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The Impacts of Climate Variability on Welfare in Rural Mexico

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Abstract

This paper examines the impacts of weather shocks, defined as rainfall or growing degree days more than a standard deviation from their respective long-run means, on household consumption per capita and child height-for-age. The results reveal that the current risk-coping mechanisms are not effective in protecting these two dimensions of welfare from erratic weather patterns. These findings imply that the change in the patterns of climatic variability associated with climate change is likely to reduce the effectiveness of the current coping mechanisms even more and thus increase household vulnerability further. The results reveal that weather shocks have substantial (negative as well as positive) effects on welfare that vary across regions (North vs. Center and South) and socio-economic characteristics (education and gender). The heterogeneous impacts of climatic variability suggest that a "tailored" approach to designing programs aimed at decreasing the sensitivity and increasing the capacity of rural households to adapt to climate change in Mexico is likely to be more effective.

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The Impacts of Climate Variability on Welfare in Rural Mexico[1]

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Key Words: Weather, household welfare, child health outcomes

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1. Introduction

While there is a great deal of uncertainty over the exact magnitudes of the global changes in temperature and precipitation, it is widely accepted that significant deviations of the variability of climate from its historical patterns are likely to occur (IPCC, 2007).[3] Considering that millions of poor households in rural areas all over the world are dependent on agriculture, there are increasing concerns that the change in the patterns of climatic variability is likely to add to the already high vulnerability of households in rural areas of developing countries, thus posing a serious challenge to development efforts all over the world. In view of this impending threat of climate change upon the poor, it is critical to have a deeper understanding of the household *adaptation* strategies and targeted measures that could mitigate the poverty impacts of erratic weather. With these considerations in mind, in this paper, we carry out an analysis of the welfare impacts of climatic variability in the rural areas of Mexico.

Our objectives are threefold. First, we try to quantify the extent to which unusual or erratic weather has any negative impacts on the welfare of households. Based on historical experience and the multiplicity of economic and institutional constraints faced, rural households in Mexico, as most rural households all over the world, have managed to develop traditional strategies for managing climatic risk. Eakin (2000), for example, documents how smallholder farmers have adapted to climatic risk in the Tlaxcala region of Mexico. Yet, quantitative evidence on how successful such risk management strategies are at protecting household welfare in Tlaxcala or elsewhere in Mexico is quite scarce.[4] To the extent that the current risk-coping mechanisms are not very effective in protecting welfare from erratic weather patterns one can be quite certain that the change in the patterns of climatic variability associated with climate change is likely to reduce the effectiveness of the current coping mechanisms even more and thus increase household vulnerability further. We use two separate nationally representative household surveys—the first two waves of the Mexican Family Life

[3] According to the Intergovernmental Panel on Climate Change (IPCC) a narrow definition of climate refers to the statistical description in terms of the mean and variability of quantities such as temperature, precipitation and wind over a period of time ranging from months to thousands of years. The norm is 30 years as defined by the World Meteorological Organization (WMO). Climate is different from weather which refers to atmospheric conditions in a given place at a specific time. The term "climate change" is used to indicate a significant variation (in a statistical sense) in either the mean state of the climate or in its variability for an extended period of time, usually decades or longer (Wilkinson 2006).

[4] Other studies relying on the perceptions of respondents about the incidence of different types of shocks, such as floods, droughts, freeze, fires and hurricanes include Garcia Verdu (2002), Skoufias (2007) and de la Fuente (2010). None of these earlier studies, however, make use of actual meteorological data.

Survey (MxFLS), carried out in 2002 and in 2005, and the 1999 National Survey on Nutrition (ENN)—to examine whether climatic variability, namely the incidence of rainfall and temperature more than one standard deviation from their respective long run means, have significant impacts on the wellbeing of rural *households* and vulnerable *individuals*. Well-being or welfare is defined by two (of many) important dimensions—household consumption expenditures per capita, and individual health outcomes.

Second, we attempt to shed light on the channels through which climatic variability can impact the two different dimensions of welfare examined. On the one hand, erratic weather may affect agricultural productivity which, depending on how effective was the portfolio of *ex ante* and *ex post* risk management strategies employed, may translate into reduced income and reduced food availability at the household level.[5] Such reductions in food availability may not affect all household members equally. On the other hand, both temperature and precipitation may affect the prevalence of vector borne diseases, water borne and water washed diseases, as well as determine heat or cold stress exposure (Confalonieri *et al.*, 2007). Many parasitic and infectious species have very specific environmental conditions in which they survive and reproduce, and a slight change in precipitation or temperature could render previously uninhabitable areas suitable for a particular parasitic and infectious species. Specifically in Mexico, several studies have shown positive correlations between temperature, and vector- and food-borne illnesses (Ministry of Environment and Natural Resources, 2007).

It is also the case, that changes in the environmental conditions do not uniformly affect the health of household members. Children are more likely to contract or die from vector borne diseases, more likely to suffer from diarrhea, more likely to suffer psychologically from extreme weather events, and more likely to suffer from maltreatment due to household economic stress (Bartlett, 2008). Early childhood health not only affects children's current wellbeing but may determine their adulthood quality of life including their productivity and cognitive development. Malnutrition, from having insufficient food intake or as a byproduct of repeated diarrheal infections, can cause structural damage to the brain and impair motor development in

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[5] For example, households may undertake ex-ante income-smoothing strategies and adopt low return-low risk crop and asset portfolios (Rosenzweig and Binswanger, 1993). Households may use their savings (Paxson, 1992), take loans from the formal financial sector to carry them through the difficult times (Udry, 1994), sell assets (Deaton, 1993), or send their children to work instead of school in order to supplement income (Jacoby and Skoufias, 1997). These actions enable households to spread the effects of income shocks through time. Additional strategies include the management of income risk through ex-post adjustments in labor supply such as multiple job holding, and engaging in other informal economic activities (Morduch, 1995; Kochar, 1988).

infants which in turn affect the cognitive development of a child (Victora et al., 2008; Guerrant et al., 2008). Furthermore, Eppig, Fincher and Thornhill (2010) find a correlation between infectious diseases and IQ. They explain their findings as the competition between energy needs for the development of the brain and energy needs needed to fight off disease. They single out diarrheal diseases as potentially being the most energy consuming ones. Overall, childhood health has been found to have an impact on adult health, and employment (Case, Fertig and Paxson, 2005), cognitive abilities (Case and Paxson, 2008; Grantham-McGregor et al., 2007; Maluccio et al., 2009), educational outcomes (Alderman, Hoddinott and Kinsey, 2006; Glewwe and Miguel, 2008; Maluccio et al., 2009), and productivity (Hoddinott et al., 2008). These findings underline the importance of focusing on the health outcomes for young children.

Third, we investigate the extent to which certain household or individual characteristics, such as gender, educational attainment, or participation in supplemental nutrition programs, or where the household lives, alter the welfare impacts of climatic variability in rural areas. It is quite possible that the resilience and the ability to adapt to changes in weather and environmental conditions differs significantly across the spectrum of socio-economic characteristics in the population and across geographical regions.

In view of these considerations, we carry out two sets of analyses. We first estimate the impact of weather shocks on household consumption controlling for a variety of socio-economic characteristics of the household and interact the weather shocks with key household characteristics. We then examine the effect of the climatic variability on child health, and again interact the weather shocks with different individual characteristics. By analyzing two aspects of welfare and separating the impacts by key sub-populations, we gain a deeper understanding of who and what aspects of welfare are most affected by weather shocks allowing for a more informed and more cost-effective policy design.

The rest of the paper is organized as follows: The next section gives an overview of past research on the impact of weather on consumption and on health outcomes. Section 3 outlines our estimation strategy. Section 4 gives background on Mexican agriculture and describes the data sources. Section 5 presents the results and Section 6 concludes.

2. Past Research

One could think of the environment, health and consumption as being part of a simple system (Figure 1) where health and consumption are two important dimensions of welfare. Consumption, measured at the household level is influenced by the environment; and health, measured at the individual level, is influenced both by the environment and consumption.[6] To see the interaction among the three facets, it is instructive to think of each of the impacts in isolation from the other two.

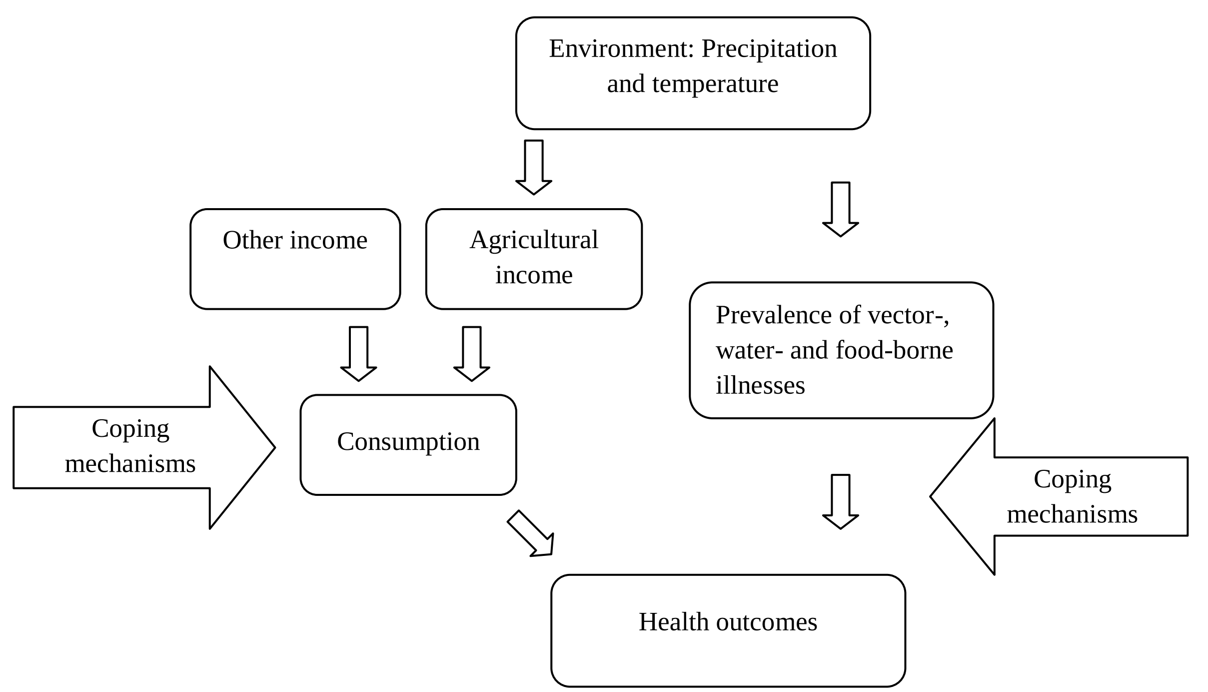


Figure 1

The environment affects consumption mainly through its impacts on current agricultural production or income. This is especially true in rural areas where crop yields are a function of precipitation and temperature, but the environment could also affect non-

[6] There may also be some feedback from the health status of an individual to his/wage earning capacity and ultimately to the consumption expenditures at the household level. For now, we do not explore this pathway. Also, health affects the consumption bundle directly in two ways—ex post (e.g. being sick requires buying medicines) and ex ante (e.g. preventive health care).

agricultural income to the extent that it is connected to weather, such as providing outdoor activities, or vendors with open-air stalls. Depending on the household's ability to cope with income fluctuations, a negative income shock brought on by bad weather may translate into a reduction in consumption (e.g. Jacoby and Skoufias , 1998; Dercon and Krishnan, 2000). In general, households are better able to insure their consumption against idiosyncratic shocks, which are shocks that affect only a particular household, such as the death of a household member, than they are able to insure against covariant shocks, shocks that affect a large number of households in the same locality, such as weather related shocks (Harrower and Hoddinott, 2005). Furthermore, when consumption is affected by a shock, different types of consumption may be impacted differently. In general, food consumption is better insured than non-food consumption, including health (Skoufias and Quisumbing, 2005).[7]

Even if at the household level there does not appear to be a significant impact on total consumption, the intra-household allocation of resources may change after a weather shock possibly leading members to be differentially impacted. Differences in the health outcomes of individuals within a household would be brought about if the food resources to a particular individual were reduced sufficiently for them to experience malnutrition or if his share of other resources, such as preventive or curative health related goods, was lower than in a typical year. Such a reduction is likely in a household which in a typical year is only barely able to access sufficient nutrition for each household member. Furthermore, an environmental shock may also directly affect the health of an individual, for example, by changing the prevalence of diseases or the risk of exposure to heat or cold stress. Assuming no changes in consumption choices, a change in the prevalence of diseases itself has an impact on individual's health and again the impact depends on the individual's characteristics. Studies have shown negative impacts of weather events, such as droughts on health outcomes (both concurrent and persistent impacts), but in most cases the studies estimate aggregate impacts and it is not clear if the impacts stem from lower consumption levels or from the changes in environmental conditions.

Studies on the impacts of shocks on individual welfare generally use some health outcome as the preferred measure. The evidence from other countries suggests that both gender and age matter. For example, Rose (1999) finds that in rural India a positive rainfall

[7] There is also some evidence that in some societies weather shocks affect household consumption differently depending on whose agricultural income (male or female) is impacted by the shock (Duflo and Udry, 2004).

shock increases the survival probabilities of girls more than the survival probabilities of boys. Similarly, Hoddinott (2006) finds that there is a small but transient effect of drought on the BMI of women, but not on men's. Also, the age of the individual at the time of the shock matters. For example, Hoddinott and Kinsey (2001) find that a drought experienced at 12 months to 24 months of age, had an impact on annual growth rate, and that the impact persisted for the four years of the study. No such impact was found for shocks experienced later in life. Maccini and Yang (2009) find a slightly different result where an individual is susceptible to weather. In their study on rural Indonesia weather shocks experienced in the first year of life have an impact on adult outcomes. Namely, women born in localities with greater than average rainfall are taller as adults, have completed more years of education, and live in wealthier households. No impacts on men's outcomes are observed.

The final impact of a weather-related shock on health is an interplay among the indirect impact of weather on health through changes in income or production, the direct impact from changes in the environmental conditions, and the changes in the types of consumption that the household and individual is able to make. That is, weather conditions not only alter the budget constraint faced by a household, but also may alter the optimal consumption composition. The impact from an environmental shock on welfare depends on the household's and individual's ability to cope against income fluctuations and changes in the environmental conditions. Such coping mechanisms may include availability of different assets, access to government sponsored programs, or access to healthcare.

A particular environmental shock may have a direct negative impact on health but a positive impact on health indirectly through consumption. Table 1 summarizes the expected direction of impacts from weather events on consumption and on health. The first column states the type of weather event, namely an extreme event or increase in rainfall or temperature within a normal range. The second column describes the impacts on agricultural production and income. Both extremes of rainfall (drought or flood) and temperature (extremely cold or extremely hot) will negatively impact yields and thus, potentially, income and consumption as well. In general within a normal range of rainfall and temperature, additional rainfall or warmer days should increase yields in temperate climates, but will most likely reduce yields in tropical climates. Specific to Mexico, Galindo (2009) identifies both states where higher temperatures lead to higher yields and states where they lead to lower yields. Given concave production functions, similar differences occur with precipitation. Malnutrition (and negative health outcomes) is possible if food consumption is reduced as a result of a weather event especially if prior to the event the household or individual was barely consuming the required nutritional needs (column 3).

The impacts of changes in weather on health are even more complex (columns 4, 5, and 6).[8] The prevalence and range of a particular pathogen, disease vector, or animal reservoir are determined by specific ranges of temperature, precipitation and humidity (Patz et *al*., 2003). Whether an atypically rainy or dry period increases the prevalence of a disease depends on the specific climate of a region. In regions bordering a pathogen's habitat, even a small deviation from the normal climate, can make large areas susceptible to the infectious disease. That is, if a region is just too cold (or too hot) for a particular pathogen or vector then an unusually hot (or cold) year could make the region susceptible to the disease caused by the pathogen or carried by the vector. Evidence of the importance of climatic factors can be seen from the seasonality of many infectious diseases, such as influenza (to temperature), and malaria and dengue (to rainfall and humidity).

In general, extreme temperatures are lethal to vector-born disease pathogens. An increase in precipitation will in general improve breeding conditions. However, extremely high precipitation, i.e. floods, may, on one hand, reduce infectious diseases by eliminating breeding grounds but, on the other hand, may cause other vectors, such as rodents, to come in more frequent contact with humans. Extremely low precipitation, or droughts, may create stagnant pools of water from streams and rivers, which are good breeding grounds for pathogens and vectors, thus increasing the prevalence of the diseases associated with the pathogen or vector.

In addition, besides vector-borne pathogens, water- and food-borne pathogens (causing enteric infections) are also susceptible to precipitation and temperature. Unlike vector-borne illnesses, both heavy and low precipitation have been found to increase enteric infections. Furthermore, there is evidence of a positive relationship between temperature and diarrheal diseases.

[8] The discussion on the impact of climate on health relies heavily on Patz *et al.* (2003).

3. Estimation Strategy

In our estimation strategy for the first set of analyses we use pooled panel data. To estimate the impact of weather variability on consumption we estimate the following equation.

$$lnPCE_{h,l,t} = \alpha + \beta W_{l,t} + \gamma X_{h,l,t} + \mu_l + \rho_t + \sigma_s + \varepsilon_{h,l,t} \tag{1}$$

where $lnPCE_{h,l,t}$ is the logarithm of consumption expenditures per capita of household, h, located in locality l, in the year t. $W_{l,t}$ is a vector describing the weather shocks in locality l, at time t, $X_{h.l,t}$ is a vector of other factors explaining consumption levels, such as assets, and household characteristics. μ_l are locality fixed effects which control for all local, time invariant characteristics including the agro-climatic characteristics of each locality, ρ_t and σ_s control for survey year and season (wet or dry) differences, respectively, and ε_h is the error term. β measures the impact of weather shocks on consumption. In the absence of insurance against income shocks any weather shock that reduces income should also reduce consumption.

In order to determine if the impact of a weather shock differs among different populations, we introduce into equation (1) an interaction term, such that it becomes,

$$lnPCE_{h,l,t} = \alpha + \beta_0 W_{l,t} + \beta_1 (W_{l,t} \cdot P_{h,l,t}) + \gamma_1 P_{h,l,t} + \gamma_2 X_{h,l,t} + \mu_l + \rho_t + \sigma_s + \varepsilon_{h,l,t} \tag{2}$$

Here $P_{h,l,t}$ identifies the type of household. It could indicate, for example, whether or not the household head is female or has completed at least primary school. In this case β_0 measures the impact of the weather shock on households without the particular characteristic and $(\beta_0 + \beta_1)$ measures the impact of weather on households with the particular characteristic, with β_1 denoting the difference in the impact between the two groups.

For the second set of analyses, relating weather shocks to health outcomes, we use cross sectional individual level data. The health outcome of an individual can be written as:

$$H_{i,l,t} = \alpha + \beta W_{l,t} + \gamma X_{i,l,t} + \mu_l + \rho_t + \sigma_s + \varepsilon_{i,l,t} \tag{3}$$

where $H_{i,l,t}$ is the health outcome of individual i in locality l at time t, $W_{l,t}$ is a vector describing the weather shocks in locality l, at time t, X_i is a vector of other factors influencing the health of an individual, such as household and housing characteristics, μ_l are location fixed-effects, ρ_t and σ_s control for survey year and season (wet or dry) differences, and $\varepsilon_{i,l,t}$ is the error term.

Similarly to the consumption equation, the health outcome equation can be expanded to include interaction terms to test for the relevance of specific policy measures. Equation (3) becomes,

$$H_{i,l,t} = \alpha + \beta_0 W_{l,t} + \beta_1 (W_{l,t} \cdot P_{i,l,t}) + \gamma_1 P_{i,l,t} + \gamma_2 X_{i,l,t} + \mu_l + \rho_t + \sigma_s + \varepsilon_{i,l,t} \qquad (4)$$

where $P_{i,h,l}$ identifies the type of individual or household. It could indicate, for example, the gender of the individual or whether or not the individual participates in a supplemental nutrition program. In the case of gender, if we set $P = 1$ for girls, β_0 would measures the impact of the weather shock on boys and $(\beta_0 + \beta_1)$ the impact of weather on girls. Again, β_1 measures the difference in the impact between the two sexes.

4. Background and Data Sources

For our empirical analyses we focus on rural households in Mexico. CONEVAL estimates that in 2005, 47% of the population lived in poverty, with 18% of the population living in extreme poverty. In 2006, 15.5% of 0 to 5 year-olds had a height-for-age z-score of less than -2 (stunted) and 3.4% of 0 to 5 year-olds had a weight-for-age z-score less than -2. In rural areas the rates were slightly higher with the height-for-age and weight-for-age z-scores below -2 for 4.9% and 24.1% of the 0 to 5 year olds, respectively (WHO). These statistics suggest that a relatively large population of the country could be at risk from even small decreases in their income.

In Mexico, about 82% of cultivated land is rainfed (INEGI, 2007), and thus being very susceptible to weather fluctuations. Corn is produced in 59% of cultivated land in the wet season and 31% of the land in the dry season. The total area cultivated is more than six times greater in the wet season than in the dry season (INEGI, 2007). More importantly, corn is used by many small-scale farmers not only as a source of income but also directly as a subsistence crop. Switching to other crops, such as wheat or barley, which have a shorter growth cycle but are not as useful for household consumption, is considered a last resort (Eakin, 2000).

Both rainfall and temperature are important factors affecting crop yields and exhibit a concave relationship with agricultural productivity (Galindo, 2009). Whether increased precipitation or temperature is beneficial to the agricultural production process depends on the crop, region, and the season in which the change occurs. For example, corn production is found to benefit from additional temperature in Hidalgo, Estado de México, Puebla and Querétaro and decrease with additional temperature in Baja California de Sur, Campeche, Chiapas and Guerrero (Galindo, 2009). Similarly, he finds the optimal levels of rainfall below and above which yields fall depend on the class of crops considered. Alternatively, Conde *et al.* (1997) find that in the long run a climatic change with an increase of 2°C and a 20% decrease in rainfall would increase the amount of unsuitable land for corn production by 8% in a sample of seven corn producing municipalities (from the states of Mexico, Puebla, Veracruz and Jalisco). Similarly a 2°C increase in temperature but a 20% increase in rainfall would increase the amount of land unsuitable for corn production by 18%. Simulating a temperature increase of 4°C over the mean temperature, the amount of land unsuitable for production, with a 20% increase and a 20% decrease in rainfall, increased by 20% and 37%, respectively. Based on actual production estimates, Appendini and Liverman (1994) estimate that in Mexico droughts are responsible for more than 90% of all crop losses.

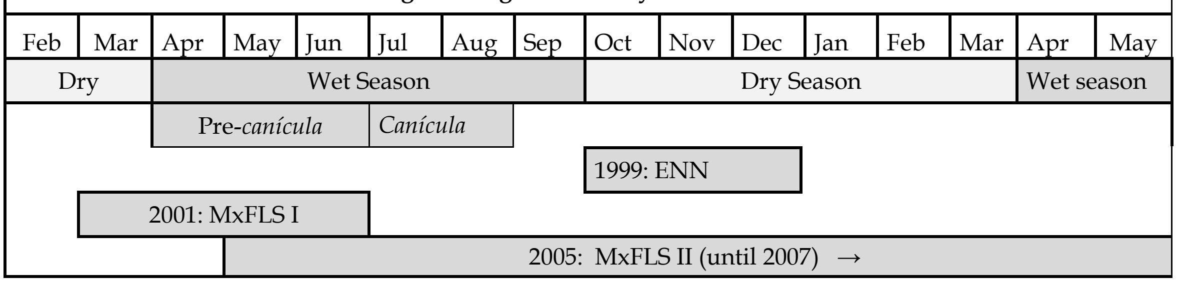
The agricultural year in Mexico runs from October to September. It is composed of a dry season, from October to the end of March, and a wet season, from April to the end of September. Given the water and temperature requirements of corn, most of the rainfed corn is planted and harvested during the wet season. The growing cycle for corn can be divided into three phases (Neild and Newman).[9] The first phase (vegetative phase) lasts between 60 to 40 days. The longer it takes for the seed to germinate (i.e. the colder it is after planting) the higher the probability that the seed is weak and subject to disease producing a lower yielding crop. For the first half of this time the growing point is usually below ground and the plant can withstand to some degree cold temperatures. After the growing point is above ground level then frost can cause significant damage to the plant. With the ear formation begins the reproductive phase with the ear forming stage lasting for about 20 days and an additional 20 to 30 days are required for the grain fill stage. Inadequate water availability during this phase greatly affects yields with the impacts being the greatest during the ear forming stage. Also extremely warm

[9] The description of corn's growth cycle is adapted from Neild and Newman.

temperature (above 32˚C) during the second half of the vegetative phase and the reproductive phase reduce yields. The last phase (maturation phase) lasts between 20 to 35 days.

Planting later in the season ensures that the seed germinates quicker, however waiting too long does not allow the crop to complete the maturation stage before the growing season ends. Furthermore, specific to Mexico, in July and August there is a period of mid-summer drought called *canícula* (Figure 2) affecting farmer's planting decisions. In general, farmers want the corn to flower (for the ear formation stage to be complete) before the onset of the *canícula* in order to better the odds of the crop survival in case it is a drier than normal *canícula* (Eakin, 2000). This implies that the months leading up to the *canícula* are of special importance in Mexico.

Figure 2: Agricultural Cycle in Mexico



For the household data we use the first two waves of surveys from the Mexico Family Life Survey (MxFLS) (Rubalcava and Teruel, 2006). The first wave of the survey in 2002 interviewed 3,353 rural households[10] in 75 different localities located in all regions of the country and was conducted between March 2002 and August 2002, with the majority of the information collected between April and June. The second wave of the survey was collected between 2005 and 2007 with the majority of the data collection occurring from May 2005 to September 2005. The follow-up survey interviewed 3,271 households in 112 rural localities.[11] Both waves collected detailed information on each household member including information on educational attainment, migration and anthropometric measures, and as well as on household

[10] Rural households are considered to be those that lived in localities with less than 2,500 inhabitants.
[11] Given that some households (or parts of households) had moved between the surveys, in Wave 2 the households are spread out over a larger number of localities.

expenditures.[12] Separate surveys were administered to the leaders of each locality on services and programs available at the locality.

For the health outcome analyses we use the *Encuesta Nacional de Nutricíon* (National Nutrition Survey) collected by the *Instituto Nacional de Estadística y Geografía* (INEGI) (National Institute of Statistics and Geography) and the *Secretaría de Salud of Mexico* (Secretary of Health) in the last quarter of 1999.[13] The survey interviewed 7,180 rural households in 767 different localities. The survey collected general information on all members of the household and more detailed information, including anthropometric measures and illnesses in the past 2 weeks, for females between 12 and 49 years of age, and for all children 12 years or younger.

The climate data used in this paper come from the Mexican Water Technology Institute (*Instituto Mexicano de Tecnología del Agua*—IMTA). The IMTA has compiled daily weather data from more than 5,000 meteorological stations scattered throughout the country. The data span a very large period of time—from as far back as the 1920s to 2007—and contain information on precipitation, and maximum and minimum temperature.

The meteorological stations registered these variables on a daily basis and we used this information to interpolate daily values of these variables for a geographic centroid in each of the country's municipalities[14]. The centroid was determined as the simple average of the latitude and longitude coordinates of all the localities listed in INEGI's 2005 catalogue corresponding to each municipality, which resulted in a locality-based centroid. We chose this method over a population-weighted average because that alternative would bias the interpolation towards urban rather than rural areas. The interpolation method used is taken from Shepard (1968), a commonly used method which takes into account relative distance and direction between the meteorological stations and the centroids (see Appendix 5).

We carried out an independent interpolation for every day between 1950 and 2007, for each municipality. Since not all meteorological stations existed throughout the entire period and

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[12] MxFLS collects information on the value spent purchasing various categories of goods—food, dining out, healthcare, transportation, personal items, education, recreation, cleaning services, communications, toys/baby articles/childcare, kitchen items and bedding, clothing, tobacco, gambling, appliances and furniture, and other expenses—as well as the value of goods consumed from own production or received as gifts. Unfortunately the value of goods consumed from own production versus the value of goods received from others cannot be separated.

[13] Although the MxFLS also collected anthropometric measures for the household members, we choose not to use them as we can only get accurate height-for-age information for the first wave observations and of the potential under 36 month olds we lose about 30% due to non-measurement and an additional 20% due to other missing information.

[14] We took INEGI's 2005 catalogue of localities, which contained 2451 municipalities.

given that during the time they were in operation they sometimes failed to report their records, each interpolation is based on a different number of data points—and indeed different weather stations. These problems as well as the accuracy of the data get worse as one looks at earlier years, which has a corresponding effect on our interpolations. Thus, interpolations for the year 1950 are less reliable than those for 2007.

From these weather data, we calculate the total rainfall and growing degree days (GDD) for each agricultural year (October to September), for each wet season (April to September) and for each pre-*canícula* period (April, May, June), or the months leading to the *canícula*, from 1951 to 2002.[15] Instead of maximum of minimum temperatures we use GDD, a cumulative measure of temperature based on the minimum and maximum daily temperatures. GDD measures the contribution of each day to the maturation of the crop. Each crop, depending on the specific seed type and other environmental factors, has its own heat requirements for maturity. Different corn varieties, for example require between 2,450 and 3,000 GDDs to mature, whereas different wheat varieties only require between 1,800 and 2,000 GDDs.[16]

Each crop has specific base and ceiling temperatures, T_{base} and $T_{ceiling}$, respectively, which contribute to growth. The base bound sets the minimum temperature required for growth and the ceiling temperature sets the temperature above which the growth rate does not increase any further. Thus, the contribution of each day, j, to the cumulative GDD is given by

$$(T_{j,\overline{min}} + T_{j,\overline{max}})/2 - T_{base} = GDD_j \qquad (3)$$

where $T_{j,\overline{min}}$ and $T_{j,\overline{max}}$ are the minimum and maximum daily temperature truncated at the base and ceiling values. In other words, any daily temperature (minimum or maximum) below the base temperature is assigned the base temperature value and any daily temperature above the ceiling temperature is assigned the ceiling temperature value.[17] To determine the cumulative GDD at any point in time for a specific cultivation the daily GDDs since planting are summed.

[15] Given that the agricultural year starts runs from October to September, the first agricultural year that we use is 1951, and we only use the last three months of the 1950 calendar year.
[16] For other important crops in Mexico the required GDDs are 2,400 for beans and 2,200 to 2,370 for sorghum. The GDD values are taken from The Institute of Agriculture and Natural Resources Cooperative Extension, University of Nebraska-Lincoln. Growing Degree Days & Crop Water Use. http://www.ianr.unl.edu/cropwatch/weather/gdd-et.html, Accessed July 22, 2010.
[17] We use the Modified Growing Degree Days formula where the minimum and maximum temperatures are adjusted prior to taking the average.

Given the mixture of different crops grown in the survey areas, we use the generalized bounds of 8° Celsius and 32° Celsius (for example, Schlenker and Roberts, 2008). In our specific case, any daily minimum or maximum temperature below 8° Celsius is treated as being 8° Celsius and any daily minimum or maximum temperature above 32° Celsius is treated as being 32° Celsius. Thus a day with a minimum and maximum temperature of 8° Celsius or below will yield no GDDs, whereas a day with a maximum and a minimum temperature of 32° Celsius or above will yield 24 GDDs.

For our measures of weather shocks we first calculate the municipal historic mean rainfall and GDD between 1951 and 1985 for the agricultural year, for the wet season and for the pre-*canícula* period. Given that there is incomplete information for some months for some of the municipalities (i.e. none of the 20 closest weather stations reported data for 5 or more consecutive days), in our sample of rural municipalities, the average climate is based on 15 to 35 years of information. 75% of the rural households in our samples live in municipalities with at least 30 years of complete weather information from 1951 to 1985.[18]

Our chosen measures of weather shocks, W, are based on the degree of deviation from the 1951-1985 average weather. A shock is defined by an indicator variable identifying those observations where the weather variable is more than one standard deviation from its long-run mean. A municipality is defined to have experienced a negative rainfall shock if the prior period's rainfall was at least one standard deviation less than the average 1951-1985 rainfall; and a municipality is defined to have experienced a positive rainfall shock if the prior period's rainfall was at least one standard deviation more than the average 1951-1985 rainfall. Thus, there are in total four measures describing the prior year's (or wet season's or pre-*canícula* period's) weather. Table 2 shows the 1951 to 1985 average weather conditions by regions for Mexico. One standard deviation rainfall shock translates to an average of about 30% difference in annual or wet season rainfall and a 50% difference for the pre-*canícula* period. The GDD shocks are, on average, about 8% deviations from the mean. The climate in each of the regions is distinct and even within a region there is much variability. In general, however, the North is drier than the rest of the country and the Center is colder than the rest of the country.

[18] To balance the need to calculate the historic means with as many years of information as possible but excluding recent years which may have been affected by changing climate, we construct the historic means and standard deviations of the weather variables using data from 1951 to 1985.

Comparing weather data from 1986 to 2002 with their historic means (from 1951 to 1985), there appears to be an increase in the number of *temperature* shocks (both negative and positive), but no similar increase in *rainfall* shocks (Table 3) in Mexico.[19] The survey date is used to match each household to the weather information. Each household is assigned the wet season and dry season prior to the survey. That is, if a household was surveyed in dry season of year *t*, the weather shocks would based on the weather in the dry season *t-1* and the wet season *t-1*. However, if the household was surveyed in the wet season of year *t*, the weather shocks would be based on weather in dry season *t* and wet season *t-1*. As an illustration, for the households in the 2002 wave of the MxFLS, the weather variables of interest are rainfall and GDD from the 2001 wet season and the 2002 dry season (Figure 2). The harvest from the 2002 wet season would not have been harvested prior to the surveys and thus the households' income and production would be based on the 2001 wet season and the 2002 dry season harvests.

Tables 4a and 4b show the distribution of rainfall and GDD shocks for the rural municipalities in the final samples from MxFLS and ENN, respectively. Although the number of municipalities from which the household surveys are drawn is relatively small, we do still have some variability in the weather variables. There are municipalities that experienced positive and negative rainfall as well as GDD events. As Table 4 shows, there are more GDD shocks than rainfall shocks in the sample.

The original MxFLS localities, those chosen for the 2002 survey, come from 16 different Mexican states and from all the different regions of the country. Although these states vary in the percentage of land cultivated under rainfed technologies, in most at least 75% of the land is rainfed (Table 5). Also, in most at least 50% of the land cultivated in the wet season is in corn and in all the area cultivated in the wet season is greater than the area cultivated in the dry season. These figures suggest that we can expect for an average rural household in our sample the income, as well as production for self consumption, to be relatively highly dependent on the weather and especially on the weather during the wet season. Also, given the relative importance of corn, the pre-*canícula* period is of interest.

[19] The correlation of the 6 different weather shock variables for the MxFLS sample is given in Appendix 1. The rainfall deviations from mean for the various periods (annual, wet season and pre-*canícula* period) are positively correlated with annual rainfall and wet season rainfall being very highly correlated. The GDD deviations from mean are all very highly correlated. Given the high correlations among the different time periods, we only include weather variables from one time period in each regression.

Besides differing in the types of crops cultivated, the localities also differ in the availability of services and programs. Table 6a summarizes some of the locality characteristics for the 2002 and 2005 MxFLS samples.[20] The information is only available for those localities in the original sample. In 2005 there were households from 85 different localities since some of the households had moved to non-MxFLS localities. In most of the original MxFLS localities there was access to primary education but access to higher education was only readily accessible in a few localities. In many localities there were health services available, as about 75% of the localities had a public health clinic, but not all had such services locally. In the majority (about 75% in the 2002 sample and 99% in the 2005 sample), but not in all, qualifying households were able to access Oportunidades.[21] Table 6b shows some characteristics of the ENN sample localities. Although on average 76% of the households in the localities have electricity, only 27% have access to a sewage system.

5. Results

Following we present the results from our analyses on the impacts of rainfall and GDD shocks on household consumption and on the health outcomes of children. To examine whether or not weather shocks impact household consumption, we estimate equation (1). We measure consumption by the logarithm of per capita expenditures on all non-health related items. We subtract health spending from the total expenditures since most health spending follows illness and thus is not welfare improving (Thomas et *al*., 2010). We also look at the impact of weather on food expenditures given that households may spend on different spending categories after weather shocks. The average share of food expenditures in our sample is 41% of total expenditures (without considering health expenditures). Included in the expenditures are the estimated value of goods consumed from own production and the value of goods received as

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[20] The information is more complete, although maybe more unreliable, for the 2002 sample. In 2005 information was sought from both official and unofficial sources. Information from official sources was used as the primary source of information and if no official information was available then the unofficial information was used instead. If more than one official source of information was used, and the information was conflicting, i.e. one source responding yes to the presence of a secondary school in the locality and the other responding no, the variable was coded as missing. Given this fact, in 2005 there are more observations with missing information than in 2002.

[21] Oportunidades, originally named PROGRESA, is a conditional cash transfer (CCT) program aimed to alleviate current poverty through monetary and in-kind benefits.

gifts.[22] That is, the expenditure measure we use reflects wellbeing after taking into account any self-production or any coping mechanisms used by households to smooth consumption (such as selling assets, help from friends and relatives, or benefits from government programs). The extent to which these impacts have long-run implications on the poverty status of the future welfare and poverty status of the household is beyond the scope of this paper.

Besides the weather shock variables we include variables that capture household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the household head (years of schooling of the household head, gender of the household head, and the age of the household head), an asset index,[23] and the characteristics of the housing unit (presence of a kitchen, access to tapped water indoors, presence of a toilet, access to piped sewage or septic tank, electricity, and flooring material). These variables are all thought to explain expenditures. To control for the agro-climatic conditions and other time invariant characteristics we introduce locality fixed effects. To account for any systematic change between the two survey periods, we control for the survey wave. Furthermore to account for the potentially different amount of resources available depending on the season in which the household responded to the survey, we introduce a season indicator variable. Appendix 2 gives the descriptive statistics of the variables used in the analyses.

5.1 Impacts of climatic variability on expenditures

We run six different specifications with different measures of welfare and different measures of weather shocks based on equation (1). Given differences in the average climatic conditions in the North, and the Centre and South regions of the country besides including all rural households, we limit the sample to only those households in the North and to only those households in the Centre and South. The first set of specifications uses the (ln) per capita expenditures on all non-health items and the second set uses the (ln) per capita expenditures on

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[22] Given the way in which the expenditure survey was administered, we are unable to separate the value of consumption from own production from the value of goods received as gifts. For about 7% of the rural households more than 50% of their food comes from non-purchased sources. On average for a rural household about 7% of all food comes from non-purchased sources.

[23] The asset index is based on the principal factor analysis of how many parcels of land the household owns, whether or not the household owns their residence, another house, bicycle, motor vehicle, an electric device, a washing machine or a stove, a domestic appliance, machinery or a tractor, bulls or cows, horses or mules, pigs or goats, or poultry.

food as the dependent variable. For each welfare measure we estimate 3 different specifications. The first uses weather shocks in the prior agricultural year's annual rainfall and annual GDD. The second uses weather shocks in the prior wet season and the third in the prior pre-*canícula* period. We introduced fixed effects first at the state level and then at the locality level. The results were relatively insensitive to which geographic fixed effects are used and we report the coefficient estimates for the weather shock variables with locality fixed effects.[24]

In terms of rainfall, on average a rural Mexican household spends more on non-health items after negative annual rainfall shocks and more on food after a positive annual rainfall shock (Table 7). Namely, if the prior agricultural year was at least one standard deviation drier than the 1951-1985 average, the per capita expenditures are 14 percent higher and per capita expenditures on food are 18 percent greater when the annual rainfall is at least one standard deviation more than the 1951 - 1985 average.

The results are quite different when equation (1) is estimated separately for each of the two regions—North and Center/South.[25] In the North, the more arid region of the country and with a higher percentage of irrigated land, a negative rainfall shock has no impacts on expenditures. However, for the Centre/South region both negative and positive rainfall shocks are associated with higher expenditures on non-health items (by 25%) and positive rainfall shocks are also associated with higher expenditures on food (Table 7). The results suggest that in the Centre/South regions both types of rainfall shocks are welfare improving. [26]

The results in terms of temperature indicate that the warmer than average wet seasons are associated with 18 percent higher expenditures per capita (Table 7). That is, on average, for our sample of Mexican households, warmer weather is in fact welfare improving. However, when we separate the sample in two—North and Center/South—positive wet season GDD shocks no longer are statistically significantly welfare improving.[27] In addition, negative GDD shocks during the pre-*canícula* period are associated with higher expenditures on all non-health

[24] Appendix 3 shows the complete set of coefficient estimates for all rural households using fixed effects at the state and at the locality level.

[25] The North includes the states of Baja California, Baja California Sur, Chihuahua, Coahuila, Durango, Nuevo Leon, Sinaloa, Sonora, Tamaulipas, and Zacatecas. All the other states are part of Center/South region.

[26] It is possible that the higher expenditure may be a consequence of the higher local prices faced by households rather than due to an increase in the quantity of goods consumed. We tried to shed some light on this issue, by regressing the average price (based on one to three stores) of a food item on the weather shocks controlling for state fixed effects. We found rather mixed results since for those municipalities in the Center/South of the country, the prices of five items are positively correlated with a positive rainfall shock (potato, lemon, chili, pork, and white bread) and four items are negatively correlated (tomato, apple, beef, and whole fish).

[27] The coefficient estimate is positive for both samples

items as well as higher expenditures on food in the Central/South sample and lower non-health expenditures in the North sample. In the North, food expenditures are also lower after a negative GDD shock during the prior agricultural year (37% lower) and during the prior wet season (28% lower). These results reflect Galindo's (2009) findings of variable impacts on agricultural production from changes in temperature by region and by the type of crop cultivated.

It is interesting to note that in our sample, on average, unusual weather (that is, weather that is at least one standard deviation from the mean) is never associated with lower welfare, with the exception of negative GDD shocks in the North. That is, even if the shocks do have a negative impact on agricultural production, the households do not see a reduction in their expenditures. This suggests that households are either able to protect themselves *ex-ante* by changing their agricultural practices in response to the weather shocks, or in the case of reduced agricultural revenue, that households are able *ex-post* to keep expenditures (and welfare) from deteriorating by drawing down on their assets, or receiving help from formal and informal safety networks, such as relatives or social programs, or accessing credit. While these types of responses used by the households are deserving of deeper analysis they are not within the scope of this paper.

5.2 Heterogeneity of impacts

The average impacts may mask difference in response between types of households to weather shocks. We examine the difference in welfare levels by the sex and by the educational attainment of the household head by estimating equation (2). Table 8 summarizes the results of interacting the gender of the household head with the weather shocks. Table 9 summarizes the results of interacting education of the household head with the weather shocks.

In general, a household headed by a female is never worse off because of a weather shock than a household headed by a male (Table 8). In fact, if there is a positive annual or pre-*canícula* period rainfall shock female headed households have a higher per capita expenditure than male headed households by 16 percent and 25 percent, respectively (Table 8a). Furthermore, with positive annual rainfall shocks food expenditures per capita are 28 percent higher in female headed households than in male headed ones (Table 8b). Similarly a female headed household in a municipality with a positive pre-*canícula* GDD shock has, on average, 44 percent higher per capita expenditures on food than male headed households.

Examining the households by the two regions—North, Center/South—separately, we find differences between female and male headed households. Female headed households in the central and southern parts of the country have higher expenditures after a positive rainfall shock than the region's male headed households. Both non-health expenditures as well as food expenditures are between 28 percent and 42 percent higher, respectively. In contrast, female headed households in the North have 30 percent lower non-health expenditures than male headed households after a positive wet season rainfall shock. However, female headed households in the North are not statistically significantly different from male headed households in terms of food expenditures, suggesting that food expenditures are protected from the effects of the positive rainfall shock. Also, it is the northern female headed households who are positively affected by a positive pre-*canícula* GDD shock.

The education level of the household head also matters (Table 9). On average, for some weather shocks, households where the head has not completed primary school have lower non-health and food expenditures per capita than households where the head has completed primary school. In terms of rainfall, on average households with less educated heads have 16% lower non-health expenditures after a positive pre-*canícula* rainfall shock, and 29% lower food expenditures after a negative pre-*canícula* rainfall shock. After separate analyses for the two regions, we do not find any statistically significant differences in the impacts of rainfall shocks on non-health expenditures, but do find regional differences on food expenditures. In the northern states, households with less educated heads have 38 percent higher expenditures on food and 51 percent lower expenditures on food than households where the head has completed primary school after a negative rainfalls shock during the prior year and the prior pre-*canícula*, respectively.

Less educated households are more affected by GDD shocks than rainfall shocks and these differential effects are observed only in food expenditures. The less educated households have on average 14% lower food expenditures after a negative annual GDD shock and 34% lower food expenditures after a positive annual GDD shock than household where the household head has completed primary schooling. Separating the household regionally, we observe no differential impacts either in the Center/South grouping or in the North after a negative GDD shock.[28] We do observe large negative differentials in the North after positive GDD shocks, regardless of the timing of the shock during the agricultural year (i.e., during the wet season or during the pre-*canícula* period). The negative differential suggests that households with less educated heads are less able to modify their agricultural practices to take advantage of more advantageous weather or to counter negative impacts of unfavorable weather. Another possibility is that households with less educated heads cannot access other mechanisms to offset negative effects of weather shocks on welfare. The only exception is a negative rainfall shock in the North when the less educated households do not have lower food expenditures whereas the more educated households do. This peculiar differential effect could be explained if crop choice is determined by education.

5.3 Impacts of climatic variability on child health

To analyze the impacts of weather on health outcomes we focus on children 36 months or younger living in rural areas. This is the age group most likely to suffer negative health outcomes and any impacts potentially have long term consequences. Between the ages of zero and three the growth rates are faster than at any other point and thus any delays have a greater probability of affecting overall growth (Martorell, 1999). Shrimpton *et al.* (2001) find that in developing countries although the children when born are on average at the mean of standardized height-for-age there is a sharp decline in the height-for-age from ages 0 months to 24 months and no subsequent catching up in the first 5 year of life. Furthermore, Martorell *et al.* (2010) find evidence that weight gain the first 2 years of life had a strong impact on schooling outcomes whereas weight gain between 2 years and 4 years of life had a weaker impact. Alderman (2010) emphasizes the fact that weather caused nutritional shocks experienced in the first years of life have lasting impacts on productivity even if the household is able to later on overcome poverty. Victora *et al.* (2008) find in their meta-analysis that height-for-age and weight-for-age are strong predictors of school achievement and that stunting between 12 and 36 months of age is associated with poorer cognitive development.

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[28] The coefficient estimates for negative annual GDD shocks are negative in both regions, but not statistically significant.

To analyze the impacts of weather on child outcomes we estimate equation (3). We use the standardized height-for-age z-score for children 36-months or younger as our measure of health.[29] Unlike weight-for-age, height-for-age is not as sensitive to very short-term and immediate scarcities or illness, but would capture more chronic conditions.[30] Given that all the data were collected during the 1999 dry season, the year and season terms drop out. Given that the weather data are at the municipal level, we use state level fixed effects to control for the time invariant characteristics, such as the agro-climatic conditions at the state level.

Besides our measures of weather shocks, we also include information on household composition (the number of children, the number of adult males, and the number of adult females), on mother's characteristics (mother's education, height, and whether she speaks an indigenous language), information about the child (gender, if the child has an older sibling who was born alive within 2 years of the child's birth, multiple birth, the birth order of the child, whether the child was characterized as very small at birth, and the age of the child at the time anthropometric measurement was taken), an asset index,[31] housing characteristics (presence of indoor toilet, tap water, type of floor), and information about the child's locality (altitude) as regressors in the analyses.[32] Table 10 describes the variables used in the analyses. Given the differences in the average climate in the North and in the Centre/South regions, we also analyze the children in each region separately.

There are 1,995 rural children less than 36 months in the ENN dataset. Our sample consists of only 1,540 children.[33] We only include those children whose mother has not moved in the past year to ensure that the weather shocks match what the child experienced. Of the excluded children, there are 138 children with missing height information and 91 children with improbable z-scores,[34] suggesting data entry errors. The other excluded children have incomplete information on the covariates. The children measured (and with probable z-scores) are statistically significantly older than those who are not measured. This poses a problem

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[29] We use, WHO Anthro for personal computers, version 3, 2009: Software for assessing growth and development of the world's children. Geneva: WHO, 2009 (http://www.who.int/childgrowth/software/en/) for calculating the standardized height-for-age scores.

[30] The measure does not capture any differences in mortality from unusual weather.

[31] The asset index is based on the principal factor analysis of the household's ownership of a radio, a television, a VCR, a telephone, a computer, a refrigerator, a washing machine, a stove, a heater, and motor vehicle.

[32] Only when analyzing the effects by participation in a nutritional program, we also include nutritional program participation as a regressor.

[33] This is the pre-*canícula* sample without nutritional supplement program variables and access to health care included as explanatory variables.

[34] That is, their height-for-age z-scores are less than -6 or more than 6.

given that those children who were not measured are different, and they may be systematically different in other characteristics besides age as well.[35] Furthermore, since only a few children (less than 2 percent of the sample) experienced a positive pre-*canícula* rainfall shock, the coefficient estimates for positive pre-*canícula* rainfall should be interpreted with caution (Table 11).

Bearing these caveats in mind, Table 12 summarizes the average relationship between weather shocks and height-for-age. The full results for the specification are included in Appendix 4. A positive rainfall shock is associated with lower height-for-age scores. This is true for both a positive annual and a positive wet season rainfall shocks. The coefficient estimate of around 0.5 points is non-trivial given that a z-score of -2 is indicative of stunting and the average height-for-age z-score for the children in the sample is -1.09.[36] The earlier results based on the MxFLS consumption data suggest that there is no correlation between a positive rainfall shock and non-health expenditures, and that households spend more on food. Yet, the height of children under three years of age is negatively affected after such a shock. Together, these results suggest that direct environmental effects are important and that an analysis of the impacts of weather shocks at the household level has serious limitations in terms of capturing the impacts of these shocks on certain individuals in the household.

The negative impacts of a positive rainfall shock during the prior agricultural year or wet season are consistent in both of the regional subsamples (Table 12). The biggest impact is from a positive rainfall shock during the wet season in the North. Children who experienced such a shock are 0.7 points shorter than children who experienced an average amount of rain. Negative rainfall shocks appear to have different impacts in the Centre/South regions than in the North. Children living in the Center/South region are taller if the prior agricultural year or wet season was at least one standard deviation drier than average. In the North, however, children are shorter after such a shock.

Not all children experience the same kind of health outcomes from weather shocks. Tables 13, 14, and 15 present the results between weather shocks and sex of the child, the

[35] If those who are not measured are more likely to be sick (and some of these illness are due to the weather), then the coefficient estimates of the weather shock variables is likely to provide a lower bound of the impact of the weather shock.

[36] The average does include the 144 children who lived in a locality where the rainfall was at least one standard deviation more than on average. However, excluding these children the average z-score does not change significantly and is -1.08.

mother's educational level, and the household's participation in a supplemental nutrition program, respectively.

Although, on average in this sample, the girls' and boys' average height-for age measures are not statistically significantly different, they are significantly different when the child experiences a positive GDD shock in the prior agricultural year (Table 13). Boys are shorter when the prior year, wet season or pre-*canícula* period was at least one standard deviation warmer than on average. Girls are statistically significantly different from the boys and in girls there are no differences between those who experienced an unusually warm year and those who did not. The result may reflect the differences in disease morbidity rates by gender. In general, infant boys, especially those with even slight malnutrition, have higher mortality and morbidity rates from early childhood infections and diseases (Wells, 2000). It is also possible that there are differences in the types of activities that the children engage in (for example boys may play more outside and be more exposed to the new set of diseases) or that there are differences in the care. The average results are driven by children in the central and southern regions of the country. In the North boys are not any worse off from a positive GDD shock than girls are. The regional result may reflect the regional differences in the climate. It may be that on average in the North positive GDD shock does not alter the environment in a way to change the prevalence of diseases or households are better apt at dealing with such changes. However, in the North, we do observe that girls are worse off than boys from rainfall shocks—from a negative pre-*canícula* rainfall shock and from positive annual and wet season rainfall shocks. Again, the result may reflect differences in the type of activities that the children engage in or indicate differences in care.

When faced with a weather shock, the mother's educational attainment is not associated with a child's height-for-age (Table 14). That is, even though children of less educated mothers—those mothers who have not completed primary school—are on average shorter than children of more educated mothers, there are no differences in the height-for-age measure associated with weather shocks.[37] These results suggest that mothers have similar resources available to adjust their caretaking practices to weather shocks regardless of their educational attainment. Furthermore, there are no regional differences in the result.

[37] The observed difference in the two groups from a positive rainfall shock in the prior pre-*canícula* period needs to be interpreted with caution given the low number of children who experienced such a shock.

Another household characteristic that may differentiate the results between heath outcomes and weather is the household's participation in some type of social protection or assistance program. Supplemental nutrition programs (such as PROGRESA and LICONSA in Mexico) attempt to improve childhood nutrition in the poorest households. Households participating in such targeted programs are from the poorest households in the country and they may have fewer resources to cope with weather shocks. For our sample of children, when faced with a positive rainfall shock the health of children living in households receiving supplemental nutrition is statistically significantly worse than the health of children not in such programs (Table 15). Since program participation is not random (that is, the participants come from the most impoverished households), the results do not suggest that participation in such programs is disadvantageous to children. The results do suggest that participation in a supplemental nutrition program does not fully level the playing field in terms of child health outcomes after a positive rainfall shock. In order to determine the causal impact of the program (and the interaction of weather shocks with program participation) we would need to determine the counterfactual, that is, the health outcomes for children who participated in such programs had they not benefitted from the programs.

6. Discussion and Conclusions

Weather-related events can have an impact on the welfare of individuals either through changes in agricultural production and therefore on consumption, and/or through changes in the prevalence of certain types of diseases and ailments associated with different weather conditions. We analyze the impacts of rainfall and temperature deviations from their long-run means on rural households and young children in Mexico. On average, we do not find any consistently strong effects from weather shocks on welfare as measured by expenditures. However, we do find regional differences as well as differential impacts based on household and individual characteristics.

Regarding rainfall shocks, we find that dry years are associated with increased per capita expenditures. The result is driven by higher expenditures in the central and southern parts of the county and not observed in the semi-arid North. In the North, rainfall shocks do not have an impact on expenditures which may partly be explained by the higher percentage of irrigated land in the North than in the rest of Mexico.

For an average rural household, food expenditures are higher after a positive annual rainfall shock. Again the result is driven by the states in the central and southern parts of the country, where per capita non-health spending is also higher after a positive rainfall shock.

Regarding temperature shocks, we do not find any evidence that warmer weather leads to lower expenditures, at least in for our sample of rural households in Mexico. In fact, we find that warmer weather during the wet season is associated with higher expenditures (and thus of income if expenditures track income). Also, we do not observe any negative impacts on welfare (as measured by expenditures) from weather shocks. These results suggest that, on average, the risk management strategies adopted by rural households ex-ante combined with their coping strategies ex-post are successful at keeping expenditures decreasing after unusual weather. In fact, households may benefit from some types of weather shocks with the average expenditures being higher than when such shocks did not occur.

However, there are significant regional differences. Households in the North have lower non-health expenditures after a cold pre-*canícula* period, and lower food expenditures after a cold agricultural year or wet season, whereas expenditures are higher after a cold pre-*canícula* period elsewhere in Mexico. That is, colder weather appears to be welfare decreasing in the North, but welfare increasing elsewhere, at least immediate after the shock.

Climatic variability also appears to have heterogenous impacts depending on the socioeconomic characteristics of the household head. Positive rainfall shocks appear to affect only female headed households as do positive GDD shocks. Some shocks (positive annual, wet season and pre-*canícula* rainfall, and positive pre-*canícula* GDD) impact female and male headed households statistically significantly differently; other shocks do not have a statistically significant impact in male headed households but do so in female headed households (positive annual rainfall, positive wet season rainfall, and positive annual GDD). In the central and southern states, all the differences are positive such that, after a weather shock, female headed households are never worse off than male headed households. In the North, female headed households have lower non-health expenditures after a positive rainfall shock during the wet season, but higher food expenditures after a positive GDD shock in the prior pre-*canícula* period. The differences depending on the gender of the household head may reflect differences in occupation and types of crops grown.

Another factor that differentiates the impact of climatic variability on household welfare is the educational attainment by the head of the household. Households headed by less educated heads (those who have not completed primary school) tend to have lower expenditures after weather shocks than households headed by more educated heads. On average after a weather shock, households with less educated heads are never better off than households with more educated heads and, in fact, households with less educated heads have, on average, lower food expenditures after a negative annual GDD shock than similar households not experiencing such a shock. The only exceptions are households with less educated heads in the North after a negative rainfall shock. The results could signal the inability of households with less educated heads to adjust their agricultural production as easily as those headed by a more educated head or their inability to draw on external resources when weather shocks affect their agricultural production to keep expenditures constant.

Exploring the impacts of weather on the health of a group of vulnerable individuals (rural children under the age of three), we find some evidence of both unusual rainfall and unusual temperature having an impact on a child's height-for-age. Precipitation has a more marked impact on height-for-age than temperature, such that an unusually rainy year or wet season is associated with lower average height-for-age everywhere in the country. That is, even though rainier than usual weather does not decrease per capita non-health or food expenditures, young children have worse health outcomes after such shocks. In the North a dry wet season and pre-*canícula* period as well as a warm prior agricultural year are all also associated with shorter children. Considering the available evidence to date linking childhood health to various aspects of adult wellbeing,[38] these results warrant further research on the policy options that might be effective at reducing the negative impact of unusually rainy weather anywhere in Mexico and dry and hot weather in the North.

The impacts of weather shocks on height-for-age are different for boys and girls, and for those children in households benefitting from supplemental nutrition programs. Although girls are not affected by positive GDD shocks, boys are negatively impacted by unusually warm

[38] Childhood health has been shown to have an impact on employment (Case, Fertig and Paxson, 2005), cognitive abilities (Case and Paxson, 2008; Grantham-McGregor et al., 2007), educational outcomes (Glewwe and Miguel, 2008), and productivity (Hoddinott et al., 2008).

years, wet seasons and pre-*canícula* periods. This is in spite of the fact that after an unusually warm wet season, households' expenditures on non-health items are higher and after an unusually warm year or pre-*canícula* period are similar to a normal year's expenditures. One possible explanation for a negative impact on boys is the difference in morbidity rates between girls and boys especially when marginally malnourished (Wells, 2000). The results suggest that, in order to mitigate any negative impact on boys, some counteractive measures need to be taken during a warmer than usual year. Furthermore, in the North, during a rainy year, especial attention needs to be given to girls who are on average, much shorter, than boys after a positive rainfall shock.

Additionally, we find that children who benefit from supplemental nutrition programs are shorter than non-beneficiaries when the prior agricultural year or wet season was unusually rainy. That is, even though all children are affected by unusually rainy weather, those who participate in supplemental nutrition programs are affected even more. Given that the households who participate in these programs are in general the poorest ones, the results suggest the additional nutrition provided does not (fully) protect the children from the impacts of a positive rainfall shock. The results also suggest that poorer families are less able to draw on other resources to counter negative health impacts associated with higher levels of precipitation.

All, in all, our results reveal that the current risk-coping mechanisms are not very effective in protecting the two dimensions of welfare examined here from erratic weather patterns. These findings imply that the change in the patterns of climatic variability associated with climate change is likely to reduce the effectiveness of the current coping mechanisms even more and thus increase household vulnerability further. Moreover, the heterogeneous impacts of climatic variability documented in this study suggest that a "tailored" approach to designing programs aimed at decreasing the sensitivity and increasing the capacity of rural households to adapt to climate change in Mexico is likely to be more effective.

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Table 1: Impact of weather conditions on consumption and health outcomes in rural areas

Weather condition	Agricultural production / Income	Impact on consumption	Incidence of disease [1]	Impact on health[2]	
				From food consumption	Direct environmental
Extremely dry	Yields will be lower.	Negative if cannot smooth consumption.	Generally reduces the prevalence of vector-born diseases, but increases water/food-born diseases	Negative, possible malnutrition, if cannot smooth food consumption	Indeterminate, but most likely positive
An increase in rainfall (within normal range)	Yields will likely increase with additional rain (temperate) or decrease (tropical)	Depends on climate	Increases the prevalence of both vector and water/food-born diseases.	Depends on specific climate	Indeterminate, but most likely negative
Extremely wet	Yields will be lower.	Negative if cannot smooth consumption.	Increases the prevalence of both vector and water/food-born diseases.	Negative, possible malnutrition, if cannot smooth food consumption	Negative
Extremely cold	Yields will be lower.	Negative if cannot smooth consumption.	May reduce the prevalence both vector and water/food-born diseases. Increases cold stress related health problems.	Negative, possible malnutrition, if cannot smooth food consumption	Indeterminate, but most likely positive
An increase in temperature (within normal range)	Yields will likely increase with warmer temperatures (temperate) or decrease (tropical)	Depends on climate	Increases prevalence of both vector and water/born diseases.	Depends on specific climate	Indeterminate, but most likely negative
Extremely hot	Yields will be lower.	Negative if cannot smooth consumption.	Generally decreases prevalence of vector-born diseases. Potentially increases water/food –born diseases. Increases heat stress related health problems.	Negative, possible malnutrition, if cannot smooth food consumption	Indeterminate

[1] As do crop yields, the impact on the incidence of disease depends on the general climatic conditions of the region. For example, if the average temperature is very high, then a decrease in the annual temperature may in fact increase the prevalence of vector born diseases.
[2] Also, there may be some impacts such as extremely cold weather inducing people to heat their homes using methods not apt for indoor use.

Table 2: Average climate (1951 – 1985) in Mexico, by region

Variable	North		Center		Pacific		Gulf and Caribbean	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Annual rainfall (mm)	533	233	966	494	1302	787	1565	574
Annual rainfall (std. dev.)	180	108	255	210	334	181	371	164
Annual GDD (days)	4444	806	3998	1082	4763	1130	5531	1184
Annual GDD (std. dev.)	307	151	308	182	401	251	273	169
Wet season rainfall (mm)	402	187	788	345	1051	532	1110	384
Wet season rainfall (std. dev.)	147	77	217	165	304	150	295	133
Wet season GDD (days)	2782	480	2243	600	2564	572	3065	603
Wet season GDD (std. dev.)	178	98	179	101	227	136	149	104
Pre-*canícula* rainfall (mm)	104	77	253	110	361	168	368	121
Pre-*canícula* rainfall (std. dev.)	71	51	112	71	145	68	157	57
Pre-*canícula* GDD (days)	1313	218	1155	278	1317	268	1531	280
Pre-*canícula* GDD (std. dev.)	95	46	95	49	122	66	82	55
Municipalities	396		919		766		354	

Average climate is calculated using weather data from IMTA from 1951 to 1985. The North includes municipalities from the states of Baja California, Baja California Sur, Chihuahua, Coahuila, Durango, Nuevo Leon, Sinaloa, Sonora, Tamaulipas, and Zacatecas; Center includes municipalities from Aguascaliente, Colima, Guanajuato, Hidalgo, Jalisco, Estado de Mexico, Michoacan, Morelos, Nayarit, Puebla, Queretaro, San Luis Potosi, and Tlaxcala; Pacific includes municipalities from Chiapas, Guerrero, and Oaxaca; and Gulf and Caribbean includes municipalities from Campeche, Quintana Roo, Tabasco, Veracruz, and Yucatan. The regional assignations are taken from Conroy, Hector V. (2009), pg. 39.

Table 3: Prevalence of weather shocks in Mexican municipalities between 1986 and 2002 from mean 1951 to 1985 weather

SD's from norm	Annual rainfall		Wet season rainfall		Pre-*canícula* rainfall		Annual GDD		Wet season GDD		Pre-*canícula* GDD	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
-2	3,487	4.27	3,122	3.69	1,476	1.74	6,102	7.47	7,312	8.63	7,598	8.93
-1	13,925	17.05	13,230	15.62	13,142	15.45	10,961	13.42	12,174	14.37	12,654	14.88
0	53,475	65.48	58,014	68.48	59,242	69.64	45,515	55.73	48,346	57.07	48,870	57.45
1	6,827	8.36	6,804	8.03	8,106	9.53	12,045	14.75	11,198	13.22	10,970	12.9
2	3,951	4.84	3,542	4.18	3,102	3.65	7,042	8.62	5,682	6.71	4,976	5.85

Average climate is calculated using weather data from IMTA from 1951 to 1985 and the shocks based on annual/wet season/pre-*canícula* weather from 1986 to 2002.

Table 4a: Weather shocks in MxFLS sample

Standard deviations from mean	Rainfall						GDD					
	Annual		Wet season		Pre-*canícula*		Annual		Wet season		Pre-*canícula*	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
-2	10	4.63	6	2.67	8	3.54	13	6.02	13	5.78	14	6.19
-1	36	16.67	39	17.33	26	11.5	35	16.2	35	15.56	35	15.49
0	142	65.74	147	65.33	167	73.89	126	58.33	135	60.00	142	62.83
1	20	9.26	22	9.78	23	10.18	33	15.28	35	15.56	29	12.83
2	8	3.70	11	4.89	2	0.88	9	4.17	7	3.11	6	2.65

NOTE: Deviations from 1951 to 1985 mean weather in rural MxFLS municipalities for agricultural years prior to household survey.

Table 4b: Weather shocks in ENN sample

Standard deviations from mean	Rainfall						GDD					
	Annual		Wet season		Pre-*canícula*		Annual		Wet season		Pre-*canícula*	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
-2	3	1.67	6	3.33	14	7.78	9	5.00	8	4.44	7	3.89
-1	31	17.22	32	17.78	83	46.11	25	13.89	15	8.33	20	11.11
0	128	71.11	128	71.11	79	43.89	93	51.67	100	55.56	100	55.56
1	15	8.33	11	6.11	3	1.67	41	22.78	40	22.22	35	19.44
2	3	1.67	3	1.67	1	0.56	12	6.67	17	9.44	18	10.00

NOTE: Deviations from 1951 to 1985 mean weather in rural ENN municipalities for agricultural years prior to household survey.

Table 5: Agricultural production in Mexican states included in the MxFLS

Region	State	Hectares cultivated		% of land in corn		% of land in beans		% of land in sorghum		% of land in other		wet season/ dry season hectares	% land rainfed
		Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season		
National production		**2,167,069**	**13,758,639**	**31**	**59**	**11**	**12**	**13**	**13**	**45**	**15**	**6.35**	**82**
North	Baja California Sur	16,722	28,987	12	41	11	11	2	8	74	41	1.73	27
	Coahuila	44,874	281,365	3	27	1	6	9	47	87	20	6.27	66
	Durango	57,155	691,738	12	42	16	30	17	6	55	22	12.10	80
	Nuevo Leon	33,360	209,576	12	49	3	3	15	39	70	9	6.28	78
	Sinaloa	418,177	588,288	63	39	13	4	3	44	21	13	1.41	54
	Sonora	276,237	341,731	4	12	1	4	2	36	94	49	1.24	41
Center	Guanajuato	38,385	823,889	13	56	4	11	0	24	83	9	5.95	67
	Jalisco	52,172	732,411	26	87	5	2	3	7	66	4	14.04	85
	Estado de Mexico	42,074	544,033	25	81	7	2	7	0	61	17	12.93	89
	Michoacán	86,904	668,846	18	79	2	1	28	13	52	7	7.70	78
	Morelos	50,639	83,328	3	37	1	3	92	43	4	16	1.65	72
	Puebla	39,153	709,046	41	73	13	9	2	3	45	15	18.11	88
Mexico City	Distrito Federal	2,924	12,297	4	42	1	2	11	0	84	55	4.21	94
South Pacific	Oaxaca	54,170	611,187	64	84	22	7	2	4	12	5	11.28	96
Gulf and Caribbean	Veracruz	106,147	517,278	83	86	9	5	1	2	8	7	4.87	97
	Yucatan	8,370	220,175	46	79	33	11	0	0	20	10	26.31	92

INEGI. Censo Agricola, Ganadero y Forestal 2007.
Regional assignations are taken from Conroy, Hector V. (2009), pg. 39.

Table 6a: Select characteristics of localities in MxFLS sample

Characteristic of locality	Localities with information in 2002	% of localities in 2002 with service / program	Localities with information in 2005	% of localities in 2005 with service / program
OPORTUNIDADES available	70	0.757	65	0.985
Primary school in locality	69	0.986	66	0.970
Secondary school in locality	70	0.343	66	0.364
Technical/trade school in locality	70	0.071	66	0.045
Public health clinic in locality	70	0.743	66	0.652

Tabulated from MxFLS Community Survey Module. In the original survey households from 70 different localities were surveyed. For the 2005 survey information from official sources was used as the primary source. If there was no information from an official source, unofficial information was used. When two or more official sources reported information and the information was conflicting, the variable was treated as a missing value.

Table 6b. Select characteristics of localities in ENN sample

Locality characteristic	Mean	Std. Dev.
Percentage of household with electricity	0.755	
Percentage of household with running water	0.585	
Percentage of household with a sewage system	0.265	
Average household size	5.19	0.89
Altitude from sea level (m)	1168	867

Based on 547 rural localities where there are households with children under 3 years of age in the *Encuesta Nacional de Nutricion*.

Table 7: Weather shocks and expenditures per capita

Variable	All rural households			Central and South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
Dependent variable: Per capita expenditures (ln) in non-health items									
Negative rainfall shock	**0.141***	0.065	-0.000	**0.246*****	0.110	-0.075	0.057	-0.030	0.121
	(0.082)	(0.096)	(0.080)	**(0.090)**	(0.112)	(0.103)	(0.143)	(0.154)	(0.189)
Positive rainfall shock	0.068	-0.008	-0.014	**0.247****	0.109	-0.026	-0.024	-0.086	0.026
	(0.087)	(0.072)	(0.086)	**(0.100)**	(0.095)	(0.104)	(0.109)	(0.094)	(0.133)
Negative GDD shock	-0.023	0.022	-0.013	-0.039	0.183	**0.205****	0.076	-0.057	**-0.328*****
	(0.093)	(0.131)	(0.129)	(0.127)	(0.111)	**(0.095)**	(0.132)	(0.209)	**(0.107)**
Positive GDD shock	0.027	**0.183****	0.081	-0.127	0.142	0.075	0.032	0.149	0.092
	(0.092)	**(0.082)**	(0.115)	(0.115)	(0.090)	(0.126)	(0.151)	(0.134)	(0.180)
Number of observations	4,929	4,950	4,951	2,624	2,641	2,642	2,305	2,309	2,309
Dependent variable: Per capita expenditures (ln) in food									
Negative rainfall shock	-0.085	0.057	-0.028	-0.070	0.126	-0.103	-0.111	-0.150	0.131
	(0.109)	(0.111)	(0.148)	(0.185)	(0.167)	(0.192)	(0.103)	(0.111)	(0.246)
Positive rainfall shock	**0.179***	0.131	0.036	**0.404****	0.322	0.030	0.085	0.019	0.062
	(0.107)	(0.119)	(0.119)	**(0.184)**	(0.209)	(0.163)	(0.102)	(0.099)	(0.155)
Negative GDD shock	-0.249	-0.041	0.221	-0.045	0.329	**0.396***	**-0.369*****	**-0.276****	0.032
	(0.162)	(0.184)	(0.159)	(0.300)	(0.231)	**(0.198)**	**(0.122)**	**(0.129)**	(0.157)
Positive GDD shock	0.150	-0.062	-0.110	0.022	-0.281	-0.020	**0.156***	0.010	-0.193
	(0.099)	(0.140)	(0.154)	(0.164)	(0.244)	(0.221)	**(0.090)**	(0.166)	(0.203)
Number of observations	4,929	4,950	4,951	2,624	2,641	2,642	2,305	2,309	2,309

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1. Calculated using MxFLS rounds 1 and 2 with locality level fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Similarly, a positive weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation more rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the household head (sex, age and education), assets (index based on how many parcels of land the household owns, whether or not the household owns their residence, another house, bicycle, motor vehicle, an electric device, a washing machine or a stove, a domestic appliance, machinery or a tractor, bulls or cows, horses or mules, pigs or goats, or poultry), characteristics of the housing unit (presence of a kitchen, access to tapped water indoors, toilet, access to piped sewage or septic tank, electricity, floor type).

Table 8a: Per capita expenditures (ln) on non-health items

Variables	All rural households			Central and South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
HH head is female	0.007	0.011	-0.084	-0.095	-0.114	-0.158	0.106	0.151	-0.001
	(0.070)	(0.083)	(0.083)	(0.113)	(0.111)	(0.122)	(0.079)	(0.109)	(0.108)
Negative rainfall shock	**0.153***	0.066	-0.010	**0.269****	0.130	-0.107	0.043	-0.051	0.118
	(0.084)	(0.101)	(0.080)	**(0.103)**	(0.130)	(0.104)	(0.140)	(0.153)	(0.191)
... X female HH head	-0.089	-0.018	0.049	-0.123	-0.091	0.153	0.211	0.209	0.000
	(0.207)	(0.236)	(0.232)	(0.258)	(0.329)	(0.243)	(0.191)	(0.176)	(0.000)
Positive rainfall shock	0.032	-0.007	-0.065	0.170	0.042	-0.118	-0.013	-0.021	0.043
	(0.088)	(0.067)	(0.086)	(0.104)	(0.089)	(0.099)	(0.107)	(0.087)	(0.150)
... X female HH head	**0.163***	-0.004	**0.250***	**0.351****	**0.284****	**0.423****	-0.042	**-0.303***	-0.083
	(0.095)	(0.120)	**(0.128)**	**(0.135)**	**(0.127)**	**(0.160)**	(0.117)	**(0.167)**	(0.159)
Negative GDD shock	0.016	0.043	-0.016	-0.016	**0.180***	**0.199***	0.103	-0.064	**-0.346*****
	(0.096)	(0.132)	(0.126)	(0.123)	**(0.106)**	**(0.099)**	(0.146)	(0.217)	**(0.112)**
... X female HH head	-0.153	-0.092	-0.020	-0.093	-0.051	-0.076	-0.108	0.014	0.102
	(0.112)	(0.115)	(0.123)	(0.166)	(0.163)	(0.169)	(0.135)	(0.123)	(0.161)
Positive GDD shock	0.043	**0.197****	0.057	-0.134	0.126	0.053	0.064	0.179	0.068
	(0.095)	**(0.090)**	(0.115)	(0.123)	(0.117)	(0.131)	(0.156)	(0.144)	(0.180)
... X female HH head	-0.078	-0.077	0.132	0.061	0.056	0.062	-0.189	-0.166	0.148
	(0.140)	(0.163)	(0.138)	(0.169)	(0.238)	(0.281)	(0.208)	(0.212)	(0.114)

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1. Calculated using MxFLS rounds 1 and 2 with locality level fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Similarly, a positive weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation more rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the household head (sex, age and education), assets (index based on how many parcels of land the household owns, whether or not the household owns their residence, another house, bicycle, motor vehicle, an electric device, a washing machine or a stove, a domestic appliance, machinery or a tractor, bulls or cows, horses or mules, pigs or goats, or poultry), characteristics of the housing unit (presence of a kitchen, access to tapped water indoors, toilet, access to piped sewage or septic tank, electricity, floor type).

Table 8b: Per capita expenditures (ln) on food

Variables	All rural households			Central and South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
HH head is female	-0.042	-0.080	-0.082	-0.060	-0.067	-0.063	-0.019	-0.098	-0.105
	(0.129)	(0.126)	(0.109)	(0.199)	(0.172)	(0.153)	(0.165)	(0.170)	(0.147)
Negative rainfall shock	-0.080	0.032	-0.024	-0.081	0.102	-0.102	-0.066	-0.174	0.120
	(0.106)	(0.117)	(0.148)	(0.183)	(0.175)	(0.195)	(0.111)	(0.117)	(0.246)
... X female HH head	-0.059	0.190	-0.061	0.060	0.136	-0.015	-0.540	0.290	0.000
	(0.190)	(0.187)	(0.223)	(0.218)	(0.240)	(0.248)	(0.603)	(0.191)	(0.000)
Positive rainfall shock	0.122	0.087	-0.015	0.320	0.235	-0.036	0.055	0.019	0.055
	(0.115)	(0.130)	(0.119)	(0.206)	(0.232)	(0.163)	(0.097)	(0.120)	(0.157)
... X female HH head	**0.279****	0.208	0.238	**0.395***	**0.384***	0.288	0.123	0.012	0.079
	(0.121)	(0.141)	(0.161)	**(0.231)**	**(0.195)**	(0.215)	(0.121)	(0.204)	(0.170)
Negative GDD shock	-0.218	-0.021	0.218	0.005	0.352	**0.400****	**-0.378*****	**-0.276***	0.017
	(0.153)	(0.174)	(0.151)	(0.288)	(0.213)	**(0.194)**	**(0.134)**	**(0.143)**	(0.166)
... X female HH head	-0.121	-0.083	-0.006	-0.166	-0.154	-0.085	-0.003	0.079	0.110
	(0.154)	(0.134)	(0.154)	(0.232)	(0.179)	(0.222)	(0.175)	(0.159)	(0.157)
Positive GDD shock	0.103	-0.107	-0.189	-0.018	-0.303	-0.080	0.118	-0.056	-0.277
	(0.116)	(0.149)	(0.168)	(0.211)	(0.254)	(0.237)	(0.092)	(0.187)	(0.220)
... X female HH head	0.244	0.244	**0.438****	0.238	0.128	0.248	0.243	0.371	**0.567****
	(0.178)	(0.185)	**(0.171)**	(0.271)	(0.198)	(0.217)	(0.249)	(0.257)	**(0.225)**
Number of observations	4,929	4,950	4,951	2,624	2,641	2,642	2,305	2,309	2,309

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1. Calculated using MxFLS rounds 1 and 2 with locality level fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Similarly, a positive weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation more rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the household head (sex, age and education), assets (index based on how many parcels of land the household owns, whether or not the household owns their residence, another house, bicycle, motor vehicle, an electric device, a washing machine or a stove, a domestic appliance, machinery or a tractor, bulls or cows, horses or mules, pigs or goats, or poultry), characteristics of the housing unit (presence of a kitchen, access to tapped water indoors, toilet, access to piped sewage or septic tank, electricity, floor type).

Table 9a: Per capita (ln) expenditure on non-health items

Variables	All rural households			Central and South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
HH head has not completed primary school	-0.154**	-0.180***	-0.168**	-0.264***	-0.348***	-0.303***	-0.089	-0.037	-0.087
	(0.064)	(0.067)	(0.066)	(0.078)	(0.083)	(0.088)	(0.107)	(0.108)	(0.093)
Negative rainfall shock	**0.184***	0.061	0.079	**0.233***	0.023	-0.107	0.085	0.023	0.277
	(0.100)	(0.123)	(0.097)	**(0.137)**	(0.176)	(0.108)	(0.160)	(0.157)	(0.194)
... X no primary school	-0.075	0.006	-0.127	0.017	0.131	0.050	-0.051	-0.099	-0.365
	(0.136)	(0.149)	(0.119)	(0.196)	(0.256)	(0.122)	(0.140)	(0.116)	(0.221)
Positive rainfall shock	0.090	0.012	0.090	**0.282*****	0.096	0.020	-0.011	-0.026	0.117
	(0.091)	(0.075)	(0.086)	**(0.099)**	(0.101)	(0.098)	(0.118)	(0.095)	(0.138)
... X no primary school	-0.038	-0.036	**-0.159****	-0.050	0.030	-0.062	-0.025	-0.107	-0.154
	(0.075)	(0.074)	**(0.079)**	(0.081)	(0.086)	(0.096)	(0.108)	(0.118)	(0.122)
Negative GDD shock	0.001	0.021	-0.041	-0.074	0.095	0.114	0.106	-0.004	**-0.316****
	(0.100)	(0.135)	(0.124)	(0.124)	(0.122)	(0.106)	(0.155)	(0.216)	**(0.129)**
... X no primary school	-0.042	0.001	0.039	0.055	0.160	0.128	-0.054	-0.106	-0.006
	(0.072)	(0.076)	(0.072)	(0.084)	(0.095)	(0.091)	(0.126)	(0.141)	(0.142)
Positive GDD shock	0.032	**0.175***	0.078	-0.074	0.102	0.041	0.061	0.209	0.139
	(0.094)	**(0.092)**	(0.109)	(0.129)	(0.125)	(0.190)	(0.153)	(0.144)	(0.150)
... X no primary school	-0.007	0.016	0.007	-0.076	0.053	0.062	-0.054	-0.119	-0.096
	(0.086)	(0.104)	(0.094)	(0.102)	(0.200)	(0.202)	(0.124)	(0.114)	(0.113)

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1. Calculated using MxFLS rounds 1 and 2 with locality level fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Similarly, a positive weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation more rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the household head (sex, age and education), assets (index based on how many parcels of land the household owns, whether or not the household owns their residence, another house, bicycle, motor vehicle, an electric device, a washing machine or a stove, a domestic appliance, machinery or a tractor, bulls or cows, horses or mules, pigs or goats, or poultry), characteristics of the housing unit (presence of a kitchen, access to tapped water indoors, toilet, access to piped sewage or septic tank, electricity, floor type).

Table 9b: Per capita (ln) expenditure on food

Variables	All rural households			Central and South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
HH has not completed primary school	0.080 (0.064)	0.052 (0.081)	0.069 (0.071)	-0.025 (0.089)	-0.103 (0.098)	-0.039 (0.100)	0.159* (0.081)	0.182 (0.117)	0.119 (0.097)
Negative rainfall shock	-0.153 (0.127)	-0.002 (0.147)	0.151 (0.136)	-0.111 (0.185)	0.005 (0.198)	0.000 (0.197)	**-0.317**** **(0.151)**	-0.161 (0.150)	**0.362*** **(0.192)**
... X no primary school	0.118 (0.180)	0.100 (0.185)	**-0.285*** **(0.157)**	0.063 (0.226)	0.174 (0.259)	-0.146 (0.196)	**0.376*** **(0.194)**	0.012 (0.171)	**-0.509**** **(0.199)**
Positive rainfall shock	**0.210*** **(0.119)**	0.156 (0.136)	0.132 (0.149)	**0.406*** **(0.240)**	0.295 (0.243)	0.097 (0.210)	0.160 (0.117)	0.103 (0.115)	0.099 (0.155)
... X no primary school	-0.035 (0.101)	-0.046 (0.111)	-0.151 (0.120)	-0.002 (0.184)	0.046 (0.175)	-0.089 (0.166)	-0.120 (0.092)	-0.159 (0.123)	-0.057 (0.103)
Negative GDD shock	-0.169 (0.173)	0.021 (0.191)	**0.272*** **(0.157)**	-0.023 (0.311)	0.342 (0.246)	**0.398*** **(0.206)**	**-0.273**** **(0.125)**	**-0.227*** **(0.126)**	0.089 (0.167)
... X no primary school	**-0.135*** **(0.080)**	-0.100 (0.086)	-0.083 (0.085)	-0.036 (0.097)	0.008 (0.117)	-0.013 (0.117)	-0.142 (0.106)	-0.085 (0.116)	-0.068 (0.125)
Positive GDD shock	**0.356***** **(0.092)**	0.041 (0.144)	-0.033 (0.162)	0.137 (0.153)	-0.396 (0.316)	-0.220 (0.384)	**0.427***** **(0.103)**	0.259 (0.157)	0.020 (0.167)
... X no primary school	**-0.344***** **(0.103)**	-0.196 (0.155)	-0.152 (0.192)	-0.168 (0.170)	0.189 (0.247)	0.338 (0.325)	**-0.531***** **(0.135)**	**-0.469**** **(0.172)**	**-0.452*** **(0.235)**
Number of observations	4,929	4,950	4,951	2,624	2,641	2,642	2,305	2,309	2,309

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1. Calculated using MxFLS rounds 1 and 2 with locality level fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Similarly, a positive weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation more rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the household head (sex, age and education), assets (index based on how many parcels of land the household owns, whether or not the household owns their residence, another house, bicycle, motor vehicle, an electric device, a washing machine or a stove, a domestic appliance, machinery or a tractor, bulls or cows, horses or mules, pigs or goats, or poultry), characteristics of the housing unit (presence of a kitchen, access to tapped water indoors, toilet, access to piped sewage or septic tank, electricity, floor type).

Table 10: Characteristics of rural children

Variable	All		Center/South		North	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Number of adult males in hh	1.375	0.942	1.349	0.857	1.434	1.114
Number of adult females in hh	1.502	0.912	1.475	0.799	1.566	1.132
Number of children (16 yrs or younger) in hh	3.449	1.893	3.693	2.000	2.876	1.464
Mother's height	148	23	146	22	152	24
Mother speaks an indigenous language	0.164		0.198		0.085	
Education mother: has not completed primary	0.456		0.526		0.293	
Sex	0.517		0.518		0.514	
Birth order	3.372	2.480	3.651	2.679	2.720	1.775
Multiple birth	0.017		0.017		0.017	
Categorized as very small at birth	0.071		0.071		0.069	
Has an older sibling less than 2 years apart	0.184		0.195		0.158	
Age: 6 months to 12 months	0.180		0.174		0.193	
Age: 12 months to 24 months	0.333		0.332		0.336	
Age: 24 months to 36 months	0.329		0.338		0.306	
Altitude of locality (in km)	1.192	0.892	1.305	0.870	0.929	0.888
Household asset score	-0.305	0.719	-0.487	0.652	0.120	0.688
Floor of dirt	0.338		0.383		0.234	
No tap water to kitchen or bath	0.866		0.908		0.766	
No proper indoor toilet	0.745		0.758		0.716	
Observations	1540		1079		461	

Data come from the *Encuesta Nacional de Salud.*

Table 11: Number of observations for different sub-populations and types of weather shocks

Sub population	Rainfall						GDD					
	Negative shock			Positive shock			Negative shock			Positive shock		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
Boys	117	128	417	59	50	7	102	57	75	238	241	227
Girls	106	127	444	85	73	14	104	73	81	238	274	249
Mother has completed primary school	112	124	443	79	77	9	100	62	75	267	301	262
Mother hasn't completed primary school	111	131	418	65	46	12	106	68	81	209	214	214
Not in a nutritional program	107	145	463	90	79	19	85	54	68	254	270	272
In a nutritional program	116	110	398	54	44	2	121	76	88	220	245	204
Total number of observations	1,536	1,536	1,540	1,536	1,536	1,540	1,536	1,536	1,540	1,536	1,536	1,540

NOTE: Based on ENN and includes all children under 36 months and with non-missing information on all co-variates.

Table 12: Impact of weather on child's height-for-age

Variables	All			Centre/South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
Negative rainfall shock	0.185 (0.150)	0.246 (0.166)	-0.025 (0.128)	**0.384*** **(0.204)**	**0.479**** **(0.228)**	0.127 (0.149)	-0.265 (0.174)	**-0.294**** **(0.142)**	**-0.371*** **(0.199)**
Positive rainfall shock	**-0.526***** **(0.111)**	**-0.513***** **(0.132)**	0.960^ (1.040)	**-0.518***** **(0.134)**	**-0.478***** **(0.142)**	**5.143***^** **(1.023)**	**-0.524***** **(0.143)**	**-0.701*** **(0.367)**	-0.401^ (0.257)
Negative GDD shock	0.004 (0.152)	0.032 (0.167)	0.008 (0.178)	0.045 (0.177)	-0.081 (0.189)	-0.062 (0.217)	-0.075 (0.256)	0.113 (0.369)	-0.034 (0.211)
Positive GDD shock	-0.100 (0.090)	-0.084 (0.092)	-0.152 (0.105)	-0.062 (0.105)	-0.048 (0.110)	-0.121 (0.127)	**-0.343*** **(0.176)**	-0.251 (0.157)	-0.313 (0.189)
Observations	1,536	1,536	1,540	1,079	1,079	1,079	457	457	461

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1.
^ Less than 2% of the sample experienced a positive rainfall shock in the pre-*canícula* period.
Calculated using ENN with state fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. A positive weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period (had at least 1 standard deviation more rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the mother (height, speaks an indigenous language and education), characteristics of the child (age, sex, birth order, multiple birth, small at birth, older sibling less than 2 years older, household assets and housing characteristics (asset index, presence of a kitchen, access to tapped water indoors, toilet, floor type), and altitude of locality.

Table 13: Impact of weather shocks on height-for-age, by sex

Variables	All			Center/South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
Girl	-0.155 (0.114)	-0.178 (0.116)	-0.091 (0.119)	-0.186 (0.142)	-0.288** (0.144)	-0.228 (0.167)	0.010 (0.194)	0.146 (0.179)	0.160 (0.197)
Negative rainfall shock	0.139 (0.192)	0.216 (0.190)	0.006 (0.148)	0.253 (0.258)	0.287 (0.279)	0.051 (0.179)	-0.140 (0.285)	-0.181 (0.203)	-0.080 (0.258)
... X girl	0.110 (0.279)	0.082 (0.250)	-0.065 (0.159)	0.272 (0.352)	0.410 (0.353)	0.139 (0.203)	-0.274 (0.439)	-0.275 (0.321)	**-0.506**** **(0.251)**
Positive rainfall shock	**-0.518***** **(0.188)**	**-0.519**** **(0.213)**	0.562^ (0.902)	**-0.651***** **(0.226)**	**-0.670***** **(0.232)**	**5.331***^** **(1.105)**	-0.153 (0.225)	-0.213 (0.458)	-0.245^ (0.299)
... X girl	-0.013 (0.226)	0.001 (0.282)	0.549^ (0.553)	0.266 (0.252)	0.326 (0.298)		**-0.699**** **(0.316)**	**-1.103***** **(0.263)**	-0.285^ (0.248)
Negative GDD shock	0.072 (0.195)	0.131 (0.267)	0.139 (0.220)	0.273 (0.226)	0.101 (0.328)	0.180 (0.280)	-0.257 (0.331)	-0.012 (0.573)	0.005 (0.300)
... X girl	-0.142 (0.212)	-0.167 (0.302)	-0.276 (0.272)	-0.464 (0.287)	-0.310 (0.368)	-0.471 (0.304)	0.335 (0.300)	0.171 (0.548)	-0.093 (0.533)
Positive GDD shock	**-0.297**** **(0.126)**	**-0.300**** **(0.121)**	**-0.294**** **(0.131)**	**-0.291*** **(0.149)**	**-0.357**** **(0.144)**	**-0.282*** **(0.158)**	-0.285 (0.267)	-0.127 (0.230)	-0.251 (0.250)
... X girl	**0.382**** **(0.178)**	**0.412**** **(0.169)**	0.270 (0.179)	**0.448**** **(0.214)**	**0.602***** **(0.206)**	0.302 (0.221)	-0.092 (0.327)	-0.239 (0.273)	-0.112 (0.294)
Number of observations	1,536	1,536	1,540	1,079	1,079	1,079	457	457	461

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1.

^ Less than 2% of the sample experienced a positive rainfall shock in the pre-*canícula* period.

Calculated using ENN with state fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the mother (height, speaks an indigenous language and education), characteristics of the child (age, sex, birth order, multiple birth, small at birth, older sibling less than 2 years older, household assets and housing characteristics (asset index, presence of a kitchen, access to tapped water indoors, toilet, floor type), and altitude of locality.

Table 14: Impact of weather shocks on height-for-age, by mother's education

Variables	All			Center/South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
Mother has not completed primary school	-0.213** (0.106)	-0.207** (0.104)	-0.162 (0.109)	-0.120 (0.121)	-0.138 (0.127)	-0.068 (0.146)	-0.222 (0.240)	-0.172 (0.218)	-0.146 (0.186)
Negative rainfall shock	0.140 (0.190)	0.159 (0.212)	-0.042 (0.141)	**0.421* (0.246)**	0.426 (0.339)	0.166 (0.157)	-0.252 (0.239)	-0.305 (0.196)	**-0.433* (0.233)**
... X mother has not completed primary school	0.068 (0.321)	0.148 (0.265)	0.028 (0.161)	-0.046 (0.393)	0.102 (0.410)	-0.087 (0.189)	-0.004 (0.424)	0.050 (0.329)	0.074 (0.306)
Positive rainfall shock	**-0.447** (0.181)**	**-0.457** (0.196)**	**1.807*^ (1.038)**	**-0.462* (0.246)**	**-0.399* (0.233)**	**5.183***^ (1.011)**	**-0.349* (0.196)**	-0.522 (0.532)	0.010^ (0.406)
... X mother has not completed primary school	-0.155 (0.241)	-0.143 (0.282)	**-1.674**^ (0.722)**	-0.088 (0.326)	-0.157 (0.332)		-0.313 (0.399)	-0.360 (0.728)	**-0.604*^ (0.341)**
Negative GDD shock	-0.105 (0.192)	-0.091 (0.201)	0.111 (0.226)	0.057 (0.247)	-0.147 (0.186)	-0.034 (0.211)	-0.225 (0.295)	-0.077 (0.592)	-0.040 (0.369)
... X mother has not completed primary school	0.206 (0.241)	0.218 (0.276)	-0.222 (0.297)	-0.017 (0.299)	0.105 (0.289)	-0.060 (0.280)	0.414 (0.402)	0.398 (0.680)	-0.043 (0.650)
Positive GDD shock	-0.125 (0.117)	-0.072 (0.119)	-0.161 (0.131)	0.025 (0.139)	0.066 (0.155)	-0.070 (0.161)	**-0.452** (0.217)**	-0.289 (0.189)	**-0.469** (0.232)**
... X mother has not completed primary school	0.054 (0.175)	-0.040 (0.174)	0.023 (0.181)	-0.175 (0.205)	-0.232 (0.214)	-0.104 (0.209)	0.504 (0.345)	0.141 (0.286)	0.533 (0.405)
Number of observations	1,536	1,536	1,540	1,079	1,079	1,079	457	457	461

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1.
^ Less than 2% of the sample experienced a positive rainfall shock in the pre-*canícula* period.
Calculated using ENN with state fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the mother (height, speaks an indigenous language and education), characteristics of the child (age, sex, birth order, multiple birth, small at birth, older sibling less than 2 years older, household assets and housing characteristics (asset index, presence of a kitchen, access to tapped water indoors, toilet, floor type), and altitude of locality.

Table 15: Impact of weather shocks on height-for-age, by participation in a nutritional supplement program

Variables	All			Center/South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
HH receives any nutritional supplement	0.195 (0.126)	0.092 (0.119)	0.154 (0.140)	0.222 (0.143)	0.107 (0.134)	0.243 (0.179)	0.253 (0.243)	0.090 (0.251)	0.065 (0.228)
Negative rainfall shock	0.173 (0.162)	0.181 (0.184)	-0.009 (0.135)	**0.428**** **(0.214)**	0.468 (0.293)	0.197 (0.152)	-0.217 (0.223)	**-0.351*** **(0.181)**	-0.348 (0.247)
... X nutritional supplement	0.001 (0.259)	0.091 (0.254)	-0.061 (0.168)	-0.090 (0.327)	-0.012 (0.395)	-0.184 (0.200)	-0.173 (0.409)	0.112 (0.347)	-0.045 (0.318)
Positive rainfall shock	**-0.377***** **(0.143)**	**-0.329**** **(0.166)**	0.708^ (1.090)	**-0.408**** **(0.161)**	**-0.352**** **(0.167)**	**6.541***^** **(0.383)**	-0.256 (0.266)	0.157 (0.456)	-0.508^ (0.321)
... X nutritional supplement	**-0.370*** **(0.207)**	**-0.611**** **(0.265)**	1.627^ (1.101)	-0.255 (0.190)	**-0.421*** **(0.252)**	**-2.860***^** **(0.389)**	-0.711 (0.537)	**-1.418***** **(0.474)**	0.617^ (0.386)
Negative GDD shock	0.039 (0.179)	-0.156 (0.163)	0.062 (0.249)	0.162 (0.288)	-0.249 (0.182)	-0.109 (0.235)	-0.024 (0.251)	-0.130 (0.340)	-0.092 (0.238)
... X nutritional supplement	-0.088 (0.242)	0.378 (0.277)	-0.136 (0.318)	-0.225 (0.373)	0.304 (0.354)	-0.028 (0.355)	-0.133 (0.318)	0.545 (0.445)	0.102 (0.380)
Positive GDD shock	-0.059 (0.115)	-0.098 (0.117)	-0.170 (0.121)	-0.016 (0.125)	-0.076 (0.137)	-0.181 (0.144)	-0.183 (0.278)	-0.182 (0.225)	-0.196 (0.262)
... X nutritional supplement	-0.123 (0.176)	-0.005 (0.173)	0.047 (0.170)	-0.133 (0.197)	0.021 (0.199)	0.100 (0.198)	-0.449 (0.419)	-0.168 (0.357)	-0.439 (0.420)
Number of observations	1,536	1,536	1,540	1,079	1,079	1,079	457	457	461

Robust standard errors in parentheses, clustered by locality, and *** p<0.01, ** p<0.05, * p<0.1.

^ Less than 2% of the sample experienced a positive rainfall shock in the pre-*canícula* period.

Calculated using ENN with state fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. Other independent variables included are: household composition (number of children in the household, number of adult males in the household, number of adult females in the household), characteristics of the mother (height, speaks an indigenous language and education), characteristics of the child (age, sex, birth order, multiple birth, small at birth, older sibling less than 2 years older, household assets and housing characteristics (asset index, presence of a kitchen, access to tapped water indoors, toilet, floor type), and altitude of locality. Also, the household's participation in a supplemental nutrition program is included.

Appendix 1. Correlations between weather shock variables (in rural MxFLS municipalities) and average (1951 to 1985) weather

	Annual rainfall: Standard deviations from1951-1985 average	Wet season rainfall: Standard deviations from1951-1985 average	Pre-*canícula* rainfall: Standard deviations from1951-1985 average	Annual GDD Standard deviations from1951-1985 average	Wet season GDD: Standard deviations from1951-1985 average	Pre-*canícula* GDD: Standard deviations from1951-1985 average
Wet season rainfall: Standard deviations from1951-1985 average	0.928					
Pre-*canícula* rainfall: Standard deviations from1951-1985 average	0.569	0.645				
Annual GDD Standard deviations from1951-1985 average	-0.206	-0.172	-0.164			
Wet season GDD: Standard deviations from1951-1985 average	-0.198	-0.176	-0.171	0.896		
Pre-*canícula* GDD: Standard deviations from1951-1985 average	-0.118	-0.093	-0.168	0.812	0.912	
Average annual rainfall (1951-1985)	-0.162	-0.154	0.142	-0.033	0.009	-0.074
Average wet season rainfall (1951-1985)	-0.176	-0.171	0.135	-0.050	-0.001	-0.088
Average pre-*canícula* rainfall (1951-1985)	-0.127	-0.114	0.131	-0.057	-0.056	-0.139
Average annual GDD (1951-1985)	0.024	0.032	0.001	0.008	0.022	0.053
Average wet season GDD (1951-1985)	0.052	0.051	-0.046	0.057	0.034	0.071
Average pre-*canícula* GDD (1951-1985)	0.034	0.031	-0.016	0.010	-0.021	-0.004

Appendix 2: Characteristics of MxFLS households

	All households		1992 households		1995 households	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Number of children in the household	1.679	1.655	1.785	1.711	1.552	1.575
Number of adult males (over 16) in the household	1.335	0.881	1.238	0.811	1.452	0.945
Number of adult females (over 16) in the household	1.468	0.887	1.361	0.769	1.595	0.996
Household head has not completed primary school	0.581		0.595		0.564	
Gender of household head (1=female)	0.196		0.195		0.198	
Age of household head	50.59	16.26	49.71	16.06	51.66	16.45
No separate kitchen	0.085		0.092		0.076	
No tap water	0.236		0.300		0.158	
No toilet	0.457		0.541		0.358	
No sewage	0.490		0.584		0.378	
No electricity	0.025		0.027		0.021	
Dirt floor	0.182		0.205		0.155	
Asset Index	0.078	0.810	0.120	0.810	0.026	0.807
Observation from 2005 survey	0.455					
Surveyed in the wet season	0.958		1		0.908	
Number of observations	4929		2687		2242	

Appendix 3: Full results of weather on expenditures

Table A3.1: Weather shocks and per capita expenditures on non-health items

	Year		Wet Season		Pre-*canícula*	
Fixed effects	State FE	Locality FE	State FE	Locality FE	State FE	Locality FE
Negative rainfall shock	0.004 (0.076)	**0.141*** **(0.082)**	-0.070 (0.079)	0.065 (0.096)	-0.110 (0.089)	-0.000 (0.080)
Positive rainfall shock	0.002 (0.079)	0.068 (0.087)	-0.031 (0.073)	-0.008 (0.072)	0.039 (0.085)	-0.014 (0.086)
Negative GDD shock	-0.066 (0.080)	-0.023 (0.093)	0.006 (0.082)	0.022 (0.131)	0.004 (0.077)	-0.013 (0.129)
Positive GDD shock	0.022 (0.056)	0.027 (0.092)	**0.120*** **(0.062)**	**0.183**** **(0.082)**	0.089 (0.086)	0.081 (0.115)
Number of children in the household	-0.140*** (0.010)	-0.136*** (0.009)	-0.140*** (0.010)	-0.137*** (0.009)	-0.141*** (0.009)	-0.137*** (0.009)
Number of adult males (over 16) in the household	-0.131*** (0.029)	-0.130*** (0.029)	-0.131*** (0.029)	-0.129*** (0.029)	-0.130*** (0.028)	-0.129*** (0.028)
Number of adult females (over 16) in the household	-0.108*** (0.018)	-0.104*** (0.018)	-0.108*** (0.019)	-0.104*** (0.018)	-0.108*** (0.018)	-0.105*** (0.018)
Household head has not completed primary school	-0.199*** (0.037)	-0.184*** (0.040)	-0.202*** (0.037)	-0.184*** (0.040)	-0.202*** (0.037)	-0.186*** (0.040)
Gender of household head (1=female)	-0.035 (0.053)	-0.033 (0.054)	-0.035 (0.052)	-0.033 (0.054)	-0.035 (0.052)	-0.034 (0.054)
Age of household head	-0.004** (0.002)	-0.004** (0.002)	-0.004** (0.002)	-0.004** (0.002)	-0.004** (0.002)	-0.004** (0.002)
No separate kitchen	-0.018 (0.054)	-0.025 (0.053)	-0.018 (0.054)	-0.024 (0.052)	-0.023 (0.053)	-0.026 (0.053)
No tap water	-0.040 (0.052)	-0.053 (0.056)	-0.038 (0.051)	-0.052 (0.055)	-0.037 (0.051)	-0.052 (0.055)
No toilet	-0.187*** (0.047)	-0.164*** (0.048)	-0.185*** (0.047)	-0.166*** (0.048)	-0.183*** (0.046)	-0.163*** (0.048)
No sewage	0.039 (0.049)	0.042 (0.054)	0.038 (0.047)	0.035 (0.053)	0.040 (0.048)	0.042 (0.053)
No electricity	-0.038 (0.137)	-0.011 (0.128)	-0.043 (0.136)	-0.018 (0.127)	-0.042 (0.138)	-0.015 (0.127)
Dirt floor	-0.235*** (0.045)	-0.238*** (0.047)	-0.230*** (0.045)	-0.233*** (0.047)	-0.234*** (0.046)	-0.238*** (0.047)
Asset Index	0.276*** (0.027)	0.267*** (0.027)	0.279*** (0.026)	0.267*** (0.027)	0.278*** (0.026)	0.267*** (0.027)
Observation from 2005 survey	-0.118** (0.046)	-0.119** (0.045)	-0.102** (0.047)	-0.097** (0.045)	-0.118** (0.046)	-0.109** (0.045)
Surveyed in the wet season	-0.208 (0.149)	-0.268* (0.152)	-0.213 (0.140)	-0.234 (0.145)	-0.232 (0.145)	-0.248* (0.145)
Annual rainfall (dm)	0.001 (0.009)		0.004 (0.009)		0.003 (0.008)	
Annual gdd / 1000 days	0.012 (0.038)		0.007 (0.038)		0.019 (0.038)	
Constant	7.393*** (0.249)	7.450*** (0.164)	7.366*** (0.236)	7.400*** (0.167)	7.346*** (0.253)	7.457*** (0.186)
Observations	4,929	4,929	4,950	4,950	4,951	4,951
R-squared	0.178	0.209	0.179	0.210	0.179	0.210

Table A3.2: Weather shocks and per capita expenditures on food

	Year		Wet Season		Pre-*canícula*	
Fixed effects	State FE	Locality FE	State FE	Locality FE	State FE	Locality FE
Negative rainfall shock	-0.049 (0.088)	-0.085 (0.109)	-0.007 (0.090)	0.057 (0.111)	-0.076 (0.093)	-0.028 (0.148)
Positive rainfall shock	**0.150*** **(0.086)**	**0.179*** **(0.107)**	0.097 (0.087)	0.131 (0.119)	0.046 (0.107)	0.036 (0.119)
Negative GDD shock	-0.101 (0.096)	-0.249 (0.162)	-0.029 (0.094)	-0.041 (0.184)	0.038 (0.088)	0.221 (0.159)
Positive GDD shock	-0.045 (0.083)	0.150 (0.099)	-0.096 (0.088)	-0.062 (0.140)	-0.082 (0.108)	-0.110 (0.154)
Number of children in the household	-0.131*** (0.014)	-0.126*** (0.014)	-0.128*** (0.014)	-0.122*** (0.014)	-0.127*** (0.014)	-0.123*** (0.014)
Number of adult males (over 16) in the household	-0.171*** (0.036)	-0.165*** (0.037)	-0.172*** (0.036)	-0.167*** (0.037)	-0.170*** (0.036)	-0.166*** (0.037)
Number of adult females (over 16) in the household	-0.055** (0.026)	-0.056** (0.027)	-0.053** (0.026)	-0.051* (0.027)	-0.052* (0.026)	-0.050* (0.027)
Household head has not completed primary school	-0.022 (0.049)	-0.011 (0.052)	-0.027 (0.049)	-0.010 (0.052)	-0.029 (0.049)	-0.007 (0.052)
Gender of household head (1=female)	0.010 (0.061)	0.008 (0.059)	0.008 (0.060)	0.009 (0.059)	0.008 (0.060)	0.009 (0.059)
Age of household head	-0.007*** (0.002)	-0.008*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)
No separate kitchen	-0.257** (0.121)	-0.246** (0.121)	-0.248** (0.122)	-0.245** (0.122)	-0.248** (0.120)	-0.240* (0.121)
No tap water	-0.076 (0.074)	-0.080 (0.078)	-0.088 (0.072)	-0.087 (0.078)	-0.094 (0.074)	-0.087 (0.079)
No toilet	-0.200*** (0.062)	-0.210*** (0.068)	-0.188*** (0.062)	-0.203*** (0.067)	-0.178*** (0.062)	-0.203*** (0.067)
No sewage	-0.066 (0.055)	-0.064 (0.060)	-0.050 (0.055)	-0.046 (0.060)	-0.048 (0.054)	-0.047 (0.060)
No electricity	0.112 (0.198)	0.148 (0.196)	0.119 (0.196)	0.154 (0.194)	0.120 (0.195)	0.153 (0.194)
Dirt floor	-0.105 (0.077)	-0.125 (0.080)	-0.106 (0.078)	-0.115 (0.081)	-0.104 (0.077)	-0.112 (0.081)
Asset Index	0.215*** (0.042)	0.208*** (0.043)	0.221*** (0.043)	0.213*** (0.044)	0.221*** (0.043)	0.214*** (0.044)
Observation from 2005 survey	0.087 (0.057)	0.066 (0.055)	0.078 (0.059)	0.056 (0.062)	0.074 (0.059)	0.044 (0.059)
Surveyed in the wet season	-0.249* (0.141)	-0.401*** (0.149)	-0.225 (0.137)	-0.371** (0.144)	-0.214* (0.128)	-0.330** (0.133)
Annual rainfall (dm)	-0.004 (0.013)		0.000 (0.012)		-0.000 (0.011)	
Annual gdd / 1000 days	0.046 (0.047)		0.036 (0.047)		0.031 (0.047)	
Constant	6.151*** (0.259)	6.503*** (0.170)	6.096*** (0.264)	6.395*** (0.177)	6.091*** (0.261)	6.333*** (0.175)
Observations	4,929	4,929	4,950	4,950	4,951	4,951
R-squared	0.078	0.098	0.076	0.094	0.075	0.095

Appendix 4: Full results of weather on child's height-for-age

VARIABLES	All			Centre/South			North		
	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*	Annual	Wet season	Pre-*canícula*
Negative rainfall shock	0.185 (0.150)	0.246 (0.166)	-0.025 (0.128)	**0.384*** **(0.204)**	**0.479**** **(0.228)**	0.127 (0.149)	-0.265 (0.174)	**-0.294**** **(0.142)**	**-0.371*** **(0.199)**
Positive rainfall shock	**-0.526***** **(0.111)**	**-0.513***** **(0.132)**	0.960^ (1.040)	**-0.518***** **(0.134)**	**-0.478***** **(0.142)**	5.143***^ (1.023)	**-0.524***** **(0.143)**	**-0.701*** **(0.367)**	-0.401^ (0.257)
Negative GDD shock	0.004 (0.152)	0.032 (0.167)	0.008 (0.178)	0.045 (0.177)	-0.081 (0.189)	-0.062 (0.217)	-0.075 (0.256)	0.113 (0.369)	-0.034 (0.211)
Positive GDD shock	-0.100 (0.090)	-0.084 (0.092)	-0.152 (0.105)	-0.062 (0.105)	-0.048 (0.110)	-0.121 (0.127)	**-0.343*** **(0.176)**	-0.251 (0.157)	-0.313 (0.189)
Number of adult males in hh	-0.021 (0.052)	-0.019 (0.051)	-0.023 (0.051)	-0.010 (0.068)	-0.010 (0.069)	-0.021 (0.070)	-0.036 (0.065)	-0.028 (0.063)	-0.039 (0.064)
Number of adult females in hh	-0.022 (0.060)	-0.028 (0.060)	-0.026 (0.059)	-0.059 (0.078)	-0.061 (0.078)	-0.053 (0.077)	0.004 (0.088)	-0.000 (0.088)	-0.001 (0.089)
Number of children (16 yrs or younger) in hh	-0.044 (0.035)	-0.044 (0.035)	-0.043 (0.035)	-0.062 (0.038)	-0.060 (0.038)	-0.056 (0.038)	0.047 (0.088)	0.053 (0.087)	0.041 (0.089)
Mother's height	-0.000 (0.002)	-0.000 (0.002)	-0.000 (0.002)	-0.002 (0.002)	-0.002 (0.002)	-0.003 (0.002)	0.005 (0.005)	0.005 (0.005)	0.005 (0.005)
Mother speaks an indigenous language	-0.172 (0.135)	-0.170 (0.135)	-0.114 (0.144)	-0.181 (0.152)	-0.192 (0.150)	-0.101 (0.170)	-0.137 (0.228)	-0.169 (0.238)	-0.245 (0.228)
Education mother: primary	-0.174** (0.075)	-0.191** (0.075)	-0.190** (0.075)	-0.196** (0.087)	-0.211** (0.087)	-0.166* (0.084)	-0.059 (0.165)	-0.105 (0.162)	-0.067 (0.165)
Sex	-0.039 (0.084)	-0.040 (0.085)	-0.065 (0.085)	-0.021 (0.107)	-0.024 (0.109)	-0.072 (0.109)	-0.075 (0.139)	-0.061 (0.142)	-0.063 (0.139)
Birth order	-0.003 (0.023)	-0.004 (0.023)	-0.004 (0.024)	0.012 (0.026)	0.009 (0.026)	0.007 (0.026)	-0.066 (0.054)	-0.063 (0.054)	-0.068 (0.055)
Multiple birth	-0.663*** (0.215)	-0.700*** (0.223)	-0.732*** (0.208)	-0.660*** (0.234)	-0.709*** (0.257)	-0.697*** (0.233)	-0.910 (0.632)	-0.933 (0.670)	-0.916* (0.482)

Categorized as very small at birth	-0.466*** (0.168)	-0.475*** (0.168)	-0.449*** (0.169)	-0.492** (0.208)	-0.502** (0.208)	-0.509** (0.214)	-0.355 (0.301)	-0.327 (0.301)	-0.349 (0.295)
Has an older sibling less than 2 years apart	-0.230** (0.096)	-0.235** (0.097)	-0.206** (0.096)	-0.240** (0.120)	-0.249** (0.120)	-0.240** (0.117)	-0.276* (0.163)	-0.247 (0.160)	-0.234 (0.153)
Age: 6 months to 12 months	-0.306** (0.139)	-0.301** (0.139)	-0.295** (0.139)	-0.493*** (0.162)	-0.472*** (0.161)	-0.480*** (0.165)	0.103 (0.257)	0.090 (0.259)	0.072 (0.248)
Age: 12 months to 24 months	-0.869*** (0.136)	-0.860*** (0.136)	-0.851*** (0.136)	-1.078*** (0.161)	-1.062*** (0.159)	-1.087*** (0.159)	-0.422* (0.248)	-0.402 (0.252)	-0.412 (0.249)
Age: 24 months to 36 months	-1.070*** (0.131)	-1.065*** (0.129)	-1.056*** (0.131)	-1.202*** (0.158)	-1.193*** (0.156)	-1.218*** (0.158)	-0.764*** (0.219)	-0.755*** (0.220)	-0.791*** (0.215)
Altitude of locality (in km)	-0.307*** (0.093)	-0.312*** (0.091)	-0.353*** (0.094)	-0.320*** (0.116)	-0.318*** (0.110)	-0.367*** (0.108)	-0.133 (0.184)	-0.180 (0.155)	-0.269 (0.197)
Household asset score	0.316*** (0.075)	0.312*** (0.077)	0.331*** (0.078)	0.312*** (0.100)	0.284*** (0.102)	0.309*** (0.104)	0.328*** (0.121)	0.339*** (0.119)	0.360*** (0.114)
Floor of dirt	-0.044 (0.103)	-0.044 (0.104)	-0.026 (0.106)	0.027 (0.119)	0.020 (0.121)	0.037 (0.121)	-0.165 (0.213)	-0.134 (0.220)	-0.155 (0.225)
No tap water to kitchen or bath	0.092 (0.150)	0.076 (0.152)	0.084 (0.149)	0.075 (0.209)	0.029 (0.212)	0.093 (0.201)	0.081 (0.221)	0.106 (0.217)	0.122 (0.215)
No proper indoor toilet	-0.045 (0.108)	-0.051 (0.109)	-0.039 (0.108)	-0.081 (0.136)	-0.085 (0.141)	-0.074 (0.140)	-0.055 (0.199)	-0.042 (0.196)	-0.040 (0.201)
Constant	0.547 (0.376)	0.553 (0.373)	0.638* (0.381)	0.956** (0.438)	0.980** (0.438)	0.979** (0.431)	-0.481 (0.846)	-0.509 (0.844)	-0.199 (0.840)
Observations	1,536	1,536	1,540	1,079	1,079	1,079	457	457	461
R-squared	0.249	0.248	0.245	0.230	0.231	0.238	0.207	0.206	0.207

Robust standard errors in parentheses, clustered by locality and *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

^ Less than 2% of the sample experienced a positive rainfall shock in the pre-*canícula* period.

Calculated using ENN with state fixed effects. A negative weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period) had at least 1 standard deviation less rain (or GDD) than in an average year. A positive weather shock identifies those municipalities which in the previous agricultural year (or wet season or pre-*canícula* period (had at least 1 standard deviation more rain (or GDD) than in an average year.

Appendix 5. Interpolation of weather data

IMTA's dataset contains daily information on several meteorological variables for more than 5,000 stations across Mexico, since the 1920s to 2007. These data were used to interpolate an observation of those three variables at the centroid of each of the 2,451 municipalities in the country, on a day-by-day basis. Municipality centroids were determined as the simple average of the latitude and longitude coordinates of all the localities listed within each municipality in INEGI's catalogue of localities.

The approach used to interpolate the weather data is the two-dimensional, weighted average method proposed by Shepard (1968). He summarizes it as follows:

"In essence, an operational solution to the problem of two-dimensional interpolation from irregularly-spaced data points is desired. It is assumed that a finite number of N triplets (x_i,y_i,z_i) are given, where x_i, y_i are the locational coordinates of the data point D_i, and z_i is the corresponding data value. Data point locations may not be coincident. An interpolation function $z=f(x,y)$ to assign a value to any location $P(x,y)$ in the plane is sought. This two-dimensional interpolation function is to be "smooth" (continuous and once-differentiable), to pass through the specified points (i.e., $f(x_i,y_i)=z_i$), and to meet the user's intuitive expectations about the phenomenon under investigation." (p. 517)

The interpolation function is simply a weighted average of the observed values from a certain number of data points (weather stations). Shepard chooses this number to be variable (ranging from 4 to 10, with an average of 7) by defining a radius around the interpolation point which, on average, will include 7 data points. Since in IMTA's dataset the weather stations are much more sparse in some areas of the country than others, choosing Shepard's number would have yielded a radius to small in some areas or too large in others. In addition, weather stations reported data intermittently, which implied that having a small number of stations to interpolate from ran the risk of not having any data values with which to do the interpolation.
Instead, for every municipality centroid, we first chose the 20 stations that were closest to it[39]. We then kept only those stations that reported information on the day to be interpolated. The result was that less than 6% of the interpolations were based on only one weather station, around 8% (the highest proportion) were based on 7 stations, and around 1% were based on 18 or more stations.

The weights (w_i) used in the interpolation function consider two aspects: Distance and direction. Distance is used to give a bigger weight to data points that are closer to the point of interpolation. Direction is used to take into account "shadowing" effects: A weather station B that is 'behind' another weather station A (as seen from the point of interpolation P) provides less information than another station C which is located in another direction—even if station B is closer to the point of interpolation than station C—because station B has been shadowed by station A (see Figure A.1)

[39] The number 20 was chosen because it was the smallest number of stations with which less than 1 percent of the interpolations would have to be made based on the data of only one station (the rest of the stations having failed to report data on that day).

Figure A.1. Weather station B is shadowed by station A.
|--*B*---*A*---***P***------------------*C*--|

The interpolation function for each of the 2,451 interpolation points *P* (for each day since January 1st, 1950 to December 31st, 2007) was the following:

$$f(P)=\begin{cases} \dfrac{\sum_N w_i z_i}{\sum_N w_i} & if\ d_i \neq 0\ \ \forall\ i \\ z_i & if\ d_i = 0\ \ for\ some\ i,\ or \\ & if\ N = 1 \end{cases}$$

Where d_i is the distance between interpolation point *P* and station *i* (among the *N* stations that reported information that day, out of the 20 stations closest to *P*), z_i is weather station *i*'s measure of the variable of interest (rain, maximum temperature, or minimum temperature), and w_i is station *i*'s weight for that day's interpolation.
The weights are defined as

$$w_i = (s_i)^2 \bullet (1 + t_i),$$

where

$$s_i = \begin{cases} \dfrac{1}{d_i} & if\ \ 0 < d_i < \dfrac{D}{3} \\ \dfrac{27}{4D}\left(\dfrac{d_i}{D} - 1\right)^2 & if\ \ \dfrac{D}{3} < d_i \leq D \end{cases}$$

(with *D* being the distance to the farthest station), and

$$t_i = \frac{\sum_{j \neq i} s_j \left[1 - \cos\left(D_i P D_j\right)\right]}{\sum_{j \neq i} s_j}$$

(with D_iPD_j being the angle between weather stations *i* and *j* with interpolation point *P* as vertex).