors' elaboration.

To provide context for the analysis, key aspects of LAC's economies relevant to the scenario analysis are presented in Figures 2.1-2.4, which are all based on the IEEM databases. Figure 2.1 summarizes the sectoral structure of LAC's economies, showing sectoral shares in value-added, production, employment, exports, and imports. Of note is that the Other services sector is generally the most important across countries, with Trade and Other manufacturing also contributing a significant share of output. Between countries, of note is the importance of the Other primary sector in Bolivia, the Construction sector in Colombia, Dominican Republic, Ecuador and Panama, and crops in Belize, Bolivia, Nicaragua, and Paraguay.

To complement, Figure 2.2 shows the split of domestic sectoral supply between exports and domestic sales, and domestic sectoral demands between imports and domestic output for the agricultural sector. Belize, Costa Rica, Ecuador, Nicaragua, Paraguay and Uruguay present a relatively large share of exports in domestic sales while Belize, Costa Rica, Mexico, Panama, and El Salvador present a relatively large share of imports in domestic supply for agricultural production.

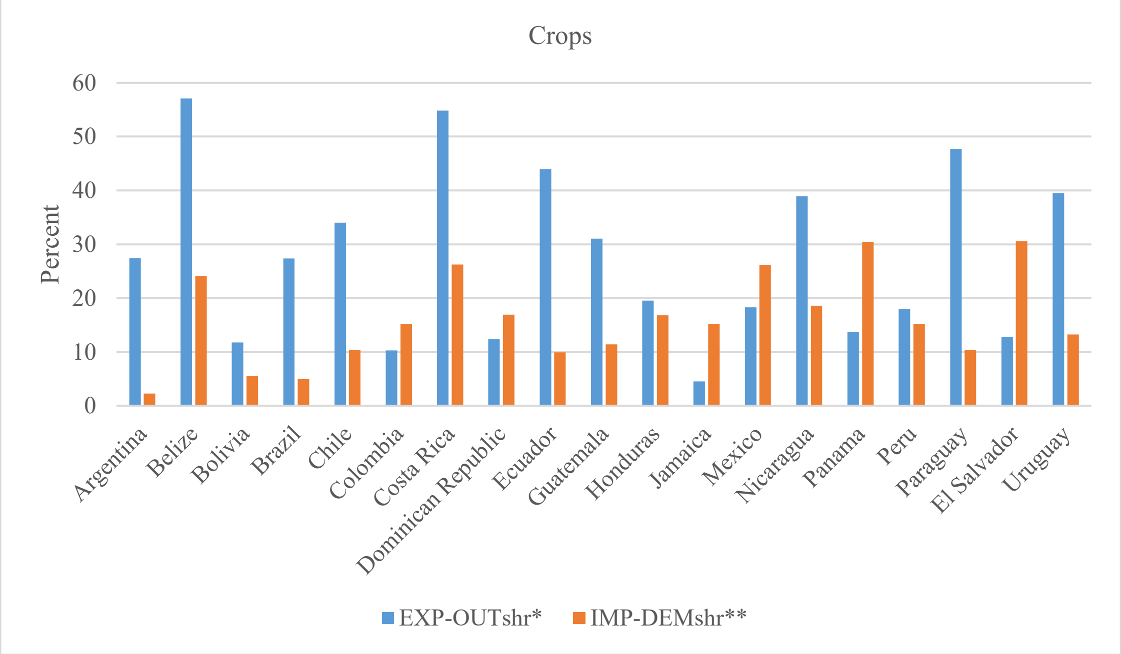
Figure 2.3 shows factor shares in the value added of each sector. In economy-wide applications such as this one, the ratios of labor, capital and natural resources of each sector have a major impact on the results and hence understanding value added of each sector is very useful when analyzing scenario results. Regarding factor intensity in agriculture, Colombia, Costa Rica, Dominican Republic, Honduras, Nicaragua and Peru are relatively more labor intense while Brazil and Paraguay are capital intense. Uruguay is the most natural capital intense country, followed by Ecuador, Chile, Argentina, Panama and Bolivia.

Figure 2.1. LAC: sectoral structure in base-year, percent.



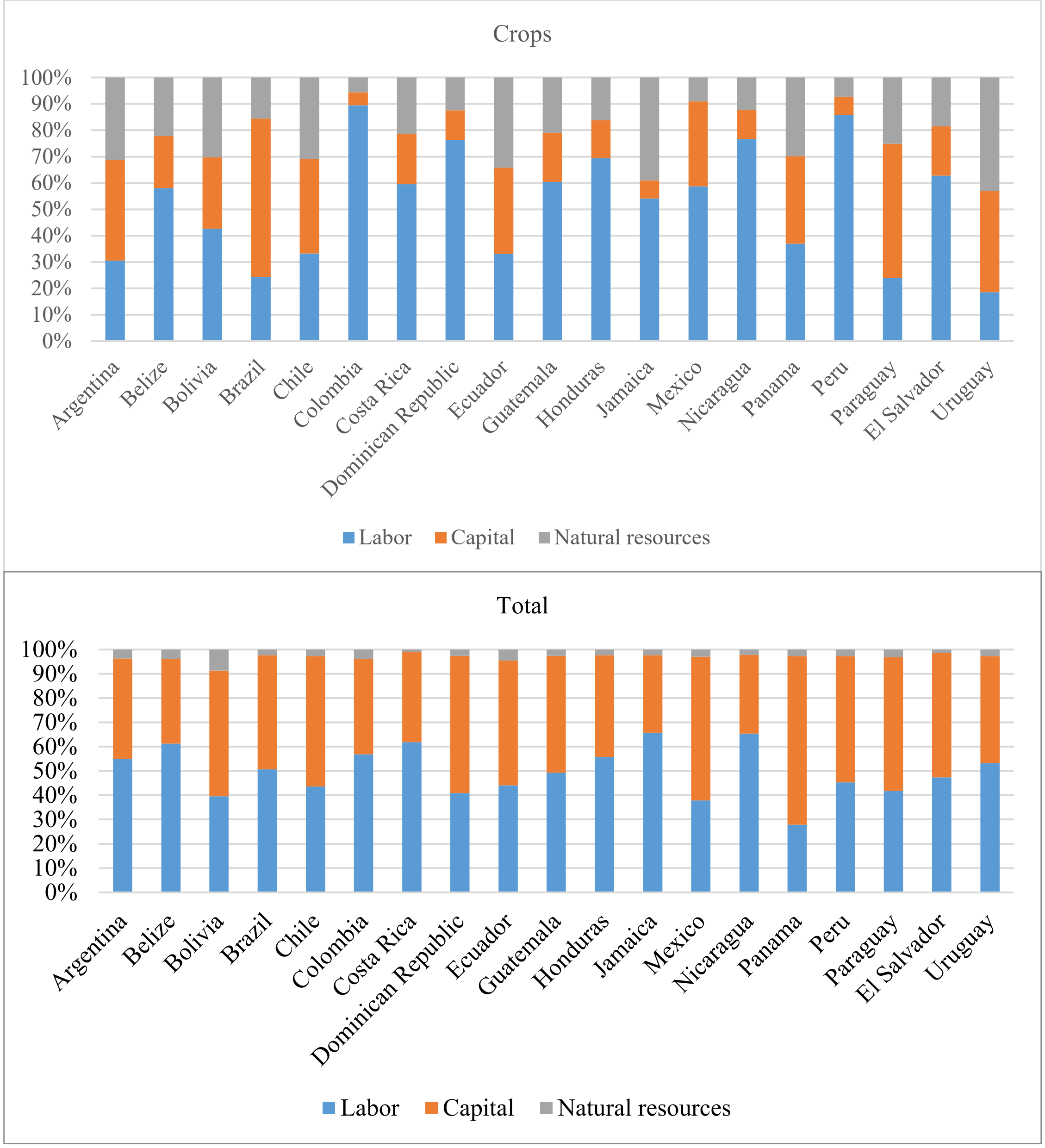
Source: Authors' calculations based on OPEN IEEM datasets.

Figure 2.2. LAC: share of exports in domestic sales (EXP-OUTshr) and share of imports in domestic supply (IMP-DEMshr) for agricultural production in the base year, percent.



*Ratio between exports and production; **Ratio between imports and consumption.
Source: Authors' calculations based on OPEN IEEM datasets.

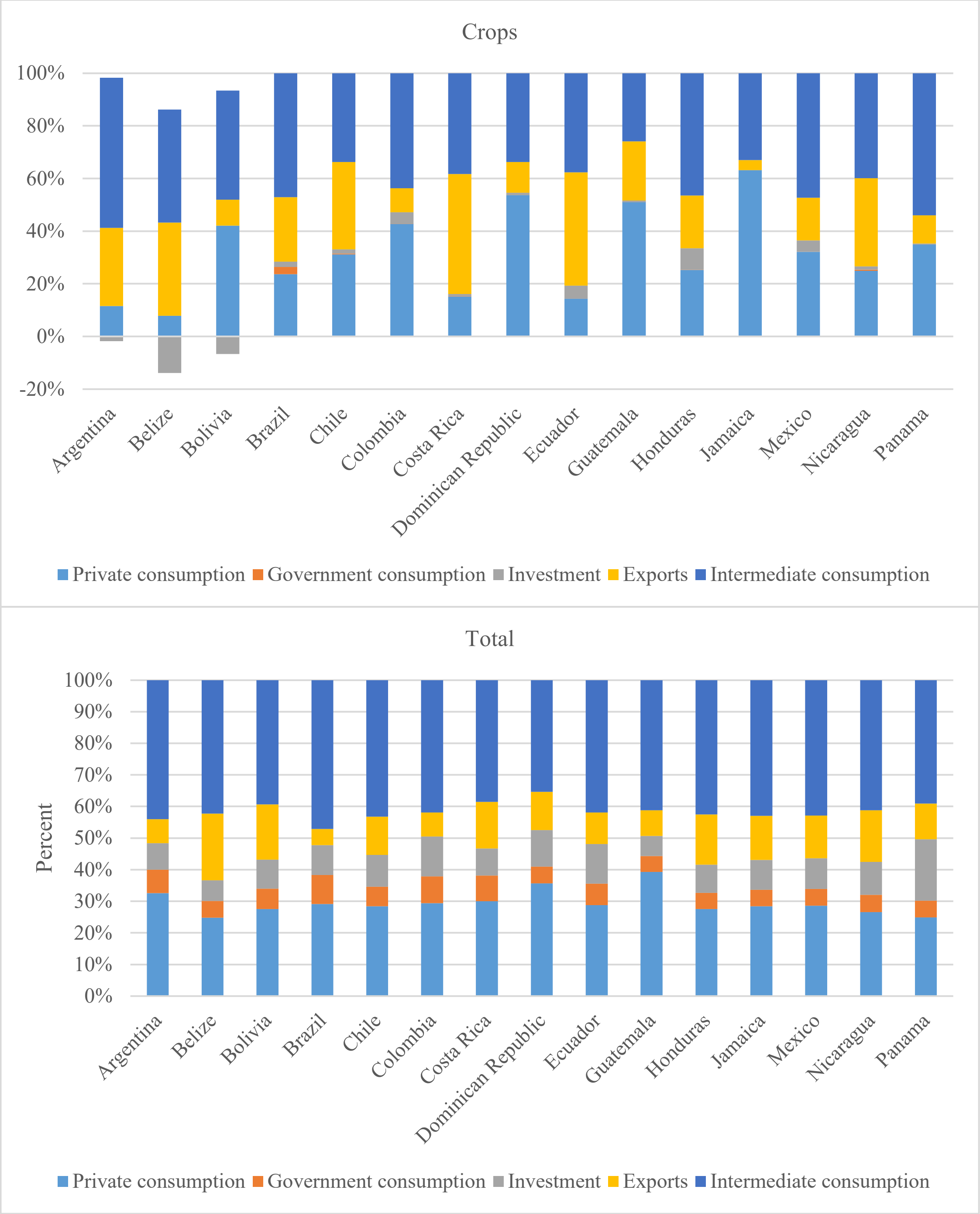
Figure 2.3. LAC: sectoral factor intensity for agriculture (top) and overall (bottom) in the base year, percent.



Source: Authors' calculations based on OPEN IEEM datasets.

Figure 2.4 shows the demand structure for each commodity in the IEEM databases. Overall, the greatest share of output is allocated to intermediate consumption and then private consumption.

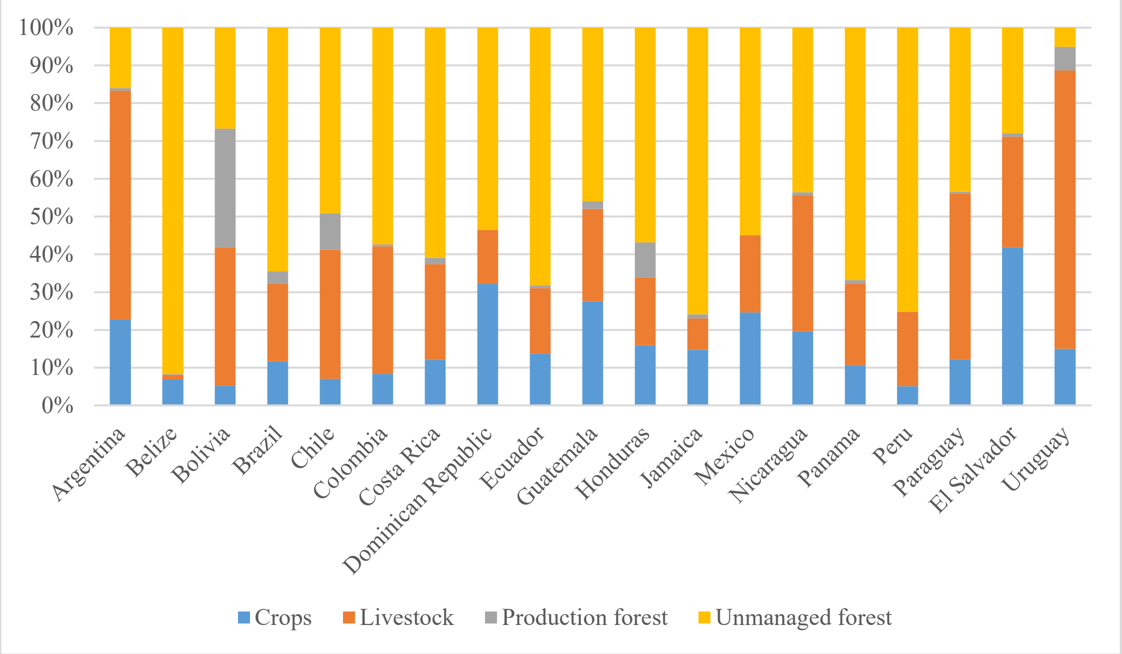
Figure 2.4. LAC: sectoral demand composition for agriculture (top) and overall (bottom) in the base year, percent.



Source: Authors' calculations based on OPEN IEEM datasets.

Figure 2.5 shows the share of land in each of the classes, namely, crops, livestock, production forest and unmanaged forest, for each country in the base year. Unmanaged forests occupy, overall, the largest share of land cover and use, with some exceptions including Argentina, Bolivia, and Uruguay.

Figure 2.5. LAC: land use structure in the base year, percent.



Source: Authors' calculations based on OPEN IEEM datasets.

3.3 Scenario Design and Results

3.3.1 Scenario Design

Impacts of Climate Change on Agricultural Yields

In order to estimate the climate change impacts on agriculture and food security for the LAC region, we draw on two sets of data of future climate modeling (Gourdji et al. 2015) and a comprehensive dataset on climate change impacts on yield (Schiek and Prager 2020). These studies have used nine general circulation models (GCMs), given their strong performance in the LAC region as reported in Prager et al. (2020). The nine GCMs used are BCC-CSM1, BNU_ESM, CCCMA_CANESM2, GFLD_ESM2G, INM-CM4, IPSL-CM5A-LR, MIROC-MIROC5, MPI-ESM-MR, and NCC-NORESM1-M (for additional details, see Table A.1 in Appendix A and Schiek and Prager (2020).

Schiek and Prager (2020) estimate the 2050 climate-induced yield changes for maize, rice, wheat, soybean, and bean using the Decision Support System for Agrotechnology (DSSAT v4.5) at a 0.5-degree spatial resolution. For a second group of crops, banana, cassava, potato, coffee (robusta and arabica varieties), sugarcane, and yam, the EcoCrop niche-based model was used to estimate crop suitability changes rather than yield[4]. In these models, suitability is defined based on how well local precipitation and temperature match the biophysical requirements of each crop. These twelve crops are important to the region for food security, their economic value, and international trade.

Yields and suitability values were estimated annually for each crop in the historical and future periods and for each GCM in the future period. Mean yield and suitability were then calculated across the baseline and for the future 30-year period[5]. For this paper, modeling results are presented both at 0.5-degree spatial resolution and at the country level. We aggregate crop yields based on IEEM's agricultural sector disaggregation. These yield estimates are implemented as productivity shocks in IEEM as discussed below.

Impacts of Climate Change on Labor Productivity

It is expected that CC will increase outdoor and indoor heat loads and have a negative impact on the health and productivity of millions of working people (see, among others, Kjellstrom et al. 2018; 2016)). Increased occupational heat exposure due to CC may significantly impact labor productivity and costs unless adaptation measures are implemented. For instance, it is expected that the phenomenon of heat stress will become more common. Heat stress refers to heat received in excess of what the body can tolerate without suffering physiological harm; such excess heat increases workers' occupational risks and vulnerability. In fact, heat stress can lead to heatstroke and if severe and prolonged, ultimately, to death.

It is estimated that temperatures above 24-26°C are associated with reduced labor productivity. In turn, at 33-34°C, workers operating at moderate work intensity lose 50 per cent of their capacity for productive work (Kjellstrom et al. 2018; 2016). Naturally, certain occupations are especially at risk because they involve more physical effort and/or take place outdoors; for instance, jobs

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[4] Yield impacts could not be assessed for these crops because the available data was insufficient to calibrate the DSSAT module, or because a DSSAT module does not yet exist for the crop. Coffee suitability was assessed using a machine learning ensemble-based approach. Suitability of the other crops was modeled using EcoCrop, based on the FAO EcoCrop database. See (Schiek and Prager 2020) for details.

[5] For more information see Gourdji et al. (2015) and Schiek and Prager (2020).

typically found in agriculture, construction, transport, tourism, among others, are at high risk. However, at high heat levels, even performing office-based tasks becomes more difficult as fatigue sets in. Consequently, workers may need to work longer hours, or more workers may be required, to achieve the same level of output. Moreover, there might also be economic costs associated with reduced productivity and/or occupational health interventions to address heat exposure. In our analysis, estimates of CC impacts on labor productivity are derived from (Kjellstrom et al. 2018; 2016).

Kjellstrom et al. (2018 and 2016) determine the impact of heat stress on labor productivity by combining estimates from climate models and global temperature projections with labor force projections and occupational health data. The International Labor Organization (ILO 2019) calculates the health risks of heat stress using the heat stress index for occupational health known as Wet Bulb Globe Temperature (WBGT). It is measured in degrees Celsius and is calculated on the basis temperature (°C), humidity (dew point in °C), air movement (wind speed) and radiated heat (primarily from the sun).[6]

We implement a base line (i.e. business-as-usual) scenario and four scenarios which are described as follows:

- **BASE**: this is the business-as-usual scenario which projects the economy of each country to 2050 without the implementation of any new public policy or investment. It is the counterfactual, reference scenario to which all subsequent scenarios are compared.
- **AGRTFP**: this scenario implements CC impacts on agricultural productivity. The yield impacts derived from Prager et al. (2020) are as follows: by 2050, the simple average across all countries is -19.0 percent for bean, -17.2 percent for maize, -1.8 percent for rice, +14.2 percent for soybean, and -4.8 percent for wheat. These yield impacts are implemented as productivity shocks in IEEM and introduced linearly between 2021 and 2050 (see Figure 3.1). Together, these five crops represent between 0.7 (Barbados) and 89.5 (Paraguay) percent of the total cultivated area in the LAC countries modeled (see Figure 3.2). For other crops, absent additional information, we assume constant yields and therefore our results provide a lower

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[6] ILO estimates are based on data from the ILOSTAT database and the HadGEM2 and GFDL-ESM2M climate models. Besides, the data are based on historical observations and on estimates obtained using the RCP2.6 climate change pathway, which envisages a global average temperature rise of 1.5°C by the end of the century.

bound for the CC impact on agricultural productivity. Interestingly, countries in the southern cone such as Argentina, Brazil, and Uruguay would experience an increase in the average yields of soybean- in all cases, one of their main crops of significant economic importance.

- **AGRLABPRD**: this scenario implements the expected CC impact on labor productivity in the agricultural sector (see Figure 3.3). This productivity shock is introduced linearly between 2021 and 2050. The areas most affected are those within the tropical and subtropical zones, including large swaths of Central America, South America, and the Caribbean. On the other hand, the risk of heat exposure and stress is lower in high-altitude areas such as the Andes. Note that we only consider CC impacts on agricultural labor productivity in this scenario.

- **LABPRD**: this scenario implements the expected CC impact on labor productivity in agriculture as well as all other economic sectors (see Figure 3.3). This productivity shock is introduced linearly between 2021 and 2050.

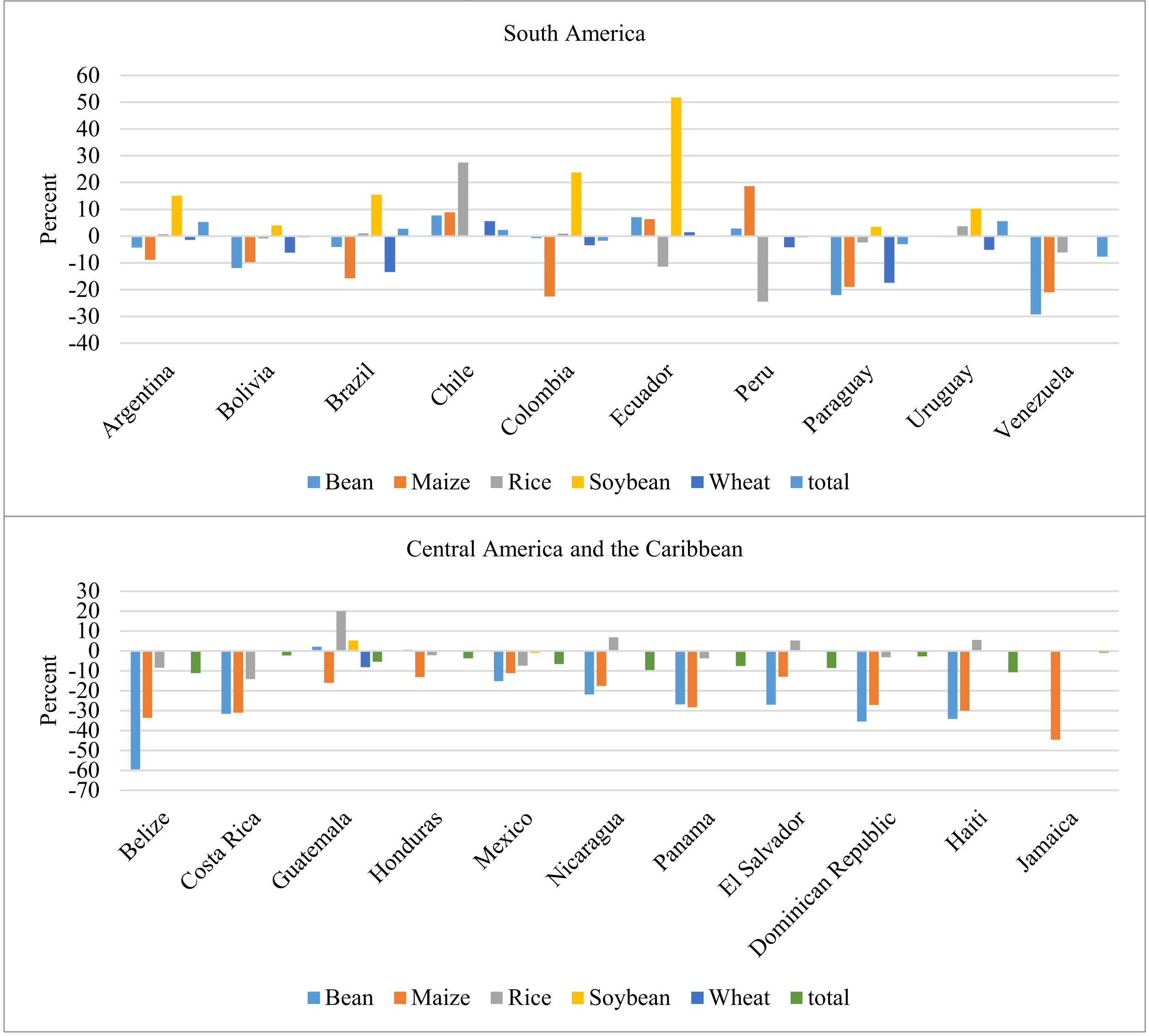
- **COMBI**: this scenario is the joint implementation of AGRTFP and LABPRD and is thus considered the overall impact of CC on the agricultural and related sectors.

In all non-BASE scenarios, we assume that deforestation rates do not change relative to the BASE. Consequently, the amount of agricultural land is the same in the BASE and non-BASE scenarios. Needless to say, future changes in crop yields are subject to several uncertainties such as (i) changes in climate; (ii) changes in atmospheric CO_2 concentrations and the subsequent impact on crop water use efficiency and CO_2 fertilization; (iii) changes in technologies for crop management and breeding, and; (iv) changes in cropping area.

Figure 3.1 summarizes the yield shocks applied to IEEM for South American, Central American and Caribbean countries. The yield shocks for South American countries are heterogeneous and dependent on the concentration of CO_2, type of soil, altitude, as well as other exogenous factors that affect agricultural productivity as previously discussed. Soybean productivity responds positively across countries, while maize responds negatively, except in the case of Ecuador. Chile is the only South American country exhibiting a productivity gain. As we move to low latitude regions, the CC effects are strictly negative, except for rice cultivation in some countries (e.g., a 20% increase in yield in Guatemala). Larger losses are expected in the case of Belize, Costa Rica, Haiti, and Dominican Republic.

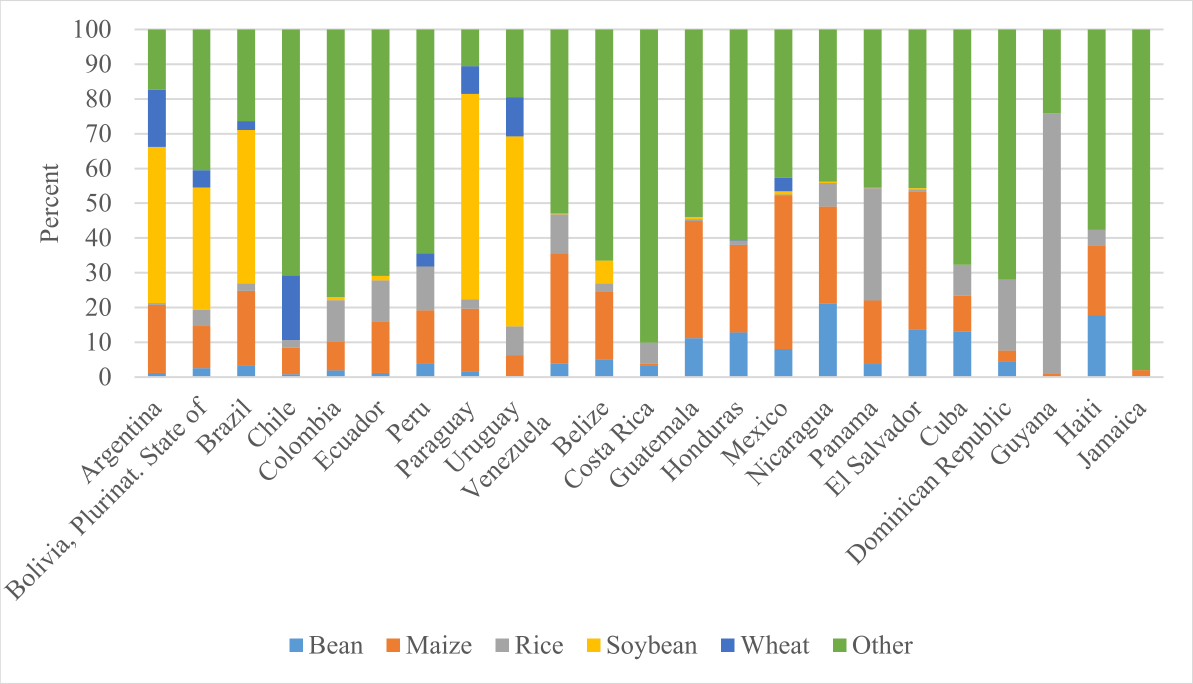
Figure 3.3 summarizes the labor productivity shocks. A similar pattern to that in the case of the yield shocks is observed, with countries in lower latitudes showing greater labor productivity losses as a result of CC. This is the case in Central American and Caribbean countries. The hours lost from work also depend on the exposure of workers to heat stress. Naturally, the agriculture and construction sectors are the most affected due to outdoor exposure and its lower capacity to adapt and mitigate heat stress. On the other hand, indoor workers are more protected and as a result, the manufacturing sector exhibits dampened labor productivity impacts. Belize, Nicaragua, and Panama present the greatest labor productivity losses compared with their Central American and Caribbean peers. For countries in South America, where the capacity to adapt to heat stress is greater, losses in labor productivity are lower. This is true in the case of Brazil, Argentina, and Colombia. Guyana and Suriname suffer the greatest impact in the region.

Figure 3.1. Changes in crop yields due to CC by country and region, average percent for the period 2022-2049.



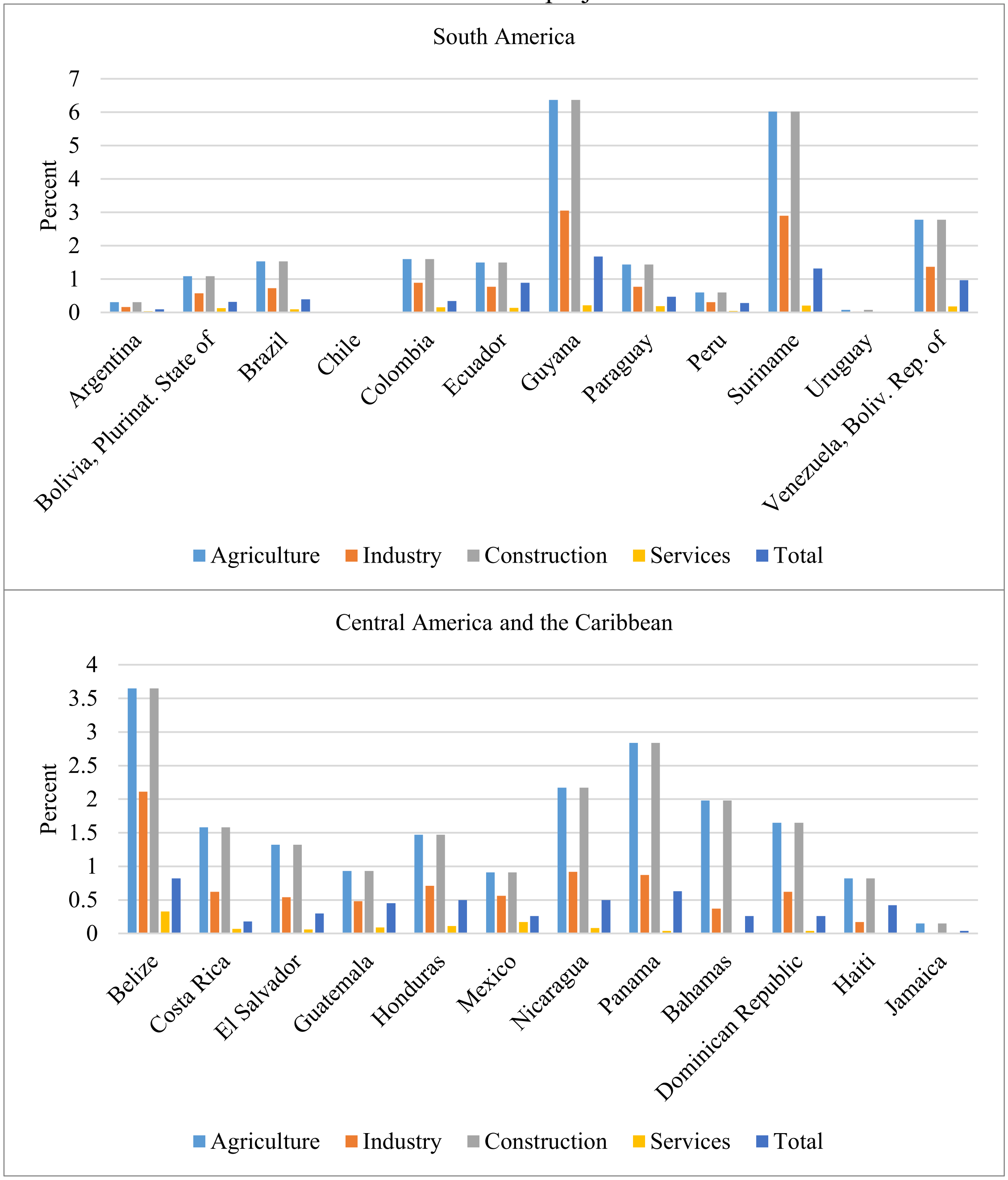
Source: Authors' calculations based on Prager et al. (2020).

Figure 3.2: Crop areas by country in 2019 as a percent of total area.



Source: Authors' calculations based on Prager et al. (2020).

Figure 3.3. Working hours lost to heat stress as a percent of the total hours worked by region, historical from 1995 and projected in 2030.



Source: Kjellstrom et al. (2018).

4. Results

In the BASE, GDP growth is assumed to be exogenous. Specifically, for each country, we impose the observed growth rates in real GDP for the period between the base-year and 2019. We use the IMF World Economic Outlook projections for the period 2020-2025. For 2025 to 2050, we maintain the IMF's 2025 growth rate for each country. The exogenous part of TFP growth is adjusted to generate these growth rates. Implicitly, we are modeling the COVID-19 economic impact as a decrease in TFP. In non-base scenarios, GDP growth is invariably endogenous. In the base, the supply of agricultural land grows by the exogenous rate of deforestation for each country.

4.1. Macroeconomic results

The economic impacts of climate-induced change in agricultural productivity have heterogenous effects in the LAC region (Figure 3.4). Under the AGRTFP scenario, soybean producing countries and agricultural exporters, such as Argentina, Brazil and Uruguay would present improvements in yield. Consequently, these countries would experience an increase in real GDP of 0.3%, 0.15%, and 0.26%, respectively. Across most other countries, the CC impact on GDP is negative with Belize, Guatemala and Nicaragua the most strongly affected (-1.8%, -1.1% and -1.1%, respectively).

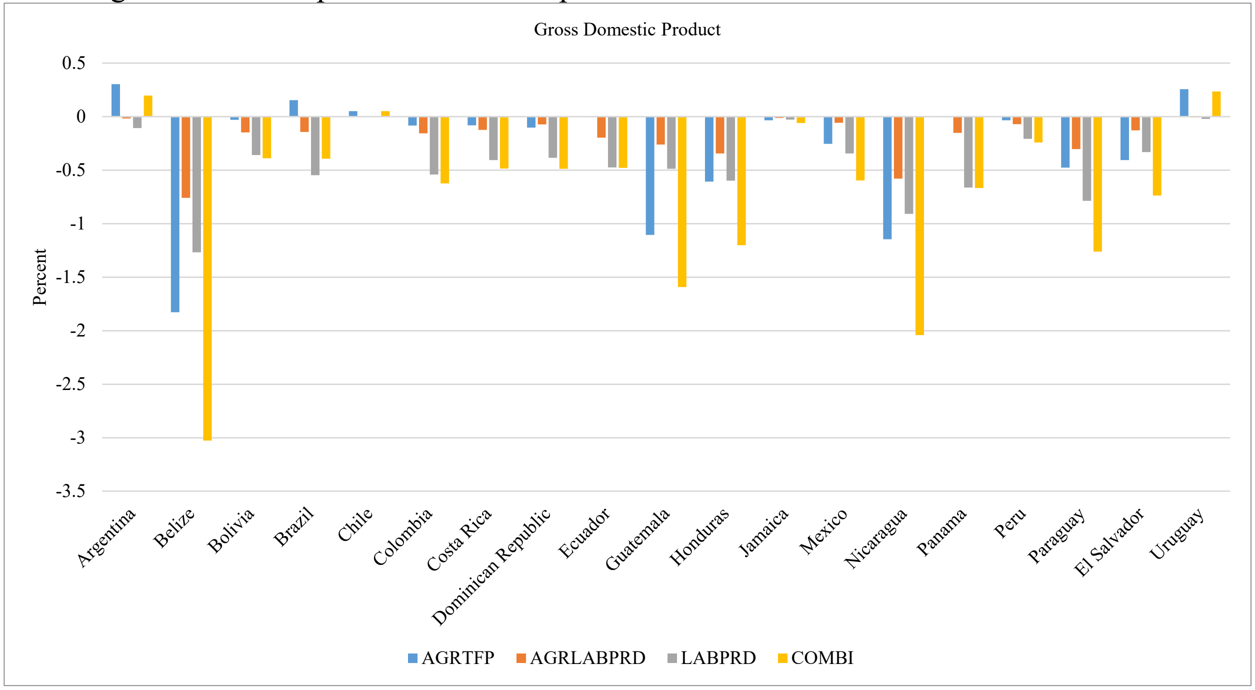
Regarding the impact of reduced agricultural labor and overall labor sector productivity, all macroeconomic indicators show a negative impact with overall sector labor productivity having the greatest effect as intuition would dictate. Belize, Nicaragua, Paraguay and Panama are the hardest hit by overall labor productivity decline in terms of GDP impacts (-1.3%, -0.9%, -0.8% and -0.7%, respectively).

When we consider the interaction effect of CC impacts on crop yields and labor productivity, the COMBI scenario, a different set of results emerge. For Brazil, the decrease in labor productivity overwhelms the positive yield impact resulting in a decline in GDP on the order of -0.39%. In the case of Argentina and Uruguay, the yield impact is dominant and the combined impact of increased yield and reduced labor productivity results in an increase in GDP of 0.20% and 0.24%, respectively. In the case of most of the remaining countries, the negative yield impact and reduced labor productivity pushes GDP further downward, with Belize suffering the greatest impact, followed by Nicaragua, Guatemala and Paraguay (-3.03%, -2.04%, -1.59%, and -1.26%, respectively).

Some countries appear to experience disproportionately negative impacts. For example, in the case of Nicaragua, the strong negative impact is explained by: (i) the relatively large decrease in yields;

and, (ii) the large share of agriculture in total employment and value added, which is around 31%. For Belize, there would be a large drop in agricultural total factor productivity; specifically, bean and maize yields would decline by 59.5% and 33.7%, respectively.

Figure 3.4: CC impacts on GDP as a percent level deviation from the BASE in 2050.

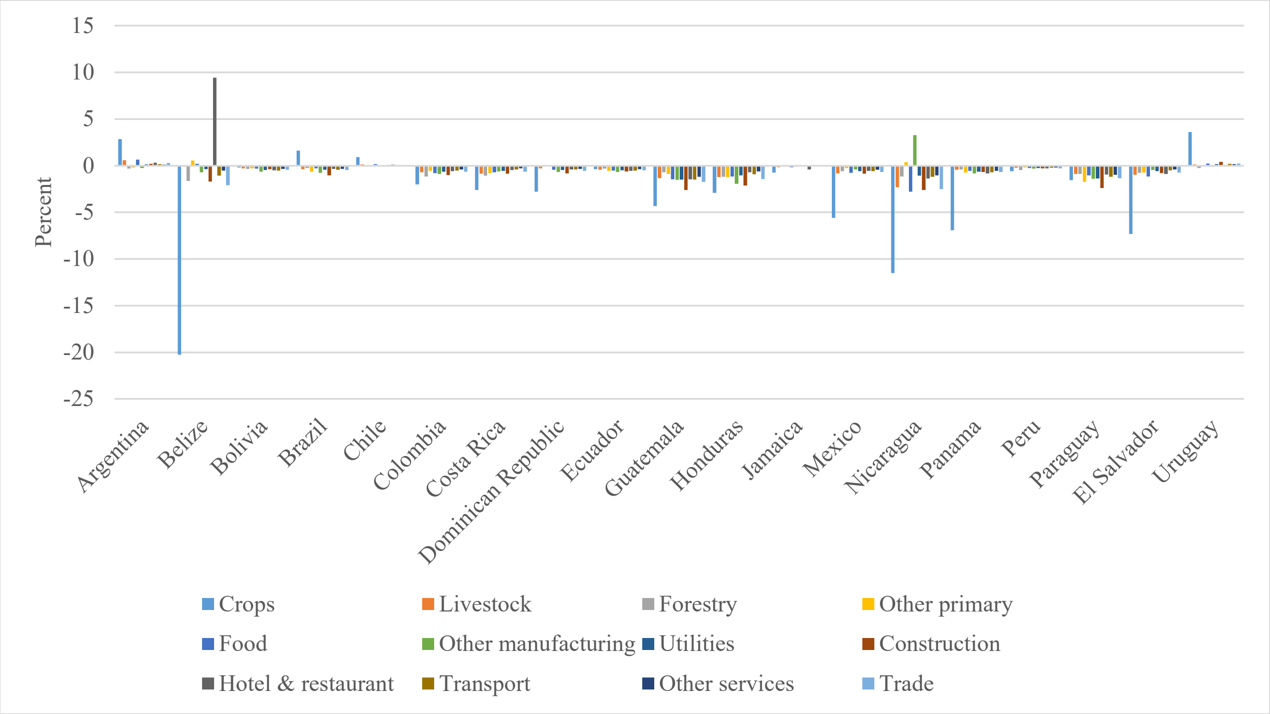


Source: Authors' calculations using IEEM simulation results.

4.2. Sectoral Impacts

CC impacts on sectoral output would generally be negative, with impacts most pronounced for the crop sector as it would face downward pressure due to the crop yield and labor productivity shocks (Figure 3.5). Under the COMBI scenario, crop production would drop by 20% in Belize, 11% in Nicaragua, 7% in El Salvador, and by 5% in Mexico. The crop sector of only a handful of countries would benefit; Argentina, Brazil, Chile and Uruguay would experience small increases in sectoral output of between 3.6% in Uruguay and 0.9% in Chile for the crop sector. Livestock output would increase in Argentina (0.6%), Chile (0.1%) and Uruguay (0.1%). Impacts across other sectors would be relatively small.

Figure 3.5: Sectoral output effects of climate change COMBI scenario as a percent level deviation from the BASE in 2050.

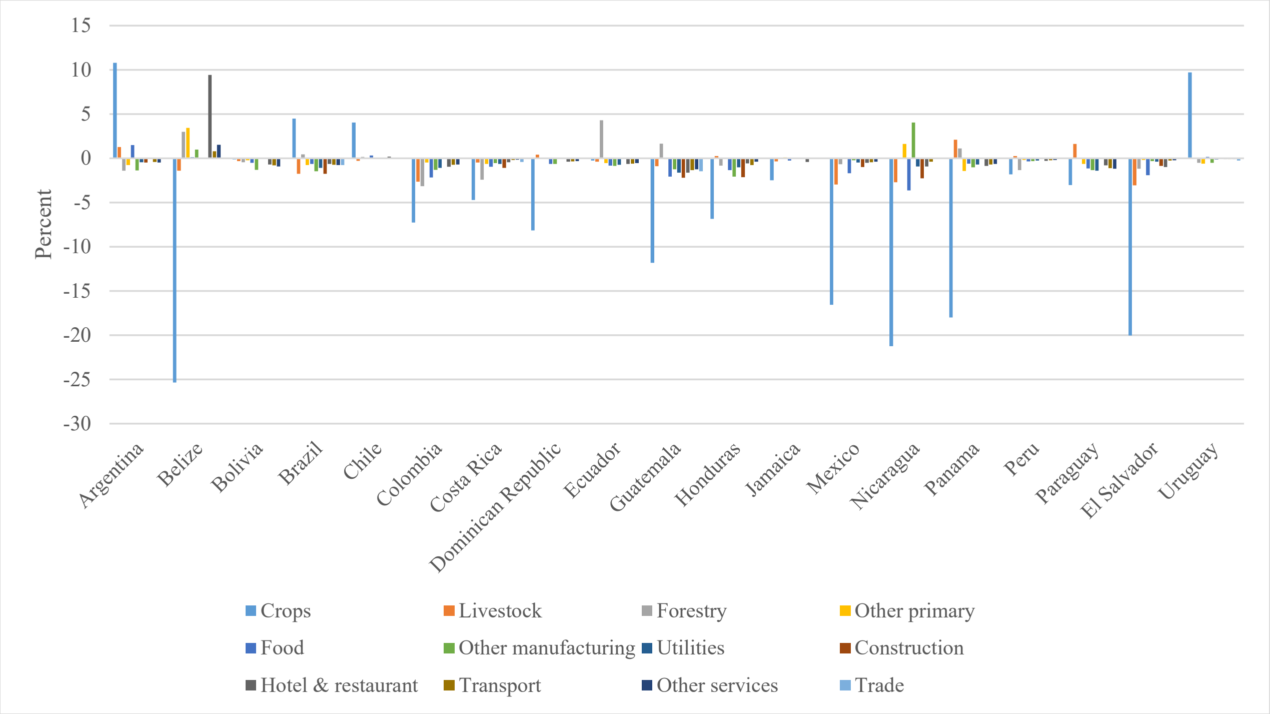


Source: Authors' calculations using IEEM simulation results.

Those countries that produce more crop and livestock output would tend to export more as well (Figure 3.6). Crop exports would increase between 10.8% in the case of Argentina, 9.7% in Uruguay, 4.5% in Brazil and 4.1% in Chile. Livestock exports would increase by 2.1% in Panama, 1.6% in Paraguay, and 1.3% in Argentina. Other impacts of note on exports would include increases across sectors with the exception of crops and livestock in Belize, a 4% increase in Other manufacturing in Nicaragua, and a 4.3% increase in Forestry in Ecuador.

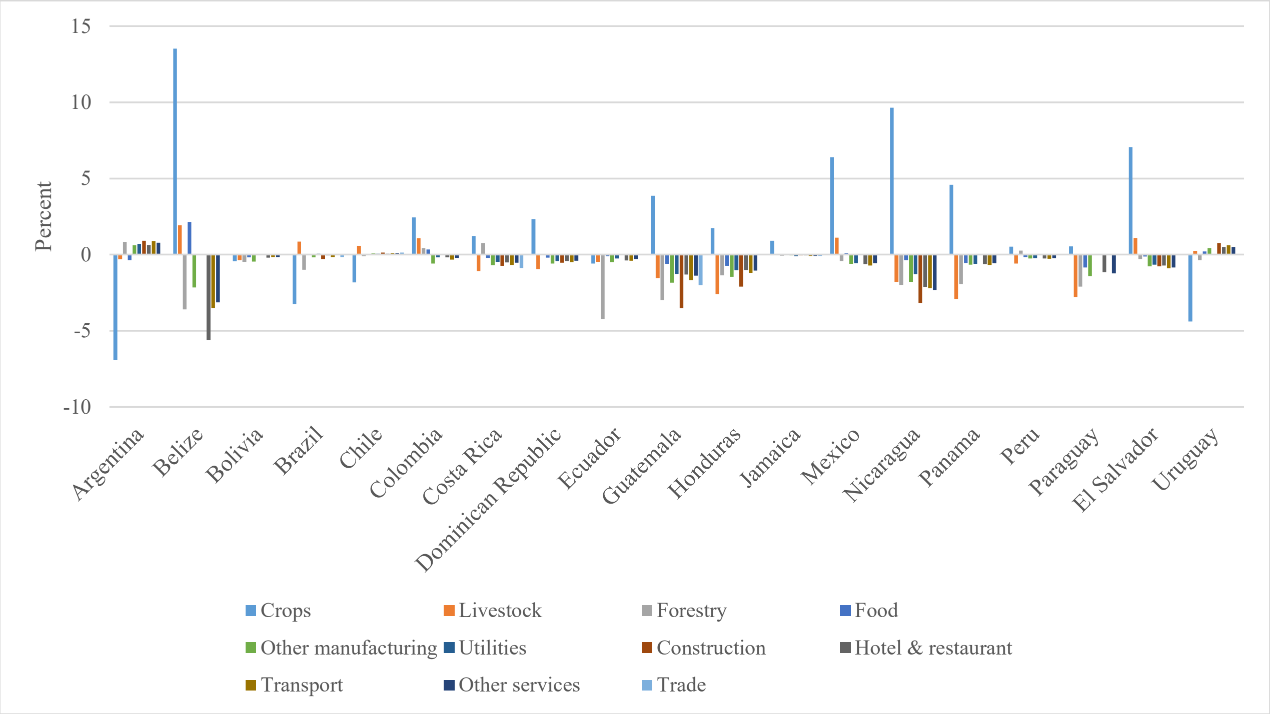
Across several countries, crop imports would increase. For instance, they would increase by 13.5% in the case of Belize, 9.7% in Nicaragua, 7.1% in El Salvador, and 6.4% in Mexico (Figure 3.7). In general, however, imports would be negatively impacted by the CC shocks. We find that while imports for crops and livestock would increase for many countries, Processed food imports would generally decline. Processed food is the main source of food for households. This implies that CC would have a decreasing impact on the dependency of households on food imports.

Figure 3.6: Sectoral exports effects of CC for the COMBI scenario as percent level deviation from the BASE in 2050.



Source: Authors' calculations using IEEM simulation results.

Figure 3.7. Sectoral imports effects of CC for the COMBI scenario as percent level deviation from the BASE in 2050.



Source: Authors' calculations using IEEM simulation results.

4.3. Land-use and emissions

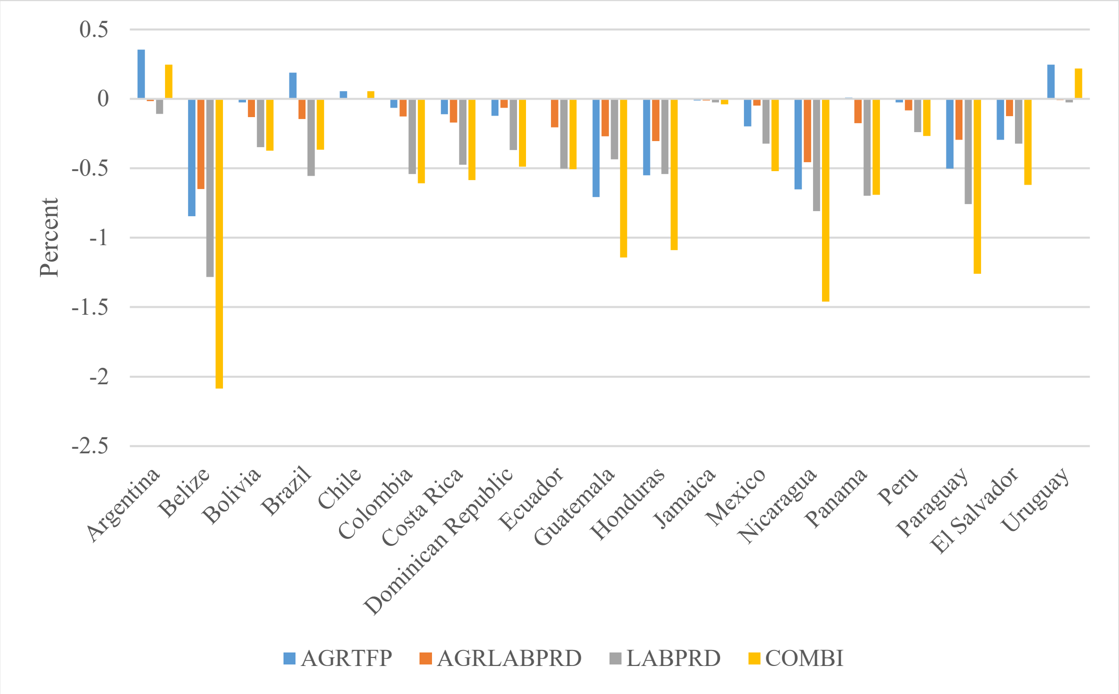
The impact of diminished labor and land productivities on land use depends on the degree of CC adaptation in each country (Figure 3.8). Under the COMBI scenario, the area dedicated to crops would decline by 0.44% overall. This would imply that about 765 thousand hectares in LAC would become idle and unproductive from an agricultural standpoint. The distribution of this reduction is important to note, however, where it is generally the larger countries that experience a decline in cropland. For example, Argentina, Brazil and Chile experience a reduction of 2.3%, 0.5%, and 1.2%, respectively. These countries currently have large areas of cropland and therefore these declines are significant regionally. Livestock areas tend to decline across countries, except for Argentina, Belize, Brazil, Chile and Uruguay.

The changes in greenhouse gas emissions are driven by changes in sectoral and overall economic output. Under the AGRTFP scenario, only Argentina, Brazil, Chile, and Uruguay would experience increased greenhouse gas emissions. The relatively small impacts on emissions in AGRTFP are explained by the relatively small share of land rent in total value added across countries. Labor productivity impacts in AGRLABPRD and LABPRD have a negative impact on emissions. Under the COMBI scenario, almost all countries would experience decreased emissions, of on average 0.6%. Only Argentina, Chile and Uruguay would experience small increases in emissions (0.2%, 0.1% and 0.2%, respectively).

Figure 3.8: Changes in land use as percent level deviation from the BASE in 2050.

Source: Authors' calculations using IEEM simulation results.

Figure 3.9. Changes in emissions as percent level deviation from the BASE in 2050.



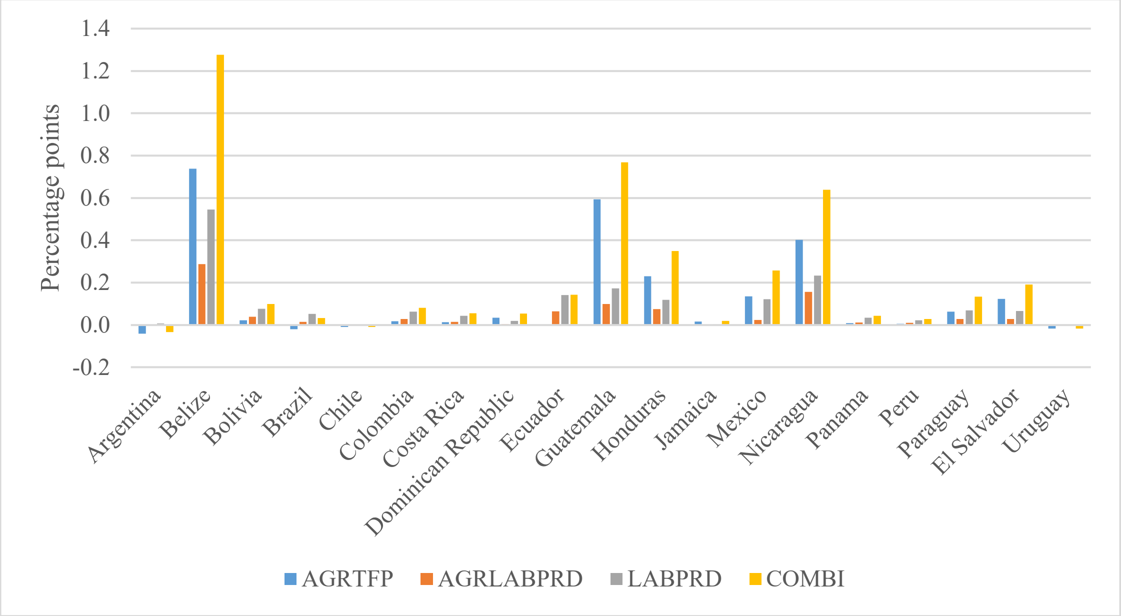
Source: Authors' calculations using IEEM simulation results.

4.4. Poverty

Figure 3.10 shows the effects of CC on poverty. CC's impact on agricultural and labor productivity would tend to increase poverty and inequality. The main transmission channel from CC impacts to households through household real income. Under future CC, household real income would decline as a result of reduced income from factors of production. On the one hand, with less area dedicated to agricultural production, returns to land would decline, though this would be the case for a subset of countries that include Argentina, Belize, Brazil, Chile and Uruguay in the case of cropland. Receipts from livestock land would decline across more countries and increase in the case of Argentina, Belize, Brazil, Chile and Uruguay.

On the other hand, the lower level of labor productivity due to heat stress would negatively impact real earnings. Workers would work fewer hours per day due to exposure to heat stress. In the COMBI scenario, the only countries that would experience a reduction in poverty would be Argentina, Chile and Uruguay. Increases in poverty would be most acute in Belize, Guatemala, Honduras and Nicaragua (1.28%, 0.77%, 0.35%, and 0.64%, respectively).

Figure 3.10. Changes in poverty as percentage points deviation from the BASE in 2050.



Source: Authors' calculations using IEEM simulation results.

5. Conclusions and Policy Implications

CC will affect both the supply and the demand side of the economy. It is resulting in both physical and biophysical impacts where physical impacts include changes in precipitation regimes, heat stress, and increasing frequency and intensity of high-risk events. Biophysical impacts include changes in agricultural, livestock and fisheries yields, and the shifting of biomes and ecosystems, and biodiversity loss. In this paper, we have used the results of previous analyses assessing physical impacts of CC and how they translate into biophysical impacts. We assess the economic impacts of CC, focusing on impacts on crop yields and agricultural and economy-wide labor productivity, using the IEEM approach and implemented for 20 countries in the LAC region.

The impact of CC on agricultural productivity would result in generally negative impacts on GDP except for soybean-producing countries which are also important exporters, namely Argentina, Brazil and Uruguay. CC impacts on agricultural labor and economy-wide labor productivity would be negative across all LAC countries, with some countries faring worse than others, namely Belize, Nicaragua, Paraguay and Panama. The combined impacts of CC on crop and labor productivity changes the direction of effect in the case of Brazil which would experience a decline in GDP of about -0.39%.

Cross-sector impacts would generally be negative and most pronounced for the crop and livestock sectors due to the crop productivity and labor shocks. Some countries suffer important declines in output, especially Belize, Nicaragua, El Salvador and Mexico. Those countries that have higher crop and livestock output tend to export more; Argentina, Uruguay, Brazil and Chile all would export more crops. Livestock exports would also increase in Panama, Paraguay and Argentina. While crop imports increase for some countries including Belize, Nicaragua, El Salvador and Mexico, food imports overall would tend to decline due to reduced economic activity attributed to CC.

The results generated here follow directly from the assessment of CC impacts on crop and labor productivity. The main insight that may be derived from this work is in the identification of those countries that would be expected to face the greatest negative impacts. This information can be used to preempt these impacts and begin design strategies for CC adaptation early on. Our results show that in terms of combined impacts of CC, Belize, Nicaragua, Guatemala and Paraguay would be the hardest hit. The number of poor in these countries would increase more relative to other countries in the region. In addition, the results presented differentiate countries most affected by crop productivity impacts and labor productivity impacts. Each of these linkages require different adaptation measures to stem impacts before they set in.

As CC advances, new forms of adaptation are urgently required for the region, targeting first those countries that will suffer the most significant impacts. Changes in agricultural productivity can shift production to marginal land or exacerbate the pressure over agriculture frontiers, resulting in greater levels deforestation, and thus greenhouse gas emissions and localized temperature increases, in a vicious cycle. At the same time, the LAC region has the greatest potential to expand agricultural output in the future through agricultural intensification and climate-adapted agriculture including climate adapted crop varieties, irrigation and precision agriculture, example (Wu et al., 2018).

Public and private investment in agricultural research and development that considers climate resilience is critical to achieve higher total factor productivity in LAC. This will translate into more food output per hectare amplifying the regional food supply. Tropical and subtropical technologies such as integrated production and no-tillage systems can contribute to increase agricultural productivity in the region by reducing the demand for land.

Regarding labor productivity, some relatively simple measures are available for adaptation to increased temperature. These include behavioral measures such as adjusting working hours to avoid the hottest times of day. Climate smart municipal and building design can also have an important impact where cross-sectoral labor productivity is concerned (Day et al., 2019). On the other hand, movement toward greater mechanization of agriculture can be an alternative to reduce the exposure of workers to heat stress, especially in those areas that are expected to experience the greatest temperature increases.

Acknowledgements

This work was funded by the Inter-American Development Bank's Integrated Economic-Environmental Modeling (IEEM) Platform project. We would like to acknowledge the ongoing collaboration of Carlos Gonzalez, Benjamin Schiek, and Steven Prager at the International Center for Tropical Agriculture. They contributed results to support the analysis from IEEM model runs using the IFPRI IMPACT model based on previous work financed in cooperation with the Inter-American Development Bank and the Policy, Institutions, and Markets research program of the CGIAR.

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Appendix A. Additional Tables and Figures

Table A.1: List of Global Circulation Models used IEEM scenarios.

GCM name	**Institute Country**	**Country**
BCC-CSM1	Beijing Climate Center, China Meteorological Administration	China
BNU_ESM	Beijing Normal University	China
CCCMA_CANESM2	Canadian Centre for Climate Modelling and Analysis	Canada
GFLD_ESM2G	NOAA Geophysical Fluid Dynamics Laboratory	United States
INM-CM4	Russian Institute for Numerical Mathematics	Russia
IPSL-CM5A-LR	Institut Pierre Simon Laplace	France
MIROC-MIROC5	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	Japan
MPI-ESM-MR	Max Planck Institute for Meteorology	Germany
NCC-NORESM1-M	Norwegian Climate Centre	Norway