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RESEARCH ARTICLE

Climate risk and food availability in Guatemala

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Abstract

In this paper, we use a computable general equilibrium model to simulate the effects of drought and a decrease in agricultural productivity caused by climate change in Guatemala. A reduction in agricultural productivity would mean a considerable drop in crop and livestock production, and the resulting higher prices and lower household income would mean a significant reduction in the consumption of agricultural goods and food. The most negative effects of a drought would be concentrated in agriculture, given its intensive use of water. Because agricultural production is essential to ensuring food availability, these results suggest that Guatemala needs a proper water-distribution regulatory framework.

Keywords: Agricultural employment; climate change; computable general equilibrium; farm household; farm input markets; natural resource

JEL Classification: R15, R22, Q12

1. Introduction

If water – one of the most important inputs in agricultural production – should become scarce, what would the impact be on a food-insecure country like Guatemala?

In recent years, shifts in precipitation and in water availability, along with increasing demographic pressures, have made the answer to this question particularly significant. Between 1950 and 2006, annual precipitation in Guatemala declined by 2.7 per cent, an effect which – combined with high deforestation – could worsen in the future (UNESCO, 2012).[1] At the same time, Guatemala's population grew at an annual

[1]In 2010, Guatemala had 3.72 million hectares of forest cover, equivalent to 34.7 per cent of the total land area. By 2015, the forest area was equivalent to 33 per cent of the total land area (FAO, 2017). Forests are important to the Guatemalan population because they are suppliers of wood, firewood, brushwood and other non-timber products. The causes of deforestation and degradation of forests in Guatemala are varied, reflected in the annual loss of 41,658.7 hectares of forest, which means an annual deforestation rate of 1.1 per cent (IARNA, 2012).

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rate of 2.0 per cent, one of the highest rates among countries in Latin America and the Caribbean (World Bank, 2016). That, in turn, places greater demands on food supply.

Guatemala is already facing food-insecurity challenges. Nationally, 46.5 per cent of children under five years of age live with chronic malnutrition, and the figure reaches 53 per cent in rural areas (MSPAS *et al.*, 2016). As of 2015, 15.6 per cent of Guatemala's population lived below minimum dietary levels, an increase from 14.9 per cent in 1991 (UN, 2016), evidence that the situation is not improving.

Food insecurity is linked to low yields in the production of grains, low investment in technology, and high transaction costs for local markets, as well as low wages and a high percentage of low-skilled workers in rural areas. In fact, yields for grains average 2.1 tons per hectare in Guatemala, below the Latin American average of 2.9 and the world average of 3.3 (FAO, 2017). A third of Guatemala's labor force is employed in agriculture, though only 6.8 per cent of these workers have formal jobs; the agricultural sector, meanwhile, makes extensive use of unskilled labor (INE, 2011). Furthermore, a high percentage of Guatemala's grain supply is imported, making Guatemala vulnerable to increases in world prices. In 2010, for instance, Guatemala imported 99.7 per cent of its wheat, 69.5 per cent of its rice, and 21.3 per cent of its corn. Rosegrant *et al.* (2014) showed that prices for these commodities will increase by 88, 79 and 104 per cent respectively by 2050. The implications of these projections for grain supply and food availability in Guatemala are worrisome. Even with elevated percentages of grain imports, a large portion of the population in rural areas grow maize for own consumption or buy locally-produced corn because they are disconnected from larger distribution networks that carry imports. According to the Living Standards Measurement Study (INE, 2011), smallholder farmers produced an average of 1,950 kg of white corn each during the last harvest, of which they set aside an average of 663 kg, or 34 per cent, for their own families' consumption. A total of 33 per cent of households in the country have some sort of agricultural production. Imports of this staple crop consist mainly of yellow sweet corn, which caters to a different target market of mainly urban consumers.

The main sources of water demand are agriculture, energy production, industries and human consumption. As the demand for water increases around the world, it is very likely that the availability of fresh water in many regions will decrease due to climate change. Global climate change is expected to exacerbate current and future stresses on water resources from population growth and land use and increase the frequency and severity of droughts and floods. It is anticipated that climate change will affect the availability of water resources through changes in rainfall distribution, soil moisture, glacier and ice/snow melt, and river and groundwater flows (UNESCO, 2013).

Scientists have largely explored the impact that climate change has on agriculture because 'water-related hazards account for 90 per cent of every natural hazard and their frequency and intensity is generally rising' (UNESCO, 2013). This means that spatial and temporal patterns of precipitation and water availability have been changing, and it implies more dry spells, droughts or floods across the world. These events could have socioeconomic effects as the increasingly erratic rainfall and high temperatures, among other factors, can significantly reduce food availability in low-latitude countries (IPCC, 2014).

In this paper, we focus on water availability for the agricultural sector because agricultural production is essential to ensure domestic food production. Climate variability

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may further restrict the supply of water to agriculture in light of Guatemala's insufficient investment in reservoirs and related infrastructure projects as well as its failure to protect natural areas that are important to fresh-water production. Between 1995 and 2014, Guatemala suffered more than most other countries from extreme weather events (Kreft *et al.*, 2015), which had and will continue to have an impact on agricultural yields. By 2030, corn yields are projected to vary between −6.7 and −3.8 per cent, bean yields from −6.9 to 1.5 per cent, and rice yields from −10.4 to −7.5 per cent (CEPAL, 2013).

Water-use regulation is lax in Guatemala, and public utilities and irrigation districts participate minimally in water supply, leaving various agents to procure water by private means, a process that means greater cost, greater uncertainty, and less efficient distribution. Vargas (2009) shows that while 78 per cent of urban and 43 per cent of rural households in Guatemala are connected to a water distribution network, they faced 4 to 5 days of water scarcity per month in the national average (in some rural areas up to 8 or 9 days) and 5 per cent of connected households have to buy water from a water tanker truck. According to the Ministry of Agriculture (MAGA, 2013), 236,243 hectares of arable land have a high need for irrigation and 895,257 hectares of agricultural land have a medium need for irrigation.

Low precipitation in some seasons means that, during sustained dry periods, water must be drilled for, pumped, diverted, and transported, all of which are expensive. Industries such as agriculture that use water more intensively face an important economic decision: whether to continue production or reallocate labor and capital to other industries despite the resulting impact on food production. Water availability is, therefore, crucial to Guatemala's economic development. To evaluate the impact of water scarcity on the Guatemalan economy, we implemented a computable general equilibrium (CGE) model that incorporated details of Guatemalan agriculture to provide a multidimensional answer to the potential effects of water scarcity. The model's general-equilibrium specification reflects Guatemala's economic structure and captures interactions among producers and consumers in a market-based economy. We assess the potential effects of a drop in agricultural productivity as a result of climate change (first scenario) or a severe drought (second scenario).

In this paper, we contribute to the literature with evidence regarding the impacts of climate change-related shocks on food availability in a developing and food-insecure country such as Guatemala.

2. Literature review

According to a comprehensive study conducted in Guatemala (IARNA *et al.*, 2015), food-security issues are a multidimensional problem, with various elements affecting food availability, access, and benefits.

Local researchers have not used CGE models to analyze the food-security situation, though non-CGE studies have been undertaken in the past (e.g. Palmieri and Delgado, 2011). CGE models can simultaneously evaluate various aspects of food-security problems, including food prices, income and expenditures, and the economy-wide implications of food policies (e.g. Rutten *et al.*, 2013). In general, applications of CGE models to the Guatemalan situation have been few. Vásquez (2008) applied an integrated macro-micro model to analyze Millennium Development Goals (MDG), and Cabrera and Delgado (2010) implemented the Model of Exogenous Shocks and Economic and Social Protection (MACEPES) to analyze the impact of external shocks on poverty and inequality.

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An increasing wealth of literature applies macro-models to assessments of climate change and food insecurity. Wiebelt *et al.* (2013), for example, examined local and global climate-change effects in Yemen, focusing on agricultural production, household income, and food security. They found that those hit hardest by losses were net buyers of food (even among food producers) and that, at the macro level, the positive effects of climate-change-mitigation efforts on yields and GDP were cancelled out by their cost. Montaud *et al.* (2017) applied macro-modeling to the effects of climate variability on agriculture in Niger and found that, although GDP and other economic indicators would all be affected negatively, investments in rural road infrastructure and modern crop varieties could offset those effects in part. Sudarshan *et al.* (2017) quantified the effects of climate change on the Nepalese economy, finding that the population's high dependence on subsistence farming increased poverty and further strained the social-welfare system. Finally, Sassi and Cardaci (2013) assessed the impact of changes in rainfall patterns on food availability in Sudan, finding a reduction in cereal supply, marked cereal-inflation pressure, and income contraction, with greater negative effects on the poorest households and a country-wide deterioration of economic performance.

Traditionally, CGE models of water-resource issues have analyzed the effects of restricting water use in agriculture and transferring water to the environment or other industries. Water is normally included as a fixed share of the value of land (e.g. Seung *et al.*, 1997), or as a factor of production that is calculated together with land in a fixed ratio in assessing agricultural crops (e.g. Berck *et al.*, 1990).

Other studies have considered water a commodity provided by an industry, which transforms 'raw' water into treated form (Tirado *et al.*, 2010; Juana *et al.*, 2011; Watson and Davies, 2011); in these cases, the water industry is viewed as a productive activity that provides treated water to other industries. These approaches, however, require that most of a country's water use be accounted for in water titles registered and monitored by regulators or as transactions between the water-producing industry and other users. In the case of Guatemala, some titles exist, but they do not represent most of the country's water use, which is for the most part unregulated. We therefore turned to Banerjee *et al.* (2016) and used an approach that links water used as an input to production with estimated changes in water stocks in a 'satellite account'. This paper contributes to the application of these developments to the case of a vulnerable, food-insecure country like Guatemala.

3. Model and data

3.1 Model

We applied a version of the PEP 1-1 Model developed by Decaluwé *et al.* (2013) with extensions for the inclusion of water based on Banerjee *et al.* (2016).[2]

Certainly, modelling water in an economy-wide framework poses its own set of challenges, particularly in the case of non-registered water, which is water that is not distributed by a water utility company and is used primarily by the agricultural sector. In our extension PEP-1-1, it is assumed that water not supplied by the water utility company and not subject to an economic transaction has, initially, a price of zero. Then, depending on supply and demand conditions, the price of water can become greater than zero.

[2]The model code, written in the GAMS language, and its Guatemalan dataset are available from the authors upon request.

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Mathematically, equations (1)–(7) show the treatment for water used in agriculture in the extended PEP-1-1 model.

$$\mathrm{WATD}_j = i\mathrm{wat}_j \cdot \mathrm{XST}_j \tag{1}$$

$$\mathrm{PP}_j \cdot \mathrm{XST}_j = \mathrm{PVA}_j \cdot \mathrm{VA}_j + \mathrm{PCI}_j \cdot \mathrm{CI}_j + \mathrm{PWAT} \cdot \mathrm{WATD}_j \tag{2}$$

$$\sum_j \mathrm{WATD}_j \le \mathrm{wats} \tag{3}$$

$$\mathrm{PWAT} \ge 0 \tag{4}$$

$$\left(\sum_j \mathrm{WATD}_j - \mathrm{wats}\right) \mathrm{PWAT} = 0 \tag{5}$$

$$\mathrm{YWAT} = \sum_j \mathrm{PWAT} \cdot \mathrm{WATD}_j \tag{6}$$

$$\mathrm{YIWAT}_{ag} = \mathrm{shrywat}_{ag} \cdot \mathrm{YWAT} \tag{7}$$

where

j: activities or industries with information on the use of unregistered water

CI_j: total intermediate consumption of industry j

PCI_j: intermediate consumption price index of industry j

PP_j: industry j unit cost

PVA_j: price of industry j value added

PWAT: water price

VA_j: value added of industry j

WATD_j: water demand

XST_j: total aggregate output of industry j

YIWAT_{ag}: institutional income from water

YWAT: total income from water

$i\mathrm{wat}_j$: water consumed per unit of output in industry j

$\mathrm{shrywat}_{ag}$: share of water income received by agent ag

wats: (exogenous) water supply

Equation (1) states that (unregistered) water use in agricultural – including crops and livestock – and non-agricultural sectors such as forestry and fishing is proportional to the corresponding output from agricultural sectors. Equation (2) shows the zero profit condition for the productive sectors, which includes payments for water used (see last term). Equations (3)–(5) represent the market equilibrium conditions in the unregistered water market. As shown, one of the following two situations can be observed: (i) water supply is larger than water demand and the price of water is zero, or (ii) water demand is equal to water supply and the price of water is positive.

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In the case of Guatemala, given the available information in the Guatemalan System of Environmental–Economic Accounting (SEEA),[3] it is assumed that water supply is initially larger than water demand and the price of water is zero. Then, as water supply decreases in a drought scenario, restriction (3) becomes binding and the price of water becomes positive. In turn, a positive price of water generates a cost for producers and income for water owners, as shown in equations (6) and (7). In practice, this additional cost may represent a cost of extracting underground water.

In model calibration, we assumed that water-derived income is allocated across institutions in proportion to their ownership of land, which is determined by the exogenous $shrywat_{ag}$ parameter in equation (7). Needless to say, income from water is added to other sources of institutional income. Besides, another effect resulting from reduction in water availability is a fall in total factor productivity (TFP).

At the macro level, our CGE model – like others – requires the specification of the equilibrating mechanisms ('closures') for three macroeconomic variables: government, savings-investment, and the balance of payments. In all simulations, the following macroeconomic closure rules are applied: (1) government consumption is adjusted to maintain a constant level of government savings[4] and to reflect difficulties which, in the Guatemalan context, would entail passing tax reforms; (2) foreign savings (the negative of the current account deficit) are fixed in foreign currency, an outcome that is achieved through changes in the real exchange rate; and (3) real gross fixed capital formation is fixed, and household savings are adjusted accordingly. In addition, we assume that both labor and capital are perfectly mobile across sectors.

3.2 Data

The Social Accounting Matrix (SAM) used in this study was constructed using four sources of information: an existing SAM for 2011 (Escobar, 2015), Supply and Use Tables (SUT) from the Central Bank of Guatemala (BANGUAT) for 2011 (BANGUAT, 2011); the relative structure of remunerations of capital and land found on the GTAP database; and the 2011 Living Standards Measurement Study (LSMS), the Encuesta Nacional de Condiciones de Vida or ENCOVI (INE, 2011). The disaggregation of our Guatemalan SAM coincides with that of the rest of the model database and, as shown in table 1, consists of eight activities and 32 commodities. The factors are split into unskilled and skilled labor, (private) capital, and natural resources (two types: agricultural land and other natural resources used in forestry, fishing, and extractive industries).

Using the 2011 LSMS (ENCOVI), households were classified into four types: rural poor, rural non-poor, urban poor, and urban non-poor. Poverty was determined using the official 2011 poverty line (INE, 2011). Information from the household survey allowed us to estimate labor income, consumption, and most transfers from other agents, according to each household type.

[3]SEEA is the first international standard for environmental–economic statistics (UN *et al.*, 2014). SEEA provides a connection between physical information about the environment and economic transactions in a way that is consistent with the definitions and classifications of the System of National Accounts.

[4]Although our assumption better reflects the reality of Guatemala, we are aware that it is difficult to conduct a welfare analysis given that government consumption is not a determinant of household utility. For welfare analysis, a closure with fixed government consumption and real savings would be preferable, using direct taxes to clear the government budget.

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Table 1. Commodity and economic activity and transaction aggregation for the micro SAM

Category	Item	Category	Item
Activities (7)	Agriculture	Products (32) – cont.	Sugar
	Livestock		Farinaceous products
	Forestry and fishing		Dairy products
	Other primary activities		Other food products
	Food processing		Beverages
	Other manufacturing		Other manufacturing
	Services		Electricity and water
Products (32)	Coffee		Hotels and restaurants
	Bananas		Other services
	Corn		Trade and transport margins
	Beans		Tax, activities
	Cereals and legumes		Subsidy, activities
	Roots and tubers		Tax, commodities
	Vegetables		Subsidy, commodities
	Fruit		Tax, imports
	Living plants		Tax, income
	Milk		Tax, factor income
	Eggs	Factors (5)	Labor, skilled
	Other animal products		Labor, unskilled
	Firewood		Capital
	Other forestry products		Land
	Fish and fishery products		Natural resources
	Minerals	Institutions (6)	Households, urban poor
	Meat and meat products		Households, rural poor
	Prepared and preserved fish		Households, urban non-poor
	Prepared and preserved vegetables		Households, rural non-poor
	Animal and vegetable oils and fats		Government
	Grain mill products		Rest of the world
	Preparations used in animal feeding		Savings-Investment
	Bakery products	Capital account (2)	Change in stocks

Source: Authors, with information from BANGUAT (2011).

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Along with the SAM, we estimated: (a) base-year employment by sector, (b) base-year water use, and (c) a set of elasticities (for production, consumption, and trade). In order to estimate employment by sector, we used the LSMS (ENCOVI) 2011 to disaggregate by activity and labor category (skilled and unskilled).[5] Thus, given the use of physical labor quantities for model calibration, our model assumes that factor remuneration can differ across activities. In other words, each activity pays an activity-specific wage.[6] For water use, we extracted estimates from the Guatemalan SEEA. In the Guatemalan SEEA, water flow accounts quantify the abstraction of water from the environment to the economy, the water flow within the economy in terms of supply and use by industries and households, and water flow back to the environment.

In turn, income elasticities of demand were estimated using microdata from LSMS (INE, 2011). For value-added elasticities, we used those provided by GTAP (Narayanan *et al.*, 2012). Finally, for production and for Armington and CET elasticities, we used Annabi *et al.*'s (2006) estimates for economies similar to that of Guatemala in terms of GDP per capita.

3.3 Guatemala's economic structure

From the SAM,[7] we extracted key features of the Guatemalan economy that help clarify the results of our simulations. The services sector contributes to more than 65 per cent of GDP, followed by industry and agriculture (table 2). Crop production uses more than 21 billion cubic meters of water, followed by forestry and fishing with 930.9 million cubic meters. Livestock and other primary activities use less, with 111.8 and 5.4 million cubic meters of water, respectively.

Food products (36.1 per cent) and other industries (15.4 per cent) make up the majority of exports. Coffee and bananas represent 9.2 per cent and 3.7 per cent of exports of agricultural products, respectively. A total of 68 per cent of coffee is exported (see table 2). The 'other manufacturing' category accounts for 80.2 per cent of total imports. Interestingly, the import-penetration rate is very high for cereals (more than 80 per cent). As a result of the importance of corn in the Guatemalan diet, it is important to emphasize that 29.4 per cent of the national consumption is covered by imports.

Table 3 shows the factor shares in total value-added by sector. For example, agriculture uses unskilled labor relatively intensively – 61.7 per cent of value-added represents payments to unskilled labor. In addition, agricultural sectors are obviously land users. On the other hand, manufacturing and services industries employ skilled labor relatively more intensively. In section 4, this information will be useful to analyze the results from the CGE simulations.

Generally speaking, households draw their income from labor, capital, land, other natural resources, and transfers. Poor urban households mainly receive income from unskilled labor (47.9 per cent), with skilled labor and capital income making up the remainder. Almost two-thirds of poor rural household income comes from unskilled labor; the remainder comes from remittances and transfers from the government. For non-poor rural households, labor income accounts for 61 per cent of total income: 41 per cent for unskilled and 20 per cent for skilled labor. For this group of households,

[5]Skilled workers are those with nine or more years of schooling.

[6]In fact, the PEP-1-1 model was also extended to allow for the use of physical – as opposed to efficiency – units for labor.

[7]For additional detail on the construction of the SAM, see Vargas *et al.* (2016).

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Table 2. Structure by sector (%)

Product	Value added	Production	Employment	Exports	Exports-output ratio	Imports	Imports-demand ratio
Coffee	1.6	1.2	4.1	9.2	95.0	0.0	0.4
Bananas	1.0	0.7	2.5	3.7	59.1	0.0	0.2
Corn	1.1	0.8	2.8	0.1	0.6	1.3	29.4
Beans	0.7	0.5	1.8	0.0	0.5	0.1	5.9
Cereals and legumes	0.1	0.1	0.2	0.0	1.2	1.2	84.0
Roots and tubers	0.5	0.4	1.3	0.1	1.6	0.0	1.2
Vegetables	1.6	1.1	4.0	3.8	21.3	0.0	1.1
Fruit	0.7	0.5	1.7	1.8	32.3	0.3	17.2
Living plants	1.4	1.0	3.6	1.2	17.6	0.7	15.7
Milk	0.2	0.2	0.3	0.0	0.0	0.0	0.0
Eggs	0.5	0.5	1.0	0.0	0.1	0.0	1.5
Other animal products	0.0	0.0	0.0	0.0	73.0	0.0	5.8
Firewood	0.3	0.3	0.8	0.0	0.0	0.0	0.0
Other forestry prod.	2.2	2.1	4.9	3.4	21.4	0.2	2.4
Fish and fishery prod.	0.2	0.2	0.5	0.6	42.6	0.1	22.8
Minerals	3.0	2.0	0.3	9.9	78.4	0.7	27.8
Meat & meat products	1.8	2.2	0.8	0.4	2.6	0.7	7.8
Prepared & preserved fish	0.1	0.1	0.0	0.3	38.2	0.2	52.6
Prepared and preserved vegetables	0.2	0.3	0.1	0.8	40.5	0.6	46.5

(continued.)

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Table 2. Continued

Product	Value added	Production	Employment	Exports	Exports-output ratio	Imports	Imports-demand ratio
Animal and vegetable oils and fats	0.7	0.8	0.3	2.7	48.3	1.9	52.8
Grain mill products	1.7	2.0	0.8	0.3	2.5	0.8	9.1
Preparations used in animal feeding	0.3	0.4	0.1	0.3	12.2	0.2	15.6
Bakery products	2.6	3.2	1.2	0.6	2.4	0.5	3.6
Sugar	1.4	1.7	0.7	5.5	44.7	0.0	0.1
Farinaceous products	0.2	0.2	0.1	0.2	13.4	0.1	9.2
Dairy products	0.7	0.8	0.3	0.1	1.5	0.8	20.3
Other food products	0.9	1.1	0.4	2.1	24.2	2.2	39.0
Beverages	0.3	0.5	0.3	0.9	21.9	0.3	16.1
Other manufacturing	8.8	14.2	9.1	36.1	30.3	80.2	65.6
Electricity and water	1.9	1.8	1.6	0.2	1.7	0.4	4.8
Hotels & restaurants	4.0	3.7	3.4	0.0	0.0	0.0	0.0
Other services	59.7	55.6	50.7	15.4	4.6	6.3	2.7
Total	100.0	100.0	100.0	100.0	13.1	100.0	22.5

Notes: VAshr, value-added share (%); PRDshr, production share (%); EMPshr, share in total employment (%); EXPshr, sector share in total exports (%); EXP-OUTshr, exports as share in sector output (%); IMPshr, sector share in total imports (%); IMP-DEMshr, imports as share of domestic demand (%).
Source: Authors' calculations.

Table 3. Factor intensity by sector (%)

Activity	Labor, skilled	Labor, unskilled	Capital	Land	Natural resources	Total
Agriculture	6.8	61.7	14.9	16.6	0.0	100.0
Livestock	6.5	59.4	16.1	18.0	0.0	100.0
Forestry and fishing	6.8	58.9	16.2	16.3	1.8	100.0
Other primary activities	7.1	25.2	40.1	0.0	27.6	100.0
Food processing	37.4	27.0	35.5	0.0	0.0	100.0
Other manufacturing	23.4	30.8	45.8	0.0	0.0	100.0
Services	33.7	19.4	47.0	0.0	0.0	100.0
Total	29.1	26.4	41.7	2.0	0.9	100.0

Source: Authors' calculations.

transfers from the rest of the world represent just under a quarter of their income. For urban non-poor households, capital income represents almost half their income, followed by skilled labor (30.3 per cent) and unskilled labor. Non-poor rural households are the main receivers of land income (40.4 per cent of total).[8] Remaining land income is distributed almost evenly across the other three household categories in the SAM.

Urban non-poor households account for 59.5 per cent of national consumption, and rural non-poor households account for just under one-fifth (18.1 per cent). National consumption by poor households accounts for 22.4 per cent of domestic consumption: 7.8 per cent for households in urban areas and 14.6 per cent in rural areas. Rural poor households spend 62.1 per cent of their income on consumption. The distribution of spending is different across households as shown in table 4. Indeed, for non-poor households, the proportion of food consumption is lower, specifically for urban non-poor households, where it represents less than a third (31.1 per cent) of total consumption.

4. Scenarios and results

4.1 Scenarios

In the first scenario (named **tfpagr**), we analyzed results from a simulation of reduced agricultural production of crops and livestock as a result of climate change. 'Climate change' is intended here to include changes in mean temperature, variability of climate, extreme events, water availability, mean sea-level rise, pests, and diseases (Gornall *et al.*, 2010). Specifically, and according to CEPAL (2013) estimates, we assumed a negative scenario of climate change in which the production of grains was reduced in corn, in beans, and in wheat.[9] Technically, and due to the lack of better data, we estimated a scenario in which the TFP of total agriculture production dropped by around 8 per cent.[10]

[8]When building the SAM, we used the LSMS ENCOVI 2011 to compute the distribution of factor incomes across our four household categories.

[9]This scenario assumes an increase in temperature by 3.5°C with a 30 per cent decrease in rainfall, which projects a fall in the yield of maize up to 34 per cent, of beans up to 66 per cent and of rice up to 27 per cent.

[10]Needless to say, this is a rough approximation, given that we cannot simulate a decrease in TFP that affects the production of selected crops.

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Table 4. Consumption composition of each household group (%)

Product	Urban, poor	Rural, poor	Urban, non-poor	Urban, non-poor
Coffee	0.0	0.0	0.0	0.0
Bananas	1.4	1.5	0.6	0.8
Corn	4.3	4.7	2.6	3.3
Beans	3.8	6.8	0.4	2.4
Cereals and legumes	0.2	0.3	0.1	0.1
Roots and tubers	2.4	2.5	1.0	1.5
Vegetables	7.0	7.4	3.0	4.9
Fruit	1.7	1.7	0.9	1.2
Living plants	0.2	0.2	0.2	0.2
Milk	0.1	0.0	0.3	0.1
Eggs	1.1	0.6	1.3	1.0
Other animal products	0.0	0.0	0.0	0.0
Firewood	1.3	1.2	0.8	0.9
Other forestry products	1.6	2.3	0.2	0.9
Fish and fishery products	0.5	0.7	0.1	0.3
Minerals	0.1	0.1	0.1	0.1
Meat and meat products	6.0	6.5	3.2	3.8
Prepared and preserved fish	0.3	0.3	0.2	0.2
Prepared & preserved vegetables	0.4	0.5	0.5	0.6
Animal & vegetable oils and fats	0.8	0.7	1.0	1.1
Grain mill products	5.3	5.1	2.5	3.5
Preparations used in animal feeding	0.2	0.3	0.1	0.2
Bakery products	4.8	11.1	6.8	9.4
Sugar	3.1	3.8	1.0	1.8
Farinaceous products	0.8	1.0	0.3	0.5
Dairy products	4.0	4.0	1.7	2.5
Other food products	2.4	1.5	2.4	2.2
Beverages	1.5	1.2	1.0	1.2
Other manufacturing	22.5	18.7	23.0	21.9
Electricity and water	1.0	0.8	1.0	1.0
Hotels and restaurants	8.4	5.2	6.5	5.3
Other services	12.8	9.3	37.3	27.3
Total	100.0	100.0	100.0	100.0

Source: Authors' calculations.

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Table 5. Real macro-indicators (percentage change from base)

Item	Base year[a]	tfpagr	Drought
Absorption	410,834	−1.1	0.7
Private consumption	316,528	−1.4	0.1
Fixed investment	54,910	0.0	0.0
Government consumption	37,803	−0.6	6.0
Exports	98,783	−2.0	0.4
Imports	138,605	−1.5	−0.2
GDP	371,012	−1.2	0.9
Real exchange rate	1	1.8	7.6

Notes: [a]In this column, the unit is one million quetzales except for the real exchange rate, which is indexed to 1.
Source: Authors' calculations.

Specifically, this fall in TFP was estimated using the coefficients obtained in Letta and Tol (2016) for annual TFP growth rates and temperature changes in poor countries (table 7, page 34) combined with the variations reported in CEPAL (2013: 25–26).

In the second scenario (named **drought**), we simulated the effects of a drought that would reduce unregistered water availability for agricultural and non-agricultural activities by 25 per cent. In fact, according to estimates on the total renewable availability of water for Central America conducted by CEPAL (2011), in a scenario where the current trend of increasing emissions is maintained,[11] the temperature could increase between 3.6 and 4.7°C, with a regional average of 4.2°C. For Guatemala, this would mean a 25 per cent reduction in water availability by the year 2050. Unfortunately, information on total water is unknown for Guatemala. Thus, we assumed that total demand was close to 90 per cent of total supply in the base year. We also had no specific basis for estimating a change in water price because Guatemala does not currently have a market for this resource. The results indicate the likely effects of drought on economic activity, however.[12] Because of dependence on rainfall for irrigation and lack of investment in irrigation systems, both scenarios are highly relevant for Guatemala.

4.2 Results

In the first scenario, we assumed that climate change would have negative effects on agricultural productivity. As expected, under the climate-change scenario, we found negative results in production and exports of crops and livestock and in wages, as well as a drop of 1.2 per cent in real GDP (see tables 5 and 6). Moreover, a drop in production and consumption of agricultural goods and industrial foods increased food insecurity as measured by the value of food production and consumption (see figure 1 and table 7). Interestingly, in order to compensate for the decrease in TFP, employment in agriculture increased. As a result, given that agricultural production tends to use unskilled labor, we found that the decrease in wages was relatively larger for skilled than for unskilled workers. Lower productivity would translate into less competitiveness in international

[11]CEPAL estimated water availability using the TURC method (1954), including the difference between rainfall and evapotranspiration (CEPAL, 2011: 103–104).

[12]The sensitivity analysis of results is included in Vargas *et al.* (2016).

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Table 6. Exports and imports by product (percentage change from base)

	Exports			Imports		
Product	Base year*	tfpagr	Drought	Base year*	tfpagr	Drought
Coffee	6,578	−19.2	−64.5	1	3.8	31.3
Bananas	2,521	−12.7	−44.2	4	6.3	43.9
Corn	29	−20.1	−68.5	1,871	6.5	41.5
Beans	14	−4.6	−18.6	176	0.8	8.9
Cereals and legumes	4	−18.2	−66.0	1,707	−0.1	8.2
Roots and tubers	35	−21.1	−70.9	25	2.0	20.9
Vegetables	1,438	−16.3	−63.8	59	−0.7	5.0
Fruit	932	−20.4	−69.7	380	1.7	19.1
Living plants	1,075	−26.3	−78.1	934	4.6	40.0
Eggs	3	−26.8	140.0	42	3.7	−10.6
Other animal products	27	−19.9	98.9	1	3.2	−6.2
Other forestry products	2,635	−2.8	22.5	242	−0.1	−3.0
Fish and fishery products	400	43.9	−23.8	158	−3.6	6.9
Minerals	9,445	5.8	36.8	939	−2.8	−5.9
Meat and meat products	335	0.1	8.9	997	−2.7	−5.8
Prepared and preserved fish	194	1.5	15.1	335	−1.6	−4.3
Prepared & preserved vegetables	671	1.1	13.3	814	−1.4	−1.7
Animal & vegetable oils and fats	2,314	3.0	25.8	2,700	−1.8	−0.7
Grain mill products	298	0.2	8.1	1,141	−0.9	0.9
Preparations used in animal feeding	270	−4.9	19.8	340	−11.1	15.7
Bakery products	455	0.5	9.1	686	−1.1	0.3
Sugar	4,638	0.8	12.1	7	−2.0	−3.8
Farinaceous products	151	0.6	10.3	91	−2.3	−5.8
Dairy products	75	0.8	11.0	1,145	−2.1	−5.0
Other food products	1,539	1.0	12.6	3,008	−1.6	−2.7
Beverages	667	1.1	11.0	381	−2.1	−4.5
Other manufacturing	25,639	1.2	12.6	111,119	−1.6	−0.8
Electricity and water	174	2.0	15.2	516	−1.3	1.1
Other services	15,182	1.3	11.2	8,787	−2.9	−6.5

Notes: *In this column, the unit is one million quetzales.
Source: Authors' calculations.

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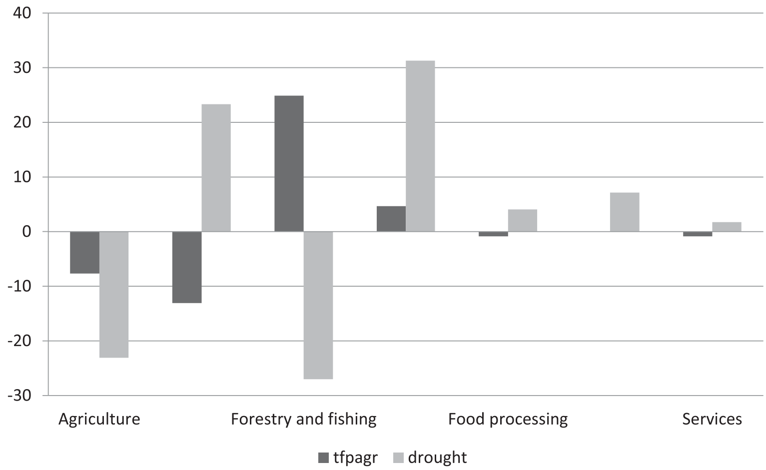

Figure 1. Value-added by sector (percentage change from base)
Source: Authors' calculations.

markets: goods such as corn, beans, and root and tuberous vegetables showed a lower decrease in output compared to exported products such as coffee, bananas, and fruit. Overall, exports would fall in real terms by 2 per cent, even though a depreciation of the real exchange rate would reduce negative effects.

In all cases, given the reduction of domestic output, demand for agricultural products would be partly covered by an increase in imports. In terms of food security (see figure 2), the tfpagr scenario showed an increase in the cereal imports dependency ratio.[13] In fact, at base-year prices, the share of imports in the overall consumption of cereals increased by 1.9 percentage points. Moreover, another food security indicator such as the value of food (excluding fish) imports over total merchandise exports[14] also shows a negative behavior. Specifically, it increased from 16.7 in the base year to 17.0 in the tfpagr scenario.

As a result of the decrease in output, the simulation also showed a reduction in fiscal space. As a consequence, and given the clearing mechanism selected for the government budget, government expenditures would have to be reduced in view of lower tax revenues which, in turn, would make less income available to households and decrease consumption.

As a result of higher prices and lower household income, moreover, lower agricultural productivity translated into a decrease in consumption of agricultural goods for each household type (see table 7). Interestingly, corn consumption would only fall in rural areas; in urban areas, the demand for this product is inelastic. The results of this scenario could affect food security for Guatemala's most vulnerable citizens, however. The consumption of beans, which are also important to the Guatemalan diet, decreased

[13] It is computed as (cereal imports − cereal exports)/(cereal production + cereal imports − cereal exports) × 100. It tells how much of the available domestic food supply of cereals has been imported and how much comes from the country's own production (FAO, 2017).

[14] Following FAO (2017), this indicator captures the adequacy of foreign exchange reserves to pay for food imports, which has implications for national food security depending on production and trade patterns.

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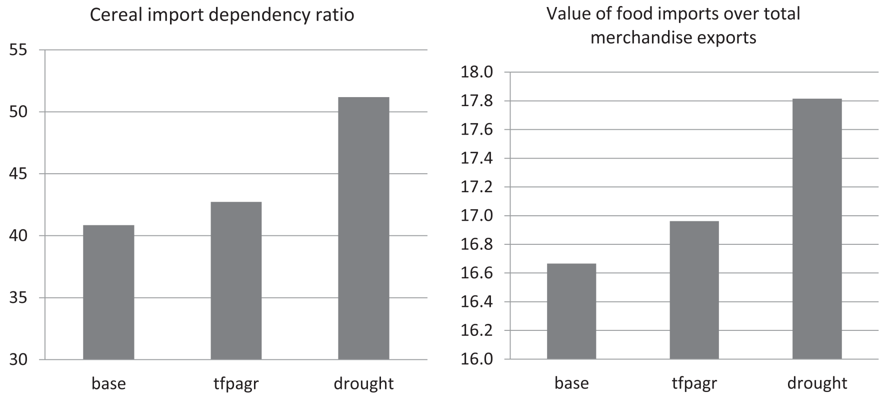

Figure 2. Food security indicators (%)
Source: Authors' calculations.

for all types of households. Again, this behavior resulted from higher prices combined with a decrease in income for all household categories. In terms of income inequality, and given the change in factor incomes described above, urban households showed the largest drop in income (note, too, that urban households have a larger endowment of skilled labor).

In the second scenario, we assessed the effects of a water shortage or drought on agricultural and non-agricultural industries such as forestry and fishing. In our base-year data, water use was concentrated in forestry and fishing and in agriculture (59 per cent of total water use). Thus most negative effects of this shock would be concentrated in these labor-intensive activities. At the macro level, we noted positive effects on output and private consumption.

In this scenario, the decrease in agricultural output promoted the movement of labor out of agriculture (crops) and into activities with higher wages. Specifically, employment in overall agriculture decreased by 16.6 per cent while employment in manufacturing and services increased by 11.2 and 6 per cent, respectively. In addition, once water became scarce, its price became a positive number, also increasing the income of households endowed with land – particularly rural non-poor households. In addition, given the decrease in agricultural output as a result of the decrease in water availability, land rents decreased. Not surprisingly, we also observed a rise in the cost of agricultural production.

Compared to the TFP scenario, the negative effects of drought on forestry and fishing and on agriculture were greater (see figure 1). Additionally, livestock production rose because the use of water in this sector is lower than it is in agriculture. In base-year data, livestock production did not make significant use of water[15]; intuitively, then, as water became scarcer, there would be a shift toward industries with relatively lower water demands and a respective increase in value-added in those industries. In fact, land would also shift from crop production to livestock. As mentioned, this

[15]Specifically, its use of water per quetzal of value added was 2 per cent that of crop production – i.e., 0.7 versus 0.02 cubic meters of water per quetzal of value added.

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Table 7. Food consumption by household category (percentage change from base)

	tfpagr				Drought			
	Urban, poor	Rural, poor	Urban, non-poor	Urban, non-poor	Urban, poor	Rural, poor	Urban, non-poor	Urban, non-poor
Coffee	−1.8	−1.5	−2.1	−1.3	−0.8	−3.4	−5.6	−0.6
Bananas	−2.3	−1.9	−2.8	−1.8	−2.8	−4.8	−7.9	−3.1
Corn	0.0	−1.1	0.0	−0.8	0.0	−1.9	0.0	0.9
Beans	−0.8	−1.1	−0.9	−0.9	−0.2	−2.4	−2.4	−0.1
Cereals and legumes	−1.8	−1.9	−1.9	−1.2	2.1	−2.6	−3.6	4.1
Roots and tubers	−2.0	−2.0	−2.3	−1.6	−0.4	−4.3	−6.0	0.0
Vegetables	−2.2	−1.9	−2.4	−1.4	0.5	−3.8	−5.8	1.3
Fruit	−2.2	−1.8	−2.4	−1.4	−0.2	−3.7	−6.2	0.3
Living plants	−2.0	−2.0	−2.3	−1.8	−1.8	−4.8	−6.5	−2.3
Milk	−1.8	−1.5	−2.1	−1.4	4.2	0.6	0.5	5.5
Eggs	−2.5	−2.1	−2.9	−1.8	6.0	0.7	0.6	8.0
Other animal products	−1.1	−1.0	−1.3	−0.8	2.5	0.0	−0.3	3.6
Firewood	0.0	−0.2	0.0	0.2	−0.1	−0.8	0.2	1.4
Other forestry products	0.1	−0.6	0.1	−0.4	−0.3	0.0	0.0	2.8
Fish and fishery products	−0.6	−0.4	−0.4	0.1	1.2	−1.2	−2.2	1.8
Minerals	−0.6	−0.6	−0.5	0.0	3.3	0.8	0.6	6.4
Meat & meat products	−1.9	−1.5	−1.8	−0.7	5.0	−0.8	−1.8	7.2

(continued.)

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Table 7. Continued.

	tfpagr				Drought			
	Urban, poor	Rural, poor	Urban, non-poor	Urban, non-poor	Urban, poor	Rural, poor	Urban, non-poor	Urban, non-poor
Prepared & preserved fish	−1.0	−0.8	−1.0	−0.4	2.2	−0.6	−1.2	3.4
Prepared & preserved vegetables	−1.1	−1.1	−1.1	−0.6	2.7	−0.7	−1.3	4.5
Animal & vegetable oils and fats	−2.0	−1.7	−2.0	−1.0	3.9	−1.6	−2.8	6.1
Grain mill products	−1.0	−0.7	−1.0	−0.4	2.6	−0.4	−1.0	3.3
Preparations used in animal feeding	−0.8	−0.8	−0.7	−0.1	2.2	−1.2	−1.7	4.3
Bakery products	−1.2	−1.2	−1.2	−0.6	3.4	−0.5	−1.1	5.9
Sugar	−0.7	−1.0	−0.7	−0.4	2.3	−0.2	−0.4	5.8
Farinaceous products	−1.3	−1.2	−1.2	−0.6	3.4	−0.6	−1.1	6.0
Dairy products	−1.3	−1.0	−1.3	−0.5	3.3	−0.6	−1.4	4.4
Other food products	−1.3	−1.1	−1.3	−0.6	3.0	−0.8	−1.4	5.0
Beverages	−1.2	−0.9	−1.1	−0.3	4.0	−0.1	−0.6	5.6
Other manufacturing	−2.6	−1.9	−2.6	−1.0	6.2	−1.4	−3.1	8.5
Electricity and water	−1.4	−0.8	−1.3	−0.3	4.7	−0.2	−1.0	4.9
Hotels and restaurants	−1.1	−0.7	−1.0	−0.2	3.9	−0.1	−0.6	4.4
Other services	−1.3	−1.1	−1.2	−0.4	4.7	−0.2	−0.7	6.9

Source: Authors' calculations.

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shock would be favorable to other industries and services that do not rely on water consumption.

In this scenario, we also observed a sharp increase in the prices of agricultural and food products, especially bananas, roots and tubers, and beans, because a small share of these products is imported and a low degree of substitution exists between local and imported goods. Given the decrease in domestic output of agricultural products, moreover, we also observed an important increase in imports of food products. Therefore, in terms of food security this scenario shows a significant increase in the share of agri-food consumption covered with imports. In fact, both food security indicators reported in figure 2 showed large increases. For instance, the cereal import dependency ratio increased from 40.9 in the base year to 51.2 in the drought scenario. In turn, the value of food imports over total merchandise exports increased by 1.1 percentage points.

Not surprisingly, agricultural exports also decreased. Thus, given their relevance as a source of foreign exchange (see table 2), we saw a depreciation of the real exchange rate required to maintain the current account balance fixed in foreign currency. In fact, given the substitution of imported food products for local ones, depreciation of the real exchange rate helped to contain increased demand for imports and improved the performance of exports for non-agricultural products (see table 7).

Overall, this scenario imposes considerable risk to food security of households that live in rural areas – i.e., to the population with the highest levels of poverty and malnutrition – who depend on their own production of food products. Indeed, our results show a decrease in food output combined with an increase in the relative price of food products.

5. Conclusions

There is consensus that climate change poses an imminent risk to development in countries around the world, but there are few analyses of its potential impact. This study provides some insights into the effects of climate risks for Guatemala. Specifically, we evaluated the impact that droughts would have on growth, household income, and food security, and we found that the most negative effects would be concentrated in agriculture because of its use of water. In fact, our results show a sharp increase in prices of agricultural and food products. Given the decrease in domestic output of food products, in addition, imports of food products would increase. Consequently, a drought scenario would impose considerable risks to food security.

In addition, we simulated a reduction in agricultural productivity related to climate change. In this case, we found negative results in production and exports of agriculture and a drop of 1.2 per cent in real GDP. Interestingly, employment in agriculture increased in order to compensate for the decrease in productivity. In turn, as a result of higher food prices and lower household income, indicators of food security deteriorated.

Our results also show the relevance of creating a legal framework to govern water resources. Guatemala could consequently draw from the experience of Australia which, because of its history of megadroughts, has reformed its water-distribution system. First, federal and state governments reached an agreement (the Intergovernmental Agreement on a National Water Initiative) to create a national water market. The idea behind this distribution system was that 'water entitlements are expressed as a share of the available resource rather than as a specified quantity of water' (Peel and Choy, 2014).

In short, despite Guatemala's National Irrigation Policy, the framework is incomplete because no water-distribution system exists that prioritizes strategic economic activities

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as a guarantee of food security. Our results suggest the importance of correctly managing natural resources such as agricultural land and water. In fact, given Guatemala's large rural population, natural resources can support development and have a positive impact on the life of the country's citizens. Without proper policies, frameworks, and oversight, however, negative shocks arising from climate change have the potential to produce significant negative effects.

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