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Summary:

This paper uses municipality level data to estimate the general relationships between climate, income and child mortality in Mexico. Climate was found to play only a very minor role in explaining the large differences in income levels and child mortality rates observed in Mexico. This implies that Mexico is considerably less vulnerable to expected future climate change than other countries in Latin America.

Keywords: Climate change, social impacts, Mexico.
JEL classification: Q51, Q54, O15, O19, O54.

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1. Introduction and justification

A simple way to gauge how climate change affects human development is to compare human development across regions with different climates. This has, for example, been done by Horowitz (2006), which uses a cross-section of 156 countries to estimate the relationship between temperature and income level. The overall relationship found is very strongly negative, with a 2°F increase in global temperatures implying a 13% drop in income. This is very dramatic, but the relationship is thought to be mostly historical and thus not very relevant for the prediction of the effects of future climate change. In order to control for historical factors, the paper includes colonial mortality rates as an explanatory variable, and finds a much more limited, but still highly significant, contemporaneous effect of temperature on incomes. The contemporaneous relationship estimated implies that a 2°F increase in global temperatures would cause approximately a 3.5% drop in World GDP.

In order to further control for historical differences, Horowitz (2006) uses more homogeneous sub-samples, such as only OECD countries or only countries from the Former Soviet Union, and the negative relationship still holds. However, as directions for further research, he recommends empirical studies of income and temperature variations within large, heterogeneous countries, which would provide much more thorough control for historical differences.

This is exactly what we will do in the present paper. Using data from 2443 municipalities in Mexico, we will estimate contemporary relationships between temperature and income as well as between temperature and child mortality. While it is always dangerous to make inferences about changes in time from cross-section estimates, these relationships can at least be used to gauge the likely direction and magnitude of effects of climate change in Mexico.

Two different types of climate change will be assessed. First, the documented recent climate change in each of the 2443 municipalities, as estimated from average monthly temperature series from 1948 to 2008 for all the Mexican meteorological stations that have contributed systematically to the Monthly Climatic Data for the World (MCDW) publication of the US National Climatic Data Center.

Second, we will use the predictions of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC4) climate models to simulate the likely effects of projected future climate change in Mexico.

The rest of the paper is organized as follows. Section 2 describes the data sources and provides descriptions of the key variables. Section 3 estimates the cross-municipality relationships between climate and human development, controlling for other key variables that also affect development. Section 4 analyzes past climate change for 22 meteorological stations across Mexico, and estimates average trends in temperatures and precipitation. Section 5 uses the results from sections 3 and 4 to simulate the effects of climate change on income and child mortality in each of the 2350 municipalities in Mexico.. Section 6 concludes.

2. The data

The data used for this paper consists of both cross-section data and time series data. The municipality level cross-section data base which was used to estimate the relationship between climate and development in Mexico was constructed using data from many different sources. Table 1 lists the variables, their definitions, and the sources of the information.

Table 1: Variables in the municipality level data base for Mexico

Variable	Unit	Source
Total population per municipality	-	Municipal Human Development Index – PNUD Mexico 2000
Urbanization rate (Percentage of population living in urban areas)	%	Municipal Human Development Index – PNUD Mexico 2000
Literacy rate (Percentage of the adult population that can read and write)	%	Municipal Human Development Index – PNUD Mexico 2000
Child mortality	Deaths per 1000 live births	Municipal Human Development Index – PNUD Mexico 2000
Per capita income	PPP-adjusted US$	Municipal Human Development Index – PNUD Mexico 2000
Latitude	Decimal degrees	Google Earth
Longitude	Decimal degrees	Google Earth
Elevation	Kilometers above sea level	Google Earth
Normal average annual temperature	Degrees Celsius	Servicio Meteorológico Nacional
Normal annual rainfall	Milimeters	Servicio Meteorológico Nacional

In order to assess the climate change trends in the different parts of Mexico, we obtained monthly temperature and rainfall data from 1948 to 2008 from the Monthly Climatic Data for the World (MCDW) publication of the US National Climatic Data Center (NCDC). This data is described in more detail in Section 4 below.

3. Modeling climate and human development

In this section, we will estimate the contemporary relationship between climate and human development in Mexico. Two dimensions of human development will be analyzed: income and health, because these are the ones that most directly could be affected by climate change. Education, on the other hand, is treated as an explanatory variable instead of a dependent variable. In order to obtain a contemporary relationship relevant for the simulation of the impacts of climate change over the past 50 years and future 50 years, we need to control for other variables that also affect human development, but are likely not affected by climate change within this time frame. Education level is by far the most important control variable, as it explains a very high percentage of the variation in both income and child mortality across municipalities (see below), and the progress achieved in the area of education is not likely to be compromised because of the modest climate changes that are expected within the next 50 years. The urbanization rate is another important control variable, which clearly affects both income and child mortality, but which is relatively unaffected by climate change in the short run (50 years).

As several researchers have pointed out, the relationship between temperature and development is likely to be hump-shaped, as both too cold and too hot climates may be detrimental for human development (Mendelsohn, Nordhaus & Shaw, 1994; Quiggin & Horowitz, 1999; Masters & McMillan, 2001, Tol, 2005). In order to allow for this possibility we include both average annual temperature and its square in the regression. The same argument also holds for rainfall and possibly also urbanization rates, which is why we also include rainfall and urbanization rates squared.

Thus, the regressions in this section will take the following form:

$$\ln y_i = \alpha + \beta_1 \cdot temp_i + \beta_2 \cdot temp_i^2 + \beta_3 \cdot rain_i + \beta_4 \cdot rain_i^2 + \beta_5 \cdot edu_i + \beta_6 \cdot urb_i + urb_i^2 + \varepsilon_i$$

where y_i is a measure of the income level in municipality i, $temp_i$ and $rain_i$ are normal average annual temperature and normal accumulated annual precipitation in municipality i, edu_i is a measure of the education level (percentage of the adult population that can read and write), urb_i is the urbanization rate of the municipality, and ε_i is the error term for municipality i.

The child mortality regression will take the same form as the income regressions, except that we will not apply the natural logarithm to the dependent variable. All regressions are weighted OLS regressions, where the weights consist of the population size in each municipality.

The regression results for both income and child mortality are reported in Table 3.

Table 3: Estimated short-term relations between climate and income/child mortality in Mexico

Explanatory variables	(1) (log per capita income)	(2) (child mortality)
Constant	5.3729	67.2665
	(25.66)	(59.43)
Temperature	-0.0313	0.2126
	(-1.84)	(2.31)
Temperature^2	0.0010	-0.0045
	(2.34)	(-1.95)
Precipitation	-0.0283	-2.0991
	(-0.68)	(-9.32)
Precipitation^2	0.0031	0.5352
	(0.25)	(7.84)
Education level	0.0326	-0.4340
	(24.40)	(-60.13)
Urbanization rate	0.0032	-0.1048
	(3.31)	(-19.91)
Urbanization rate^2	0.0001	0.0004
	(7.92)	(7.96)
Number of obs.	2350	2350
R^2	0.7377	0.8940

Source: Authors' estimation based on assumptions explained in the text.
Note: Numbers in parenthesis are t-values. When t-values are numerically larger than 2, we will consider the coefficient to be statistically significant, corresponding to a confidence level of 95%.

The results at the bottom of the table show that just these four explanatory variables (temperature, precipitation, education, and urbanization rates) explain more than 74% of the variation in incomes between the municipalities in Mexico. This is a very good fit, which suggests that we have included the most important explanatory variables, and that including addition variables would make little difference. The same four variables explain about 89% of the variation in child mortality, which is even more impressive.

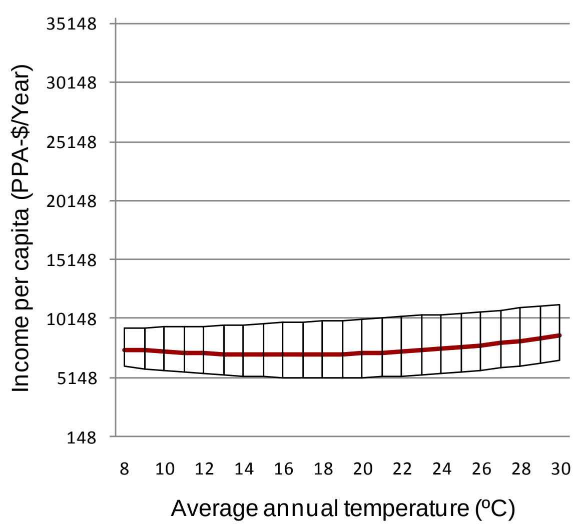
Education level, here measured as the percentage of the adult population that can read and write, is by far the most important variable, explaining about 62% of the variation in incomes and about 82% of the variation in child mortality. The remaining variables are also all statistically significant, but in a non-linear way. As it is difficult to judge the non-linear effects of the remaining variables by looking at the estimated coefficients and t-values, we have plotted the estimated relationships in Figure 2 together with 95% confidence intervals on each relationship. The axes are scaled to represent the actual range of temperatures, precipitation, incomes, and life expectancies experienced in different Mexican municipalities, so that the magnitude of climate impacts can be seen in the appropriate perspective.

Panel (a) shows an almost flat relationship between temperature and per capita income. There is a tremendous variation in incomes between municipalities, but this variation has little to do with average temperatures.

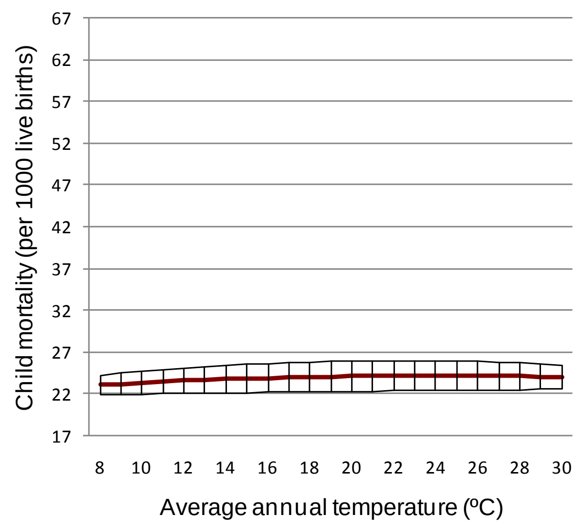
Panel (b) also shows an almost completely flat relationship between temperature and child mortality.

Figure 2: Estimated contemporary relations between temperature/rainfall and income/child mortality in Mexico

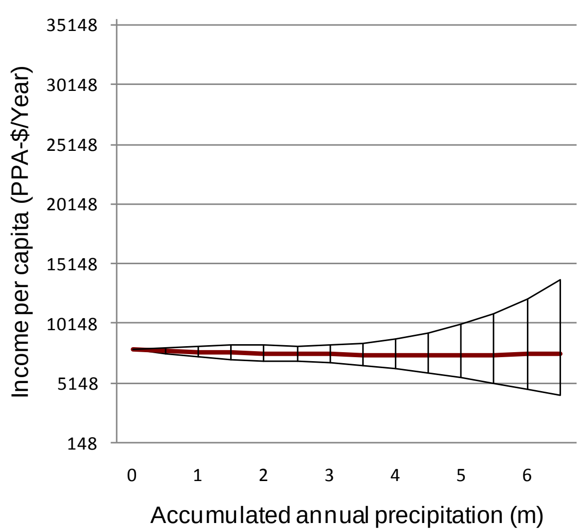
(a) Temperature and Income



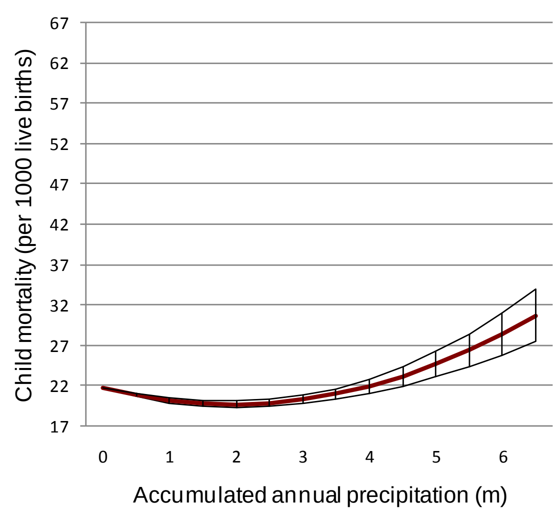
(b) Temperature and child mortality



(c) Rainfall and Income



(d) Rainfall and child mortality



Source: Graphical representation of the estimation results from Table 3. The thick red line represents the point estimate, while the thin black lines delimit the 95% confidence interval as estimated by Stata's lincom command.

The only statistically significant climate-development relationship found for Mexico is shown in panel (d) which suggests that child mortality is lowest in regions with moderate amounts of rainfall, and higher in regions with either very little or very much rain.

4. Recent climate change in Mexico

In this section we will analyze climate data from Mexico from May 1948 to May 2008 to test whether there are any significant trends, and whether these trends differ between regions.

We will use the Monthly Climatic Data for the World database collected by the National Climatic Data Center (NCDC) in the US. This project started in May 1948 with 100 selected stations spread across the World, including 15 in Mexico. Since then, many more stations have been included in the data base, but only 21 stations in Mexico have contributed systematically throughout the period, with only inconsequential gaps. These are listed in Table 4.

Table 4: High quality climate stations in Mexico used for trend analysis

MEXICO	Latitude	Longitude	Altitude (m)
PACIFIC MEXICO			
Guaymas	27º55'N	110º53'W	4
La Paz, B.C.S.	24º10'N	110º10'W	18
Colonía Juan Carrasco, Mazatlan	23º12'N	106º20'W	4
Manzanillo, Col.	19º03'N	104º10'W	3
Acapulco, Gro.	16º50'N	99º56'W	3
Tapachula, Chis.	14º55'N	92º15'W	118
Salina Cruz	16º10'N	95º12'W	4
CENTRAL MEXICO			
Chihuahua, Chihuahua	28º38'N	106º00'W	1433
Monclova, Coah.	26º53'N	101º20'W	615
Monterrey, N.L.	25º44'N	100º10'W	515
Torreon, Coah.	25º32'N	103º20'W	1124
Zacatecas	22º47'N	102º35'W	2612
Guanajuato, Gto.	21º00'N	101º10'W	1999
Guadalajara, Jal.	20º40'N	103º20'W	1589
Morelia, Mich.	19º42'N	101º10'W	1913
Mexico (Central), D.F.	19º26'N	99º04'W	2303
ATLANTIC MEXICO			
Tampico, Tamps	22º12'N	97º51'W	25
Merida Int. Airport	20º59'N	89º39'W	9
Chetumal, Q. Roo	18º29'N	88º18'W	7
Veracruz	19º09'N	96º07'W	13
Coatzalcoacos, Ver.	18º08'N	94º25'W	22

The "normal" temperature for each station-month was calculated as the average temperature observed for the reference period 1961-1990. Some stations had so few and scattered observations that it was impossible to calculate reliable "normal" temperatures, and measurements from these stations have therefore been discarded. Only the stations that have at least eight observations for each calendar month, during the reference period, were included in the analysis in this chapter. An additional requirement for inclusión in the present analysis is that each station should have at least 300 out of the 721 possible monthly observations. Extreme outliers[1] for which no explanation could be found (e.g. a strong El Niño/La Niña event), were discarded as typing errors.

Temperature trends

We use the temperature anomaly series—calculated for each station—to test whether there are any significant trends during the 1948-2008 period. Table 5 shows the estimated trend for each of the 21 stations. Using a 95% confidence criterion, the trend is statistically significant if the estimated P-value for the trend variable is lower than 0.05. According to this criterion, 12 out of 21 stations show a significant positive trend in temperatures, 3 stations show a significant negative trend, and the remaining 6 show no significant.

Table 5: Estimated temperature trends (ºC/decade) for 21 stations in Mexico

MEXICO	Trend	t-value	P-value	# of obs.
PACIFIC MEXICO				
Guaymas	-0.39	-5.33	0.000	336
La Paz, B.C.S.	0.20	5.97	0.000	508
Colonía Juan Carrasco, Mazatlan	0.11	4.06	0.000	481
Manzanillo, Col.	-0.01	-0.39	0.694	546
Acapulco, Gro.	-0.09	-3.51	0.000	507
Tapachula, Chis.	0.33	15.52	0.000	459
Salina Cruz	0.21	4.08	0.000	328
CENTRAL MEXICO				
Chihuahua, Chihuahua	0.05	1.29	0.197	504
Monclova, Coah.	0.32	6.16	0.000	403
Monterrey, N.L.	0.07	1.66	0.097	508
Torreon, Coah.	0.15	3.70	0.000	482
Zacatecas	0.10	1.78	0.076	348
Guanajuato, Gto.	0.13	4.99	0.000	521
Guadalajara, Jal.	0.04	0.93	0.356	375
Morelia, Mich.	0.20	6.89	0.000	477
Mexico (Central), D.F.	0.25	6.44	0.000	437
ATLANTIC MEXICO				
Tampico, Tamps	0.16	5.16	0.000	510
Merida Int. Airport	0.11	3.98	0.000	506
Chetumal, Q. Roo	0.17	5.65	0.000	461
Veracruz	-0.21	-3.59	0.000	363
Coatzalcoacos, Ver.	0.06	1.90	0.058	348

Source: Authors' estimation based on monthly temperature anomalies calculated from data from the Monthly Climatic Data for the World data base published by the NCDC.

Since individual stations are subject to idiosyncratic variations (e.g. local effects due to construction close to the climate station), it is necessary to average over several stations in order to get reliable trends for the region. Table 6 presents the average temperature trends

[1] Extreme here being defined as temperaturas deviating more tan 8ºC from normal for the month and precipitation deviating more than 500 mm from normal for the month.

by climatic region. According to this table, the central zone of Mexico is warming about 3 times faster than the coastal zones. The estimated trends correspond to a change over 50 years of about 0.25ºC in the coastal regions and 0.75ºC in the central region.

Table 6: Estimated temperature trends (ºC/decade) for the 3 main climate regions in Mexico

Trends	Average	Maximum	Minimum
PACIFIC ZONE	0.0514	0.3300	-0.3900
CENTRAL ZONE	0.1456	0.3200	0.0400
ATLANTIC ZONE	0.0580	0.1700	-0.2100

Precipitation trends

Precipitation varies tremendously across Mexico. The Sonoran desert in the Northwest receives less than 10 cm of rain per year, while the tropical rainforest of southern Mexico receives more than 2 meters of rain annually. The wettest place, San Juan Comaltepec in Oaxaca, receives 6.1 meters of precipitation annually. According to Liverman (1999), the various climates of Mexico are determined by the latitudinal belts of atmospheric circulation which shift seasonally and include the westerlies which bring precipitation to northern Mexico in winter, the sub-tropical highs associated with stable, dry conditions, and the trade winds which bring summer rainfall to the central and southern regions of the country. Precipitation is also affected by fall hurricanes on both the Caribbean and Pacific coasts and summer monsoons in the north. The mountainous topography of Mexico is also of key importance, creating rain shadows behind coastal mountains.

Small shifts in the natural paths of fall hurricanes and summer monsoons can create large inter-annual variation in precipitation, which means that precipitation in any specific place is very variable.

A trend analysis, however, reveals no systematic changes in rainfall over the period 1948-2008. All stations except one show no significant trend in monthly precipitation anomalies (see Table 7). We will therefore conclude that there have been no systematic changes in precipitation in Mexico during the last 6 decades.

Table 7: Estimated precipitation trends (ºC/decade) for 19 stations in Mexico

MEXICO	Trend	t-value	P-value	# of obs.
PACIFIC MEXICO				
Guaymas	1.26	1.22	0.223	295
Colonía Juan Carrasco, Mazatlan	-0.64	-0.34	0.737	453
Manzanillo, Col.	1.90	0.90	0.370	512
Acapulco, Gro.	-0.84	-0.33	0.741	473
Tapachula, Chis.	-0.39	-0.16	0.876	430
Salina Cruz	-0.57	-0.19	0.846	300
CENTRAL MEXICO				
Chihuahua, Chihuahua	-1.06	-1.01	0.315	477
Monterrey, N.L.	1.34	0.87	0.382	495
Torreon, Coah.	0.01	0.01	0.993	444

Zacatecas	-0.45	-0.27	0.789	331
Guanajuato, Gto.	0.07	0.04	0.964	502
Guadalajara, Jal.	0.89	0.55	0.585	371
Morelia, Mich.	0.85	0.76	0.445	466
Mexico (Central), D.F.	0.04	0.03	0.973	423
ATLANTIC MEXICO				
Tampico, Tamps	2.26	1.12	0.263	493
Merida Int. Airport	1.57	0.87	0.387	500
Chetumal, Q. Roo	4.39	2.03	0.043	441
Veracruz	-0.62	-0.20	0.838	341
Coatzalcoacos, Ver.	-1.93	-0.50	0.615	334

Source: Authors' estimation based on monthly precipitation anomalies calculated from data from the Monthly Climatic Data for the World data base published by the NCDC.

5. Simulating the impacts of climate change

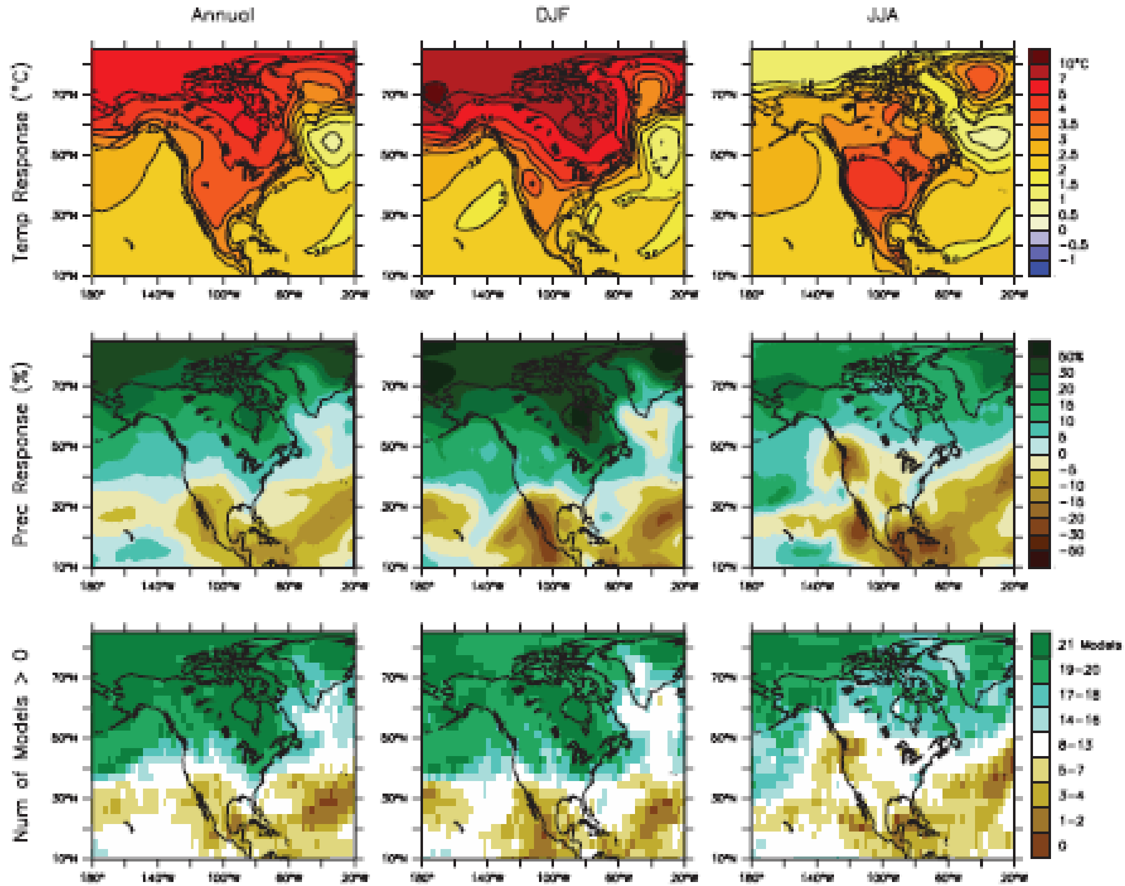
In this section, we planned to use the two models estimated in Table 3 above to simulate the impacts of the climate change experienced during the last 50 years on per capita income and child mortality in each of the 2443 municipalities in Mexico.

However, since income and child mortality were not found to be significantly related to temperatures, and since precipitation does not seem to have changed systematically over the last 50 years, there is nothing left to simulate, and our conclusion must be that the gradual climate change experienced over the last 50 years has not had a statistically significant effect on neither incomes nor child mortality in Mexico.

Notice, however, that we are only talking about systematic climate change (i.e. the slight temperature increases of 0.25ºC-0.75ºC), not extreme events.

In terms of the effect of future climate change, there is a potential impact on child mortality from changes in precipitation. Most of the models in the IPCC ensemble of 21 Atmosphere-Ocean General Circulation Models suggest precipitation reductions over the coming decades, but at least a handful of models show increases, which means that future changes are highly uncertain (see Figure 5). In the simulations of the effects on child mortality we will assume modest reductions of 5% over the next 50 years all over Mexico.

Figure5: Temperature and precipitation changes predicted by the climate models used by IPCC 4, 1990-2090



Source: Christensen *et al* (2007, Figure 11.12).

To find the impacts of climate change we will compare the following two scenarios: 1) Climate Change and 2) No Climate Change, where the only difference between the two are in the climate variables.
The Climate Change level of child mortality can be written as:

$$CM_{i,CC} = \hat{\beta}_1 \cdot t_{i,CC} + \hat{\beta}_2 \cdot t_{i,CC}^2 + \hat{\beta}_3 \cdot r_i + \hat{\beta}_4 \cdot r_i^2 + \sum_{j=1}^{k} \hat{\alpha}_j X_{j,i} + \hat{\varepsilon}_i,$$

where the index i refers to municipality i; t and r are the temperature and precipitation variables; the $\hat{\beta}$s are the estimated coefficients on the temperature and precipitation variables; the X_js are the remaining j explanatory variables including the constant term; the $\hat{\alpha}_j$s are the coefficient to these variables; and $\hat{\varepsilon}_i$ are the estimated error terms for each municipality.

Equivalently, the counterfactual level of child mortality under the assumption of No Climate Change can be written as:

$$CM_{i,NCC} = \hat{\beta}_1 \cdot t_{i,NCC} + \hat{\beta}_2 \cdot t_{i,NCC}^2 + \hat{\beta}_3 \cdot r_i + \hat{\beta}_4 \cdot r_i^2 + \sum_{j=1}^{k} \hat{\alpha}_j X_{j,i} + \hat{\varepsilon}_i ,$$

where only the climate variables differ.

The difference between the two scenarios is the difference in child mortality that can be directly attributed to climate change:

$$\Delta_{CC} CM_i = CM_{i,CC} - CM_{i,NCC} = \hat{\beta}_1 \cdot (t_{i,CC} - t_{i,NCC}) + \hat{\beta}_2 \cdot (t_{i,CC}^2 - t_{i,NCC}^2) + \hat{\beta}_3 \cdot (r_{i,CC} - r_{i,NCC}) + \hat{\beta}_4 \cdot (r_{i,CC}^2 - r_{i,NCC}^2)$$

Since the coefficients $\hat{\beta}_1$ and $\hat{\beta}_2$ were found to be statistically indifferent from zero, however, this relationship reduces to:

$$\Delta_{CC} CM_i = CM_{i,CC} - CM_{i,NCC} = \hat{\beta}_3 \cdot (r_{i,CC} - r_{i,NCC}) + \hat{\beta}_4 \cdot (r_{i,CC}^2 - r_{i,NCC}^2)$$

At the aggregate level, future climate change in Mexico is estimated to cause a small increase in average child mortality of about 0.07 deaths per thousand live births. The most adverse effect found in any municipality was an increase of 0.24 while the most beneficial effect was a reduction of 1.25 deaths per 1000 live births. Thus, the expected effect of future climate change on child mortality is minimal.

6. Conclusions

In this paper we used a municipal level cross-section database to estimate the cross-sectional relationships between climate and income/child mortality in Mexico. We found that average temperatures and average precipitation are not significantly related to income. Only the relationship between precipitation and child mortality was found to be statistically significant, with higher child mortality rates in regions with either very little or very large quantities of precipitation.

Past changes in climates were analyzed using historical data from 21 meteorological stations spread across the territory, and estimating average trends in temperature and precipitation for each station. It was found that average annual temperatures have increased by about 0.75ºC over the last 50 years in the central part of Mexico and by about 0.25ºC in the coastal regions. No systematic changes in precipitation were found. Since the only climate variable found to have a statistically significant effect on human development, was not found to change over the last 50 years, we must conclude that recent climate change has probably not had a significant effect on neither income levels nor child mortality levels.

Warming in the future is expected to be stronger, and models predict that precipitation may decrease slightly, which means that we were able to simulate the effect of future climate change on child mortality. However, the impacts found were extremely modest, with the most adversely affected municipality showing an increase in child mortality in the order of 1 extra death per 4000 live births. .

The conclusion is that Mexico appears to be considerably less vulnerable to climate change than most other Latin American countries. In Brazil, for example, a similar analysis showed losses in income from future climate change of up to 29% in some municipalities and an overall loss of 11.9% for the whole country (see Andersen, Román & Verner, 2010). In Peru, an analysis using the same methodology found reductions in incomes of up to 15% in some regions and an overall loss in incomes of 2.3% due to expected climate change over the next 50 years (see Andersen, Suxo & Verner, 2009).

Some qualifications to these results are in order. First of all, the simulations have been carried out by varying temperature and rainfall, but holding all other factors constant. Holding everything else constant is of course not realistic. Education levels are likely to increase and the structure of the economy is likely to keep changing towards activities that are less sensitive to the climate. In addition, there is likely to be a positive effect from CO_2 fertilization, which is also not included in the present analysis. Taking into account such changes would likely further reduce the small adverse effects estimated in this paper.

Second, this paper compares equilibrium situations before and after climate change, but ignores transition costs. Since climate changes are expected to happen in slow motion, especially compared to the natural variation from month to month and from place to place, such transition costs are likely small, but they may include additional investments in water reservoirs and irrigation systems.

Finally, it should be highlighted that this paper has only analyzed the impacts of climate *change* (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*. The latter likely has more drastic effects. Mexico has been plagued by recurrent episodes of drought since Pre-Columbian times[2], and despite the spread of irrigation systems, Mexican agriculture is still vulnerable to droughts (Liverman 1999).

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[2] It has been suggested that drought played a part in the collapse of Mayan and other Meso-American civilizations (e.g. Dahlin 1983; Hodell *et al* 1995).

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