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Abstract

Climate change may have devastating effects on agricultural productivity and food security, impacting significantly the poorest households. In this study, we analyse the effect climate change is expected to have on agricultural productivity, caloric consumption, and vulnerability to food insecurity of household agricultural producers in Paraguay. Our results suggest that increasing temperatures and reduced precipitation will reduce agricultural productivity and caloric consumption, and increase vulnerability to food insecurity. Specifically, a 1 percent increase in average maximum temperatures is associated with a 5 percent reduction in agricultural productivity. A 5 percent reduction in agricultural productivity translates into nearly a 1 percent reduction in caloric consumption. Vulnerability to food insecurity in Paraguay is expected to increase by 28 percentage points by 2100 due to climate change, increasing fastest in areas where temperatures are increasing and rainfall is diminishing. We estimate that improvements in infrastructure, farm technology, and education may reduce nearly half of the expected future adverse effects of climate change on household vulnerability to food insecurity. With current climate trends in Paraguay, policy makers will need to prioritize and tailor adaptive and mitigating interventions to the needs of the different geographical locations of the country.

Keywords: climate change, agriculture, productivity, food insecurity, Latin America.

JEL codes: Q12, Q18, Q54.

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1 Introduction

Continued increases in greenhouse gas emissions are predicted to contribute to the warming of the Earth by 3°C this century (UNFCCC, 2007). Increases in global temperatures may have profound effects on agricultural productivity and food security, particularly impacting the poorest households in developing countries that lack the resources to adapt (UNFCCC, 2007). Climate change is not only expected to affect the dynamics of agricultural production, but also increase extreme weather events and pose a risk to biodiversity (CEPAL, 2014). Climate change can affect countries in different ways, and can have different impacts within countries. To prepare for the potential impacts of climate change and to guide public policies, policy makers require information on the likely impact of climate change and the locations within the country that will be more severely affected.

An increasing number of studies are emerging, which seek to understand the effects of climate change. In particular, several studies have focused on understanding the impact of climate change on food security in developing countries. Capaldo *et al.* (2010) proposes a methodological framework in order to assess the impact of climate change on agricultural productivity and food security in Nicaragua. Other studies follow this framework to examine the impact of climate change on food security in countries like Nicaragua and Peru (Karfakis *et al.* 2011; Anríquez and Toledo, 2016). However, the potential impact in different regions and countries is not clear (Wheeler and von Braun, 2013). This leads to an urgent need to understand the potential impact of climate change in a specific country context.

The objective of this study is to assess the impact of climate change on food security of agricultural households in Paraguay. This is a developing, landlocked country situated in the middle of South America, whose sub-tropical weather is ideal for agriculture and cattle raising. Its economy is highly dependent on these two activities, making it highly vulnerable to climate change.

In this study, the analysis follows previous methodological frameworks developed to assess climate change on agricultural productivity (Karfakis *et al.* 2011; Anríquez and Toledo, 2016). The existing studies provide a conceptual model that can be adapted to estimation with Paraguayan household survey data to understand how household caloric consumption and food insecurity may respond to climate change and weather shocks, and the location where negative impacts may be the largest. The methodological framework developed in these studies relates caloric consumption and food insecurity to climate change through climate change's impact on agricultural yields and agricultural income.

To empirically study the relationship between climate change and food insecurity, we appeal to the Instrumental Variables methodology. Using data drawn from household surveys and climate data from the National Meteorology and Hydrology Institute (DINAC), we first estimate the effects of rainfall and temperatures on agricultural productivity, using these variables as instruments, and then we estimate climate change's impact on caloric consumption and food insecurity through its effect on agricultural productivity.

The results obtained suggest that climate change will significantly affect food security by lowering agricultural productivity and income, hence, increasing vulnerability to food insecurity in Paraguay. Furthermore, the analysis at the geographical level indicates that risk to food insecurity will increase faster where temperatures are increasing faster. In particular, the departments of San Pedro, Caaguazú, and Alto Paraná are expected to be the most affected.

This information is useful as it can help policy makers to prioritize and tailor adaptive and mitigating interventions to the needs of the different geographical locations of the country.

The remainder of this study proceeds as follows. Section 2 provides an overview of Paraguay and discusses the related literature. Section 3 discusses the climate trends in Paraguay and Section 4 describes the data and methods used in this study. Section 5 presents the results of estimating climate variations on household agricultural productivity and caloric consumption. Section 6 explores climate change projections and simulates the potential effect climate change will have on agricultural households in the future. Section 7 concludes the study.

2 Paraguayan context and related literature

Paraguay is a landlocked country located near the Southern Cone region in South America, bordered by Brazil, Argentina and Bolivia. The country is rich in natural resources. It is home to the biggest hydroelectric power dam and the largest drinking water reservoir in the world. Paraguay's economy is dominated by the agricultural sector, and its main export products are in agriculture and livestock. Despite the country's relatively small population of approximately 7 million, Paraguay is the sixth largest producer of soy and the eighth largest exporter of beef in the world (FAO, 2017).

Paraguay has the largest rural population of South America, with approximately 40 percent of its population residing in rural areas (DGEEC, 2002). Poverty is highly concentrated in rural areas. As of 2016, about 40 percent of the rural population was in poverty, while 12 percent was in extreme poverty, based on national poverty lines (DGEEC, 2016).

Paraguay's sub-tropical climate in the Oriental Region (southern part of the country) permits agricultural production 12 months of the year (Ferreira and Vázquez, 2015). While the Occidental Region (northern part of the country), also known as the Chaco, is mostly characterized by a tropical climate. The divergent climates in these two regions have resulted in agriculture being practiced mostly in the Oriental Region, while the Occidental Region concentrates cattle raising. The most important crops for the economy are soy, corn, wheat, and more recently, rice, which are mostly cultivated by business agriculture (Servin and Rojas Viñales, 2014; Ferreira and Vázquez, 2015). Among these, soybean cultivation stands out in terms of quantity produced, logistics, and value chain (Ferreira and Vázquez, 2015). Family agriculture, however, cultivates primarily beans, cassava, corn, and sugar cane among other products used primarily for own consumption.

Given the high dependency of the Paraguayan economy on agriculture, and its currently limited ability to mitigate agricultural risks (Arce and Arias 2015), economic growth has been historically volatile. In fact, the country had one of the most volatile economies in Latin America between 2001 and 2011 (Koehler-Geib, Mustafaoglu, Caballero Cabrera, *et al.*, 2014). Although economic growth has been relatively stable in recent years.

The social, economic, and demographic characteristics of Paraguay make this country particularly sensitive to changes in climate. For instance, there is a high correlation between the Gross Domestic Product (GDP) and soybean production (Ferreira and Vázquez, 2015). In years where droughts affected soy production, the negative effects have been reflected in the contraction of the economy, such as in 2009 and 2012, where the GDP decreased by 4 percent and 1.2 percent, respectively (Ferreira and Vázquez 2015). Therefore, it is important to understand how climate will affect agricultural production and food insecurity in Paraguay, so that the country can be better prepared to mitigate and adapt to the effects of climate change.

A limited, but rapidly growing, number of studies exist that explore the effects of climate change on agriculture and food security. Early studies analysed food security in a static way; however, Capaldo *et al.* (2010) indicate that this type of analysis fails to provide policy makers with forward-looking information. These authors propose a model of vulnerability analysis that considers the dynamics of food insecurity, and test their model with data from Nicaragua. The results provide estimates of the probability that a given household will lose or gain access to sufficient food in the near future. In another study, Karfakis *et al.* (2011) simulate the impact of expected temperature changes on farm level productivity, and on household food consumption in Nicaragua. These authors find that climate change will significantly impact vulnerability to food security, and that social protection measures and farm-level adaptations strategies can help reduce vulnerability, although not eliminate it. In this same line, Anríquez and Toledo (2016) analyse the implications of climate change in the design of public policies to combat food insecurity in Perú.

In the case of Paraguay, CEPAL (2014) analyses the economic effects of climate change on the macroeconomy of Paraguay. This study shows that temperatures and rainfall will likely increase by 2040, and continue to increase until the end of this century, affecting most of the country. While this is the only study on the impact of climate change on the Paraguayan macroeconomy, the present study seeks to assess the impact of variations in temperatures and precipitations on farm-level productivity and household food consumption, in order to obtain a better idea about the impact of climate change on household agriculture production and food insecurity.

3 Evolution of climate in Paraguay

Paraguay's subtropical climate is ideal for agricultural production, however, volatile and extreme weather conditions in the past have negatively affected agricultural production. This in turn has impacted economic growth due to the country's high dependency on the agricultural sector (Koehler-Geib *et al.*, 2014).

Rainfall and temperatures, weather indicators, are important factors that affect crop yields (Skoufias and Vinha, 2013). Thus, the analysis of the variability of climate is highly relevant to understand the effects that climate change can have on food insecurity (Ray *et al.,* 2015). To examine rainfall and temperatures in Paraguay, we first identify two seasons based on the historical cumulative rainfalls patterns. These seasons are named the *wet season*, and the *dry season*, and are defined as described in Table 1 below. The wet season covers the months between June though January. While, the dry season runs from February to May.

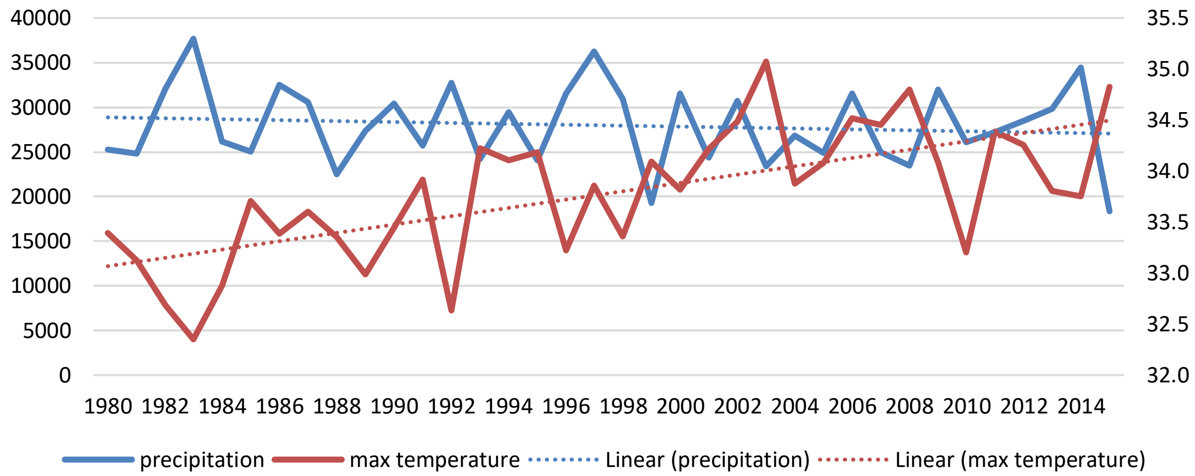
Table 1. Average cumulative rainfall by month in Paraguay, 1980–2015 (milliliters)

Year$_t$						***Year$_{t+1}$***					
June	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**
2 291.3	2 652.2	2 727.2	2 621.2	2 927.7	2 742.1	2 450.5	2 480.4	1 966.4	1 798.0	1 829.6	1 926.9
Wet season								Dry season			

Source: Authors' calculations based on downscaled weather data provided by DINAC.

Figure 1 shows the evolution of monthly average cumulative rainfall and monthly average maximum temperature for the period between 1980 and 2015, nationally.

Figure 1. Evolution of cumulative rainfall and average maximum temperature in Paraguay 1980–2015

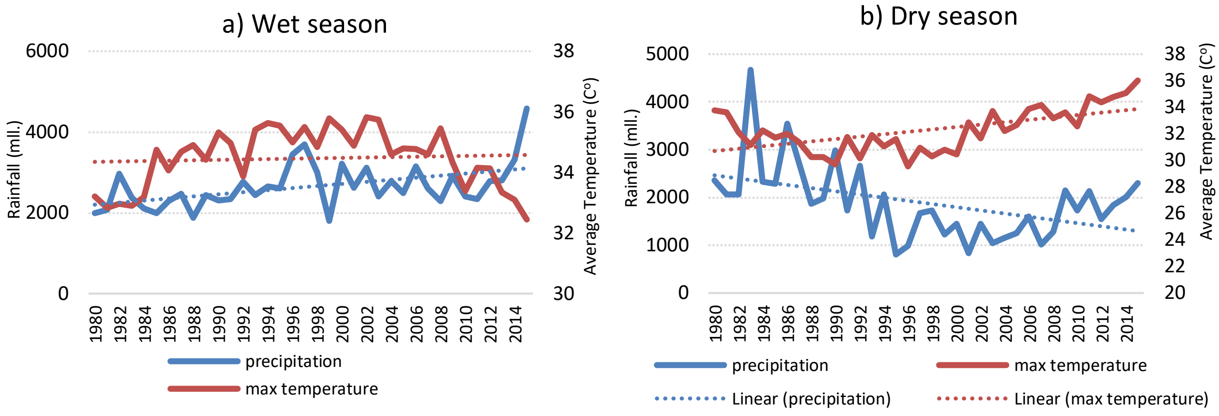


Source: Authors' calculations based on downscaled weather data provided by DINAC.

In Figure 1 we observe a positive trend of maximum temperature over the period. While in the case of cumulative rainfall, the trend seems slightly negative between 1980 and 2015.

Figure 2 presents trends in precipitation and maximum temperatures by season. We observe that monthly average cumulative rainfall in wet seasons has increased, while precipitation has declined in dry seasons over the 1980 to 2015 period.

Figure 2. Evolution of cumulative rainfall and average maximum temperature in Paraguay 1980–2015 by season

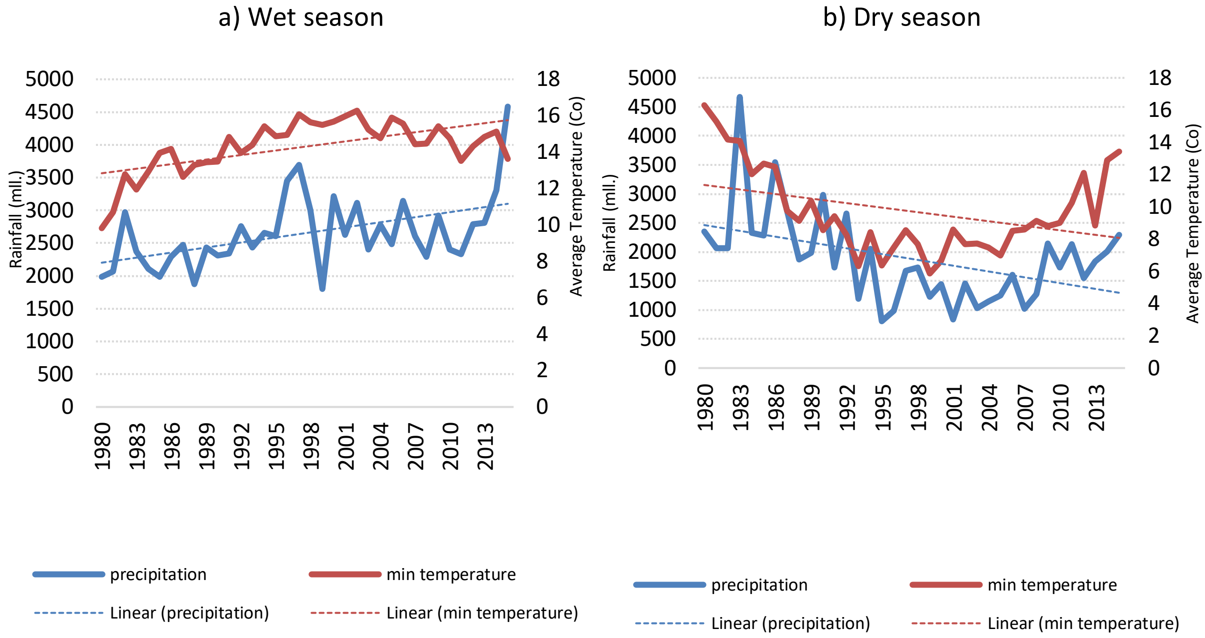


Source: Authors' calculations based on downscaled weather data provided by DINAC.

Furthermore, in the case of dry season, we observe that precipitation is falling while maximum temperatures are increasing. This is of particular interest as this combination may be increasing the probability of experiencing droughts. In fact, more extreme temperatures and low precipitation can prevent crops from growing and reduce yields (EPA, 2016). In Paraguay droughts have been particularly harmful for the economy (Ferreira and Vázquez 2015).

Regarding minimum temperatures, marked patterns can also be seen. Panel (a) of Figure 3 shows the evolution of minimum temperatures as well as cumulative rainfalls for the wet season. In this season, minimum temperatures have increased on average, over the period between 1980 and 2015. In contrast, minimum temperatures in the dry season show a negative trend in most of the years, but with an increasing trend in the last few years of the period.

Figure 3. Evolution of cumulative rainfall and average minimum temperature in Paraguay 1980–2015 by season

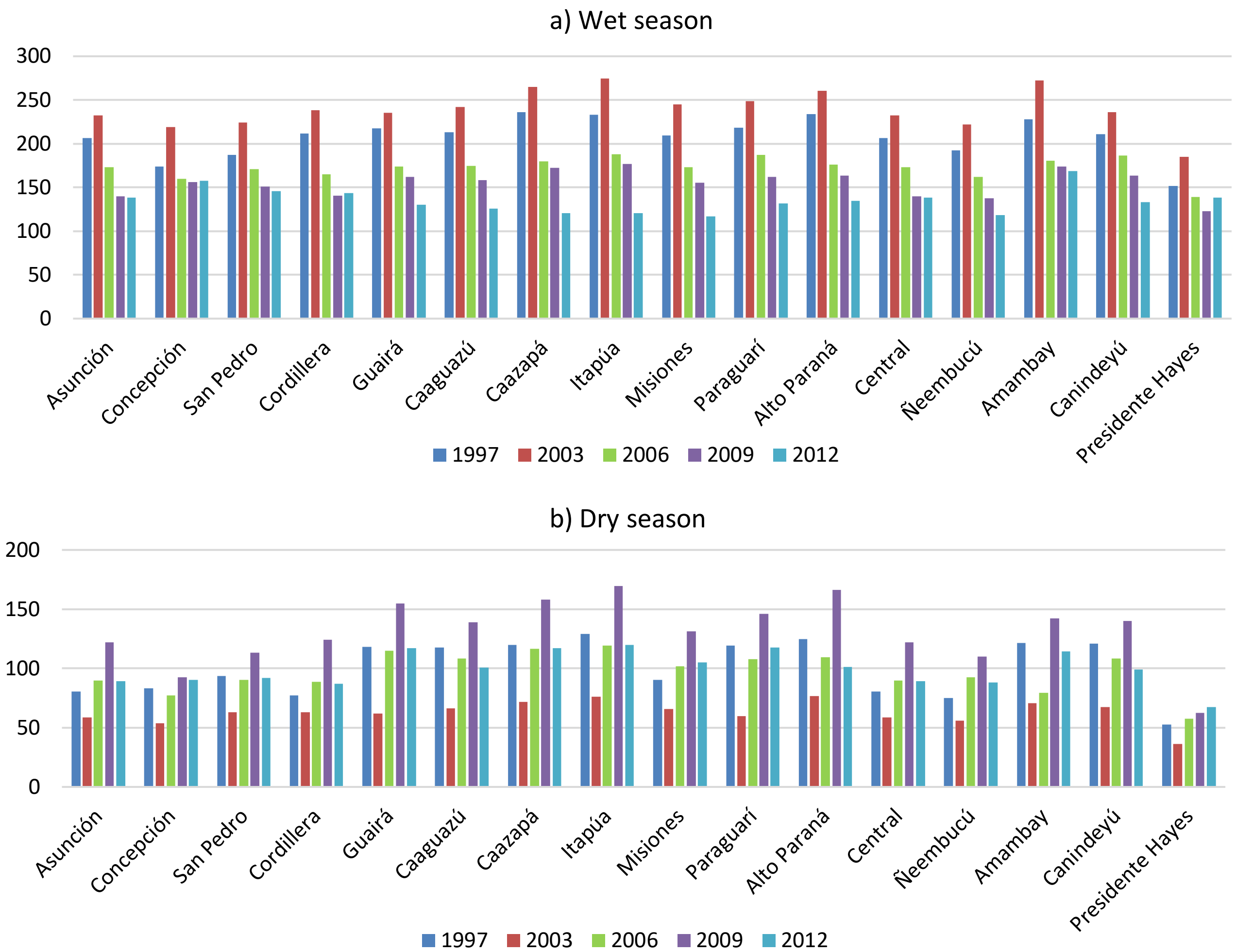


Source: Authors' calculations based on downscaled weather data provided by DINAC.

The spatial distribution of rainfalls and temperatures throughout the country is an additional factor to consider. Figure 4, panel (a) shows average cumulative precipitation per department by year in the wet season, while panel (b) displays the same for the dry season. An important finding of this analysis is that weather trends tend to be consistent across departments. For example, in all departments rainfall in the wet season was highest in the year 2003. This consistency was also observed in temperatures.

In general, the observed climate data show that wet seasons are getting wetter with relatively lower temperatures in recent years. In contrast, dry seasons are becoming drier with higher temperatures in more recent years. This combination may be increasing the probability of floods in the wet season and droughts in the dry season.

Figure 4. Average cumulative rainfalls (mm) per department - year season



Source: Authors' calculations based on downscaled weather data provided by DINA.

4 Data and methods

In this section, we introduce the methodology used to assess the impact of climate change on food insecurity in Paraguay. This is followed by a description of the data and the sample used in the study.

4.1 Data

In order to assess the impact of climate change on food insecurity, we match weather data to household survey data. We pool data from five national household surveys. These are the Encuesta Integrada de Hogares 1997/98, the Encuesta Permanente de Hogares 2003, 2006, and 2009, and the Encuesta de Ingresos y Gastos y Condiciones de Vida 2011-2012. The Encuesta Integrada de Hogares 1997/98 is the precursor to the Encuesta Permanente de Hogares and similar to the Encuesta de Ingresos y Gastos y Condiciones de Vida 2011-2012 contains additional modules on household consumption and expenditure. Each survey contains identical survey modules on housing, education, health, labour, income, and agriculture, as well as identical sampling and survey methodologies.[1] Each survey is representative at the national and subnational levels and comparable across survey rounds.

The decision to pool data from multiple household surveys was made to better capture variation in the weather data. Figure (4) above shows that weather trends are common across departments. Performing the analysis on one survey round might provide results that are driven by a lack of variation in climate across departments and lead to the erroneous conclusion that changes in climate variables have no significant impact of agricultural productivity. We further describe the household survey and the weather data in the following sections.

Food consumption and household demographics

In Paraguay, while there is a number of data sources available, only two household surveys contain the necessary information to calculate caloric consumption and caloric requirements, agricultural productivity and agricultural income. These are 1) the "Encuesta Integrada de Hogares 1997/98" and 2) the "Encuesta de Ingresos y Gastos y de Condiciones de Vida 2011–2012" (EIG 2011/12). Both surveys are nearly identical and include modules on employment, income, living conditions, agricultural production, and caloric consumption.

In order to better capture the effects of climate on agricultural production, we complement the data from the surveys above, with data drawn from three additional household surveys, the "Encuesta Permanente de Hogares" (EPH) for the years 2003, 2006, and 2009. These surveys are similar to the surveys described above, but do not contain data on caloric consumption. The household agriculture production, employment, and living condition modules are identical across surveys, have similar sampling methodologies, and data appear comparable across surveys. Therefore, household agricultural productivity is estimated using data from all five rounds of household surveys. Each of these surveys is nationally representative and sub-nationally representative of areas (rural/urban) or departments (Asunción, San Pedro, Caaguazú, Itapúa, Alto Paraná, Central, and "Rest"- a grouping of the remaining 12 departments except for Alto Paraguay and Boquerón in the North).

[1] Surveys were also administered in the same season (around October to February in the following year).

The final dataset contains data from 10,554 household for the years 1997, 2003, 2006, 2009, and 2012. The sample is restricted to agricultural households. The list of the variables incorporated in the models, and their definitions are shown in Table A1 (Annex). In addition, a complete set of descriptive statistics is presented in Table A2 (Annex) along with descriptive statistics by each survey year in Table A3 (Annex). All datasets are publicly available from the Paraguayan National Statistics Office (DGEEC).[2]

Weather data

The weather data were obtained from the National Direction of Meteorology and Hydrology (DINAC). The data used were downscaled by departments for the purposes of this study. In particular, we focus on department level data on precipitation and maximum and minimum temperatures.

More specifically, we use seasonal cumulative precipitation and seasonal average maximum and minimum temperatures. Mean temperatures were also available, however, after performing several diagnoses based on non-parametric graphical analyses of the relationship between weather variables and agricultural productivity and Goodness-of-Fit measures, such as R squared, and considering the characteristics of the climate in Paraguay, we use only maximum and minimum temperatures, along with precipitation, in the empirical analysis to reduce collinearities.

4.2 Methodology

The impact of climate change on food insecurity in Paraguay is estimated following Capaldo *et al.* (2010) and Karfakis *et al.* (2011). In these studies, the authors propose the term vulnerability as the likelihood a household will experience food insecurity in the future. To this end, we estimate climate change's effect on caloric consumption through its effect on household agriculture productivity. The estimated parameters are then used to explore household vulnerability to food insecurity.

The empirical estimation of vulnerability to food insecurity faces several challenges, namely endogeneity and heteroskedasticity. The problem of endogeneity arises because the agricultural productivity is correlated with food consumption (Karfakis *et al.*, 2010). To address endogeneity, we apply the Instrumental Variables (IV) methodology. This methodology requires a set of instruments that should be correlated to agricultural productivity but not to caloric consumption. Because climate is exogenous to the farmer and mostly affects caloric consumption through agricultural productivity and income, climate variables appear to be valid instruments.

To estimate vulnerability to food insecurity due to climate change, we apply 2 Stage Least Squares (2SLS). We first regress the value of agricultural production on a set of climate instruments, in addition to other variables, such as demographic characteristics of the household and head characteristics, among others. The climate instruments consist of seasonal cumulative precipitation and maximum and minimum temperatures, which are exogenous to household agricultural producers. In the second stage, we estimate a model of caloric consumption per capita and its variance using the predicted value of agricultural productivity obtained in the first stage along with other variables, while omitting the climate

[2] Dirección General de Estadistica, Encuestas y Censos (DGEEC) (see www.dgeec.gov.py).

instruments (seasonal cumulative precipitation and maximum and minimum temperatures). Finally, to address the problem of heteroskedasticity, we weight observations in accordance with their estimated variance.[3]

The estimations are performed using the pooled sample of data. This allows us to account for time effects with a series of dummy variables for survey years, as well as time invariant department characteristics with a series of dummy variables for departments with Asuncion as the base department.

After estimating the set of equation in (1), vulnerability to food insecurity is then defined as the probability that household *j* may experience a shortfall of caloric consumption or caloric deficit conditional on household characteristics such that,

$$V_j = p\left[\left(\ln \hat{K}_j - \ln K_j\right) > 0\right], \tag{2}$$

where $\hat{K}_j$ is the predicted caloric consumption per capita for household *j,* and K_j is the caloric requirement per capita for household *j*. Following the assumption that the logarithm of food consumption is normally distributed, estimated vulnerability to food insecurity is provided by

$$\hat{V}_j = \frac{1}{\sqrt{2\pi\hat{\sigma}^2_{\varepsilon,j}}} \exp\left\{-\frac{\ln \hat{K}_j - \ln K_j}{2\hat{\sigma}^2_{\varepsilon,j}}\right\}, \tag{3}$$

where $\hat{\sigma}^2_{\varepsilon,j}$ is the estimated variance of household per capita caloric consumption.

Equipped with the fixed parameter estimates from the set of equations in (1), policy simulations can be performed by simulating values of household characteristics in the matrix X_j and/or weather variables in the matrix W_j and estimating household agricultural productivity $\hat{A}_j$, household per capita caloric consumption $\hat{K}_j$, the variance of caloric consumption $\hat{\sigma}^2_{\varepsilon,j}$, and, finally, vulnerability to food insecurity $\hat{V}_j$.

[3] See Annex A1 for additional details on the methodology.

5 Results

In this section we present the regression results for the set of equations (1). A key result of our study is that increases in maximum temperatures are associated with reducing agricultural productivity and that reduced agricultural productivity translates into lower caloric consumption. Specifically, we find that a 1 percent increase in maximum temperatures reduces agricultural productivity by about 5 percent, and that a 5 percent reduction in agricultural productivity is associated with nearly a 1 percent decrease in caloric consumption. We find that a number of inputs and socioeconomic factors are associated with higher household agricultural productivity and caloric consumption. We then perform select policy simulations on vulnerability to food insecurity to explore how improvements in socioeconomic characteristics may offset increased vulnerability to food insecurity due to climate change.

5.1 Regression results

Table 2 presents three sets of results. First, we present the results for weather variables and agricultural inputs—the instruments affecting caloric consumption and vulnerability to food insecurity indirectly through their effect on agricultural productivity. Second, we present the results of the effect of household socioeconomic and demographic characteristics on productivity and caloric consumption. Third, we explore the relationship between agricultural productivity and caloric consumption.

The first stage regression results provide evidence that increases in temperatures are negatively associated with agricultural productivity. Specifically, the results indicate that a 1 percent increase in maximum temperature decreases productivity by about 5 percent (5.6 percent in wet seasons, and by 4.9 percent in dry seasons). High temperatures may reduce crop productivity, development, and reproduction, when temperatures exceed the crop's optimal temperature range, which varies crop-to-crop (Hatfield and Prueger, 2015), and this appears to be the case in Paraguay.

Increases in cumulative precipitation in the dry season are positively associated with productivity, for example a 1 percent increase in precipitation is associated with a 0.58 percent increase in agricultural productivity, and this result is statistically significant at conventional levels. In the wet season, however, increases in cumulative precipitation are negatively associated with agricultural production, but this effect is not statistically significant.

With respect to inputs, both expenditures in agricultural inputs as well as in livestock are positively related to agricultural production, and these results are statistically significant at conventional levels. A 1 percent increase in expenditures of agricultural inputs increases productivity by 0.1 percent, while a 1 percent increase in livestock expenditure increases productivity by 0.03 percent. Households with access to farm technology, e.g. those that own sprayers and seeders, have, on average, higher levels of productivity as well, and both effects are statistically significant.

Socioeconomic characteristics of the household have different effects on agricultural productivity and caloric consumption. Larger households tend to be more productive, suggesting each member contributes to agricultural production. However, each member tends to consume less calories, indicating that larger households may have less access to food. Households with more children under the age of 5 consume less calories and this effect, while small, is statistically significant, suggesting children in agricultural households may be particularly vulnerable to food insecurity. Education plays a differential role in household productivity and caloric consumption. Increasing the average years of schooling of male household members increases agricultural productivity. Whereas increasing the average years of schooling of female members is associated with consuming more calories. This may be associated with the different roles males and females play in the household. Finally, more exposure to agriculture, e.g. household head's primary occupation in agriculture, increases agricultural productivity, but lowers calories consumed. None of these variables were statistically significantly related to the estimated variance of caloric consumption.

Variables that are proxies for community infrastructure, such as piped water and access to transportation are positively related to agricultural productivity. For instance, having access to water inside the house or on the property increases the productivity of the household by over 12 percent compared to households without access to water on the property. Having access to transportation (automobile, truck, or motorcycle) is associated with a 10 percent increase in productivity versus not having a means of transportation. These variables, however, were not statistically significantly, directly related to caloric consumption.

The second stage regression results provide evidence that agricultural productivity is positively associated with household caloric consumption. Specifically, a 1 percent increase in agricultural productivity is associated with a 0.19 percent increase in caloric consumption, and this effect is statistically significant beyond the 1 percent significance level. This finding links climate, and other variables that are statistically related to agricultural productivity, such as technology and inputs, indirectly to caloric consumption through their effect on agricultural productivity. Households that are more productive appear to use the income earned on agricultural production to purchase and consume more calories. For example, owning a sprayer is associated with a 17 percent increase in agricultural productivity. This increase in agricultural productivity is associated with an increase in household caloric consumption by over 3 percent.[4] These results imply that agricultural households could partly offset the negative effects of climate change on productivity by increasing input expenditures and technology adoption. The effect of select policy options on household vulnerability to food insecurity are explored in the next section.

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[4] Such calculations are performed using the parameter estimates in Table 2. For example, the parameter estimate on owning a sprayer is 0.171. Thus, households with sprayers are approximately 17.1 percent more productive than those without given the natural log functional form on the dependent variable. The parameter estimate on agricultural productivity suggests a 1 percent increase in productivity is associated with a 0.186 percent increase in caloric consumption. Therefore, 17.1*0.186=3.18 percent more calories.

Table 2. Selected results

	Log value of ag prod./ha.		Log of calories per capita		Var. of log of food cons. pc	
	Coeff.	t - stat	Coeff.	t - stat	Coeff.	t - stat
Natural log of household agriculture production per hectare			0.186***	(4.77)		
Natural log of household size	0.138***	(2.63)	-0.358***	(-12.01)	-0.1050	(-0.55)
Members under 5 years old (%)	0.0002	(0.13)	-0.00261***	(-3.51)	0.0009	(0.15)
Members between 6 and 15years old (%)	-0.0003	(-0.26)	-0.0006	(-1.09)	-0.0005	(-0.09)
Members over 65 years old (%)	-0.0013	(-1.08)	-0.0004	(-0.66)	0.0016	(0.38)
Female members (%)	-0.0005	(-0.53)	-0.00118**	(-2.31)	-0.0027	(-0.88)
Natural log of average schooling years of adult females	0.0355	(1.04)	0.0648***	(3.11)	-0.0299	(-0.27)
Natural log of average schooling years of adult males	0.0726**	(2.28)	-0.0289	(-1.38)	0.0903	(0.67)
Natural log of age of household head	0.152**	(2.15)	-0.0473	(-1.13)	0.0720	(0.28)
Head female	-0.0351	(-0.64)	0.0520*	(1.92)	0.0823	(0.60)
Head works in agriculture	0.143**	(2.54)	-0.171***	(-5.91)	-0.0642	(-0.45)
Natural log of rooms per person	0.0357	(0.85)	0.0586**	(2.37)	0.1100	(0.54)
Household water access inside the house	0.188***	(2.94)	-0.0205	(-0.54)	-0.3930	(-1.55)
Household water access on the property	0.124***	(2.62)	0.0061	(0.21)	-0.2290	(-1.29)
Household has transportation	0.101**	(2.33)	0.02640	(1.14)	0.1760	(1.30)
Natural log of livestock tropical unit	0.0166*	(1.81)	0.00326	(0.56)	-0.0325	(-1.23)
Natural log of sown land	-0.215***	(-14.71)	0.0665***	(6.69)	0.0014	(0.04)
Natural log of input expenditure	0.100***	(8.35)				
Natural log of livestock expenditure	0.0252***	(2.73)				
Share of agricultural income	0.636***	(5.03)				
Household owns sprayer	0.171***	(4.63)				
Household owns seeder	0.0840**	(2.13)				
Natural log of cumulative precipitation in the WET season	-0.286	(-1.02)				
Natural log of cumulative precipitation In the DRY season	0.580***	(2.91)				
Natural log of maximum temperature In the WET season	-5.606**	(-2.14)				
Natural log of maximum temperature In theDRY season	-4.854**	(-2.11)				
Natural log of minimum temperature In theWET season	-0.322	(-0.34)				
Natural lof of minimum temperature In the DRY season	0.935***	(3.10)				
R^2	*0.16*		*0.275*		*0.0286*	
Number of observations	*10 554*		*3 332*		*3 332*	
F test	17.28		24.38		1.706	

Notes*:* * p<0.1, **p<0.05, ***p<0.01. Covariates in all regressions include a full set of dummy variables for departments (states), dummy variables capturing whether households are composed by only males or only females, dummy variables for employment status of the household head, and household assets. All variable definitions are presented in Table A1 (Annex). Full regression results are presented in Table A4 (Annex).

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

5.2 Policy simulations on vulnerability to food insecurity

Table 3 presents several policy simulations and their average effect on vulnerability to food insecurity. All policy simulations are based on improvements over baseline levels observed in 2012.

Table 3. Policy simulations and reductions in vulnerability to food insecurity

Policy	Improvement over baseline (2012) household characteristic[b]	Reduction over baseline (2012) vulnerability[c]
All houses have sprayers	(1-0.263)=0.73	(0.226-0.197)=0.029
All houses have seeders	(1-0.236)=0.764	(0.226-0.208)=0.018
All houses have access to transportation	(1-0.638)=0.362	(0.226-0.208)=0.018
All houses have access to water at least on property[a]	(0.503-0.414)=0.089	(0.226-0.214)=0.012
All adults complete at least 6 years of education.	[Female] (7.26-6.06)=1.2 yrs. [Male]: (7.36-6.43)=0.93 yrs.	(0.226-0.199)=0.027
Total		**0.103**

Notes: [a] Policy simulation adds access to water on the property to households with water access off property. Houses with access to water inside the house are not changed. [b] (Policy mean – 2012 mean) = Improvement. [c] (2012 mean – Policy mean) = Reduction.

Source: Authors calculations based on household survey data (DGEEC) and climate data (DINAC).

Technology has a large positive impact on agricultural productivity and agricultural income, which ultimately reduce vulnerability to food insecurity. Increasing the proportion of houses with sprayers and seeders by 0.73 and 0.764, respectively, increases agricultural productivity and reduces vulnerability to food insecurity by 0.029 and 0.018, respectively. This means that if all houses had seeders and sprayers vulnerability to food insecurity would be reduced by 4.7 percentage points on average, i.e. vulnerability to food insecurity would be reduced for 1 household in every 20. If the proportion of households with access to transportation increased by 0.362, so that all houses had access to transportation, the probability a household will lose access to sufficient food in the future would further be reduced by 0.018, or rather vulnerability to food insecurity would be reduced by 1.8 percentage points. Increasing access to water on the property also improves agricultural productivity and reduces vulnerability to food insecurity by 1.2 percentage points. Finally, if all household adults completed at least 6 years of schooling, average years of schooling would increase by about a year of schooling (1.2 years for females and 0.93 years for males). Such increases in education are expected to reduce the probability a household loses access to sufficient food by 0.027, or 2.8 percentage points.

In total, by improving agricultural technology adoption, improving infrastructure (water and transportation), and education, policy makers could reduce vulnerability to food insecurity by

10.3 percentage points, on average, and reduce the risk of falling into food insecurity for 1 in every 10 households. As is shown in the next section, climate change is expected to increase household vulnerability to food insecurity nationally by 8 percentage points by 2050 and by 28 percentage points by 2100. Thus, such policies will become increasingly important to reduce the future impacts of climate change.

6 Climate change projections and simulations

In this section we present simulation results of a hypothetical climate change scenario, in which all climate variables follow a linear trend estimated for each season and department using climate data over the 1980 to 2015 period (see Figures A1 to A3 in the Annex). Specifically, we simulate changes in climate variables according to this climate change scenario, while holding all the remaining variables in the model at their 2012 mean values and apply the parameter estimates from the regressions presented in Section 6 (see Tables A3 to A5 in the Annex).

Table 4 summarizes the climate change scenario used in the simulation. Based on the historical weather data, cumulative precipitation in the wet season is expected to increase by 70 mm per department by 2100, increasing fastest in the central east and slowest in the northwest. In the dry season cumulative precipitation is expected to decline by 65 mm per department by 2100, decreasing the fastest in the central east and slowest in the southwest. The expected changes in maximum and minimum temperatures by 2100 and their intensity by region are also shown in Table 4.

First, the simulation results indicate that agricultural productivity will monotonically decrease, as a consequence of variations in climate. The results shown in Figure 5a imply that if actions to adapt and mitigate the potential effects of climate change are not taken, climate change will negatively affect agricultural production. Similarly, the effects of climate change are expected to negatively affect caloric consumption, due to the loss in agricultural productivity (Figure 5b). Lastly, the simulation results indicate that the risk to food insecurity will increase as a result to climate change. These results represent the risk that households are expected to be exposed, absent interventions aiming at adapting and mitigating the effects of climate change.

Table 4. Climate change scenario used in simulations. Median national change and intensity by region

Variable	National		Intensity by region	
	Median change to year 2100	**Region range** [min, max]	**Minimum**	**Maximum**
Precipitation (in millilitres, wet season)	70	[40 to 80]	Northwest (e.g. Boquerón)	Central east (e.g. Canindeyú)
Precipitation (in millilitres, dry season)	-65	[-83 to -46]	Central East	Southwest (e.g. Ñeembucú)
Maximum temperature (C^0. wet season)	1.5	[0.55 to 2.5]	Southwest	Central east
Maximum temperature (C^0. dry season)	6.9	[4 to 15]	Southeast (e.g. Itapúa)	Northeast (e.g. Alto Paraguay)
Minimum temperature (C^0. wet season)	8	[4 to 11]	Northwest	North central (e.g. Amambay)
Minimum temperature (C^0. dry season)	-0.79	[-1.15 to -0.5]	Southwest	North central

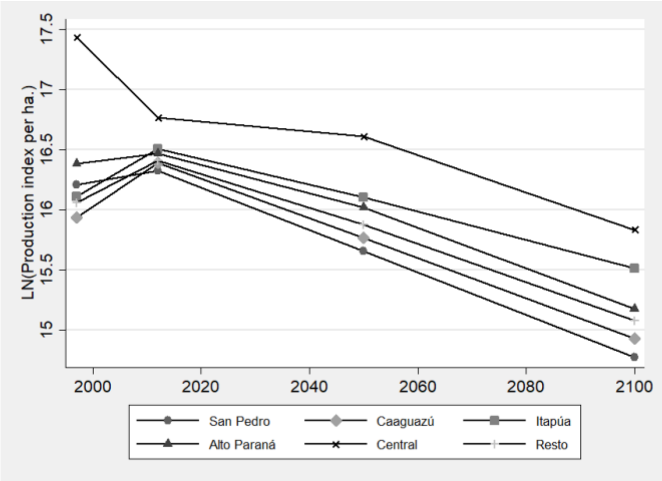
Note: Changes in climate variables are based on linear trends estimated for each season and department using climate data over the 1980 to 2015 period (see Figures in the Annex). The table reports expected changes in maximum and minimum temperatures and their intensity by region. For example, cumulative precipitation in the wet season is expected to increase by 70 mm per department by 2100, increasing fastest in the central east and slowest in the northwest.

Source: Authors' calculations based on downscaled weather data provided by DINAC.

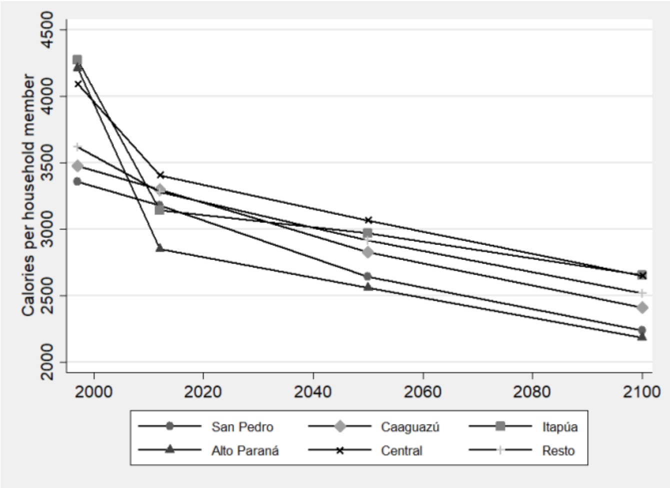
The analysis of the simulation results by departments indicate that weather patterns will result in differences in the intensity of the effects of climate change. Figure 6 shows the maps of caloric consumption for three years: 2012 (based on observed data), and estimations for 2050 and 2100. While all departments in the country are expected to see increased vulnerability to food insecurity due to climate change, the departments of San Pedro, Caaguazú, and Alto Paraná are expected to be the most affected, due to temperatures increasing faster in these regions. By 2100 nearly 60 percent of all household agriculture producers in these departments are expected to be at risk of suffering from food insecurity due to climate change. And other agricultural households throughout the country are expected to face a significant increase in the risk to food insecurity due to climate change.

Figure 5. Simulation results: agricultural production index, caloric consumption and vulnerability

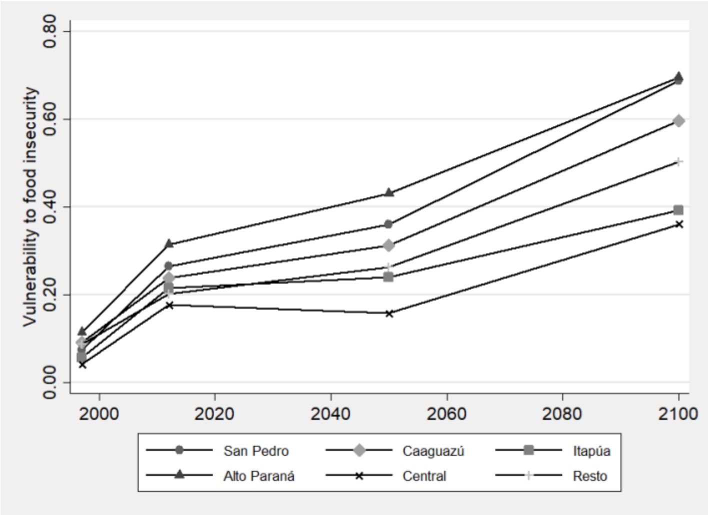
a) Agricultural production index



b) Caloric consumption



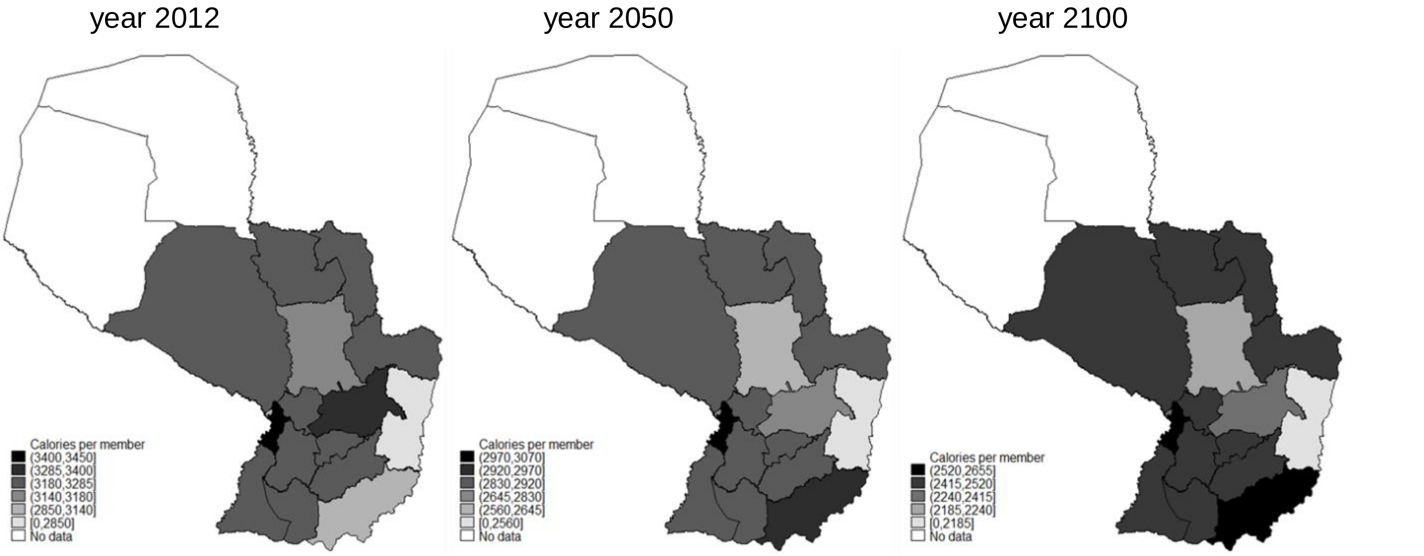
c) Vulnerability



Note: 1997 and 2012 based on observed data.

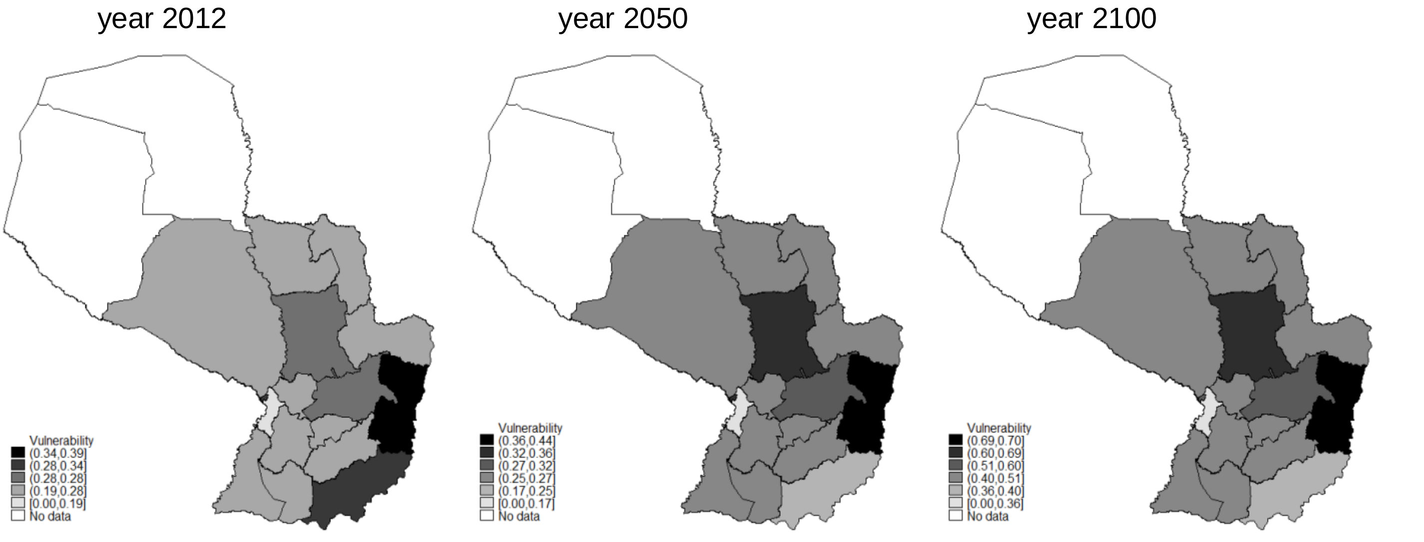
Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

Figure 6. Simulation results: maps of consumption of calories



Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

Figure 7. Simulation results: maps of vulnerability



Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

7 Concluding remarks

In this study, we find evidence that climate change is expected to have a significant negative impact on household agriculture and food security in Paraguay. If current climate trends of increasing temperatures and reduced precipitation continue, climate change is expected to lower household agricultural productivity and reduce income from household agricultural production. Households with lower income will purchase and consume less calories, increasing vulnerability to food insecurity. We estimate that climate change is expected to increase household vulnerability to food insecurity nationally by 8 percentage points by 2050 and by 28 percentage points by 2100.

Vulnerability to food insecurity will increase fastest in departments where temperatures are expected to increase faster, but reduced precipitation will also play a role. In particular, San Pedro, Caaguazú, and Alto Paraná are expected to be the most affected with over 60 percent of agricultural households expected to be at risk of food insecurity due to climate change by 2100, if action is not taken.

Our findings represent an urgent call for the design and implementation of policies to manage future risks to climate change. Our results suggest improving education, transportation infrastructure, access to water, and promoting adoption of farm technology may have a large, positive impact on agricultural productivity, increasing income derived from household agricultural production, and ultimately reducing vulnerability to food insecurity. Specifically, simulation results suggest adoption of sprayers and seeders alone may reduce vulnerability to food insecurity by nearly 5 percentage points, on average, and improvements in education could further reduce vulnerability to food insecurity by 2.8 percentage points. Furthermore, transportation infrastructure improvements could reduce vulnerability by 1.8 percentage points, while improving access to water is associated with an additional 1.2 percentage point reduction in vulnerability to food insecurity.

Our simulation results suggest that by following a multipronged strategy of promoting agricultural technology adoption, improving infrastructure (water and transportation), and education, policy makers may be able to reduce nearly half of the expected future adverse effects of climate change on household vulnerability to food insecurity, nationally. Further improvements may be possible by tailoring adaptive and mitigating interventions to the specific needs of the different geographical locations of the country.

Finally, our study focused on the effect of climate change on agricultural production, but climate change will likely directly impact livestock producers as well. Livestock is important to the livelihoods of many Paraguayans. Thus, we anticipate that climate change will have an even more severe impact on the Paraguayan economy than described in our analysis. Long-term planning, regional targeting, and climate change adaptation and mitigation programs will need to be developed to overcome the future challenges of climate change.

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Annexes

Annex A1. Methodology notes

Specifically, we estimate the following set of equations:

$$\begin{aligned} K_j &= \alpha + \beta_1 X_j + \gamma A_j + d_k + t_k + \varepsilon_j \\ A_j &= \theta + \beta_2 X_j + \psi W_j + d_A + t_A + e_j \ , \\ \sigma^2_{\varepsilon,j} &= \lambda + \beta_3 X_j + d_\varepsilon + t_\varepsilon + u_j \end{aligned} \quad (1)$$

where K_j is household per capita caloric consumption of household *j*, X_j is a vector of various household characteristics, A_j is agricultural productivity, W_j is a matrix of weather variables influencing agricultural productivity, and $\sigma^2_{\varepsilon,j}$ is the variance of household per capita caloric consumption. ε_j, e_j, and u_j are idiosyncratic error terms and $\alpha,\theta,\lambda,\beta_1,\beta_2,\beta_3,\gamma,\psi$ are the parameters to be estimated. The parameters *d* and *t* in the set of equations in (1), are dummies for departments and survey year, respectively.

Table A1. List of variables and their definitions

Variables	Definition
Household demographics	
Natural log of household size	Natural log of number of members of the household
Members under 5 years old (%)	Number of household members under 5 years old as a share of total number of members in percentage
Members between6 and 15 years old (%)	Number of household members between 6 and 15 years old as a share of total number of members in percentage
Members between 16 and 65 years old (%)	Reference category
Members over 65 years old (%)	Number of household older than 65 years old as a share of total number of members in percentage
Female members (%)	Number of females as a share of total number of members in percentage
Natural log of average schooling years of adult females	Natural log of average years of education of female adults in the household
Natural log of average schooling years of adult males	Natural log of average years of education of male adults in the household
Male adults only	Dummy variable. Equals 1 if the household has only male adults
Female adults only	Dummy variable. Equals 1 if the household has only female adults
Farmer characteristics	
Head female	Dummy variable. Equals 1 if the head of the household is female
Head works in agriculture	Dummy variable. Equals 1 if the head of the household works in agriculture
Natural log of age of household head	Natural log of age of household head
Head employed	Dummy variable. Equals 1 if household head is employed
Head unemployed	Dummy variable. Equals 1 if household head is unemployed
Head inactive	Reference category

Variables	Definition
Head owner	Dummy variable. Equals 1 if household head is a business owner or employer
Head Guarani	Dummy variable. Equals 1 if the household head is monolingual Guarani
Head bilingual	Dummy variable. Equals 1 if the household head is bilingual in Spanish and Guarani
Housing characteristics	
Natural log of rooms per person	Natural log of of rooms per person
Household water access inside the house	Dummy variable. Equals 1 if household has water access inside the house
Household water access on the property	Dummy variable. Equals 1 if household has water access on the property
Household water access off the property	Reference category
Household has refrigerator	Dummy variable. Equals 1 if household has refrigerator
Household has television	Dummy variable. Equals 1 if household has television
Household has antenna	Dummy variable. Equals 1 if household has antenna
Agricultural inputs	
Natural log of sown land	Natural log of sown land in hectares
Natural log of input expenditure	Natural log of total agricultural input expenditures, which includes expenditures on seed, plants, and part of plants, insecticides and fungicides, and fertilizers
Natural log of livestock expenditure	Natural log of total livestock expenditures, which includes expenditures on vaccines and veterinary products, mineral supplements for animals, processed food for animals, and corn
Natural log of livestock tropical unit	Natural log of number of animals in livestock tropical unit
Share of agricultural income	Agricultural income as a share of total income
Household owns sprayer	Dummy variable. Equals 1 if household owns a sprayer
Household owns seeder	Dummy variable. Equals 1 if household owns a seeder
Climate variables	
Natural log of cumulative precipitation in the wet season	Natural log of average cumulative rainfall in the wet season (month1, month 6-month12)
Natural log of cumulative precipitation in the dry season	Natural log of average cumulative rainfall in the dry season (month2-month5)
Natural log of maximum temperature in the wet season	Natural log of average maximum temperature in the wet season (month1, month 6-month12)
Natural log of maximum temperature in the dry season	Natural log of average maximum temperature in the dry season (month2-month5)
Natural log of minimum temperature in the wet season	Natural log of average minimum temperature in the wet season (month1, month 6-month12)
Natural log of minimum temperature in the dry season	Natural log of average minimum temperature in the dry season (month2-month5).
Geographical characteristics	
Department of residence	Department where the household resides
Area of residence	Area where the household resides

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

Table A2. Pooled descriptive statistics for variables in the model

	Mean	Std. Dev.
Natural log of household agriculture production per hectare*	-3.65	1.31
Natural log of household caloric consumption per capita*	8.02	0.51
Natural log of household size	1.41	0.57
Members under 5 years old (%)	10.65	14.73
Members between 6 and 15years old (%)	22.26	20.70
Members over 65 years old (%)	9.90	23.07
Female members (%)	46.70	21.54
Natural log of average schooling years of adult females	1.50	0.63
Natural log of average schooling years of adult males	1.56	0.61
Male adults only	0.07	0.26
Female adults only	0.07	0.25
Natural log of age of HH head	3.87	0.31
Head female	0.21	0.41
Head works in agriculture	0.64	0.48
Head employed	0.01	0.09
Head unemployed	0.88	0.33
Head Guarani	0.74	0.44
Head bilingual	0.15	0.36
Head other languages	0.05	0.22
Natural log of rooms per person	-0.73	0.60
Household water access inside the house	0.33	0.47
Household water access on the property	0.51	0.50
Household has refrigerator	0.62	0.48
Household has television	0.57	0.49
Household has antenna	0.05	0.21
Household has transportation	0.39	0.49
Natural log of livestock tropical unit	-0.10	2.10
Natural log of sown land	-0.54	2.41
Natural log of input expenditure	10.71	1.84
Natural log of livestock expenditure	11.63	2.99
Share of agricultural income	0.25	0.20
Household owns sprayer	0.30	0.46
Household owns seeder	0.24	0.43
Natural log of cumulative precipitation WET season	7.16	0.21
Natural log of cumulative precipitation DRY season	5.96	0.29
Natural log of maximum temperature WET season	3.53	0.02
Natural log of maximum temperature DRY season	3.48	0.05
Natural log of minimum temperature WET season	2.70	0.06
Natural log of minimum temperature DRY season	2.15	0.18
Number of observations	10 554	

Note: * denotes a smaller sample size of 3 332 observations. Statistics calculated with sample weights.

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

Table A3. Complete descriptive statistics by survey year

Variable	1997	2003	2006	2009	2012
Natural log of household agriculture production per hectare*	16.13	16.47	16.17	16.43	16.43
	(0.05)	(0.03)	(0.04)	(0.06)	(0.05)
Household size	5.42	5.04	4.72	4.47	4.33
	(0.09)	(0.05)	(0.08)	(0.08)	(0.07)
Members under 5 years old (%)	15.49	11.58	9.97	8.90	9.05
	(0.82)	(0.32)	(0.37)	(0.41)	(0.44)
Members between 6 and 15 years old (%)	25.12	22.56	22.81	20.71	21.28
	(0.65)	(0.40)	(0.64)	(0.64)	(0.62)
Members over 65 years old (%)	8.03	9.46	9.95	11.23	10.07
	(0.72)	(0.47)	(0.75)	(0.76)	(0.72)
Female members (%)	46.08	46.75	45.82	46.68	47.80
	(0.53)	(0.40)	(0.68)	(0.66)	(0.79)
Natural log of average schooling years of adult females	4.19	5.32	5.46	6.12	6.01
	(0.09)	(0.08)	(0.11)	(0.12)	(0.11)
Natural log of average schooling years of adult males	4.38	5.77	5.85	6.26	6.40
	(0.12)	(0.07)	(0.11)	(0.12)	(0.11)
Male adults only	0.05	0.06	0.08	0.07	0.08
	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Female adults only	0.03	0.06	0.06	0.08	0.09
	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Natural log of age of household head	48.43	49.55	50.54	51.43	50.71
	(0.62)	(0.31)	(0.42)	(0.53)	(0.56)
Head female	0.11	0.19	0.17	0.27	0.26
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Head works in agriculture	0.81	0.62	0.70	0.58	0.58
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)
Head employed	0.92	0.86	0.88	0.84	0.91
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Head unemployed	0.00	0.02	0.01	0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Head Guarani	0.86	0.73	0.74	0.72	0.71
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)
Head bilingual	0.05	0.14	0.17	0.18	0.19
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Head other languages	0.07	0.06	0.05	0.04	0.05
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Rooms per person	0.45	0.54	0.59	0.63	0.63
	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)
Household water access inside the house	0.10	0.29	0.30	0.38	0.48
	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Household water access on the property	0.71	0.57	0.61	0.31	0.42
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)
Household has refrigerator	0.35	0.59	0.61	0.70	0.76

Variable	1997	2003	2006	2009	2012
	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)
Household has television	0.54	0.65	0.70	0.77	0.83
	(0.03)	(0.01)	(0.02)	(0.01)	(0.01)
Household has antenna	0.02	0.05	0.06	0.05	0.04
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Household has transportation	0.15	0.24	0.32	0.49	0.64
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)
Livestock tropical unit	8.13	17.57	4.73	27.84	13.74
	(2.67)	(3.78)	(1.05)	(12.69)	(3.59)
Sown land	6.46	5.99	6.86	5.69	6.00
	(0.89)	(1.21)	(1.18)	(1.52)	(1.68)
Rural area	0.92	0.78	0.88	0.78	0.79
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Department of Asuncion	0.00	0.01	0.00	0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Department of Concepcion	0.05	0.03	0.06	0.04	0.03
	(0.02)	(0.01)	(0.03)	(0.02)	(0.02)
Department of San Pedro	0.21	0.11	0.12	0.10	0.11
	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)
Department of Cordillera	0.06	0.07	0.07	0.07	0.05
	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)
Department of Guaira	0.04	0.05	0.06	0.05	0.06
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
Department of Caaguazu	0.14	0.13	0.14	0.11	0.13
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Department of Caazapa	0.07	0.05	0.05	0.06	0.07
	(0.02)	(0.01)	(0.02)	(0.02)	(0.03)
Department of Itapua	0.15	0.16	0.14	0.14	0.17
	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)
Department of Misiones	0.03	0.04	0.05	0.03	0.02
	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)
Department of Paraguari	0.06	0.08	0.08	0.09	0.08
	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)
Department of Alto Parana	0.05	0.10	0.10	0.07	0.11
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Department of Central	0.03	0.08	0.05	0.17	0.09
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Department of Neembucu	0.02	0.03	0.02	0.02	0.01
	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
Department of Amambay	0.01	0.01	0.00	0.01	0.00
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
Department of Canindeyu	0.09	0.04	0.05	0.04	0.05
	(0.04)	(0.01)	(0.02)	(0.02)	(0.02)
Department of Presidente Hayes	0.00	0.01	0.00	0.01	0.01
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)

Variable	1997	2003	2006	2009	2012
Agriculture Input expenditure	511 372	691 886	184 478	255 283	1 010 460
	(203 899)	(143 481)	(26 883)	(42201)	(486 612)
Livestock input expenditure	2 012 976	7 812 545	3 218 177	11466551	14 491 259
	(763 460)	(1 062 441)	(841 511)	(1814607)	(2 193 443)
Share of agricultural income	0.37	0.29	0.32	0.27	0.07
	(0.01)	(0.00)	(0.01)	(0.01)	(0.00)
Household owns sprayer	0.44	0.28	0.32	0.24	0.28
	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
Household owns seeder	0.30	0.21	0.27	0.19	0.25
	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
Cumulative precipitation WET season	1842	1250	1407	1240	1038
	(22.42)	(3.69)	(4.73)	(10.92)	(10.72)
Cumulative precipitation DRY season	433	265	413	461	442
	(5.36)	(0.79)	(3.50)	(9.17)	(5.44)
Maximum temperature WET season	34.63	34.65	34.03	34.12	33.70
	(0.05)	(0.03)	(0.04)	(0.05)	(0.03)
Maximum temperature DRY season	30.11	32.90	33.10	32.46	33.58
	(0.06)	(0.03)	(0.06)	(0.07)	(0.06)
Minimum temperature WET season	15.79	14.84	15.10	15.07	13.76
	(0.08)	(0.02)	(0.03)	(0.06)	(0.03)
Minimum temperature DRY season	8.09	7.26	8.15	8.59	11.19
	(0.04)	(0.02)	(0.05)	(0.05)	(0.09)
Number of observations	*1439*	*3976*	*1855*	*1563*	*1721*

Note: dep denotes department, equivalent to state, in Paraguay. Statistics calculated with sample weights.

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

Table A4. Complete regression results

	Log value of ag production per ha		Log of calories per capita		Variance of log of food consumption pc	
	Coeff.	t - stat	Coeff.	t - stat	Coeff.	t - stat
Natural log of household agriculture production per hectare*			0.186***	(4.77)		
Natural log of household size	0.138***	(2.63)	-0.358***	(-12.01)	-0.1050	(-0.55)
Members under 5 years old (%)	0.0002	(0.13)	-0.00261***	(-3.51)	0.0009	(0.15)
Members between 6 and 15 years old (%)	-0.0003	(-0.26)	-0.0006	(-1.09)	-0.0005	(-0.09)
Members over 65 years old (%)	-0.0013	(-1.08)	-0.0004	(-0.66)	0.0016	(0.38)
Female members (%)	-0.0005	(-0.53)	-0.00118**	(-2.31)	-0.0027	(-0.88)
Natural log of average schooling years of adult females	0.0355	(1.04)	0.0648***	(3.11)	-0.0299	(-0.27)
Natural log of average schooling years of adult males	0.0726**	(2.28)	-0.0289	(-1.38)	0.0903	(0.67)
Male adults only	0.0015	(0.02)	0.0665	(1.06)	-0.0792	(-0.23)
Female adults only	0.0027	(0.03)	-0.0563	(-1.02)	0.1260	(0.41)
Natural log of age of household head	0.152**	(2.15)	-0.0473	(-1.13)	0.0720	(0.28)
Head female	-0.0351	(-0.64)	0.0520*	(1.92)	0.0823	(0.60)
Head works in agriculture	0.143**	(2.54)	-0.171***	(-5.91)	-0.0642	(-0.45)
Head employed	-0.3200	(-0.98)	0.195	(1.40)	-0.8620	(-1.03)
Head unemployed	-0.0885	(-1.24)	0.161***	(2.93)	-0.2600	(-1.36)
Head Guarani	-0.0457	(-0.39)	0.0742	(1.55)	-0.2950	(-1.24)
Head bilingual	-0.0697	(-0.57)	0.0992**	(1.97)	-0.1640	(-0.66)
Head other languages	-0.0034	(-0.02)	-0.115	(-1.30)	-0.3220	(-0.88)
Natural log of rooms per person	0.0357	(0.85)	0.0586**	(2.37)	0.1100	(0.54)
Household water access inside the house	0.188***	(2.94)	-0.0205	(-0.54)	-0.3930	(-1.55)
Household water access on the property	0.124***	(2.62)	0.0061	(0.21)	-0.2290	(-1.29)
Household has refrigerator	-0.0116	(-0.29)	0.0188	(0.82)	-0.204	(-1.46)
Household has television	0.100**	(2.37)	0.0076	(0.35)	0.1270	(0.75)
Household has antenna	0.114	(1.61)	-0.151**	(-2.54)	0.1400	(0.44)
Household has transportation	0.101**	(2.33)	0.02640	(1.14)	0.1760	(1.30)
Natural log of livestock tropical unit	0.0166*	(1.81)	0.00326	(0.56)	-0.0325	(-1.23)
Natural log of sown land	-0.215***	(-14.71)	0.0665***	(6.69)	0.0014	(0.04)
Rural area	0.689***	(10.86)	-0.0924**	(-2.20)	-0.1110	(-0.69)
Year 2003	1.057***	(4.43)	---	---	---	---
Year 2006	0.335	(1.50)	---	---	---	---
Year 2009	0.169	(0.88)	---	---	---	---
Year 2012	0.0343	(0.11)	-0.282***	(-10.88)	0.2260	(1.45)
Department of Concepcion	0.454	(1.41)	0.0155	(0.08)	-0.1650	(-0.21)
Department of San Pedro	0.471	(1.60)	-0.0593	(-0.32)	-0.1840	(-0.24)
Department of Cordillera	0.590*	(1.92)	-0.0121	(-0.06)	-0.1610	(-0.21)
Department of Guaira	0.526	(1.61)	-0.141	(-0.74)	-0.5370	(-0.67)
Department of Caaguazu	0.197	(0.62)	-0.0713	(-0.38)	-0.0475	(-0.06)
Department of Caazapa	0.0545	(0.16)	0.0396	(0.20)	0.2450	(0.32)
Department of Itapua	-0.161	(-0.43)	-0.0228	(-0.12)	0.2360	(0.31)

	Log value of ag production per ha		Log of calories per capita		Variance of log of food consumption pc	
	Coeff.	t - stat	Coeff.	t - stat	Coeff.	t - stat
Department of Misiones	-0.172	(-0.49)	-0.0722	(-0.38)	0.2750	(0.36)
Department of Paraguari	0.0799	(0.25)	-0.0528	(-0.28)	-0.1030	(-0.13)
Department of Alto Parana	0.0014	0.00	-0.0713	(-0.38)	0.0677	(0.09)
Department of Central	0.692**	(2.28)	-0.0865	(-0.45)	-0.0256	(-0.03)
Department of Neembucu	-0.0739	(-0.22)	0.0345	(0.19)	-0.2460	(-0.31)
Department of Amambay	0.0816	(0.25)	-0.0519	(-0.27)	-0.5140	(-0.58)
Department of Canindeyu	0.125	(0.40)	-0.121	(-0.64)	-0.4720	(-0.56)
Department of Presidente Hayes	0.695*	(1.75)	0.01	(0.06)	-0.85	(-0.80)
Natural log of input expenditure	0.100***	(8.35)				
Natural log of livestock expenditure	0.0252***	(2.73)				
Share of agricultural income	0.636***	(5.03)				
Household owns sprayer	0.171***	(4.63)				
Household owns seeder	0.0840**	(2.13)				
Natural log of cumulative precipitation in the WET season	-0.286	(-1.02)				
Natural log of cumulative precipitation in the DRY season	0.580***	(2.91)				
Natural log of maximum temperature in the WET season	-5.606**	(-2.14)				
Natural log of maximum temperature in the DRY season	-4.854**	(-2.11)				
Natural log of minimum temperature in the WET season	-0.322	(-0.34)				
Natural log of minimum temperature in the DRY season	0.935***	(3.10)				
R^2	*0.16*		*0.275*		*0.0286*	
Number of observations	*10554*		*3332*		*3332*	
F test	17.28		24.38		1.706	

Note: Department is equivalent to statein Paraguay.

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

Table A5. Agricultural Productivity (mean)

Agricultural productivity				
Department	Year			
	1997	2012	2050	2100
Asunción	16,14	15,43	15,25	14,47
San Pedro	16,21	16,33	15,66	14,77
Caaguazú	15,94	16,39	15,77	14,93
Itapúa	16,11	16,51	16,10	15,51
Alto Parana	16,39	16,47	16,02	15,18
Central	17,43	16,77	16,61	15,83
Rest	16,06	16,41	15,87	15,08

Note: Agricultural productivity is defined as the ln (agricultural value/hectare). The years 1997 and 2012 are based on observed values, while 2050 and 2100 are based on simulations from the regression model.

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

Table A6. Caloric consumption per household member (mean)

Caloric consumption per household member				
Department	Year			
	1997	2012	2050	2100
Asunción	3 277,45	3 073,29	2 768,19	2 391,89
San Pedro	3 354,71	3 178,51	2 642,44	2 237,73
Caaguazú	3 475,08	3 299,82	2 826,22	2 412,50
Itapúa	4 273,70	3 139,86	2 968,89	2 654,80
Alto Parana	4 211,96	2 849,89	2 559,14	2 183,70
Central	4 093,44	3 406,94	3 066,96	2 650,04
Rest	3 620,54	3 282,27	2 919,22	2 518,71

Note: The years 1997 and 2012 are based on observed values, while 2050 and 2100 are based on simulations from the regression model.

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

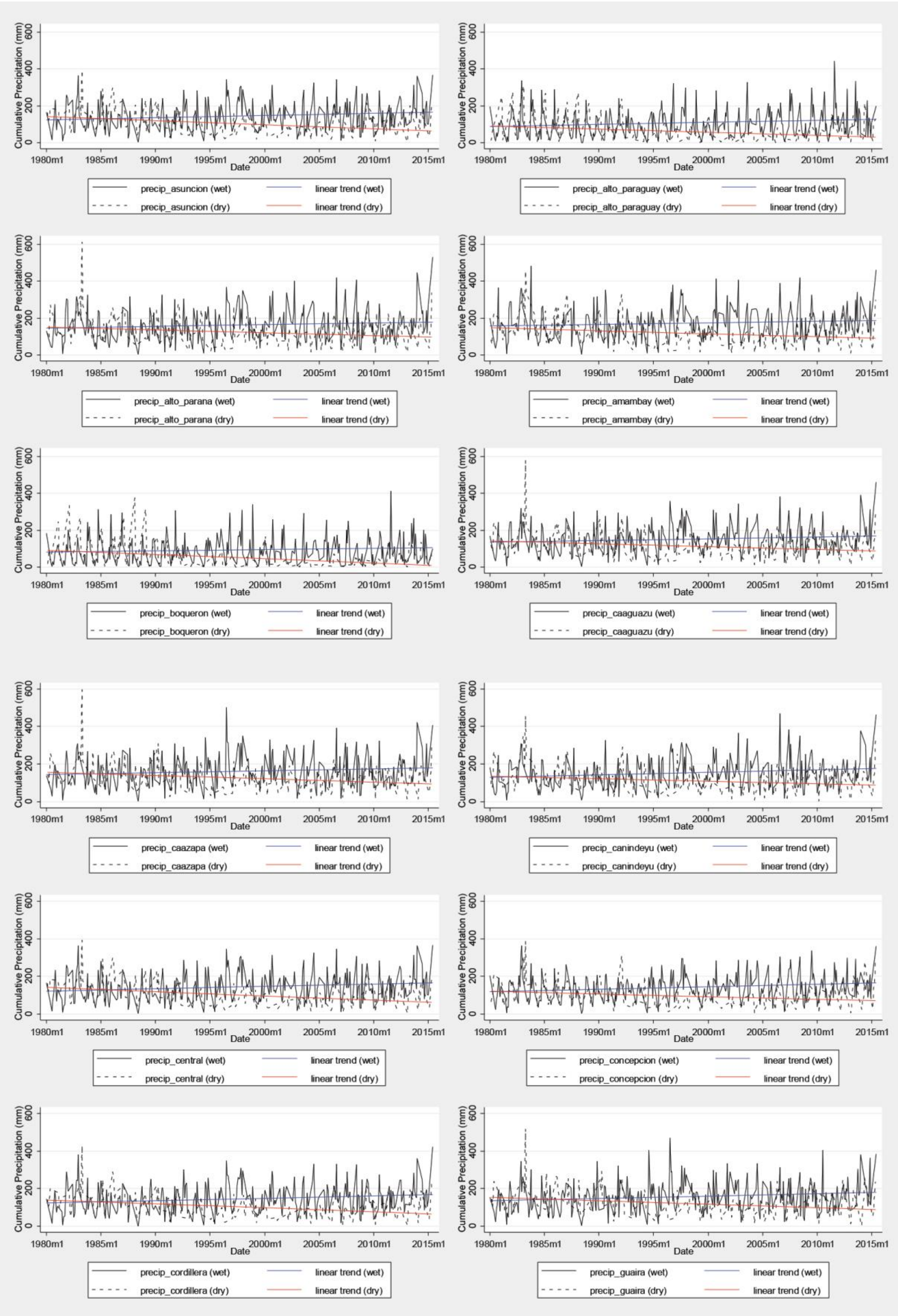
Table A7. Vulnerability to food insecurity (mean)

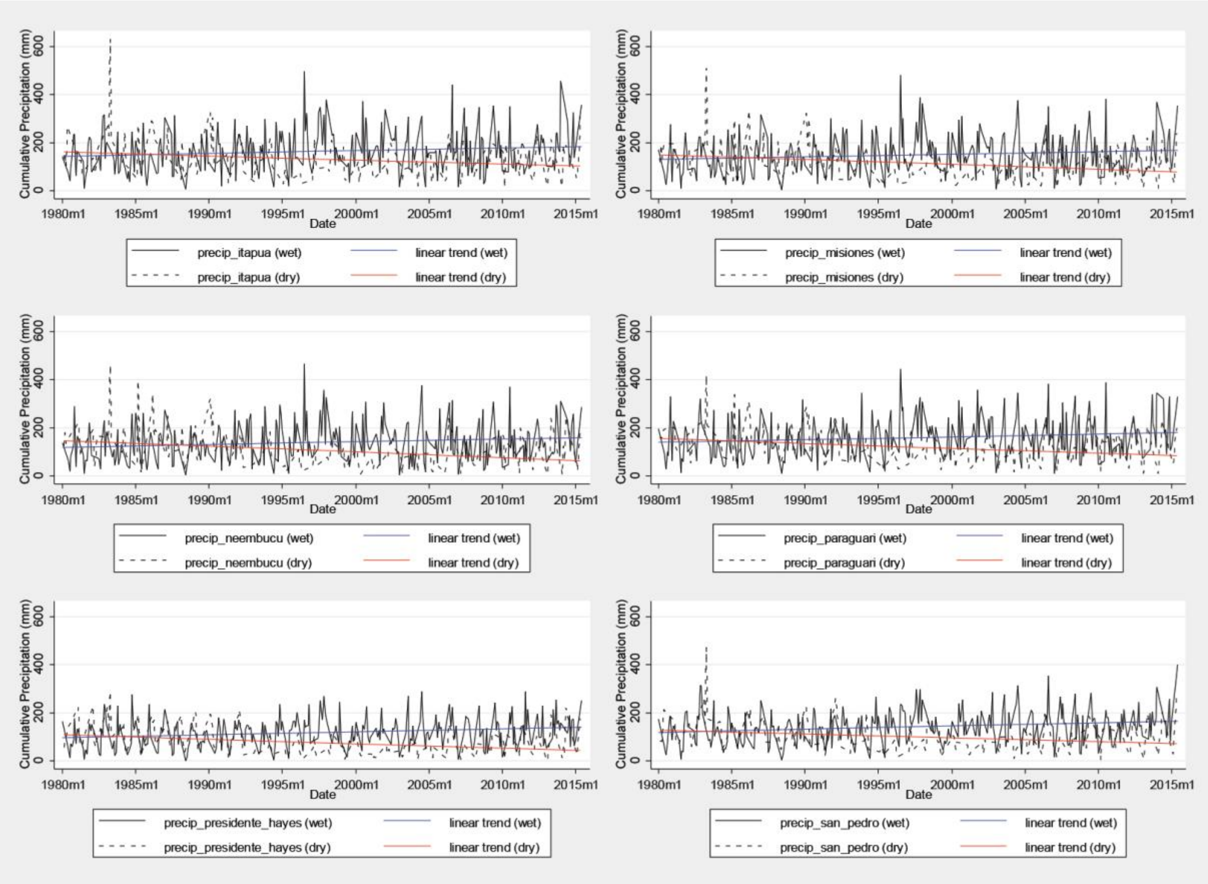
Vulnerability to food insecurity				
Department	Year			
	1997	2012	2050	2100
Asunción	0,13	0,31	0,32	0,55
San Pedro	0,07	0,26	0,36	0,69
Caaguazú	0,09	0,24	0,31	0,60
Itapúa	0,06	0,22	0,24	0,39
Alto Parana	0,11	0,31	0,43	0,70
Central	0,04	0,18	0,16	0,36
Rest	0,09	0,20	0,26	0,50

Note: The years 1997 and 2012 are based on observed values, while 2050 and 2100 are based on simulations from the regression model.

Source: Authors' calculations based on household survey data (DGEEC) and climate data (DINAC).

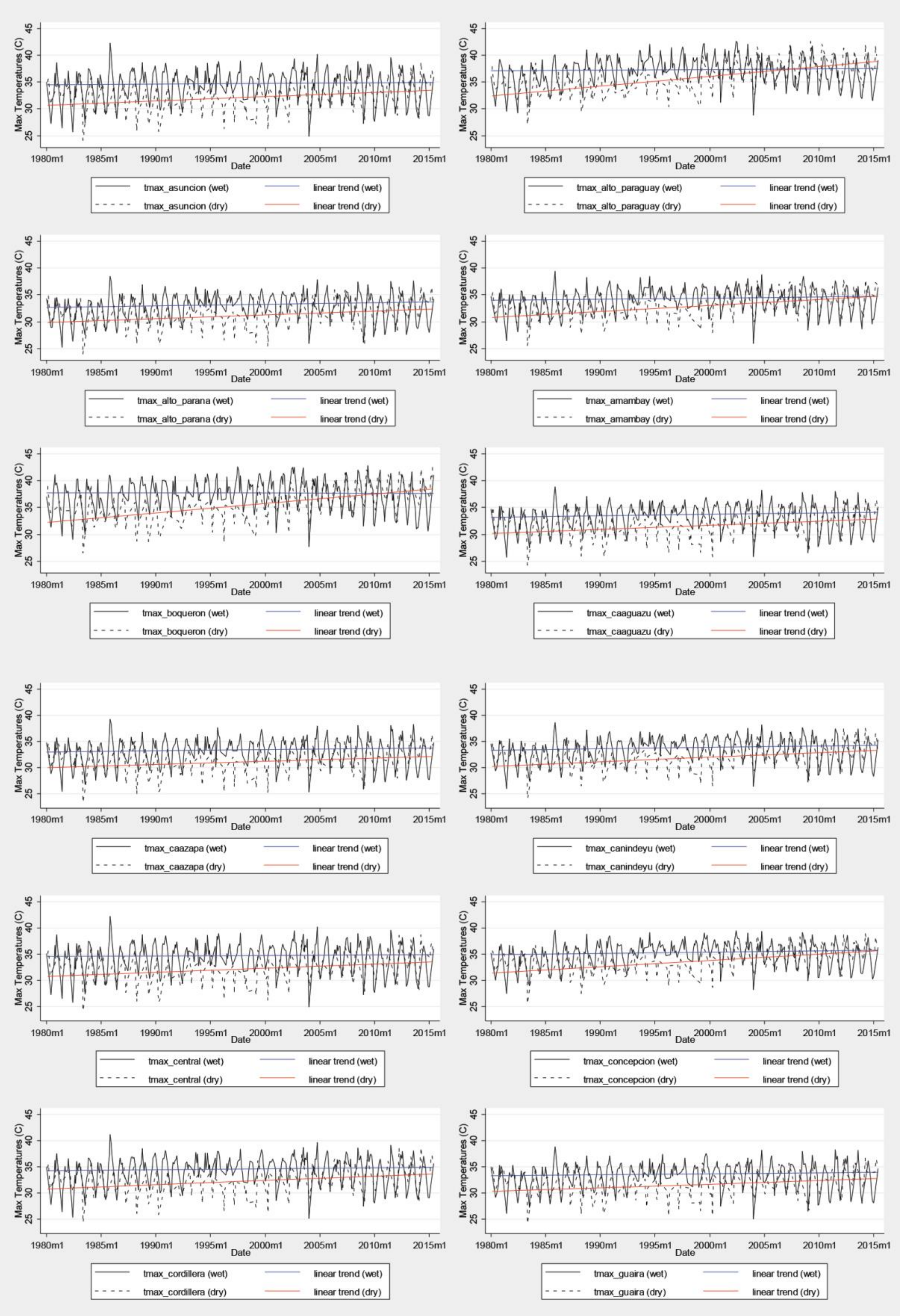
Figure A1. Cumulative precipitation trends

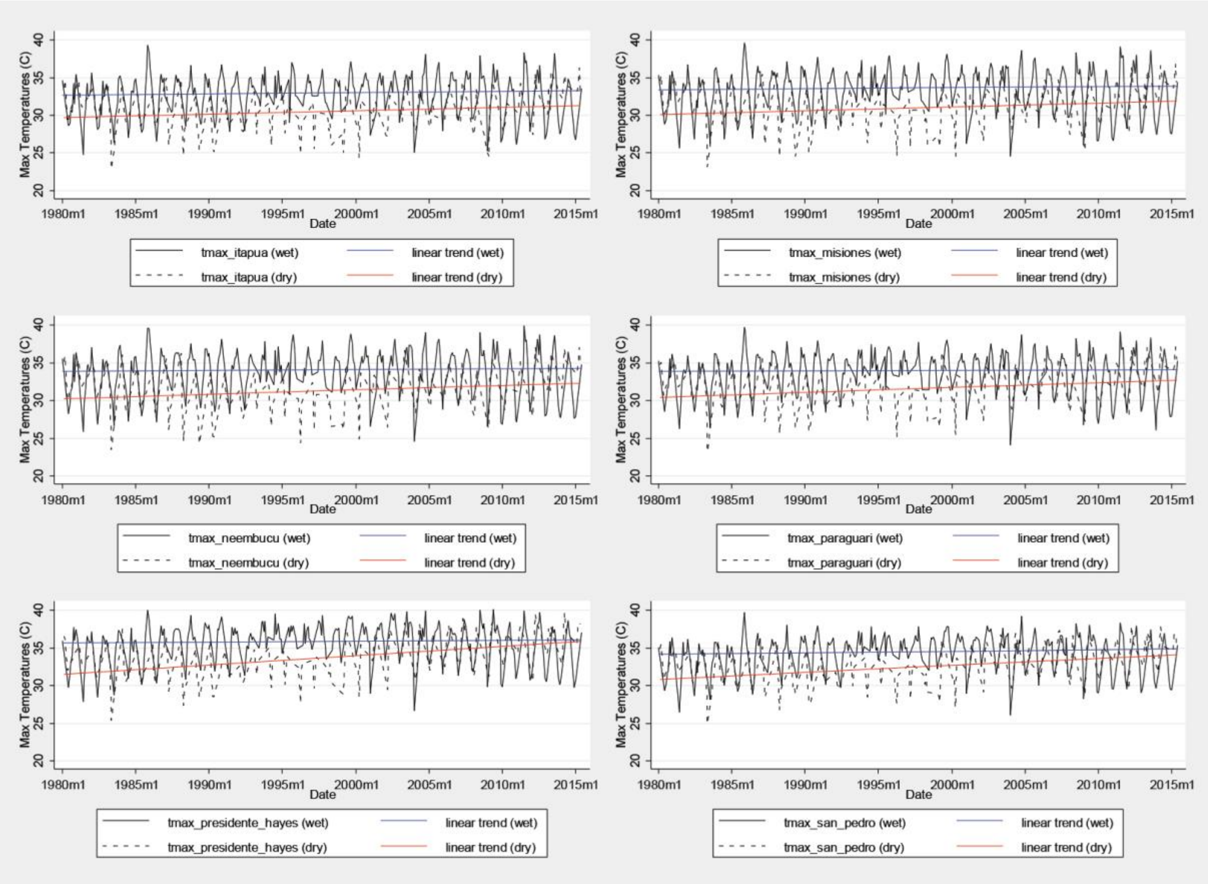




Source: Authors’ calculations based on downscaled weather data provided by DINAC.

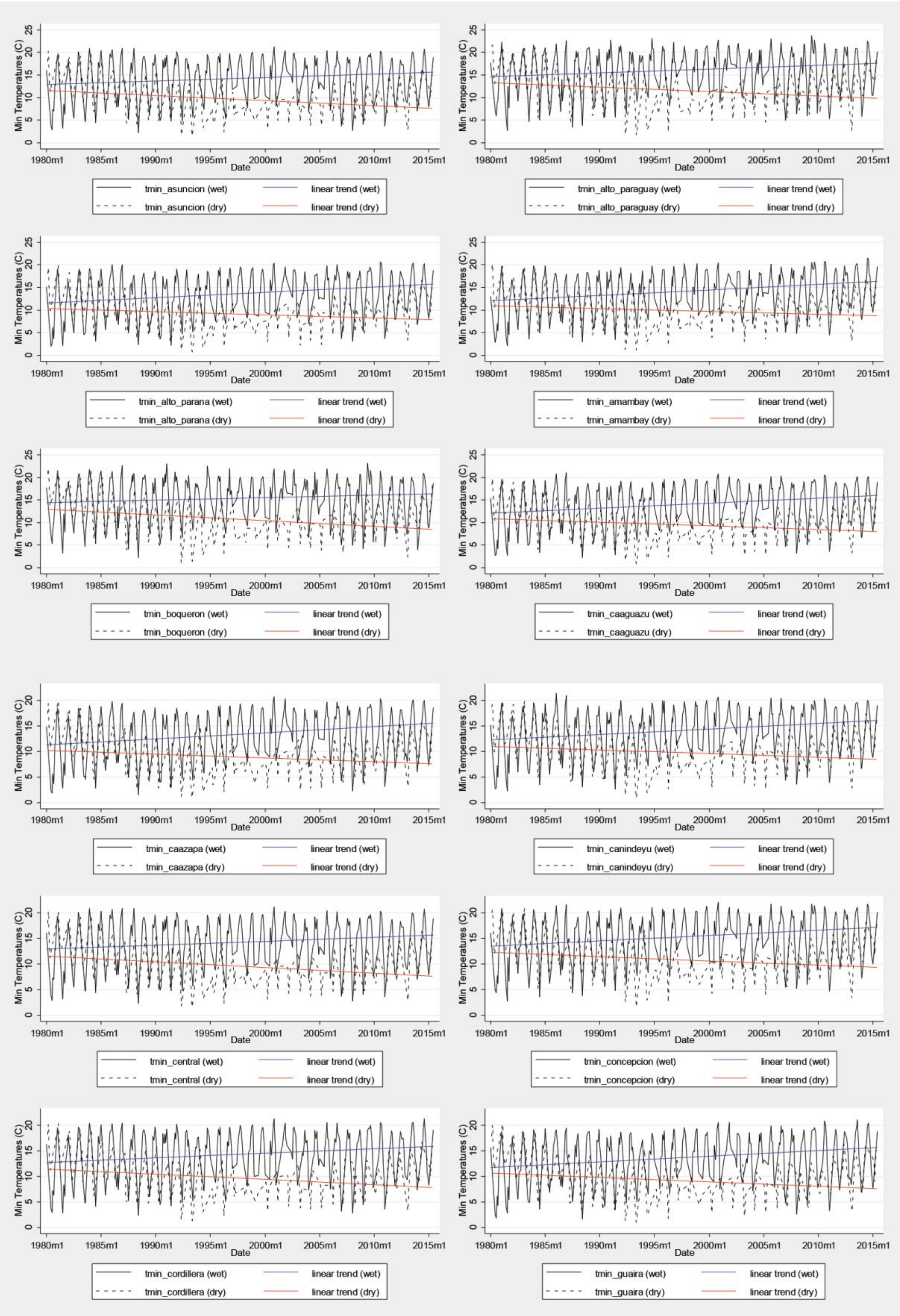
Figure A2. Average maximum temperatures

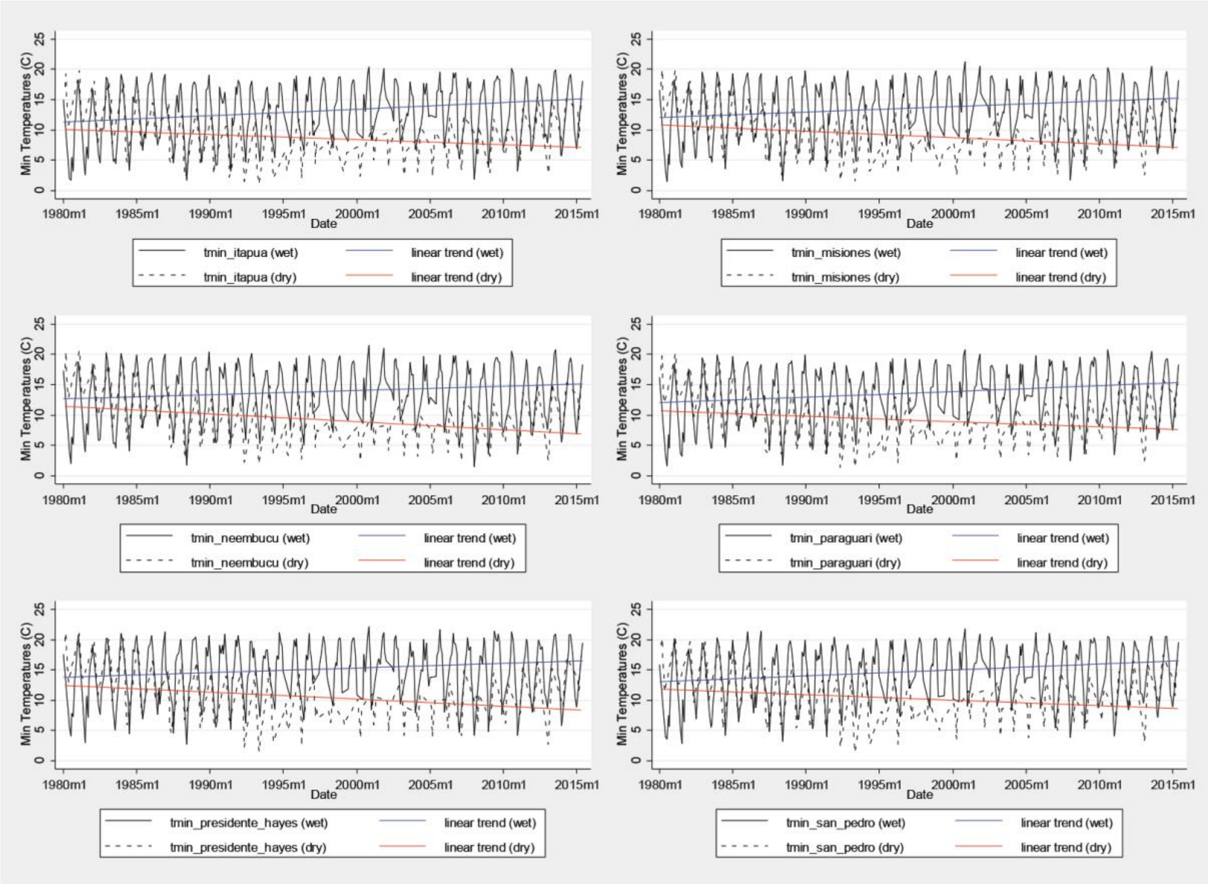




Source: Authors’ calculations based on downscaled weather data provided by DINAC.

Figure A3. Average minimum temperatures





Source: Authors' calculations based on downscaled weather data provided by DINAC.

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