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# The Poverty Impact of Climate Change in Mexico

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## Abstract

This paper examines the effects of climate change on poverty through the relationship between indicators of climate change (temperature and rainfall change) and municipal level gross domestic product, and subsequently between gross domestic product and poverty. The evidence suggests that climate change could have a negative impact on poverty by 2030. The paper proposes a two-stage least squares regression where it first regresses temperature and rainfall (along with geographic controls and state and year fixed effects) on municipal gross domestic product per capita for 2000 and 2005 The resulting gross domestic product per capita is used in a second equation to estimate municipal poverty on the same years. The authors then incorporate projections of temperature and rainfall changes by 2030 into the estimated climate-gross domestic product coefficients to assess the effects of climate change in economic activity and how this in turn will influence poverty. At the same time, they account for the potential adaptive capacity of municipalities through higher population densities and economic growth. Both would reduce poverty by 31.72 percentage points between 2005 and 2030 with changing climate. However, poverty could have been reduced up to 34.15 percentage points over the same period had there been no climate change. This suggests that climate change slows down the pace of poverty reduction. An alternative reading is that poverty is expected to increase from 15.25 percent (without climate change) to 17.68 percent (with climate change) by 2030. Given the existing population projections for 2030, this represents 2,902,868 people remaining in poverty as a result of climate change.

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**JEL Codes:** I30, I32, O10, O54, Q54

**Sector Board:** Social Development [1]

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# 1 Introduction

Global warming is expected to increase temperature and rainfall averages and their variability (IPCC, 2007).[2] Such changes are particularly worrying for developing countries because large portions of their populations rely on climate dependent activities, and have limited income to adapt.

In response, economic analysis has attempted to estimate the possible impacts of climate change in developing societies. One strand of literature focuses on the link between income and climatic factors often looking at cross-country data, with most studies finding a negative relationship between income and temperature (Dell et al., 2009; Bansal, 2009).

Another strand focuses on the effects of climate-related disasters on macroeconomic indicators or country-level variables, including GDP or its growth. Studies differ in their techniques, data and findings: Some encounter negative effects (Auffret, 2003), while others encounter positive effects (Skidmore and Toya, 2002). Loayza et al (2009) reconcile the seemingly contradictory results estimating the medium-term effects of climate-related disasters such as droughts, floods, storms (separately and simultaneously) on economic growth using a model with three main sectors (agriculture, industry, and services) and with the whole economy. Severe disasters have adverse effects regardless of type, but moderate floods, for instance, do increase industrial growth.

All these studies of climate change effects or climatic disasters focus on local and economy-wide effects on output. However, it is known that output measures are an imperfect way to gauge society's overall well-being. Therefore, this paper will focus on the effects of climate change on poverty, as opposed to economic growth.

A few studies have analyzed the possible impact of climate change on poverty in Mexico, some modeling the channels and the heterogeneity of impacts across income groups while others concentrate on poverty at the municipal level. Hertel et al. (2010)[3] use a global Computable General Equilibrium model (the Global Trade Analysis Project or GTAP) to mimic the effect of productivity shocks in agriculture (model the consumption and production for all commodities of the national economy), and then link those estimates to household data. They use three

[2] Climate change is defined as the slow change in average temperatures and average precipitation predicted to result from the build-up of greenhouse gases in the atmosphere and not of climate variability.

[3] Hertel, T., M. Burke and D. Lobell. (2010) "The Poverty Implications of Climate-Induced Crop Yield Changes by 2030" GTAP Working Paper No. 59.

scenarios of climate change on agricultural productivity (low, medium, or high productivity)[4] to evaluate the changes by 2030 on global commodity prices and the incidence on the poverty headcount rate (defined as the portion of the country's population living on less than $1 a day).

Ahmed et al. (2009) also analyze the climate-agriculture-poverty link. Their model is practically identical to that in Hertel et al. (2010) above, and is applied to 16 countries including Mexico. The main difference is the origin of the shocks to agriculture, which in this paper is derived from three different sources: (i) the percent of annual total precipitation due to events exceeding the 1961 to 1990 95th percentile; (ii) the maximum number of consecutive dry days; and (iii) the heat wave duration index. They analyze these effects for 30-year periods from 1970 to 2000 and 2071 to 2100 through simulations under the IPCC's A2 scenario. When they simulate the poverty impacts from extreme dry events for the period 2070 to 2100, an additional 1.8% of the population in Mexico becomes impoverished by extreme climate in the future.

Andersen and Verner (2010, 2010a) employ municipal data in Mexico (and other Latin American countries) to estimate the cross-sectional relationship between climate and income in 2000. The estimated relationships are then used to simulate the impact of the climate changes for the next 50 years. They find that average temperatures and precipitation are not significantly related to income. They assume that a negative relationship exists between per capita income and poverty, and so their conclusion is that Mexico appears to be less vulnerable to climate change than most other Latin American countries. However, the analysis is very crude. They do not estimate the poverty-output elasticity, and do not consider income and population projections which are accounted for in this paper.

To assess the effects of climate change on poverty we propose a two-stage least squares regression (2SLS) where we first regress temperature and rainfall (along with municipal controls for elevation, longitude, latitude, distance from the municipality to the nearest road and state and year fixed effects) on municipal GDP per capita for 2000 and 2005, and then such predicted GDP per capita is used in a second equation to estimate municipal poverty on the same years.

Changes in GDP per capita affect poverty and vice versa. This is why we use rainfall and temperature in a first stage to instrument GDP and hence circumvent the problem of endogeneity. In other words, we explain the variation in GDP per capita through differences in

[4]The low productivity scenario depicts a world with rapid temperature change, high sensitivity of crops to warming, and a CO2 fertilization effect at the lower end of published estimates. The high productivity scenario represents a world with relatively slow warming, low sensitivity of crops to climate change, and high CO2 fertilization.

the climatic conditions of the municipality; and subsequently this serves to predict the effects of climate change on poverty. This exercise is carried out for poverty levels in the three officially-defined alternative measures of poverty for Mexico until last year: food poverty, capacity poverty and asset poverty as published by the National Council for Evaluation of Social Development Policy in Mexico (CONEVAL).

As expected, climate affects output. Temperature increases of 1 Celsius degree lower GDP per capita by around 5.6%. Overall, climate change is predicted to diminish output by 1.45% percent on average for the entire sample.

In the second stage of the model, where we regress the poverty rates at the municipal level on municipal GDP per capita, we find high and negative poverty elasticity to growth: A one percent increase in GDP per capita brings down poverty by 1.74%. Indeed, prosperity rises as population densities and output increase. If GDP grows as projected over the next 25 years, asset poverty would fall from 49.4% in 2005 to 15.25% in 2030.

To infer the poverty impacts of climate change, the estimated impacts of temperature and precipitation on output were multiplied by the predicted change in climate by 2030. The predicted changes in GDP per capita serve in turn to re-estimate poverty. The expected asset poverty rate by 2030 through climate-induced changes in GDP is 17.68%.

Comparing the expected asset poverty rate by 2030 with and without climate change (17.68% vs. 15.25%), we observe that poverty would increase by 2.43 percentage points in 2030 due to climate change. Indeed, higher population densities and prosperity reduce poverty, but climate change slows down the pace of poverty reduction.

It is worth noting several caveats to this simulation exercise. First, climate change and output scenarios carry with them a certain degree of uncertainty. This uncertainty is intrinsic to long-term projections and at the geographical scale that were provided. Second, the climate-output elasticities employed assume that climate change is very gradual over the next 25 years. Third, the output-poverty elasticity is assumed to stay constant over time. While strong, this is not entirely implausible for a middle-income country like Mexico where profound changes to its economic structure have already occurred. And finally, poverty scenarios by 2030 with and without climate change assume no adaptation to climate change in the sense that the projections on economic development and population growth used did not account for climate change. Given the stated caveats, the findings presented should be read more as indicative of the direction and possible magnitude of the poverty effects from climate change in Mexico, rather than actual forecasts.

The rest of this paper proceeds as follows. Section 2 introduces key definitions and data sources applied. Section 3 presents the empirical methodology followed by a discussion of the results in Section 4. Section 5 concludes.

## 2 Data

This study is carried out in 2,069 municipalities from all states in Mexico, representing 84% of the total number of municipalities in the country. Missing municipalities are largely from Oaxaca and Puebla where climate model projections could not be fitted into smaller municipalities. Both states display pockets of high poverty (see Figure 3). However, their highly fragmented political geography, especially Oaxaca, it made unfeasible to analyze climate data (available at a resolution of 50 x 50 km approx) in some small municipalities.

The analysis uses five types of information: (i) income and geographic data, (ii) climate and weather data, (iii) poverty rates, (iv) climate change scenarios, and (v) population and output (GDP) projections. Per capita GDP and geographic controls come from the National Institute of Statistics and Geography (INEGI). Daily precipitation in millimeters and temperature come from meteorological stations and the National Weather Service (Servicio MeteorolÃşgico Nacional - SMN). Historical Climate data were aggregated at the municipality level from a gridded historical dataset derived from observational data produced by the Climatic Research Unit (CRU) of University of East Anglia (UEA). These datasets were accessed through the World Bank Climate Change Knowledge Portal (CCKP)[5].The CRU TS 2.1 Global Climate Dataset is comprised of 1,224 monthly time series of climate variables, including temperature and precipitation, for the period 1901-2009, and covering the global land surface, excluding Antarctica, at 0.5 degrees resolution. Poverty rates were obtained through small area estimation techniques using data from the 2000 Census on Population and Housing and the Count of Population and Housing 2005. Population projections come from the National Population Council (CONAPO). All data are available at the municipal (county) level (See Annex 1 for summary statistics).

[5]http://climateknowledgeportal.wordlbank.org.

## 2.1 GDP and Geographic Data

Historic data on GDP per capita come from INEGI for 2000, 2005 and 2010. The geographic location of the municipality affects productivity, which in turn impacts poverty. Therefore we account for each municipality s latitude, longitude and elevation above sea level in the analysis. Distance from the municipality to the nearest federal and state road are also used as a proxy measure of connectivity.

## 2.2 Climate and Weather Data

Historic weather data were imputed to municipalities using a Variable Infiltration Capacity Model (VIC) for Mexico, developed by Liang et al. (1994)[6]. The VIC model interpolates data using grids by: i) creating correlation matrices between existing rainfall stations and radar stations that indicate the presence of rain, but cannot capture its amount; ii) computing the corresponding means for both types of stations from the grids within the municipality; and iii) using those values multiplying the values of the core stations by the means ratio to scale them, through the reconstruction of a climatic model.

The climatic variables employed for the study are annual average precipitation (in millimeters) and temperature, both estimated from daily records.

## 2.3 Climate Change Scenarios

Climate change modifies the mean and variance of rainfall and temperature. Different scenarios proposed by IPCC were tailored for different regions in Mexico to predict climate change. We assembled one global scenario of rainfall and temperature obtained for 22 climate models assembled by the World Bank Climate Change Knowledge Portal (2011)[7]. Global climate change

[6]VIC as a semi-distributed macroscale hydrological model, VIC balances both the water and surface energy within the grid cell; and its sub-grid variations are captured statistically. Distinguishing characteristics of the VIC model include: subgrid variability in land surface vegetation classes; subgrid variability in the soil moisture storage capacity; drainage from the lower soil moisture zone (base flow) as a nonlinear recession; and the inclusion of topography that allows for orographic precipitation and temperature lapse rates resulting in more realistic hydrology in mountainous regions. VIC uses a separate routing model based on a linear transfer function to simulate the streamflow. Adaptations to the routing model are implemented in VIC to allow representation of water management effects including reservoir operation and irrigation diversions and return flows. Since its existence, VIC has been well calibrated and validated in a number of large river basins over the continental US and the globe. Applications using the VIC model cover a variety of research areas.

[7]Future climate data was provided by the WB Climate Change Knowledge Portal (http://climateknowledgeportal.worldbank.org). All climate models are credited to the Coupled Model Inter-comparison Project Phase 3 (CMIP3) of the World Climate Research Programme (WCRP) produced a multi-model dataset, referenced in the Intergovernmental Panel on Climate Change's (IPCC) Third and the

modifies local rainfall and temperature averages. Hence, the resulting projections from the various global climate models were tailored to different regions in Mexico by Climate Change Knowledge Portal at a resolution of 50 x 50 km approx. Baseline data on daily temperature and precipitation employed for the projections cover the period from 1950 to 2000, and projections for average daily temperature and precipitation are for 2030 âĂŞ 2039.

To determine how greenhouse emission will affect changes in precipitation and temperature, climatic models need to be combined with emission models that predict the amount of man-made greenhouse emissions[8]. The Third IPCC Assessment Report accepts several emission models. We choose A2 which assumes a business as usual scenario (i.e., same trend changes in economic growth, use of fossil fuels and population growth).

Annual temperatures are expected to rise between 0.49 and 2.46 degrees Celsius in 2030-2039, compared to the historic average from 1950-2000. The largest increases in temperature are expected in coastal areas, including the Yucatan Peninsula and the southern region of the Gulf of Mexico, comprising the states of Quintana Roo, Yucatan, Tabasco, Campeche and Veracruz. In the Pacific, the states of Sonora, Sinaloa, Nayarit, Guerrero and central Jalisco exhibit the greater increases in temperature. Central Mexico appears less warm than coastal regions; although some desertic areas in Hidalgo and Queretaro display temperature increases (see Fig. 1).

Annual rainfall will change between -169 mm and +57mm. However, as Fig. 2 shows, almost the entire country will be facing a drier world by 2030-39. Desertic areas in states like Chihuahua, Nuevo Leon, Zacatecas and San Luis will become drier, as will the states of Chiapas, Tabasco, Veracruz and Puebla.

### 2.4 Poverty

The integration of income and consumption data from household surveys with census data has enabled the creation of municipal poverty maps in Mexico[9]. We rely on such information for 2000 and 2005, using income poverty levels in three officially-defined (until 2011) alternative

Fourth Assessment Report.

[8]Information about the basic characteristics of the emissions scenarios used can be found at the SRES Emissions scenarios. http://sdwebx.worldbank.org/climateportal/index.cfm.

[9]Briefly, poverty mapping involves, first, discovering relationships between household characteristics and the welfare level of households as revealed by the analysis of a detailed living standards measurement survey; and second, applying a model of these relationships to data on the same household characteristics contained in a national census to determine the welfare level of all households in the census. The resulting estimates of household welfare and poverty derived from the census are spatially disaggregated to a much higher degree than is possible using survey information (Elbers et al., 2004; Bedi, Coudouel and Simler, 2007).

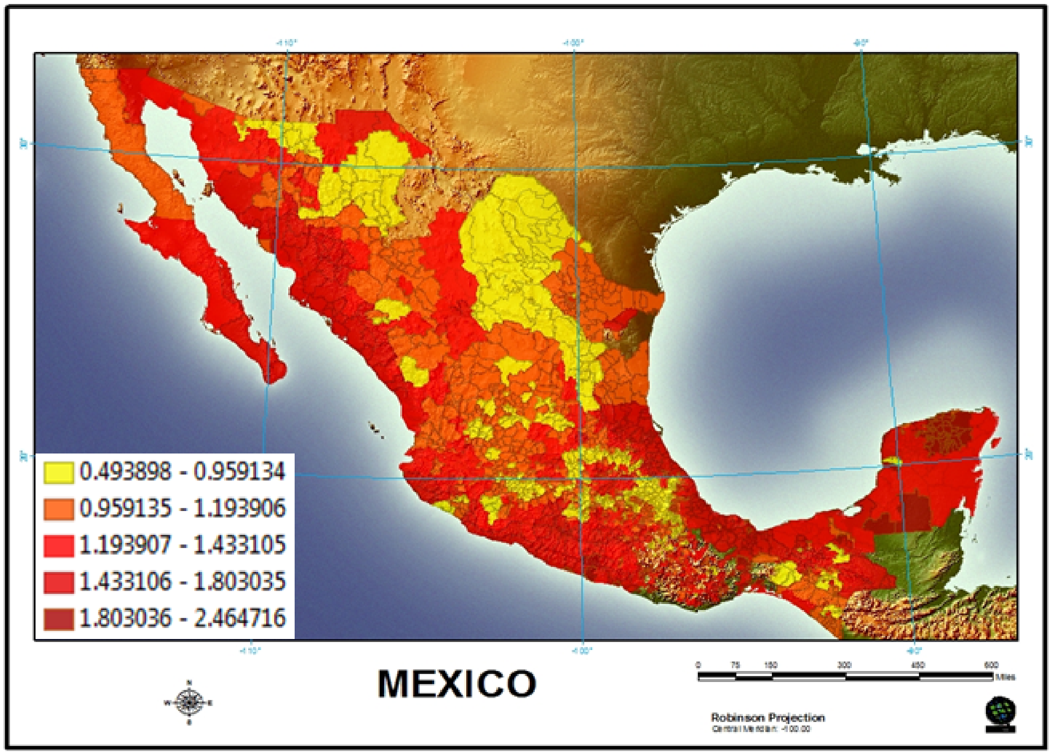


Figure 1: Absolute Temperature Changes in Celsius degrees between 2005-2030.

measures of poverty: food poverty, capabilities poverty and asset poverty (somewhat equivalent to extreme poverty, poverty and moderate poverty) as published by the National Council for Evaluation of Social Development Policy in Mexico (CONEVAL, 2008).

A household is considered food poor if its members income falls below the lowest income necessary to afford a minimum basket of food. A household is considered to be capacity poor if its members cannot afford to cover their basic expenses on food, health and education, according to an officially defined basket. Finally, a household is considered to be in asset poverty if its members cannot cover their expenses of food, health, education, dressing, home and public transportation.

Average asset poverty in our sample is 49.4% (national average is 47%). Some of the poorest states in the country include Guerrero, Michoacan, Chiapas, Oaxaca, Puebla and Veracruz. Northern and Central states are typically wealthier, though without excluding pockets of poverty inside some of them as Fig. 3 3 shows.

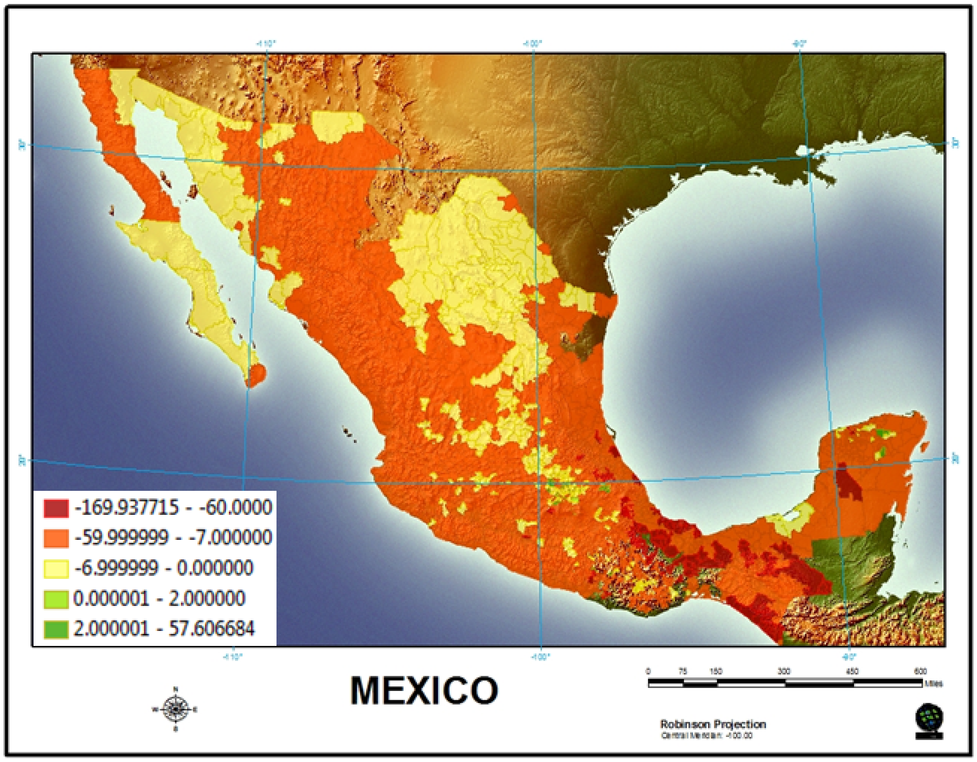


Figure 2: Absolute Precipitation Changes in mm between 2005-2030.

## 2.5 GDP and Population Projections.

Population projections come from the National Population Council in Mexico (CONAPO). We consider population dynamics at the municipal level between 2005 and 2030. The population census is usually available every decade for Mexico, and inter-censal population counts also provide inputs for updating projections.

## 2.6 GDP Projections.

The projection of GDP follows the methodology applied by Malone, et al (2004) using historic data on GDP for 2000, 2005 and 2010[10]. Malone et al create GDP growth scenarios based on assumptions for a series of variables which include: growth rates per year for labor efficiency, capital stock per worker, working age population over 15 and literacy levels, both to determine labor force participation of the population. Unemployment remains stable over time. Under these assumptions, GDP per capita would grow at 2.38% per year from 2005 to 2030, while total GDP would grow at an average of 4.0%. The growth rate was calculated at the state level and extrapolated at the municipal level using the labor participation of the population and

[10]Malone, E. et. al. (2004) "Developing Socio-Economic Scenarios for Use in Vulnerability and Adaptation Assessments" http://www.adaptationlearning.net/sites/default/files/sec.pdf.

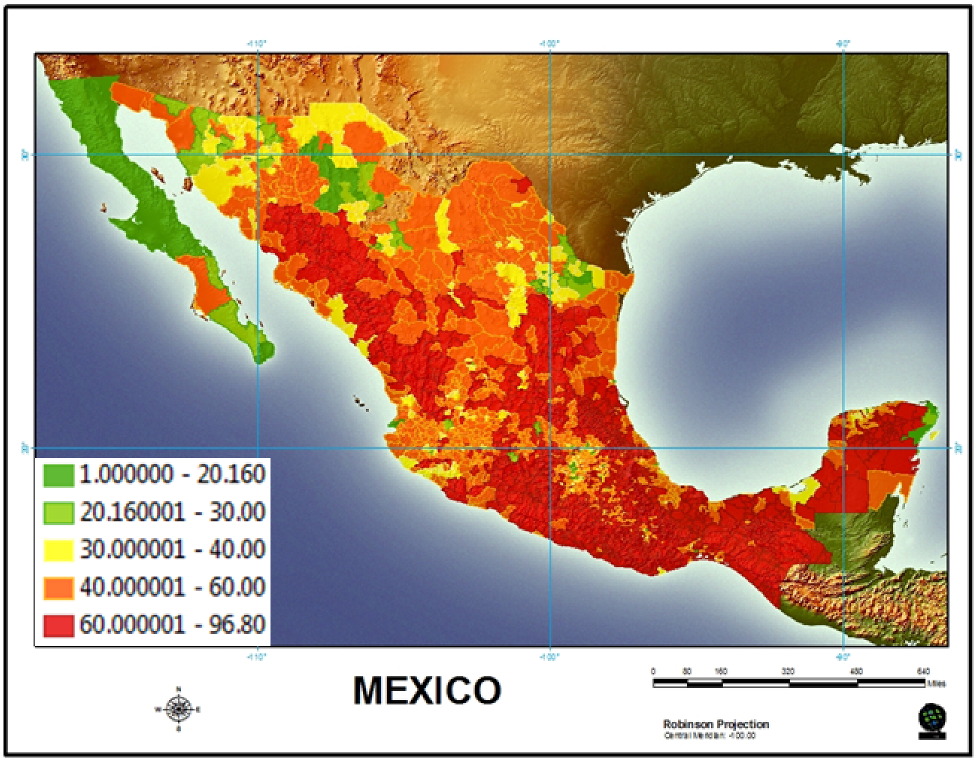


Figure 3: Asset Poverty Rates, 2005.

the "Gross Value Added" obtained by INEGI through a census of production, both available for 2030 at municipal level. We assume that all the municipalities within the state grow at the same rate.

# 3 Estimation Strategy

We propose a two-stage least squares regression (2SLS) to assess the effects of climate change on poverty. In a first stage we regress temperature and rainfall (along with geographic controls for municipal elevation, latitude, longitude and proximity to roads, and state and year fixed effects) on municipal GDP per capita, and then such predicted GDP per capita becomes our main variable of interest in a second equation were we regress GDP against poverty.

Changes in GDP per capita affect household poverty and vice versa; this is why, in fact, we use rainfall and temperature in a first stage to instrument GDP and hence circumvent the problem of endogeneity between GDP and poverty at a second stage. In other words, we explain the variation in per capita GDP through differences in the climatic conditions of the municipality; and this in turn serves to predict the effects of climate change on poverty.

## 4 Climate Effects on Income

We propose the following model to assess the effects of temperature and rainfall (and their projections due to climate change) on municipal income for municipality (county) m at year t:

$$LOGGDP(m,t) = \beta_1 TEMP_{mt} + \beta_2 RAINFALL_{mt} + \beta_3 TEMP2_{mt} \tag{1}$$
$$+\beta_4 RAINFALL2_{mt} + \beta_5 G_m + \varepsilon_{mt}$$

In equation 1 our dependent variable is log GDP per capita in municipality (county) $m$ at year $t$. Climatic variables comprise linear and quadratic terms for annual temperature and precipitation means, and the matrix $G_{mt}$ includes geographic variables (latitude, longitude and elevation above sea level and state and year fixed effects).

Once we have estimated the output parameters, we introduced changes in temperature and precipitation by 2030 in equation 1 to predict output changes by 2030. In other words, we obtain the economic impacts caused by climate change by multiplying the predicted change in climate in 2030 by the estimated output parameters.

### 4.1 Climate-Induced GPD Effects on Poverty

Changes in GDP per capita affect household poverty and vice versa. This is why, in fact, we use rainfall and temperature in equation 1 to instrument GDP and hence circumvent the problem of endogeneity between poverty and output. For empirical applications of rainfall as an instrumental variable for economic conditions, see also Pyndick (2011), Miguel et al. (2004), and Dercon and Christiaensen (2007).

This instrumented log of GDP per capita through temperature and rainfall in equation 1 becomes our main regressor of interest in the OLS poverty model of equation 2; in other words, once instrumented output will be used as explanatory variables in the poverty equation to compute the relevant parameters.

$$LOGPOVERTY(w,m) = \beta_1 LOGGDP(mt) + \beta_2 G_{m,t} + \varepsilon_m \tag{2}$$

In equation 2 our dependent variable is headcount municipal poverty, and is constructed as follows:

$$P(c,z,\alpha) = \frac{1}{N}\sum_{h=1}^{n} T[\frac{Z-c_h}{Z}] \tag{3}$$

where $z$ is the poverty line, c is current income for household h, N is the total population size, and the total sum T is taken only on poor households ordered from bottom to top: c1, c2,...,cT. So P is equal to the share of the population which is poor. In equation 2, GDP is already weighed by the population for each municipality $m$. The term $G_{mt}$ represents the same municipal geographic characteristics as in model 1 (i.e., latitude, longitude, elevation and proximity to roads).

# 5 Results.

## 5.1 Regression Results on Output

In this section we report the estimates of the cross-sectional two-stage least squares (2SLS) regression between poverty and per capita income, which was instrumented through temperature and rainfall in the first stage of the regression.

The results of the climate-income relationship are presented in the lower panel of Table 1. There is a non-linear relationship between temperature and rainfall and per capita output. In our most complete specification (column 2), a 1mm increase in average precipitation reduces per capita income by 2.72 percent on average; and a 1 Celsius degree increase reduces municipal per capita income by 5.60 percent on average.

The estimation also employs municipal controls that act as fixed effects in the model, such as geographic controls for location and elevation (latitude, longitude, elevation above sea level) and connectivity of the municipality (distance to the nearest primary and secondary road).

Tests were developed to validate the use of the proposed instrumental variable model (2SLS). We tested the strength of our instruments. The common rule of thumb for models with one endogenous regressor is that the F-statistic against the null that the excluded instruments are irrelevant in the first-stage regression should be larger than 10. Our general test confirms the validity or joint significance of the model. We also confirmed the exogeneity of our instruments (i.e., the assumption that the instruments are not correlated with the error term in the equation of interest) through the Kleibergen-Paap test (2006) and Hansen J statistic tests.

## 5.2 Regression Results on Poverty

The relationship between per capita income and poverty is explored in the second-stage regression of municipal poverty in 2000 and 2005 against the predicted log of GDP per capita from equation 1. We added geographic fixed effects (latitude, longitude and elevation above sea level).

We present estimates between per capita income and asset poverty (results for other poverty measures are available on request) in the upper panel of Table 1. As expected GDP growth

Table 1: Effect of Climate Change on Poverty.

| VARIABLES | (1) Asset Poverty (in log) | (2) Asset Poverty (in log) |
|---|---|---|
| **GDP per capita 2000-2005 (in log)** | **-1.684*** ** | **-1.746*** ** |
| | (0.0923) | (0.104) |
| Geographic Coordinates | yes | yes |
| State effects | | yes |
| Year effects | | yes |
| Constant | 11.72*** | 10.81*** |
| | (0.345) | (0.903) |
| Observations | 4,192 | 4,192 |
| R-squared | 0.4523 | 0.5222 |
| Wald chi2 | (4) 1548.84 | (36) 2440.30 |
| $Prob > chi2$ | 0.0000 | 0.0000 |
| **First Stage Instrumental Variables** | | |
| | (1) GDP per capita 2000 - 2005 (in log) | (2) GDP per capita 2000 - 2005 (in log) |
| Precipitation | -0.0133** | -0.0288*** |
| | (0.00646) | (0.00618) |
| Precipitation squared | 0.000932 | 0.00158*** |
| | (0.000568) | (0.000527) |
| Temperature | -0.0536*** | -0.0576*** |
| | (0.00980) | (0.00945) |
| Temperature squared | 0.00162*** | 0.00150*** |
| | (0.000240) | (0.000230) |
| Distance to nearest road | yes | yes |
| Distance to nearest road | yes | yes |
| Geographic Coordinates | yes | yes |
| State effects | | yes |
| Year effects (2005) | | yes |
| Constant | 3.474*** | 4.140*** |
| | (0.141) | (0.436) |
| Observations | 4,192 | 4,192 |
| R-squared | 0.234 | 0.360 |
| Test | (9,2059) 73.64 | (41,2027) 27.67 |
| $Prob > F$ | 0.0000 | 0.0000 |

Notes: ( Standard errors). *** $p < 0.01$, ** $p < 0.05$. 2SLS Instrumental Variable Regression

decreases poverty. Our study finds poverty elasticity to growth of -1.74%. In other words that, when average per capita GDP increases by 1 percent, the proportion of municipal poverty declines by around 1.74 percent. Past studies have found a growth elasticity of poverty ranging from -2.59 to -0.69 (For a review see Székely and Foster, 2001).

## 5.3 Simulated Impacts of Climate Change on Per Capita GDP and Poverty

This section provides estimates of the poverty impacts of climate-driven changes in output. Thus far we have estimated the impact of historic temperature and precipitation on GDP per capita in each municipality. Now, we use IPCC's temperature and rainfall projections for 2030 tailored for Mexico to build a different climate vector for each municipality, which then helped to obtain the percent change in output induced by climate change.

To calculate the effects of global warming on GDP in the study areas, we calculate the difference in GDP per capita at projected temperature and rainfall scenarios from the predicted GDP at the historical mean. Predicted impacts of climate change on output result from combining predicted coefficients in model (1) with climate projections.

Our estimates suggest that global warming is expected to decrease output (GDP per capita) in the sample by 1.45 percent, with municipality-specific estimates ranging from -2.25 to +5.86%.

How much will such output declines due to climate change affect poverty? To obtain the poverty impacts of climate change by 2030, we have projected changes on temperature and rainfall and then obtained their effect on GDP in equation (1). Then we simulate poverty rates in equation (2) for the new projections of GDP per capita under climate change in 2030.

In our sample, 48.1 million Mexicans live in asset poverty conditions, 25.2 million people in capacities poverty , while 18.6 million Mexicans are in a situation of food poverty.

Based on Table 1 estimates we simulate the impacts of climate change on poverty by projecting changes in temperature and rainfall. The impacts of climate change on poverty partially undermine the potential adaptive capacity of municipalities through economic growth and population mobility. Without climate change, higher population densities and prosperity would reduce poverty 34.15 percentage points between 2005 and 2030 (from 49.4% in 2005 to 15.25% in 2030), but once climate change is taken into account, poverty falls only from 49.4% to 17.68%. Poverty reduction gains would be 2.43 percentage points less once climate change is factored in. Climate change slows down the pace of poverty reduction. Monitoring changes in poverty over time is valuable, but we cannot determine conclusively whether, or by how much, warming contributes to poverty changes as long as other time-varying factors exist

Table 2: Climate Change and Income Poverty Estimates for Mexico, 2005-2030

| | Food Poverty | Capabilities Poverty | Asset Poverty |
|---|---|---|---|
| Poverty rate, 2005 (national) | 18.2% | 24.7% | 47% |
| Poverty rate, 2005 (own sample) | 18.50% | 25.66% | 49.40% |
| Population in poverty, 2005 (own sample) | 18,673,294 | 25,286,752 | 48,157,443 |
| Poverty rate in 2030 without climate change | 2.05% | 3.86% | 15.25% |
| Population in poverty in 2030 without climate change | 2,459,082 | 4,626,202 | 18,247,694 |
| Poverty rate in 2030 with climate change | 2.36% | 4.56% | 17.68% |
| Population in poverty in 2030 with climate change | 2,822,406 | 5,447,740 | 21,150,562 |
| New poor in 2030 due to climate change | 363,324 | 821,538 | 2,902,868 |

Source: Authors calculations

that are affecting poverty. In the strictest sense, the poverty impact of climate change is not what happens to baseline poverty 25-years from 2005 with a warming climate, but what future poverty (in 2030) is with and without climate change. In this case, asset poverty is expected to increase 2.43 percentage points (from 15.25% to 17.68%). A similar magnitude has been found in a study of the impact of climate change on municipal rural poverty by 2030 in Brazil, where climate change reduces poverty 2 percentage points on average (Assuncao and Chein, 2009). For Mexico, in absolute numbers, given the existing population projections for 2030, an increase of2.43 percent represents 2,902,868 people remaining in poverty as a result of climate change.

Our results are quite heterogeneous across the country, with climate change impacts on municipal poverty rates ranging from -29% to +37%. When aggregated at state level, as Table 3 shows, less poverty is expected in the Northwest and Peninsula regions, while North, Central Mexico (except Distrito Federal), West and South regions are expected to suffer more from global warming. The Northwest region may experience an increase in poverty of 0.47 percentage points only, while poverty is expected to increase by 3.68 percentage points in the West region.


Figure 4: Asset Poverty Impacts of Climate Change in 2030 (change in percentage points).

Table 3: Poverty Impacts of Climate Change, 2030.

| State | Poverty Without Climate Change | Poverty With Climate Change | Change in Poverty (pp) |
|---|---|---|---|
| Distrito Federal | 11.55 | 11.34 | -0.21 |
| Querétaro Arteaga | 6.24 | 8.33 | 2.09 |
| México | 11.44 | 13.67 | 2.23 |
| Hidalgo | 14.13 | 17.27 | 3.13 |
| Morelos | 23.54 | 27.96 | 4.42 |
| Tlaxcala | 28.33 | 33.05 | 4.73 |
| Puebla | 15.80 | 20.53 | 4.73 |
| Guanajuato | 22.15 | 26.91 | 4.77 |
| **Central Mexico** | **16.81** | **14.19** | **2.62** |
| Tabasco | 7.81 | 8.19 | 0.38 |
| Veracruz de Ignacio de la Llave | 12.10 | 13.97 | 1.88 |
| Tamaulipas | 13.93 | 19.03 | 5.10 |
| **Gulf** | **14.41** | **11.87** | **2.54** |
| Baja California Sur | 2.41 | 2.47 | 0.06 |
| Baja California | 6.61 | 6.87 | 0.26 |
| Sonora | 7.27 | 7.95 | 0.68 |
| Sinaloa | 13.35 | 14.13 | 14.13 |
| **Northwest** | **8.48** | **8.01** | **0.47** |
| Nuevo León | 5.81 | 6.99 | 1.18 |
| Zacatecas | 7.98 | 9.44 | 1.46 |
| Chihuahua | 8.12 | 10.04 | 1.92 |
| Aguascalientes | 7.78 | 10.17 | 2.40 |
| Coahuila de Zaragoza | 17.87 | 21.35 | 3.48 |
| San Luis Potosí | 16.23 | 20.62 | 4.39 |
| Durango | 25.89 | 31.68 | 5.80 |
| **North** | **14.23** | **11.60** | **2.63** |
| Colima | 16.07 | 17.31 | 1.24 |
| Nayarit | 8.42 | 9.86 | 1.44 |
| Jalisco | 14.07 | 17.81 | 3.74 |
| Michoacán de Ocampo | 19.14 | 23.83 | 4.69 |
| **West** | **18.81** | **15.13** | **3.68** |
| Campeche | 40.08 | 40.20 | 0.13 |
| Quintana Roo | 6.48 | 7.09 | 0.61 |
| Yucatán | 9.93 | 12.54 | 2.61 |
| **Peninsula** | **13.31** | **11.89** | **1.42** |
| Guerrero | 35.34 | 37.10 | 1.75 |
| Chiapas | 45.87 | 47.79 | 1.92 |
| Oaxaca | 28.90 | 33.74 | 4.84 |
| **South** | **42.45** | **40.11** | **2.34** |
| **National** | **17.68** | **15.25** | **2.43** |

Note: Poverty estimates at regional and state levels are population-weighted.

## 6 Conclusion.

Climate change will increase temperature and rainfall variability, which combined will reduce income in Mexico: GDP per capita for our sample of municipalities in Mexico will vary by 1.45 percent by 2030 given projected changes in rainfall and temperature.

It is hard to anticipate if output losses (due to climate change) will increase poverty in the study regions. Some municipalities will experience important readjustments in their productive composition and population mobility will modify the outlook. Households can adapt to changing climate conditions through spatial mobility and increased mean per capita output due to economic growth, so we account for both of these mechanisms over the next 25 years.

The main impact of climate change on poverty is a reduction of the gains that would result from improved spatial mobility and increased mean per capita output due to economic growth adaptive capacity. This is based on the fact that higher population densities and prosperity reduce poverty. Our estimates suggest that population and economic growth reduce poverty by 34.15 percentage points (pp) in 2030 relative to baseline poverty in 2005. However, such gains in poverty reduction over the next 25 years will fall by 2.43% due to climate change: Poverty in 2030 gets reduced 31.72 pp instead of 34.15 pp once climate change is accounted for.

While monitoring changes in poverty over time is a valuable exercise, we cannot determine conclusively whether -or by how much- global warming will contribute to changes in poverty rates, as long as there are other time-varying factors that affect poverty. Following Skoufias et al. (2011), the proper way to present poverty estimates associated with future climate change would be to predict the poverty rate by 2030 (not the poverty rate in 2005) in a world with and without such warming. Having obtained elasticities to predict the impact of climate on output and then subsequently of output on poverty in 2005, we used those elasticities with projected climate and output to compare the poverty rate by 2030 with and without climate change. According to these estimates, asset poverty is expected to increase 2.43% due to climate change.

Predicting the impacts of climate change on GDP and poverty is a starting point to address the vulnerability of those people and municipalities who have low resilience to adverse climatic events. It remains to be seen how fast municipalities will adapt to changing climate conditions, and if current policies are conducive to this end. The adaptive capacity of households is heterogeneous, and we account for some of this adaptive capacity through spatial mobility and economic growth. The government can also improve adaptation through prices, transfers and insurance.

Finally, the analysis presented here provides average estimates of income and poverty increases associated with temperature and rainfall changes. It is also necessary to assess the distributional impact of climate change across population groups.

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Table 4: Annex 1: Municipal-Level Summary Statistics.

| **Variables** | **Unit** | **Minimum** | **Maximum** | **Mean** | **Standard Deviation** |
|---|---|---|---|---|---|
| Asset Poverty, 2000 | % | 9.24 | 99.5 | 53.6 | |
| Asset Poverty, 2005 | % | 1 | 96.8 | 47 | |
| Population, 2000 | # | 109 | 1,773,343 | 39,615 | 118,947 |
| Population, 2005 | # | 102 | 1,820,888 | 42,454 | 127,136 |
| GDP per capita, 2000 | $USD | | | 4,211 | 756 |
| GDP per capita, 2005 | $USD | | | 6,234 | 1,124 |
| Rain (Accumulated mm3 per year) | mm | 0 | 5,449 | 877 | 802.25 |
| Temperature Average per Day | Celsius | 8.17 | 29.24 | 20.57 | 4.17 |
| **Variables** | | | | | |
| Population, 2030 | # | 611 | 1,900,087 | 51,772 | 172,943 |
| GDP per capita, 2030 | $USD | | | 13,737 | 5,851 |
| Rain (Accumulated mm3 per year), 2030 | mm | 0 | 3,522 | 619 | 557 |
| Temperature Average per Day, 2030 | Celsius | 8.70 | 31.00 | 21.80 | 4.37 |

Note: N = 2,039 municipalities.