Mortality, Temperature, and Public Health Provision: Evidence from Mexico

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Abstract

We examine the impact of temperature on mortality in Mexico using daily data over the period 1998-2017 and find that 3.8 percent of deaths in Mexico are caused by suboptimal temperature (26,000 every year). However, 92 percent of weather-related deaths are induced by cold (<12°C) or mildly cold (12-20°C) days and only 2 percent by outstandingly hot days (>32°C). Furthermore, temperatures are twice more likely to kill people in the bottom half of the income distribution. Finally, we show causal evidence that the *Seguro Popular*, a universal healthcare policy, has saved at least 1,600 lives per year from cold weather since 2004.

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Introduction

Climate change is a major threat for human health in the 21st century. The World Health Organisation estimates that it could result in 250,000 additional deaths every year between 2030 and 2050. However, these effects will likely be unequally distributed across countries and regions. The effects of temperature shocks on mortality – one of the most direct ways in which climate change may affect health – have been shown to be quite mild in the US (Braga *et al.*, 2001; Deschenes and Moretti, 2009; Deschenes and Greenstone, 2011; Barreca, 2012), but recent evidence from developing countries suggests much greater impacts (Burgess *et al.*, 2017; Carleton *et al.*, 2018). Lower-income countries are expected to be affected the most not only because they already have warmer climates but also because they have lower adaptive capacity. Indeed, access to individual protection measures such as air conditioning explains the declining heat-related mortality that has been observed in the US over time (Barreca *et al.*, 2016; Heutel, Miller and Molitor, 2017), but such strategies are unlikely to be available to poorer households in the developing world (Kahn, 2016). Therefore, understanding how much weather shocks affect human health in low- and middle-income countries, and to what extent public policies can alleviate the impact of these shocks, is of major research interest and of great policy importance.

In this paper, we contribute to this literature by investigating the relationship between temperature, mortality, inequality and public health provision in Mexico based on data of unusually high quality. We use a large dataset of over 14 million daily mortality rates from 1998 to 2017 for 2,297 Mexican municipalities, representing around 90 percent of the country's population, in combination with weather data from the closest meteorological stations, to analyse the impact of weather shocks on mortality. The use of daily data at the local level has major advantages: the inclusion of municipality-by-calendar-day, municipality-by-year and day fixed effects allows us to purge the estimates from a large number of confounding factors that might be correlated with both temperatures and mortality, while distributed lag models account for possible mortality displacement effects.

We then match the characteristics of individuals as reported in death records to the Mexican census data. This allows us to estimate the income level of each individual in our dataset at the time of their death and to analyse the vulnerability to temperature shocks across income groups. This paper is the first analysis of the heterogeneous relationship between temperature and mortality in a middle-income country that combines daily mortality data with individual estimates of income level. Findings coincide with the general expectation that the poor are more

vulnerable to inclement weather, and that this may explain part of the life expectancy gap between and within countries.

Finally, we exploit the progressive implementation of a large social insurance programme targeted at low-income households – the *Seguro Popular* – to analyze the impact that extending universal healthcare has on reducing weather vulnerability. To our knowledge, this paper is also the first to assess the causal impact of pro-poor public health policies on resilience to weather shocks.

The paper begins by confirming the extent to which the population of a middle-income country like Mexico is vulnerable to weather compared to those in developed countries. Applying our estimates to the typical daily average temperature distribution in Mexico, we find that around 26,000 deaths annually (3.8 percent of deaths in Mexico) are induced by suboptimal temperature (outside the human body comfort zone). To put things in perspective, this is equivalent to road-related deaths in the country. However, the first interesting contribution of this study is to document the impact of mildly cold temperatures on mortality. Whereas the media usually pay attention to extreme heat and cold, these events are infrequent and only account for a minority of weather-related deaths in our analysis. In a hot country like Mexico, even days with a mean temperature below 20°C (68°F) are associated with statistically significant increases in the daily mortality rate compared to a day at 24-28°C. Therefore, while unusually cold days with a mean temperature below 12°C are responsible for the deaths of around 5,700 people each year, we estimate that 71 percent of weather-induced deaths – around 18,700 people per year – occur in the aftermath of days with mean temperatures between 12°C and 20°C.[1] This may be because these days imply low temperatures at night, which favour the development of respiratory pathologies and put the human body at higher cardiovascular risk. The elderly and people with metabolic diseases such as diabetes are also more at risk while poor housing conditions across Mexico may exacerbate the impact of mildly cold temperatures on mortality. In contrast, extremely hot days over 32°C trigger a comparably small amount of additional deaths (around 500 annually).[2]

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[1] Daily average temperatures are calculated as the average between the minimum and maximum daily temperatures. On average, in our dataset, daily minimum temperatures are 7.5°C below the daily average. Days recording an average temperature of 12°C typically imply a minimum temperature of around 2.5°C at night. Likewise, mildly cold days, e.g. averaging 12-16°C, expose people to fairly cold temperatures (on average 6.6°C) at night. This is well below the comfort zone of the human body which lies between 20 and 25°C.

[2] This finding is for the direct impact of weather on mortality only. It stands in sharp contrast with most recent economic analyses of both developed and developing countries, which tend to predict that climate change will significantly increase temperature-induced mortality (e.g. Deschenes and Greenstone, 2011; Burgess et al. 2017). The difference in findings can be partly explained by our focus on short-term impacts: we do not account for the

The second contribution of this study is to show that vulnerability to extreme weather is negatively correlated with personal income. Overall, death following cold and mildly cold days (all days below 24°C compared to 24-28°C) is more than twice as frequent for people living below the national median personal income. Hence, a large majority of cold-related deaths concentrates on the poorest income groups. Analyses by death causes show that the higher vulnerability of the poor comes to a large extent from respiratory diseases and circulatory system diseases.[3] In contrast, we find no statistically significant differences in vulnerability to heat across income groups. These results may be relevant in the context of the COVID-19 pandemic, since they suggest that poorer communities are usually more exposed to respiratory diseases than other households.

The final contribution of this study is to assess the impact that improved access to healthcare has on reducing weather-related vulnerability. Our epidemiological analysis shows that policies targeting the most vulnerable people (particularly young children and the elderly in low-income households) could significantly reduce weather-related mortality. However, such policies should not focus on extremely cold days – unlike, for example, early warning systems – but provide protection all year round, since mildly cold days are responsible for the vast majority of weather-related deaths. This suggests that expanding access to healthcare (particularly for vulnerable groups) may significantly reduce weather vulnerability. During our study period, Mexico implemented a nationwide policy, the *Seguro Popular*, to increase access to healthcare for low-income households. This policy provides protection against a set of diseases that happen to be particularly sensitive to weather conditions (e.g. pneumonia).[4]

We assess if the rollout of the *Seguro Popular* led to a reduction in the extra mortality triggered by cold and mildly cold temperatures. To do so, we focus on the population eligible to the *Seguro Popular* and interact the availability of the *Seguro Popular* in each municipality with temperature bins. To control for the endogenous enrolment of municipalities into the policy as well as for seasonality, we include a full range of interaction terms between temperature bins and municipality-by-month fixed effects. In addition, we use month-by-year fixed effects interacted with temperature bins to control for the autonomous evolution of weather

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indirect effects of temperature, e.g. on agriculture and income, which influence health outcomes. In that regard, our results strongly align with the scientific literature on the direct, physiological impact of cold and heat waves on mortality (Barnett et al., 2012; Guo et al., 2014; Ma, Chen, and Kan, 2014; Gasparrini et al., 2015; Yang et al., 2015; Hajat and Gasparrini, 2016; Gasparrini et al., 2017). Recent epidemiological research insists on the strong health burden of cold, especially during the winter.

[3] This suggests that flu pandemics or coronaviruses may constitute a stronger threat for low-income households.

[4] Access to healthcare is a major issue in Mexico: according to the 2000 Mexican Census, over 80% of people in the first income quartile do not have access to social security.

vulnerability over time. We find that the *Seguro Popular* saved at least 1,600 lives per year from mildly cold weather, representing around 6.6 percent of weather-induced deaths. While our analysis focuses on weather vulnerability, which is only one specific aspect of the impact of the *Seguro Popular* on mortality, it is in fact one of the few assessments of the impact of the *Seguro Popular* on mortality more generally[5] and thus also contributes to the literature assessing the impact of healthcare extensions in emerging countries, where important data constraints usually exist (Dupas and Miguel, 2017).

The relevance of this paper goes beyond the borders of Mexico. Even in hot countries where coldest temperatures almost never reach 0°C, cold remains a risk factor with potentially high health impacts. Low-income households, particularly in the developing world, are ill-equipped to protect themselves against low temperatures. This puts them at a higher risk at all ages, and particularly when they become older. Furthermore, these households are at risk over longer time periods in the year than richer households, since they appear to be vulnerable to even mildly cold temperatures. We show that access to universal healthcare can successfully reduce this high vulnerability.

The remainder of this paper is structured as follows. Section I discusses the previous empirical literature on the impact of weather on mortality. Section II describes the data. The general impact of temperatures on mortality is presented in Section III. Results by quartiles of income are presented in section IV, and the impact assessment of universal healthcare on reducing weather-related mortality is presented in section V. A concluding section summarizes our findings and discusses the implications of our results.

I. Previous empirical literature on temperature and mortality

A review of the epidemiological literature focusing on the physiological impact of cold and heat on human health is presented in Appendix A1, but we summarize the most important results of this literature in this section. To quantify heat- and cold-related mortality, epidemiological studies usually correlate daily death counts with temperature data at the city level and rely on a Poisson regression framework. Recent studies have established the existence of a U-shape relationship between temperature and mortality at the daily level (Curriero *et al.*, 2002; Hajat *et al.*, 2006; Hajat *et al.*, 2007; McMichael *et al.*, 2008). Human beings face lowest

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[5] Other papers looking at the *Seguro Popular* have focused on health spending (King et al., 2009), health expenditure and self-declared information on health issues (Barros, 2008), access to obstetrical services (Sosa-Rubi, Galarraga and Harris, 2009) and prenatal services (Harris and Sosa-Rubi, 2009). Research by Pfutze (2014, 2015) suggests that the *Seguro Popular* may have reduced infant mortality and miscarriages.

mortality risk at a given threshold temperature, which differs from one location to another (e.g. due to acclimation) and may possibly change over time. Above and below this threshold, mortality increases and, the farther away from the threshold, the greater the numbers of heat- and cold-related mortalities. This is in line with medical evidence that the human body starts being at risk outside a comfort zone which varies across individuals but is generally believed to lie in the range of 20°C to 25°C. From a methodological perspective, such a nonlinear relationship between mortality and temperature calls for the use of nonlinear specifications in panel data analyses (Deschenes and Greenstone, 2011). With temperature bins, the impact between temperature and mortality is separately evaluated at different levels of temperature stress.

Despite evidence from the medical literature that even mildly cold or hot days can negatively affect human health, the economic literature has primarily focused on the impact of extremely hot and cold days (see for example Deschenes and Moretti, 2009; and Deschenes and Greenstone, 2011), plausibly because these extreme weather events tend to concentrate media attention. However, while the impact of a mildly cold or hot day is definitely less dangerous than that of an extremely hot or cold day, days lying just outside the typical human body comfort zone are much more frequent. They may be also associated with the development of viruses. For example, the transmission of influenza and other respiratory diseases are strongly influenced by ambient air temperature and humidity (Lipsitch and Viboud, 2009; Prel et al., 2009; Shaman and Kohn, 2009; Tamerius et al., 2011; Shaman and Karspeck, 2012; Tamerius et al., 2013; Lowen and Steel, 2014).

This media misrepresentation of the relative burden of extreme temperatures is particularly striking in the case of very hot days. Whereas unusually hot days receive significant media attention, the question of their actual impact on mortality remains controversial once account is taken of displacement effects, i.e. the impact of a day's temperature on the mortality levels of the following days. Extra deaths on hot days were often found to be offset by lower mortality rates on the following days, suggesting that mortality on hot days largely corresponds to a "harvesting" effect (Braga *et al.*, 2001; Hajat *et al.*, 2005; Deschenes and Moretti, 2009).[6] Recent developments in epidemiology show that the impact of cold weather on human health is in fact seemingly much stronger than the impact of hot weather (Barnett et al., 2012; Guo et

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[6] For example, Gouveia et al. (2003) show that the positive relationship between mortality and heat in Sao Paulo dissipates within three weeks. Based on data for Beirut (Lebanon), El-Zein et al. (2004) show that the statistically significant effect of hot days on mortality dissipates within fourteen days.

al., 2014; Ma, Chen, and Kan, 2014; Gasparrini et al., 2015; Yang et al., 2015; Hajat and Gasparrini, 2016; Gasparrini et al., 2017). In particular, Gasparrini et al. (2015) collect data from 384 locations in 13 countries and find that both extreme cold and extreme heat have strong marginal impacts on mortality. However, because cold days are more frequent than hot days, they find that 7.29% of all deaths are attributable to cold while only 0.42% are caused by heat, with most cold-related deaths caused by pathologies triggered by mildly cold temperatures. Extremely cold and hot temperatures are jointly responsible for only 0.86% of total mortality.

However, uncertainty remains on the true mortality impact of hot days because extreme weather events may not only directly affect human physiology, they may also reduce agricultural output, drinkable water availability and household income. These impacts may in turn affect health or access to healthcare and lead to extra mortality. In order to account for these longer-term impacts, a few economic studies have used monthly or annual panel data rather than daily data (Deschenes and Greenstone, 2011; Barreca, 2012; Guerrero Compeán, 2013; Burgess *et al.*, 2017; Barreca *et al.*, 2016).[7] These studies establish a clear correlation between hot temperatures and monthly or annual mortality. Burgess *et al.* (2017) find a strong impact of extreme temperatures on annual mortality in India, plausibly because temperature shocks affect agricultural productivity, and therefore the food intake and income of populations located in rural areas. In Mexico and using annual data, Guerrero Compeán (2013) also finds that hot days are associated with strong increases in mortality rates. The difference with our findings likely comes from the fact that, while our estimates based on daily data focus on the short-term biological response of the human body to unusual weather, those of Guerrero Compeán (2013) should additionally include the effect of weather on mortality through economic channels (such as reduced agricultural productivity and household income), as suggested by the much greater impact found in rural areas compared to urban ones.[8] Similar differences in the estimated temperature-mortality relationship across daily and annual specifications has also been observed in the U.S. (see for example Deschenes and Moretti, 2009, vs Deschenes and Greenstone, 2011).

The existence of such economic factors in addition to the standard epidemiologic ones suggests that people's vulnerability to cold and hot temperatures depends on their access to protection measures. For example, Barreca *et al.* (2016) establish a strong correlation between the

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[7] See Basu (2008) and Deschenes (2014) for thorough literature reviews.
[8] Another possibility is that some of our mortality impacts are for people that are weak and would have died anyway within a year. This is however unlikely to explain most of the difference in estimates since we already largely account for displacement effects (at 30 days).

declining heat-related mortality that has been observed in the US over time and the gradual deployment of air conditioning. Heutel, Miller and Molitor (2017) similarly argue that the deployment of air conditioning explains regional differences in the health impact of heat on the elderly in the US. Deschenes and Greenstone (2011) predict that climate change in the US would lead to a 3 percent increase in age-adjusted mortality by the end of the 21st century and to a 12 percent increase in electricity consumption as households resort to air-conditioning to protect themselves from the negative consequences of temperature rises. Other potential adaptation measures include migration to places with a more temperate climate (Deschenes and Moretti, 2009) or a reduction in the time spent outdoors (Graff-Zivin and Neidell, 2010).

Differences in the ability of populations to adapt to temperature shocks have been documented both within and between countries, with potentially large effects on economic development (Dell, Jones and Olken, 2012). In epidemiological studies, McMichael *et al.* (2008) show vast heterogeneity in the impact of temperature on mortality across twelve cities in medium- and low-income countries. Using long-term climate change scenarios, Barreca (2012) finds a very small reduction in mortality for the US as a whole (-0.08 percent), but this hides significant heterogeneity: mortality would decrease in the coldest States whereas it would significantly increase (by up to 3 percent) in the warmest and most humid States. In India, Burgess et al. (2017) find a significant increase in heat-related mortality, but only in rural areas. In these regions, climate change impacts would translate into a large increase in mortality by the end of the century of 12 to 46 percent.

Overall, evidence suggests that weather vulnerability in middle-income economies may substantially differ from that in developed countries. In particular, developed countries have already experienced an epidemiological transition: cancers and other non-transmissible diseases have long been the leading cause of death in these countries, contrary to many developing countries. Furthermore, elemental protection measures (e.g. proper clothing) are available to all in industrialized countries, and national programs such as Medicare and Medicaid provide universal healthcare coverage in life-threatening cases.

II. Data and summary statistics

To evaluate the relationship between temperature and mortality in Mexico, we combine mortality data from the Mexican National Institute of Statistics and Geography (INEGI, 1990-2017) and weather data from the National Climatological Database of Mexico (CONAGUA, 2018).

II.A Mortality data

Our mortality data comes from the Mexican general mortality records (*defunciones generales*) from 1990 onwards as assembled by INEGI. The micro-data provides information about each case of death in Mexico, including cause, municipality, date and time of death along with socioeconomic information on the deceased. A template of the death certificate used in Mexico is provided in Appendix A2. Based on this dataset, we are able to construct daily municipal mortality rates for all Mexican municipalities over the period 1998-2017. The exact date of death is not available before 1998. However, we are able to construct monthly mortality rates over the full period (1990-2017) and use this information in all monthly analyses.

Table 1 displays the average daily mortality rate by cause of death, gender and age, together with the average population within each group for the period 1998-2017.[9] The average daily mortality rate across all municipalities is around 1.4 deaths per 100,000 inhabitants. This figure is about twice as low as the current rate in the United States (see Deschênes and Moretti 2009), a feature that is explained by the larger proportion of young people in Mexico. The death rate is lowest for children aged 4-9 and rises non-linearly until it reaches 21.3 per 100,000 inhabitants for people aged 75 years and above.

We break down mortality rates by cause of death, based on the typology of the 10th version of the International Classification of Diseases (10-ICD) of the World Health Organization (WHO). We consider seven types of cause of death: infectious and parasitic diseases; malign neoplasms; endocrine, nutritional and metabolic deaths (including diabetes which account for 80 percent of deaths in this category, followed by malnutrition); diseases of the circulatory system; diseases of the respiratory system; violent and accidental deaths; and other causes. As reported elsewhere, the primary cause of death is circulatory system diseases, which has been shown to be affected by temperature in the epidemiological literature. The importance of each cause of death differs by age and gender. For example, the prevalence of violent and accidental death is four to five times greater among men than among women. It is also the main cause of death for people aged between 10 and 44. The significance of circulatory system diseases rises with age and peaks above 75, when it becomes the primary cause of death.

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[9] We calculate daily municipal mortality rates by dividing the amount of deaths in a municipality on a specific day with the population in this municipality. To do so, we use municipal population data available from the INEGI for the years of the national censuses (INEGI, 1990, 1995, 2000, 2005 and 2010). We perform a linear interpolation of the population for the years between two censuses to obtain estimates of the Mexican population in each municipality for each year between 1998 and 2017. This may introduce measurement errors in the dependent variable, a problem known to reduce model efficiency but not the consistency of estimates.

II.B Weather and climate data

The National Climatological Database of Mexico (CONAGUA, 2018) provides daily temperature and precipitation records for around 5,500 operating and formerly operating land-based stations in Mexico, of which around 2,500 were operative in any given year on average between 1998 and 2017. Information on the longitude and latitude of the stations is also provided. In order to compute mean temperatures and precipitations at municipal level, we match the municipalities in Mexico with the closest land-based stations.[10] This leads us to exclude a few municipalities that are either located too far from any weather station, or close to a weather station that did not efficiently record both minimum and maximum temperatures. Our combined daily temperature-mortality dataset covers 2,297 Mexican municipalities over the period 1998-2017[11] and includes over 14 million observations. Figure 1 presents the historical distribution of daily average temperature in Mexico from 1998 to 2017.[12] The temperature data is weighted according to the population of each municipality to reflect the average exposure of Mexican people to low and high temperatures. We use seven temperature bins: "below 12°C", "above 32°C" and five 4°C bins in between. In the empirical models presented hereafter, we use the same temperature bins to estimate the relationship between temperature and mortality. In Figure 1, each bar represents the average number of days in each temperature category for the average person in Mexico. The mode of the distribution is between 16°C and 20°C, and about 70 percent of days lie in the range 12°C-24°C. At the extremes of the distribution, the average Mexican is exposed to 17 days per year below 12°C (around 54°F) and 2.2 days per year above 32°C (90°F). Mexico's climate is much warmer than that of the US, featuring fewer

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[10] To do so, we use the information on the longitude and latitude of municipalities from the INEGI's National Geostatistical Framework (INEGI, 2020). We calculate the longitude and latitude of the centroid of each municipality (averaging the coordinates of all locations that are part of a municipality), and then the distance between this centroid and all the land-based stations in the climatological data. Based on their distance from the centroid of each municipality, land-based stations are matched with municipalities. We consider a land-based station to be within a municipality if it is less than 20km from its centroid. Municipalities in very remote zones feature less than 5 active stations in the 20km radius. In this case, we match each municipality with the five closest stations within a maximum radius of 50km. Once we have identified the land-based stations relevant to a municipality, we compute the daily mean temperature and precipitation levels in a municipality by averaging the records of all stations considered to be relevant to a given municipality.

[11] In 2008, there were 2,454 municipalities in Mexico (INEGI, 2008).

[12] Daily average temperature is defined as the average between the maximum and minimum temperatures of that day, following recommendations by the World Meteorological Organization (2011).

days below 12°C and many more days above 32°C.[13] The distribution is also more spread out in the US.

[FIGURE 1 ABOUT HERE]

II.C Socioeconomic data

Information from the Mexican 2000 census of population and housing is used in this paper to estimate the income of the deceased (INEGI, 2000). We use the publicly available sample of the 2000 Census covering 10 percent of the Mexican population. We extract socioeconomic information on income, educational attainment, social insurance coverage, profession, age, etc. This data source is described in detail in Appendix A3. In a nutshell, the 2000 Census shows large differences in the average personal income between the poorest and richest households. The average personal income of people in the first income quartile is 18 times lower than that of people in the top quartile. This high inequality is a feature of the Mexican economy that we will use in the next sections to investigate differences in the weather-mortality relationship across income groups. In addition, these high inequalities translate into low healthcare coverage of the very poor: more than 80 percent of the people in the 1st income quartile have no social security.

III. The effect of temperatures on mortality in Mexico

III.A Method

We use daily data to estimate the impact of temperature on mortality, allowing us to causally identify the impact of exposure to unusual temperatures on mortality. Daily specifications also allow us to look at short-term dynamics and evaluate how long it takes for pathologies to develop after populations are exposed to particular temperatures. We complement our daily specifications with estimates obtained with data aggregated at monthly level in Appendix A4. The results obtained from these regressions at monthly level are similar in magnitude to the ones found with our daily specifications.

In order to assess the impact of daily temperatures on mortality, we correlate daily temperatures with daily mortality rates using a fixed-effect linear regression. We use three sets of fixed effects. First, the model includes municipality-by-calendar-day (1st January to 31st December) fixed effects to control for differences in mortality rates due to seasonal phenomena at

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[13] Deschenes and Greenstone (2011) provide a distribution of daily mean temperatures in the U.S. On average, temperatures are much lower: there are around 120 days with a mean temperature below 10°C and 1.3 days with temperatures greater than 90°F (32.2°C).

municipality level. With these fixed effects, parameters are identified from year-to-year deviations in temperature from the municipality average of a given calendar day. Second, the model includes time fixed effects for every day in the sample (e.g. 1st January 2006, 2nd January 2006, etc), which control for unobserved factors that affect daily mortality across all Mexican municipalities. Third, municipality-by-year fixed effects control for differential trends in mortality rates over time across municipalities.

All these fixed effects strongly improve the comparability of observations across municipalities and time. However, they could absorb some of the effect since our model only compares mortality in the same calendar day across different years. Prior to running such models, we checked that there was enough variance within calendar days and location to estimate differences in effects across temperature bins.[14]

To model the temperature-mortality relationship, we estimate equations of the following form:

(1) $\quad Y_{i,d,m,t} = \theta.T_{i,d,m,t} + \mu_{i,d,m} + \mu_{i,t} + \mu_{d,m,t} + \varepsilon_{i,d,m,t}$

where $Y_{i,d,m,t}$ is the mortality rate of municipality i on day d of month m and year t, θ is a vector of parameters, $T_{i,d,m,t}$ is a vector of climatic variables that we discuss in detail below, $\mu_{i,d,.m}$ is a vector of municipality-by-calendar-day fixed effects, $\mu_{i,t}$ corresponds to municipality-by-year fixed effects, $\mu_{d,.m,t}$ is a vector of day-by-month-by-year fixed effects and $\varepsilon_{i,d,m,t}$ is the error term.[15] Standard errors are clustered at the municipality level.[16] In addition, the regression coefficients are weighted by the population in each municipality.[17]

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[14] Within calendar days (1-365) and municipalities, the standard deviation of the average temperature recorded across different years is about 2°C. There is a 4.5°C difference between the 10 percent highest and lowest temperatures recorded within the same calendar day and municipality, and a 10°C difference between the 1 percent highest and 1 percent lowest. Therefore, the model can generally compare a cold day at 10°C with days in the range of 14-20°C, and days at 33°C with days in the range of 23-29°C.

[15] The specification being used is fully linear. Alternatively, we could have opted for a log-linear specification. In the present case, the linear specification is preferable because there are many zeros in the dependent variable since it corresponds to daily mortality rates. After weighting for population, around 29 percent of daily death rates have zero mortality. A log-linear specification would drop these zeros. A convenient transformation could be using the logarithm of the death rate plus 1, i.e. ln(Y+1) instead of Y. We have run our model with such a transformation and the results were very similar. Furthermore, results are similar with a specification using monthly data (see Appendix A4). Monthly data naturally includes less zero values since deaths are aggregated over a month.

[16] In a preliminary test, we also checked that our main results were robust to the use of larger clusters, namely State-level clusters. Standard errors increase but the statistical significance of the effects remains. State-level clusters would strongly relax the assumption of zero correlation between municipalities. In the baseline regressions, we do not use State-level clusters because this choice for the clusters would be overly restrictive. We would assume some correlation between two daily death rates occurring during different years and geographical areas, i.e. 28th June 1999 in Tijuana and the 3rd of December 2006 in Bahía de los Ángeles.

[17] This is because, without any weights, coefficients would be representative of municipalities and not of the population.

$T_{i,d,m,t}$ includes our climatic variables of interest. One issue of importance is to account for non-linearity (Dell, Jones and Olken, 2014). A conservative approach consists in using temperature bins to specify the relationship between temperature and mortality (Deschenes and Greenstone, 2011). The model requires as many dummy variables in $T_{i,d,m,t}$ as temperature bins (excluding a baseline temperature bin), each one taking the value of 1 when the day's temperature falls within the range of the bin. We use 4°C temperature bins between 12°C and 32°C (e.g. 12°C-16°C, 16°C-20°C and so on) to construct the vector $T_{i,d,m,t}$. The lowest bin covers days with a temperature below 12°C, and the highest bin covers days with a temperature above 32°C. In Appendix A5, we run the model with 2°C bins. This provides very similar results.

Furthermore, $T_{i,d,m,t}$ cannot only consist of the impact of today's temperature on today's mortality. The temperatures of previous days also have an impact on mortality (e.g. because some people may catch influenza on a cold day and die a few days later) and are obviously correlated to today's temperature. Empirically, Deschenes and Moretti (2009) show that dynamic effects related to the impact of temperature on mortality can spread over 30 days and need to be accounted for. To simultaneously account for non-linearities in the temperature-mortality relationship and for dynamic effects, Deschenes and Greenstone (2011) mention the possibility of combining temperature bins with a distributed lag model. We consider 7 temperature bins and include 30 lags for each bin. In practice, this choice is rather conservative since all effects seem to fade out after 15-20 days. The expression for the distributed lag model is as follows:

$$(2) \qquad Y_{i,d,m,t} = \sum_{k=0}^{K=30} \sum_{s} \theta_{s,-k}.B_{s,i,d-k,m,t} + \sigma.P_{i,d,m,t} + \mu_{i,d,m} + \mu_{i,t} + \mu_{d,m,t} + \varepsilon_{i,d,m,t}$$

The subscript *s* stands for the various temperature bins, and $B_{s,d-k,i}$ is a dummy variable equal to one if the temperature on day (d-k) in municipality *i* falls within bin *s*. We use 24-28°C as the baseline temperature bin. Furthermore, we use on-the-day average precipitation ($P_{i,d,m,t}$) to control for the confounding effect of precipitations on mortality. Due to the lag structure of the model, the effect of a cold or hot day on mortality is the sum of all the coefficients for the contemporaneous and lagged variables representing this temperature bin. This model is computationally intensive, but our very large sample allows us to overcome the multicollinearity problems arising when many lags and temperature bins are considered simultaneously.

The fixed-effect models are estimated using the *reghdfe* command in Stata based on Guimaraes and Portugal (2010) and Gaure (2010). The command allows us to flexibly include the three sets of fixed effects mentioned previously.

III.B Main results

We now present the results obtained with the distributed lag model. Figure 2 displays the cumulative impact of temperature on 31-day mortality for the whole population and all causes of death, as estimated with our distributed lag model. We find the classic U-shaped relationship between temperatures and mortality identified in previous studies. Regarding heat, we find statistically significant impacts of the two bins above 28°C, suggesting that hot days (28-32°C) and extremely hot days (>32°C) displace death by more than one month and not only by a few days.[18] However, relatively mild days that are unusually cold in the Mexican setting also lead to extra mortality. A day with an average temperature below 12°C kills about 30 percent more than a day with an average temperature above 32°C. These results are consistent with the dynamic effects of hot and cold days on mortality as reported previously (e.g. Deschenes- and Moretti, 2009; Guo et al., 2014; Gasparrini et al., 2015). Like these authors, we find evidence of "harvesting" for hot days whereas the impact of cold days accumulates after the event (more details can be found in Appendix A6).

[FIGURE 2 ABOUT HERE]

Furthermore, we find statistically significant and strong impacts on mortality for all temperatures bins below 20°C. A day between 12°C-16°C increases mortality by 0.12 deaths per 100,000 inhabitants, while a day below 12°C increases mortality by around 0.26 deaths per 100,000 inhabitants compared with a day falling in the 24-28°C bin. Therefore, two mildly cold days between 12°C and 16°C convey nearly the same mortality impact as one unusually cold day below 12°C.

The comparison between these marginal effects needs to be considered along the fact that the average person in Mexico is exposed to 72 days at 12°C-16°C per year, but to only 17 days per year below 12°C. Table 2 combines the results presented in Figure 2 with the distribution of

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[18] Guerrero Compeán (2013) conducted a similar study on temperature and mortality in Mexico. Our results differ from Guerrero Compeán (2013) since this study finds that heat could have a stronger impact than cold on mortality. Nonetheless, the point estimates of Guerrero Compeán (2013) are imprecisely estimated (e.g. the 10-12°C bin is not statistically different from any other bin, except for the 26-28°C bin). Furthermore, Guerrero Compeán (2013) uses a specification at annual level. Specifications with annual variations recover the impact that temperatures may have on health through indirect channels, e.g. reductions in agricultural yields or income. Results are therefore not directly comparable.

hot and cold days in Mexico shown in Figure 1. Applying our estimates to the typical daily average temperature distribution in Mexico, days under 12°C cause the death of around 5,700 people each year (95 percent confidence interval is 4,548–6,863).[19] This represents 0.8 percent of the number of deaths in Mexico in 2017. However, because mild temperatures between 12°C and 20°C are much more frequent, the total number of additional deaths associated with moderately low temperatures between 12°C and 20°C is around 18,700 per year[20] (95 percent CI: 13,292–24,063), or 2.7 percent of the number of deaths in Mexico in 2017. This suggests that the total impact of mild temperatures on mortality is much larger than the impact of unusually cold days.[21] At the other end of the spectrum, unusually hot days over 28°C trigger a comparably small amount of additional deaths (around 2,300 annually, 95 percent CI: 1,465–3,150), because although the marginal impact of such days is large, extremely hot days, especially above 32°C, have been rare so far.

[TABLE 2 ABOUT HERE]

In Table 3, we look at the impact of temperature on mortality by gender, age and cause of death. This exercise is useful to identify the type of people at risk during cold spells and heat waves.

Applying our estimates to the typical daily average temperature distribution in Mexico, we find that people over 75 concentrate nearly 58 percent of deaths and are therefore particularly at risk. For example, the marginal impact of days below 12°C on mortality is 22 times higher for this group than for the whole population. However, most age groups are vulnerable to unusually cold days (<12°C), including the very young (<5 years old) and all age groups above 35. In contrast, the vulnerability to mildly cold temperatures only concerns older age groups (above 45). As to heat, extreme heat seems to have an impact on mortality that strongly increases with age, starting with people aged 35. Effects by disease type are provided in panel B of Table 3. Cold appears to have a particularly strong impact on metabolic, circulatory and respiratory diseases. These three causes of death are estimated to concentrate more than 80 percent of the deaths induced by suboptimal weather exposure.[22]

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[19] This is obtained for the 2017 population estimate of 129 million people, a death rate of about 0.26 deaths per 100,000 inhabitants for a day below 12°C compared to a day at 24-28°C and around 17 days below 12°C per year.
[20] This excludes the impact of days below 12°C.
[21] We are comparing days with an average temperature between 12°C and 20°C with days with an average temperature between 24°C and 28°C. Minimal temperatures at night can be cold (e.g. 0-10°C) for mildly cold days, whereas maximal temperatures can be high in the reference bin (depending on intra-day variations).
[22] Existing studies similarly report that people over 75 are much more vulnerable than the rest of the population. The causes of cold-related deaths in Mexico look different than in the U.S., where two-thirds of cold-related deaths have a cardiovascular origin and around 20 percent are caused by respiratory diseases, while diabetes and infectious diseases respectively account for only about 3 percent and 2 percent of cold-related deaths (Deschenes

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We provide years of life lost estimates in Appendix A7. Most years of life lost are due to cold weather effects on people over 55. Moreover, we can use our model to simulate the impact that climate change may have on mortality in Mexico. This is only a partial effect of climate change since our model only identifies short term responses to cold and hot waves within a reduced time frame. The details of this analysis are provided in Appendix A8. Because the frequency of cold and mildly cold days is expected to decrease, the number of deaths imputable to temperature reduces with the forecasted temperatures implied by climate change as compared to historical ones. Meanwhile, a much larger share of people could die because of heat. Under the very high RCP 8.5 emissions scenario, we calculate that around 70 percent of weather-induced deaths could be due to heat by 2075-2099 under climate change. Ceteris paribus (e.g. with constant population), the change in the number of hot days would increase the number of heat-related deaths per year from around 2,300 to around 15,000.

III.C Robustness

We conduct a series of robustness checks and complementary analyses in Appendix B. We look separately at minimum vs. maximum temperature (Appendix B1). We furthermore separate the dataset in different years, look at the effect on weekdays vs. weekends, and in rural vs. urban areas (Appendix B2). We also show that acclimation may play a role (Appendix B3): cold days have a stronger mortality effect in hot regions, and hot days in cold regions. However, the results are very similar when defining temperature relative to the municipality average. We also reduce the number of fixed effects (Appendix B4). We use temperature leads as a placebo test (Appendix B5), and present the results obtained with a simpler model with no lags, therefore considering only the contemporaneous relationship between temperature and mortality (Appendix B6). We include additional control variables related to precipitation, humidity and pollution (Appendix B7). Finally, we provide a brief comparison of our results with other studies in Appendix B8.

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and Moretti, 2009). Looking at the corresponding estimates for Mexico, we find that cardiovascular diseases account for 38.3 percent of deaths, followed by metabolic ones (27.4 percent, including mostly diabetes), and respiratory diseases (16.8 percent). However, a large share of the difference in the causes of weather-induced deaths between Mexico and the US is likely due to differences in the classification of diseases. Diabetes doubles the risk of cardiovascular disease and most deaths from diabetes are due to coronary artery disease. We find no statistically significant impact of cold weather on deaths from infectious diseases.

IV. The role of income in weather-related mortality

Our data allows us to explore the hypothesis that weather vulnerability is correlated with differences in income. To do so, we run our distributed lag model separately for each income quartile. Methodological details on how we construct death rates by income quartile are provided in Appendix C1. In short, since income is not directly available on death certificates, we use data from the 2000 Mexican census to estimate income levels at the moment of death based on individual characteristics provided on deaths certificates (e.g. age, gender, profession) and use predicted income to produce daily mortality rates by predicted income quartile.

The method includes two steps. First, we run a simple regression with data from the Mexican census where we predict income as a function of independent variables also present on death certificates. This includes gender, age, civil status, occupation, education level and registration with public or private healthcare. We also include municipality by rural/urban area fixed effects, to separate rural from urban areas within the same municipality, since we expect people living in the city centre to be richer than those living in nearby rural areas. The model also includes a quadratic term for age and interaction terms between age (and age squared) and occupation, to account for experience at work. Because professions are recorded with a different, non-comparable nomenclature from 2013 onwards, we performed the analysis with data from 1998 to 2012 only. The output of this estimation is presented in Appendix C1. The regression results are consistent with economic theory (higher experience or education is correlated with higher income) and the model captures a large share of the variation in revenues ($R^2=0.44$).

Second, we use the predicted income values to construct predicted income quartiles. Based on the sample of the 2000 Mexican census, we first compute the proportion of people in each municipality i whose predicted income would have fallen within income quartile κ. We then calculate the proportion of deaths in each municipality with a predicted income in each quartile κ and compute daily mortality rates by predicted income quartile for each municipality i at time t.[23]

The results of these regressions by predicted income quartile are reported in Figure 3. Impacts between quartiles are statistically different from one another.[24] Results show a strong difference

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[23] With this method, we are able to assign an income quartile to 81.6% of deaths (not all death certificates record all the sociodemographic variables we need). We finally use the mortality rates by income quartile to run separate distributed lag models for each income quartile. We augment all estimated coefficients by a factor of 1/0.816 to account for the deaths for which no income quartile could be attributed.

[24] We ran a joint regression estimating the coefficients for the 1st and 4th quartiles of income in order to determine if the coefficients for the temperature bins were statistically different between both quartiles. The p-value of the F-test is <0.01, with an F-statistic of 2.00, with 180 numerator and 2281 denominator degrees of freedom.

in vulnerability to cold at unusual and mild levels between the first two and last two quartiles. For example, an unusual cold day below 12°C conveys 0.37 deaths per 100,000 inhabitants for the first quartile of income, versus 0.20 for the last quartile. In contrast, we do not find any statistically significant difference in the impact of unusually hot days on mortality across income quartiles. This is likely to be caused by some lack of statistical power since only a minority of weather-related deaths are associated with excessive heat.

[FIGURE 3 ABOUT HERE]

The results of Figure 3 could be driven by differences in baseline mortality rates across quartiles. In Table 4, panel A, we normalize the mortality estimates by quartile and express them as a proportion of the average daily mortality rate of each income quartile. After normalization, vulnerability to cold temperatures is still clearly higher for the 1st quartile of income, especially for mildly cold days (12-20°C). We also report the magnitude of the impacts in number of annual deaths by income quartile based on the typical daily average temperature distribution in Mexico of Figure 1. Cold and mildly cold days (below the reference bin of 24-28°C) lead to more than twice as many deaths in the first two quartiles of predicted income compared to the 3rd and 4th quartiles.[25]

Panels B to D of Table 4 provide a series of robustness checks confirming these findings. Firstly, when running separate regressions by income quartile, demographics are likely to play a role in explaining the differences in vulnerability across income groups. We have shown previously that the elderly constitutes by far the most vulnerable group. However, people in the lowest quartiles of income are older on average because access to pensions is insufficient. In addition, poor families tend to have more children and young people tend to be poorer. The young and the very old are thus overrepresented in the lowest quartiles. To account for this, age-corrected results are provided in Table 4, Panel B (the methodology is presented in Appendix C1). Correcting for age does not affect our conclusion: the first two quartiles of income are about 35% more vulnerable to mildly cold days compared to the last two quartiles. The difference between quartiles is statistically significant.[26] Therefore, a sizeable difference in vulnerability levels correlates with differences in living conditions and social protection.

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[25] The total number of deaths (for all quartiles) estimated in Table 4 is slightly different from the one reported in Table 2. This is because the estimates of Table 4 are based on the results of the regressions reported in Figure 3, while the estimates of Table 2 are based on our baseline regression (Figure 2). However, differences are small: there are 26.324 deaths in Table 2 and 27,355 in Table 4, panel A.

[26] An F-test between the 1st and 4th quartile of income suggests that the coefficients for the temperature bins are statistically different at 1 percent.

[TABLE 4 ABOUT HERE]

Because we use income declarations from the 2000 Census, results could be sensitive to the fact that respondents may misreport their income. In Table 4, Panels C, we make sure that our findings by quartiles of predicted income are robust to using a different measure of living conditions. We use a poverty index instead of predicted income. The Mexican Council of Population (CONAPO) defines a marginality index based on a set of questions asked to Mexican households in the 2000 census. The answers to this set of questions are less easy to manipulate by respondents. We define and predict a poverty index for each deceased person in a way that is very similar to the CONAPO and construct quartiles based on this alternative metric. The methodology is detailed in Appendix C1 but results are summarized in Table 4, Panel C. They corroborate the findings obtained with predicted income levels. Table 4, Panel D also provides age-corrected results using the poverty index to define quartiles and similarly shows that the most deprived groups are more vulnerable to unusual weather.

Finally, we run the quartile-specific econometric models for separate causes of death.[27] Results by cause of death are reported in Appendix C2 and corroborate that low-income households are more vulnerable to cardiovascular and respiratory diseases.

The policy implications of these results are substantial. They suggest that the poor are not only much more vulnerable to unusually cold temperatures, they are also more vulnerable to temperatures that are less likely to affect richer households. This definitely puts poor households at risk, since mildly cold days are relatively frequent. Furthermore, the results obtained for respiratory diseases may have implications for the COVID-19 pandemic: low-income households appear at a much higher risk against respiratory diseases.

These results by income group are not surprising considering that low-income families have insufficient access to quality housing, drinking water and health insurance (as reported in the Census data – see Appendix A3). While access to electricity is widespread, it is rarely used for heating. According to the 2018 Mexican National Survey of Energy Use in Residential Housing, only 6.3% of housing units are equipped with some form of heating equipment.

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[27] We have also tried to run the model for different age groups. Unfortunately, running the model by age group significantly reduces model efficiency and results are inconclusive. The reader may note that breakdowns by cause of death and income group are not always very efficient.

V. Weather-related mortality and universal healthcare

The analysis of sections III and IV shows strong vulnerability of low-income groups to cold weather. An important question is whether public policies can substantially reduce this vulnerability. During our study period, Mexico implemented a nationwide policy – the *Seguro Popular* – to increase access to healthcare for low-income households.[28] Considering that financial constraints may prevent developing countries from protecting their citizens against the consequences of cold and heat, targeted health programs may offer the possibility to restrict the population of recipients to vulnerable groups. They can also restrict the range of diseases covered to those that are known to arise because of cold weather. Below, we provide evidence that the *Seguro Popular* has reduced weather-related mortality.

In Mexico, the two major providers of health insurance, the Mexican Social Security Institute (IMSS) and the Institute for Social Security and Services for State Workers (ISSSTE), are directly linked to employment. Before the *Seguro Popular*, this meant that a large share of the population (around 60%) was not covered by these institutions or any other health insurance provider.

The *Seguro Popular* was initially launched as a pilot exercise (2001-2003) to increase universal healthcare. Access to the *Seguro Popular* was open to all. In practice, it focused on people who were not eligible to employment-based health insurance, i.e. low-income households working in the informal sector. Enrolment was free in most cases even though a fee could be due from families above a certain level of income. This fee then grew in proportion to income. Another feature of the *Seguro Popular* is that health coverage was restricted to a reduced list of priority diseases. This list mostly included preventive health actions (e.g. vaccines), ambulatory medicine (e.g. measles, tuberculosis), reproductive health, selected emergencies (in particular caused by hypertension and diabetes) and surgeries (e.g. appendectomy, treatment of fractures). A wide spectrum of covered diseases were weather-sensitive, especially respiratory pathologies. In contrast, a long list of varied pathologies and treatments still remained excluded from the program, or were only covered for children and teenagers. To give a few examples, many types of cancers, diseases such as chronic kidney insufficiency, access to blood and

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[28] Formerly, low-income families working in the informal sector did not have access to healthcare insurance, and the country still suffers from chronic under-financing of free public hospitals. Mexico is the OECD country with the lowest budget dedicated to health: in 2015, current expenditure per capita in purchasing power parity was $1,052, compared to $3,814 on average in other OECD countries, and $9,451 in the US (see OECD Health Statistics 2016).

homoderivatives, or organ transplants were not covered by the *Seguro Popular*. The treatment of leukemias was only offered to minors.

By 2004, the Mexican government decided to progressively extend the program to the entire population, municipality after municipality. In 2004, the Mexican government also promoted the *Fondo de Protección contra Gastos Catastróficos*, which provides financial support to families affected by chronic, long-term diseases, in particular cancer and HIV.[29] The *Fondo de Protección contra Gastos Catastróficos* is still ongoing, while the *Seguro Popular* has been replaced since 1st January 2020 with a new program called *Instituto para la Salud y el Bienestar* (Insabi).

In 2004, the extension of the *Seguro Popular* to the whole Mexican population required either integrating the existing medical infrastructure into the scheme or building new infrastructure. The INEGI reports the number of people that received medical attention under the *Seguro Popular* by municipality and year.[30] At its start in 2004, the *Seguro Popular* provided around 315,000 external consultations. This figure radically increased to 11 million in 2005, 61 million in 2010 and up to near-full coverage of Mexican municipalities from 2012 onwards.

The evidence so far suggests that there have been clear benefits of the rollout of the *Seguro Popular*. King et al. (2009) and Avila-Burgos et al. (2013) find that out-of-pocket health expenditure and catastrophic health expenditure reduced for the beneficiaries of the program. Sosa-Rubi, Galárraga and Harris (2009) also find that pregnant women strongly preferred being attended in units sponsored by the *Seguro Popular* rather than paying out of pocket for attendance in private centres.

However, the *Seguro Popular* was also criticized for being insufficiently funded (Lakin, 2010). There may also have been a perverse effect of the policy on the job market, since access to universal healthcare has been found to reduce employment in the formal sector (Aterido, Hallward-Driemeier and Pagés, 2011; Bosch and Campos-Vazquez, 2014).

The overall health impacts of the program are difficult to assess. The study by King et al. (2009) finds no discernible effect of the *Seguro Popular* on health outcomes after 10 months of

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[29] Furthermore, additional protection has been provided to children under 5 born after 1 December 2006 with the implementation of a policy called the *Seguro Médico para una Nueva Generación*.

[30] The implementation of the *Fondo de Protección contra Gastos Catastróficos* was done through specialized institutions that required accreditation. The rollout of the program was therefore very similar to that of the *Seguro Popular*. We make the simplifying assumption that the municipalities who benefitted from the *Seguro Popular* also benefitted from the *Fondo de Protección contra Gastos Catastróficos* since we unfortunately do not have this exact piece of information.

implementation, possibly because health effects could require more time to materialize. In contrast, other studies have identified health benefits. Knox (2008) find effects of the program on the utilization of healthcare services. Parker, Saenz and Wong (2018) find similar effects of higher healthcare utilization among the elderly. Likewise, Servan-Mori (2015) found that access to prescribed medicine was higher among the beneficiaries of the program. For infant mortality, Pfutze (2014, 2015) provides evidence of a possible reduction in miscarriages and infant mortality from the implementation of the *Seguro Popular*.

Cohen (2020) provides the preliminary results of a staggered difference-in-difference model to assess the impact of the *Seguro Popular* on all-cause mortality. While some of the assumptions underlying this analysis (such as the stable unit value treatment assumption) may not be fully valid, it suggests that the policy led to a reduction in all-cause mortality after 2 years of implementation, of around 7.4 percent on average during the 3rd and 4th years of implementation. We reproduce the relevant figure from Cohen (2020) in Appendix D1. In the rest of this section, we focus on the impact of the *Seguro Popular* on weather-related mortality, as temperature provide an exogenous source of variation enabling us to recover the causal effects of the policy.

V.A Method

We aim to assess if the rollout of the *Seguro Popular* led to a reduction in weather-related vulnerability. We focus the analysis on the population that was targeted by the *Seguro Popular*: people without health insurance suffering from the diseases covered by the *Seguro Popular*. We define a monthly mortality rate for the people eligible to the *Seguro Popular*, i.e. those without a traditional health insurance and dying from the diseases covered by the *Seguro Popular*.[31] We construct this mortality rate with the information present on the death certificates, since death certificates report the cause of death and whether the deceased was affiliated to an insurance scheme. People without a standard health insurance are those that report having either no health insurance, the *Seguro Popular* or a scheme called *IMSS Oportunidades* (destined to vulnerable, low-income households beneficiaries of *Oportunidades*) as a health insurance. To construct mortality rates, we use population estimates

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[31] We identify these diseases with the 2016 nomenclature of covered diseases for the *Seguro Popular*, the *Fondo de Protección contra Gastos Catastróficos* and the *Seguro Médico Siglo XXI*, the scheme that complements the *Seguro Popular* for children (Comisión Nacional de Protección en Salud. 2016). The list of covered diseases had been stable after 2010, with only a few additions/subtractions.

that account for the share of people with no affiliation to a standard health insurance in each municipality.[32]

We then use an econometric method similar to Barreca *et al.* (2016). These authors look at the impact of air conditioning, electricity access and healthcare on weather vulnerability by interacting temperature bins with key variables of interest, e.g. the number of doctors per capita. We similarly interact temperature bins with the availability of *Seguro Popular*.

An important feature of an interacted model is that it controls for the impact of the *Seguro Popular* on all-cause mortality and only focuses on the impact of the *Seguro Popular* on weather-related vulnerability. This is statistically more robust than looking at the impact of the *Seguro Popular* on all-cause mortality because fluctuations in weather provide an exogenous source of variation to assess the effect of the *Seguro Popular* on mortality when comparing the municipalities that adopted the policy with those that have not adopted it yet.

To assess the impact of the *Seguro Popular* on weather vulnerability, we create a dummy variable that takes the value of 1 if the *Seguro Popular* is available in municipality i in month m and year t, and 0 otherwise. We obtain this information directly from the mortality data: we assume that the *Seguro Popular* is available in municipality i as soon as we record one death from someone covered by the *Seguro Popular* in municipality i.[33] Based on this definition, we observe that the *Seguro Popular* spread very rapidly, with 48 percent of the population having some access to it in 2004, 76 percent in 2005 and 89 percent in 2006. We include this variable in the model and interact it with our temperature bins (below 12°C; 12-16°C; 16-20°C; 20-24°C; 24-28°C (reference bin); 28-32°C; and above 32°C) to look at the impact of the *Seguro Popular* on weather-related mortality.[34]

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[32] The estimates of the general population without health insurance come from the INEGI censuses of population and housing. The information is provided for years 2000, 2005 and 2010. We use a linear extrapolation to estimate the relevant population between two censuses and beyond 2010. For the estimates of the population without health insurance by age group, we estimate the share of population without health insurance by age group using the 2000 census. We then multiply this share by our overall population estimates by municipality and year.

[33] This identifies very precisely the introduction of the *Seguro Popular* in large municipalities, since there are enough deaths per month to ensure that the introduction of the policy coincides with a death from someone receiving the policy. In small municipalities, there may be measurement error since several months could pass between the introduction of the policy and the first death of someone affiliated with the *Seguro Popular*. We check whether this has an impact on the results in the Table D4 of Appendix D2: we simply re-run the model after excluding all municipalities with less than 10,000 inhabitants. Results are very similar.

[34] We are only interested in the interaction terms since the *Seguro Popular* variable in simply provides information on the difference in mortality levels between treated and non-treated observations. We consider it to be exogenous: the exact timing of the policy, e.g. in February versus March, is deemed exogenous after accounting for the municipality by year fixed effects. Furthermore, in Table D3 of Appendix D2, we use a variable that takes the value of 1 in municipality i and year t if, during this year or the previous years, someone has died in this municipality while being covered by the *Seguro Popular*. The variable is then absorbed by the fixed effect, while

We introduce two types of additional interaction variables. The first one is a full set of interaction parameters between the temperature bins and municipality-by-month fixed effects. These parameters allow us to control for differences in weather vulnerability across municipalities and seasons. We also include interactions between each temperature bin and month-by-year fixed effects. This set of interactions controls for the autonomous evolution of weather vulnerability in Mexican municipalities that is unrelated to the deployment of the *Seguro Popular*.

With so many additional control variables, the model with daily data becomes unsolvable. This is because we would need to have municipality interaction terms for each of the 6 x 30 bin-specific lags. We circumvent this problem by aggregating the data at monthly level. Our temperature bins are redefined as "the number of days falling within a given bin during month *m*, year *t* and for municipality *i*". With the data aggregated at monthly level, the number of temperature-bin-by-municipality interactions becomes manageable. Furthermore, the sample size is divided by 30.

A drawback with a dataset aggregated at monthly level is that we can no longer include municipality-by-calendar-day fixed effects. Alternatively, we include three sets of overlapping fixed effects: municipality-by-year fixed effects, municipality-by-month fixed effects, and month-by-year fixed effects. This allows the monthly model to be as close as possible to the original daily specification. The results for a monthly model without the interactions with the *Seguro Popular* (corresponding to the baseline results presented in Section 3) are reported in Appendix A.4 and are very close to our general results of Figure 2 for the impact of weather on mortality.

V.B Results

In Table 5, we present our estimates for the effect of the *Seguro Popular* on weather vulnerability. In all columns, the sample is composed of people eligible to the *Seguro Popular* because (i) they do not have any standard health insurance such as the IMSS and ISSSTE and (ii) they died from a pathology covered by the *Seguro Popular*. Columns (1) to (4) are for the whole population; columns (5) and (6) focuses on people aged 55 and over who are significantly more at risk of dying following weather shocks, as shown in Table 3. Columns (1) to (3) and column (5) focus on weather-sensitive death causes (excluding infectious and parasitic diseases,

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we can still assess the impact of the interaction terms. Results lose precision but are however similar to our baseline results.

neoplasms, and accidental and violent deaths, which we have found to be only weakly correlated with cold weather – see Table 3) whereas columns (4) and (6) include all causes of death.

The results in Table 5 show a clear reduction in mortality for the 12-16°C bin as well as a likely reduction in mortality for the 16-20°C bin, particularly for people over 55 years old. This result is consistent with the results by income quartile of section IV, which show that the lower sensitivity of higher-income households to temperature shocks is highest for mildly cold days.[35] When applying the baseline estimates from column (1) to the historical distribution of temperatures in Mexico, we can derive that the statistically significant reduction in mortality from the 12-16°C bin implies that the *Seguro Popular* saved around 1,600 lives (95% confidence interval is 334 – 2,850) every year since 2004.[36]

[TABLE 5 ABOUT HERE]

This result is robust to variations in the interaction parameters between the temperature bins and the fixed effects. When using less of these interaction parameters (columns 2 and 3), point estimates remain almost identical while confidence intervals reduce. The 16-20°C becomes statistically significant at 10 percent. The estimates for this bin would correspond to an additional 1,350 lives saved every year.[37]

Furthermore, our baseline model (columns 1-3) excluded infectious and parasitic diseases, neoplasms and violent and accidental deaths. These are included in column (4). Point estimates are very similar, but precision decreases slightly. In columns (5) and (6), we show that the *Seguro Popular* had the strongest impact on the weather-related mortality of people over 55. Additional results for all-cause mortality and detailed results by age group, death cause and income quartiles are presented in Appendix D2.

So far, we used specifications that focus on the population that was eligible to the *Seguro Popular* (those without any other health insurance and dying from diseases covered by the scheme), who could undoubtedly benefit from the policy. However, the *Seguro Popular* may

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[35] In Appendix D2, we provide additional evidence that the impact of the *Seguro Popular* is stronger in poorer municipalities (see Tables D5 and D6).

[36] This is using the coefficient for the interaction between the *Seguro Popular* and the 12-16°C temperature bin (-0.035 per 100,000 inhabitants) and applying it to the typical distribution of days at 12-16°C in Mexico (an average of 72.6 per year). Furthermore, in the estimation sample, 92% of the population had access to the *Seguro Popular* between 2004 and 2017. The figure is also for a total population of 129 million people, of which 60% would have no access to any other health insurance: 0.031 / 100,000 x 72.6 x 129,000,000 x 0.92 x 0.60 ≈ 1,600.

[37] This is using the same formula as above, with the coefficient for the interaction between the *Seguro Popular* and the 16-20°C temperature bin (-0.020 per 100,000 inhabitants) and applying it to the typical distribution of days at 16-20°C in Mexico (an average of 112.5 per year): 0.017 / 100,000 x 112.5 x 129,000,000 x 0.92 x 0.60 ≈ 1,350.

have had spill-over effects on other groups. In Table 6, column (1), we focus on people without any other health insurance, whether or not their cause of death was covered by the *Seguro Popular* (all results in Table 6 focus on weather-sensitive death causes). They could have benefited from the policy for pathologies which did not lead to death. Marginal effects for mildly cold days increase substantially, particularly for the 16-20°C bin which becomes statistically significant at 5 percent. They suggest that the policy might have had positive health effects on people without health insurance that died from non-covered diseases. We look at this group separately in Table 6, column (2): impacts are negative and statistically significant at 10 percent for the 16-20°C bin, suggesting the existence of spillovers to non-covered diseases, even if the bulk of the effects are concentrated on covered diseases.

Similarly, the *Seguro Popular* could have had an impact on the health of those who already had a health insurance, for example by reducing the prevalence of transmissible diseases. In Table 6, columns (3) to (5), we look at the population that already had health insurance and check for potential spill-over effects on this group of the population. Column (3) includes all diseases while columns (4) and (5) respectively focus on pathologies covered (col. 4) and not covered (col. 5) by the *Seguro Popular*. Coefficients are mostly insignificant, suggesting that the policy mainly had an effect on people without a traditional health insurance. An exception is days below 12°C for people with a health insurance and dying from diseases covered by the *Seguro Popular* (column 4). This effect could be explained if the policy had reduced the diffusion of contagious diseases covered by the *Seguro Popular*, which would positively impact the health of those with a health insurance.

Finally, we provide estimates for the entire population in column (6). This is the combination of groups in columns (1) and (3). While impacts for cold days remain negative, they unsurprisingly lose statistical significance as we found no statistically significant effect for the people with a health insurance in column (3).

We conclude from Table 6 that our main specification focusing on people without health insurance and covered diseases is likely to provide a lower bound of the impact of the *Seguro Popular* on death through temperature shocks, as we report suggestive evidence that other groups could have also benefited from the policy due to spill-over effects.

[TABLE 6 ABOUT HERE]

VI. Conclusion

Because investments in protective measures are determined by income, climate change is generally predicted to have the greatest effect on the poorest people in developing countries. This study analyzes the heterogeneous impact of temperature shocks on mortality across income groups in Mexico using individual death records and census data for the period 1998-2017. When applying our econometric estimates to the historical distribution of temperatures in Mexico, we find that random variation in temperatures is responsible for the death of around 26,000 people every year in Mexico, representing 3.8 percent of annual deaths in the country. However, extreme weather events only account for a small proportion of weather-related deaths: unusually cold days (<12°C average temperature) trigger around 5,700 deaths each year, extremely hot days (>32°C) kill around 500 annually, while 71 percent of weather-related deaths are induced by mildly cold days (average temperature between 12°C and 20°C).

A consequence of our findings is that climate change should significantly reduce the number of weather-related deaths in Mexico (by at least 20 percent) by the end of the 21st century, even in the absence of any adaptation. This illustrates the vast heterogeneity in climate change impacts across countries and regions, even though the reader should be aware that only the short-term impact of weather shocks is considered in this paper. Longer-term impacts of climate change on human health through reductions in agricultural output or financial losses are not captured by our econometric specifications based on daily information.

We find that vulnerability to weather shocks is strongly correlated with individual income. The impact of suboptimal temperature exposure is much greater for those living below the median average income. This suggests that not only are poorer households more vulnerable to unusual cold, but they are also more vulnerable at relatively mild temperatures. Therefore, protecting low-income households from cold all year round should be effective in reducing the life expectancy gap between and within countries.

Under these circumstances, there is a role for public policies to reduce the mortality inequalities caused by weather. Healthcare systems can be used to reduce the mortality of vulnerable groups while targeting diseases that are known to respond to weather shocks. We exploit variation in universal healthcare coverage caused by the deployment of the *Seguro Popular* to assess its contribution to reducing weather vulnerability. Applying the historical distribution of temperature in Mexico to our estimates, we find that the scheme saved around 1,600 lives per year since 2004 from exposure to mildly cold temperature (12°-16°C). This represents – a 6.6 percent reduction in weather vulnerability from days below 20°C. This effect is a clear lower

bound: we also find evidence of an effect at other temperature levels, particularly for people aged 55 and over, as well as suggestive evidence of spillover effects on non-covered diseases and already insured patients.

The overall welfare implications of weather vulnerability in low- and middle-income countries are very large: in the sole case of Mexico, we estimate that 26,000 deaths each year are triggered by temperatures from which people in low-income households are inadequately protected. We show that access to universal healthcare can successfully reduce this high vulnerability, but more research is required to assess which protection measures are capable of reducing cold-related vulnerability in the most cost-effective manner.

Conflict of interest

The authors declare having no conflict of interest or financial interest related to the content of this research.

References

Aterido, Reyes, Mary Hallward-Driemeier, and Carmen Pagés. *Does Expanding Health Insurance Beyond Formal-Sector Workers Encourage Informality?: Measuring the Impact of Mexico's Seguro Popular*. The World Bank, 2011.

Ávila-Burgos, Leticia, et al. "Efectos del Seguro Popular sobre el gasto en salud en hogares mexicanos a diez años de su implementación." *Salud pública de méxico* 55 (2013): S91-S99.

Barnett, A. G., Hajat, S., Gasparrini, A., & Rocklöv, J. (2012). Cold and heat waves in the United States. *Environmental research*, *112*, 218-224.

Barreca, Alan, 2012. "Climate change, humidity, and mortality in the United States," *Journal of Environmental Economics and Management*, Vol. 63, Issue 1, Pages 19–34.

Barreca, Alan; Karen Clay; Olivier Deschenes; Michael Greenstone and Joseph S. Shapiro, 2016. "Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century," *Journal of Political Economy*, Vol. 124, Issue 1, Pages 105–159.

Barros, R., 2008. "Wealthier but not much healthier: effects of a health insurance program for the poor in Mexico". Unpublished working paper.

Basu, Rupa. "High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008." *Environmental health* 8.1 (2009): 40.

Bosch, Mariano, and Raymundo M. Campos-Vazquez. "The trade-offs of welfare policies in labor markets with informal jobs: The case of the" Seguro Popular" program in Mexico." *American Economic Journal: Economic Policy* 6.4 (2014): 71-99.

Braga, Alfésio Luís Ferreira; Antonella Zanobetti and Joel Schwartz, 2001. "*The time course of weather-related deaths*," *Epidemiology*, Vol. 12, Issue 6, Pages 662–667.

Burgess, Robin; Olivier Deschenes; Dave Donaldson and Michael Greenstone, 2017. "Weather, Climate Change and Death in India," unpublished working paper.

Carleton, Tamma A., et al. *Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits*. No. w27599. National Bureau of Economic Research, 2020.

Cohen, Francois (2020) The Impacts of Universal Healthcare Extension in Mexico. Unpublished working paper.

Comisión Nacional de Protección en Salud. 2016. *Catálogo Universal de Servicios de Salud: CAUSES 2016*.

Coordinación General del Servicio Meteorológico Nacional de la Comisión Nacional del Agua *(CONAGUA)*. 2018. *Base de datos climatológica nacional de Mexico: datos diarios*. Data accessed after requesting it from the CONAGUA and downloaded on 14th December 2018.

Curriero, F.C.; K.S. Heiner; J.M. Samet; S.L. Zeger; L. Strug and J.A. Patz, 2002. "Temperature and mortality in 11 cities of the Eastern United States," *American Journal of Epidemiology*, Vol. 155, Pages 80–87.

Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, Vol. 4, Issue 3, Pages 66–95.

Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, Vol. 52, Issue 3, Pages 740–98.

Deschênes, Olivier and Enrico Moretti, 2009. "Extreme Weather Event, Mortality and Migration," *The Review of Economics and Statistics*, Vol. 41, Issue 4, Pages 659–681.

Deschenes, Olivier and Michael Greenstone, 2011. "Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US," A*merican Economic Journal: Applied Economics,* Vol. 3, Pages 152–185.

Deschenes, Olivier, 2014. "Temperature, human health, and adaptation: A review of the empirical literature," *Energy Economics*, Vol. 46, Pages 606–619.

Dirección de Monitoreo Atmosférico. 1998-2017. Índice de Calidad del Aire. http://www.aire.cdmx.gob.mx/default.php?opc=%27aqBjnmU=%27 (last accessed on 2nd January 2021).

Dupas, P., & Miguel, E. (2017). Impacts and determinants of health levels in low-income countries. In *Handbook of economic field experiments* (Vol. 2, pp. 3-93). North-Holland.

El-Zein, A.; M. Tewtel-Salem and G. Nehme, 2004. "A time-series analysis of mortality and air temperature in Greater Beirut," *Science of the Total Environment*, Vol. 330, Pages 71–80.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., ... & Leone, M. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet*, *386*(9991), 369-375.

Gasparrini, A., Guo, Y., Sera, F., Vicedo-Cabrera, A. M., Huber, V., Tong, S., ... & Ortega, N. V. (2017). Projections of temperature-related excess mortality under climate change scenarios. *The Lancet Planetary Health*, *1*(9), e360-e367.

Gaure, Simen. "OLS with Multiple High Dimensional Category Dummies". Memorandum 14/2010, Oslo University, Department of Economics, 2010.

Gouveia, Nelson; Shakoor Hajat and Ben Armstrong, 2003. "Socioeconomic differentials in the temperature–mortality relationship in São Paulo, Brazil," *International Journal of Epidemiology*, Volume 32, Issue 3, Pages 390–397.

Graff-Zivin, Joshua and Matthew J. Neidell, 2010. "Temperature and the Allocation of Time: Implications for Climate Change," *National Bureau of Economic Research*, Working Paper No. 15717.

Guerrero Compeán, Roberto. "The death effect of severe climate variability." *Procedia Economics and Finance* 5 (2013): 182-191.

Guimaraes, Paulo and Pedro Portugal. "A Simple Feasible Alternative Procedure to Estimate Models with High-Dimensional Fixed Effects". Stata Journal, 10(4), 628-649, 2010.

Guo, Y., Gasparrini, A., Armstrong, B., Li, S., Tawatsupa, B., Tobias, A., ... & Tong, S. (2014). Global variation in the effects of ambient temperature on mortality: a systematic evaluation. *Epidemiology (Cambridge, Mass.)*, *25*(6), 781.

Hajat, S., & Gasparrini, A. (2016). The excess winter deaths measure: why its use is misleading for public health understanding of cold-related health impacts. *Epidemiology (Cambridge, Mass.)*, *27*(4), 486.

Hajat, S.; R.S. Kovats and K. Lachowycz, 2007. "Heat-related and cold-related deaths in England and Wales: who is at risk?" *Occupational and Environmental Medicine*, Vol. 64, Pages 93–100.

Hajat, Shakoor; Ben Armstrong; Michela Baccini; Annibale Biggeri; Luigi Bisanti; Antonio Russo; Anna Paldy; Bettina Menne and Tom Kosatsky, 2006. "Impact of high temperatures on mortality," *Epidemiology*, Vol. 17, Issue 6, Pages 632–638.

Hajat, Shakoor; Ben Armstrong; Nelson Gouveia and Paul Wilkinson, 2005. "Mortality displacement of heat-related deaths," *Epidemiology*, Vol. 16, Issue 5, Pages 613–620.

Harris, J. E., & Sosa-Rubi, S. G., 2009. "Impact of "Seguro Popular" on Prenatal Visits in Mexico, 2002-2005: Latent Class Model of Count Data with a Discrete Endogenous Variable," Workip paper No. 14995. National Bureau of Economic Research.

Heutel, Garth; Nolan H. Miller and David Molitor, 2017. "Adaptation and the Mortality Effects of Temperature Across U.S. Climate Regions," NBER Working Paper No. 23271.

INEGI (Instituto Nacional de Estadística y Geografía). 1990-2017. *Microdatos de mortalidad: defunciones registradas (mortalidad general)*. Available at https://www.inegi.org.mx/programas/mortalidad/default.html#Datos_abiertos (last accessed on 2nd February 2020).

INEGI. 1990, 1995, 2000, 2005 and 2010. Censos de Población y Vivienda. Conjunto de datos: Población total (con información hasta localidad). Data available on INEGI website (www.inegi.org.mx) and last accessed on 2nd January 2021.

INEGI. 2000. Censo de Población y vivienda 2000: Microdatos de la muestra (cuestionario ampliado) de las 32 entidades federativas de México. https://www.inegi.org.mx/programas/ccpv/2000/#Microdatos (last accessed 2nd January 2021).

INEGI, 2008. *Mexico y sus municipios*.

INEGI. 2008b. Conjunto de datos vectoriales escala 1:1 000 000. Unidades climáticas. https://www.inegi.org.mx/contenido/productos/prod_serv/contenidos/espanol/bvinegi/product os/geografia/tematicas/CLIMAS/702825267568_s.zip (last accessed 2nd January 2021).

INEGI. 2010. Marco geoestadístico 2010 versión 5.0 (Censo de Población y Vivienda 2010). https://www.inegi.org.mx/contenido/productos/prod_serv/contenidos/espanol/bvinegi/product os/geografia/marc_geo/702825292805_s.zip (last accessed 2nd January 2021).

INEGI. 2020. *Catálogo Único de Claves de Áreas Geoestadísticas Estatales, Municipales y Localidades*. *Marco Geoestadístico National de México*. Fecha de corte de la información: Octubre de 2010. https://www.inegi.org.mx/app/ageeml/ (last accessed 2nd January 2021).

Kahn, Matthew E. "The climate change adaptation literature." *Review of Environmental Economics and Policy* 10.1 (2016): 166-178.

King, G. and others, 2009. "Public policy for the poor? A randomised assessment of the Mexican universal health insurance programme, " *The lancet*, Volume 373, Issue 9673, Pages 1447-1454.

Knox, Melissa. "Health insurance for all: an evaluation of Mexico's Seguro popular program." *Unpublished manuscript, Department of Economics, University of California Berkley* (2008).

Lakin, Jason M. "The end of insurance? Mexico's Seguro Popular, 2001–2007." *Journal of Health Politics, Policy and Law* 35.3 (2010): 313-352.

Lipsitch, Marc, and Cécile Viboud. "Influenza seasonality: lifting the fog." *Proceedings of the National Academy of Sciences* 106.10 (2009): 3645-3646.

Lowen, Anice C., and John Steel. "Roles of humidity and temperature in shaping influenza seasonality." *Journal of virology* 88.14 (2014): 7692-7695.

Ma, W., Chen, R., & Kan, H. (2014). Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. *Environmental research*, *134*, 127-133.

McMichael A.J.; P. Wilkinson; R.S. Kovats; S. Pattenden; S. Hajat, B. Armstrong, N. Vajanapoom, E.M. Niciu, H. Mahomed; C. Kingkeow *et al.*, 2008. "International study of temperature, heat and urban mortality: the 'ISOTHURM' project," International Journal of Epidemiology 2008, Vol. 37, Pages 1121–1131.

Parker, Susan W., Joseph Saenz, and Rebeca Wong. "Health insurance and the aging: Evidence from the Seguro Popular program in Mexico." *Demography* 55.1 (2018): 361-386.

Pfutze, Tobias. "Does access to health insurance reduce the risk of miscarriages? Evidence from Mexico's Seguro popular." *Latin American Economic Review* 24.1 (2015): 8.

Pfutze, Tobias. "The effects of Mexico's Seguro Popular health insurance on infant mortality: An estimation with selection on the outcome variable." *World Development* 59 (2014): 475-486.

Prel (du), Jean-Baptist, et al. "Are meteorological parameters associated with acute respiratory tract infections?." *Clinical infectious diseases* 49.6 (2009): 861-868.

Secretaría General del Consejo Nacional de Población – CONAPO, 2010. "Principales causas de mortalidad en México: 1980-2007," Working paper for the 43rd period of sessions of the *Comisión de Población y Desarrollo "Salud, morbilidad, mortalidad y desarrollo"*.

Servan-Mori, Edson, et al. "Access to medicines by Seguro popular beneficiaries: pending tasks towards universal health coverage." *PloS one* 10.9 (2015): e0136823.

Shaman, Jeffrey, and Alicia Karspeck. "Forecasting seasonal outbreaks of influenza." *Proceedings of the National Academy of Sciences* 109.50 (2012): 20425-20430.

Shaman, Jeffrey, and Melvin Kohn. "Absolute humidity modulates influenza survival, transmission, and seasonality." *Proceedings of the National Academy of Sciences* 106.9 (2009): 3243-3248.

Sosa-Rubi, S. G., Galárraga, O., & Harris, J. E., 2009. "Heterogeneous impact of the "Seguro Popular" program on the utilization of obstetrical services in Mexico, 2001–2006: a

multinomial probit model with a discrete endogenous variable," *Journal of health economics*, Volume 28, Issue 1, Pages 20-34.

Sosa-Rubi, Sandra G., Omar Galárraga, and Jeffrey E. Harris. "Heterogeneous impact of the "Seguro Popular" program on the utilization of obstetrical services in Mexico, 2001–2006: A multinomial probit model with a discrete endogenous variable." *Journal of health economics* 28.1 (2009): 20-34.

Tamerius, James D., et al. "Environmental predictors of seasonal influenza epidemics across temperate and tropical climates." *PLoS Pathog* 9.3 (2013): e1003194.

Tamerius, James, et al. "Global influenza seasonality: reconciling patterns across temperate and tropical regions." *Environmental health perspectives* 119.4 (2011): 439-445.

Universidad Nacional Autónoma de México. Centro de Ciencias de la Atmósfera. Unidad de Informática para las Ciencias Atmosféricas y Ambientales, 2014. Modelo GFDL-CM3, resolución espacial de 30'' por 30''. Horizonte 2075-2099. Temperatura promedio para RCP 4.5 y temperaturas mínimas y máximas para RCP 8.5. Last downloaded on 6th March 2021: RCP 4.5, average temperature (http://ri.atmosfera.unam.mx:8550/geonetwork/srv/eng/catalog.search#/metadata/b57acb62-785e-4a62-8ee4-fd4578ab27e5), RCP 8.5, minimum temperature (http://ri.atmosfera.unam.mx:8550/geonetwork/srv/eng/catalog.search#/metadata/55e45dd2-12dc-4af7-9361-55b4ee592f09), RCP 8.5, maximum temperature (http://ri.atmosfera.unam.mx:8550/geonetwork/srv/eng/catalog.search#/metadata/acb5564f-416b-4670-9067-0ab31b82a2a2).

WHO. 2010. Mexico Life Table 2010. Global Health Observatory data repository: expectation of life at age x by age group in 2010. https://apps.who.int/gho/data/view.main.61060 (last accessed 19th March 2021).

World Meteorological Organization, 2011. *Guide to Climatological Practices*. WMO-No. 100.

Yang, J., Yin, P., Zhou, M., Ou, C. Q., Guo, Y., Gasparrini, A., ... & Luan, G. (2015). Cardiovascular mortality risk attributable to ambient temperature in China. *Heart*, *101*(24), 1966-1972.

Tables and figures

Table 1: Summary of death statistics

Group	Average pop. per mun.	Average daily municipal mortality rate (deaths per 100,000 inhabitants)			
		All causes	Respir. diseases	Circul. Diseases	Metab. Diseases
Total	44,418	1.36	0.117	0.323	0.221
			(8.6)	(23.8)	(16.3)
Men	21,696	1.54	0.13	0.337	0.215
			(8.4)	(21.9)	(14)
Women	22,722	1.18	0.104	0.309	0.227
			(8.8)	(26.2)	(19.2)
Aged 0-4	4,317	0.96	0.097	0.014	0.03
			(10.1)	(1.5)	(3.2)
Aged 5-9	4,533	0.07	0.005	0.002	0.003
			(6.1)	(3.3)	(4.1)
Aged 10-19	8,861	0.15	0.005	0.007	0.004
			(3.3)	(4.4)	(2.6)
Aged 20-34	10,830	0.39	0.012	0.025	0.015
			(3.2)	(6.5)	(3.9)
Aged 35-44	5,880	0.66	0.025	0.076	0.062
			(3.9)	(11.6)	(9.4)
Aged 45-54	4,140	1.36	0.056	0.233	0.25
			(4.1)	(17.1)	(18.4)
Aged 55-64	2,643	3.07	0.159	0.659	0.755
			(5.2)	(21.5)	(24.6)
Aged 65-74	1,586	5.11	0.265	1.1	1.26
			(5.2)	(21.5)	(24.7)
Aged 75+	1,032	21.31	2.85	7.71	3.49
			(13.4)	(36.2)	(16.4)

Group	Average daily municipal mortality rate (deaths per 100,000 inhabitants)			
	Infect. diseases	Neopl.	Violent and accid.	All other
Total	0.045	0.168	0.151	0.335
	(3.3)	(12.4)	(11.1)	(24.6)
Men	0.056	0.168	0.249	0.385
	(3.6)	(10.9)	(16.2)	(25)
Women	0.034	0.168	0.058	0.28
	(2.9)	(14.2)	(4.9)	(23.7)
Aged 0-4	0.066	0.013	0.075	0.669
	(6.8)	(1.4)	(7.8)	(69.3)
Aged 5-9	0.005	0.013	0.024	0.022
	(7.1)	(17.3)	(32.4)	(29.6)
Aged 10-19	0.005	0.016	0.081	0.033
	(3.4)	(10.5)	(54)	(21.8)
Aged 20-34	0.029	0.03	0.2	0.076
	(7.5)	(7.7)	(51.7)	(19.6)
Aged 35-44	0.046	0.085	0.189	0.175
	(6.9)	(12.9)	(28.8)	(26.6)
Aged 45-54	0.056	0.225	0.185	0.355
	(4.1)	(16.5)	(13.6)	(26.1)
Aged 55-64	0.082	0.529	0.202	0.684
	(2.7)	(17.2)	(6.6)	(22.3)
Aged 65-74	0.136	0.882	0.336	1.131
	(2.7)	(17.3)	(6.6)	(22.1)
Aged 75+	0.373	2.21	0.56	4.117
	(1.8)	(10.4)	(2.6)	(19.3)

Notes: The table shows cause-specific daily mortality rates as number of deaths per 100,000 inhabitants. The share of average group mortality is presented in brackets, in percentage points. The sample includes 2,456 municipalities over 19.94 years on average from 1998 to 2017. All means are weighted by the relevant population group in municipalities.

Table 2: Estimated number of deaths per year by temperature bin

Average daily temperature	Average deaths per year
<12°C	5,705
	(591)
12-16°C	11,142
	(1,494)
16-20°C	7,536
	(1,449)
20-24°C	-367
	(718)
24-28°C	-
28-32°C	1,769
	(403)
>30°C	539
	(75)
Total	26,324
	(3,609)

Notes: The standard errors are in brackets. They only take into account the uncertainty of the impact of temperature bins on mortality. This table is based on the 1998-2017 average and does not take into account the variability of hot and cold days in Mexico from one year to the other. Population is assumed to be 129 million. The reference bin is 24-28 Celsius degrees.

Table 3: Mortality and death estimates by age group and type of disease

Sample	Mortality per 100,000 inhabitants				Deaths per year
	<12°C	12-16°C	16-20°C	>32°C	
A. Age groups					
0-4	0.199	0.015	0.004	-0.004	328
	(0.033)	(0.025)	(0.021)	(0.055)	(602)
5-9	-0.001	-0.008	-0.006	-0.008	-237
	(0.01)	(0.007)	(0.005)	(0.012)	(163)
10-19	0.012	-0.003	-0.008	0.043	-286
	(0.01)	(0.007)	(0.006)	(0.015)	(350)
20-34	0.002	-0.004	-0.01	0.02	-393
	(0.014)	(0.011)	(0.009)	(0.032)	(713)
35-44	0.052	0.016	-0.011	0.063	56
	(0.028)	(0.022)	(0.017)	(0.038)	(832)
45-54	0.243	0.064	0.019	0.255	1,956
	(0.047)	(0.037)	(0.027)	(0.073)	(986)
55-64	0.531	0.325	0.211	0.433	5,536
	(0.092)	(0.059)	(0.046)	(0.151)	(1,121)
65-74	0.872	0.52	0.342	0.698	5,327
	(0.152)	(0.097)	(0.074)	(0.247)	(1,083)
75+	5.70	2.52	1.07	4.53	15,243
	(0.526)	(0.301)	(0.237)	(0.621)	(2,142)
B. Selected disease types					
Infectious and parasitic	0.002	-0.001	-0.001	0.007	-219
	(0.002)	(0.002)	(0.001)	(0.004)	(443)
Neoplasms	0.008	0.002	0.002	-0.003	626
	(0.004)	(0.003)	(0.003)	(0.008)	(825)
Endocrine, nutritional and metabolic	0.060	0.032	0.014	0.049	7,216
	(0.007)	(0.005)	(0.004)	(0.008)	(1,221)
Circulatory	0.080	0.047	0.024	0.044	10,079
	(0.011)	(0.006)	(0.005)	(0.013)	(1,562)
Respiratory	0.056	0.023	0.007	0.015	4,410
	(0.007)	(0.004)	(0.003)	(0.006)	(934)
Violent and accidental	-0.002	-0.006	-0.005	0.033	-1,021
	(0.005)	(0.004)	(0.003)	(0.01)	(1,117)
All other causes	0.052	0.022	0.011	0.054	5,232
	(0.007)	(0.005)	(0.004)	(0.011)	(1,251)

Note: The estimates in each row come from separate regressions by age group (panel A) and selected disease type (panel B). They rely on similar specifications to Figure 2: the dependent variable is the daily mortality rate per 100,000 inhabitants, the regressions control for the daily precipitation level and include day-by-month-by-year fixed effects, municipality-by-calendar-day (1st January to 31st December) fixed effects, and municipality-by-year fixed effects. Standard errors are in brackets and clustered at the municipality level. The first four columns provide mortality estimates due to unusually cold (<12°C), mildly cold (12-16°C and 16-20°C) and unusually hot (>32°C) temperatures, as compared to a day with an average temperature of 24-28°C. The last columns provide estimates of the number of deaths per year, taking into account the frequency of cold, mildly cold and hot days. Population is assumed to be 129 million in total and age-specific population estimates are based on our linear extrapolation of population for 2017. Note that, because death causes represent competing risks, an increase in the likeliness of dying from one cause reduces the likeliness of dying from something else. This element is not taken into account in our regressions, since we are estimating these effects separately.

<h1>Table 4: Impact of cold temperatures by predicted income quartile</h1>

Model	% change in average daily mortality			Average deaths per year		
	<12°C	12-16°C	16-20°C	<12°C	12-24°C	>28°C
A. Predicted income quartiles						
1st	0.265	0.136	0.068	2,037	8,313	267
	(0.028)	(0.018)	(0.013)	(212)	(1,335)	(168)
2nd	0.193	0.105	0.031	1,617	5,435	761
	(0.031)	(0.022)	(0.017)	(256)	(2,000)	(243)
3rd	0.154	0.073	0.021	1,089	2,706	861
	(0.031)	(0.023)	(0.017)	(221)	(1,631)	(277)
4th	0.179	0.084	0.014	1,096	2,782	391
	(0.038)	(0.026)	(0.018)	(235)	(1,599)	(239)
B. Age-corrected predicted income quartiles						
1st	0.249	0.133	0.072	1,624	7,193	241
	(0.029)	(0.02)	(0.014)	(191)	(1,234)	(157)
2nd	0.178	0.099	0.029	1,364	4,843	628
	(0.029)	(0.021)	(0.017)	(221)	(1,791)	(210)
3rd	0.177	0.075	0.019	1,335	3,050	632
	(0.028)	(0.023)	(0.016)	(212)	(1,774)	(235)
4th	0.207	0.103	0.031	1,502	4,675	762
	(0.038)	(0.023)	(0.016)	(275)	(1,613)	(283)
C. Predicted quartiles based on poverty indicator						
1st	0.248	0.137	0.068	1,803	7,904	194
	(0.028)	(0.018)	(0.013)	(201)	(1,312)	(175)
2nd	0.2	0.104	0.04	1,522	5,400	600
	(0.028)	(0.021)	(0.017)	(211)	(1,754)	(197)
3rd	0.173	0.088	0.029	1,190	4,282	786
	(0.027)	(0.023)	(0.016)	(185)	(1,586)	(250)
4th	0.18	0.074	0.007	1,395	2,116	689
	(0.037)	(0.023)	(0.017)	(284)	(1,797)	(303)
D. Age-corrected predicted quartiles based on poverty indicator						
1st	0.245	0.138	0.066	1,852	8,224	210
	(0.026)	(0.018)	(0.013)	(200)	(1,332)	(176)
2nd	0.182	0.09	0.029	1,481	4,509	627
	(0.027)	(0.02)	(0.016)	(217)	(1,741)	(198)
3rd	0.207	0.106	0.046	1,648	6,629	953
	(0.032)	(0.025)	(0.018)	(256)	(2,030)	(290)
4th	0.172	0.067	-0.007	971	576	538
	(0.045)	(0.027)	(0.019)	(255)	(1,450)	(240)

Notes: Standard errors in brackets (clustered at the municipality level). Each row refers to the output of a separate regression. The mortality estimates correspond to the 31-day long-run cumulative effect of a day at a given temperature on mortality for all death causes. The dependent variable is the daily mortality rate in deaths per 100,000 inhabitants, normalised to one according to the average daily mortality rate in each quartile. For example, for the first quartile of income, a day below 12°C leads to a 26.5% increase in the daily mortality rate. Each regression controls for the daily precipitation level and includes day by month by year fixed effects, municipality by calendar day (1-365) fixed effects, and municipality by year fixed effects. Reference day is 24-28 degrees Celsius. The estimates for the average number of deaths are based on the coefficients displayed on the first four columns, and the frequency of cold days provided in Figure 1.

Table 5: Impact of the *Seguro Popular* on the eligible population

|	(1)	(2)	(3)	(4)	(5)	(6)
Age group	All age groups				55 and over	
Death cause	Weather-sensitive[a]			All	Weather-sensitive[a]	All
Seguro Popular:						
x days below 12°C	0.013	0.010	0.010	0.012	0.091	0.271
	(0.022)	(0.019)	(0.019)	(0.026)	(0.223)	(0.252)
x days at 12-16°C	-0.031**	-0.032***	-0.034***	-0.043***	-0.433***	-0.538***
	(0.012)	(0.011)	(0.011)	(0.016)	(0.129)	(0.154)
x days at 16-20°C	-0.017	-0.017*	-0.016*	-0.020	-0.186*	-0.129
	(0.011)	(0.009)	(0.009)	(0.014)	(0.106)	(0.127)
x days at 20-24°C	0.001	-0.005	-0.005	-0.003	-0.101	-0.214
	(0.011)	(0.010)	(0.010)	(0.014)	(0.119)	(0.138)
x days at 28-32°C	-0.008	-0.001	-0.001	-0.024	-0.177	-0.170
	(0.014)	(0.012)	(0.012)	(0.018)	(0.152)	(0.181)
x days above 32°C	-0.010	-0.011	-0.017	-0.037	-0.105	-0.853
	(0.078)	(0.052)	(0.054)	(0.097)	(0.712)	(0.799)
<u>Interacted fixed effects</u>						
Temperature bins and precipitations:						
x month by year	X	X	X	X	X	X
x municipality by month	X			X	X	X
x State			X			

Notes: (a) Weather-sensitive death causes are all death causes excluding infectious and parasitic diseases, neoplasms and violent and accidental deaths. They therefore include endocrine, nutritional, metabolic, circulatory and respiratory diseases as well as all other death causes. *, ** and *** means statistically significant at 10, 5 and 1 percent. The dependent variable is the monthly mortality rate per 100,000 inhabitants for the people without any other health insurance, dying from the diseases covered by the *Seguro Popular*. All specifications include municipality by month, municipality by year and month by year fixed effects, as well as a dummy variable for the presence/absence of the *Seguro Popular*. The specifications also control for the interaction between the *Seguro Popular* and precipitations. We use additional fixed effects that are interacted with the temperature bins. These interactions vary across specifications and are reported directly in the table. Standard errors in brackets are clustered at the level of municipalities and the model is weighted by the population in each municipality with no access to any other health insurance. Reference day is 24-28 degrees Celsius.

Table 6: Effects of the *Seguro Popular* on other groups

|	(1)	(2)	(3)	(4)	(5)	(6)
Health insurance status	Without		With			With and without
Death cause (weather-sensitive[a])	Covered and not	Not Covered	Covered and not	Covered	Not Covered	Covered and not
Seguro Popular:						
x days below 12°C	0.007	-0.007	-0.054	-0.064**	0.010	-0.025
	(0.028)	(0.018)	(0.046)	(0.032)	(0.032)	(0.026)
x days at 12-16°C	-0.038**	-0.007	0.020	0.0001	0.020	-0.025
	(0.018)	(0.012)	(0.034)	(0.024)	(0.021)	(0.017)
x days at 16-20°C	-0.035**	-0.018*	-0.010	-0.012	0.002	-0.028*
	(0.016)	(0.010)	(0.031)	(0.022)	(0.019)	(0.016)
x days at 20-24°C	-0.005	-0.005	0.022	0.014	0.008	0.0004
	(0.016)	(0.011)	(0.031)	(0.023)	(0.019)	(0.016)
x days at 28-32°C	-0.024	-0.016	0.027	0.022	0.005	-0.024
	(0.020)	(0.013)	(0.038)	(0.027)	(0.025)	(0.020)
x days above 32°C	0.067	0.077	0.005	-0.146	0.151	0.058
	(0.103)	(0.058)	(0.191)	(0.136)	(0.122)	(0.088)

Notes: (a) Weather-sensitive death causes are all death causes excluding infectious and parasitic diseases, neoplasms and violent and accidental deaths. They therefore include endocrine, nutritional, metabolic, circulatory and respiratory diseases as well as all other death causes. *, ** and *** means statistically significant at 10, 5 and 1 percent. The dependent variable is the monthly mortality rate per 100,000 inhabitants from the selected population (with/without access to standard health insurance) and pathologies (covered and/or not by the *Seguro Popular*), for all death causes except infectious and parasitic diseases, neoplasms, and violent and accidental deaths. All specifications include municipality by month, municipality by year and month by year fixed effects, as well as a dummy variable for the presence/absence of the *Seguro Popular*. The specifications also control for the interaction between the Seguro Popular and precipitations. We also interact the temperature bins and the level of precipitations with the month by year fixed effects and the municipality by month fixed effects. Standard errors in brackets are clustered at the level of municipalities. Reference day is 24-28 degrees Celsius.

Figure 1: Population-weighted number of days per year falling within each temperature bin (in °C) for historical data (1998-2017)
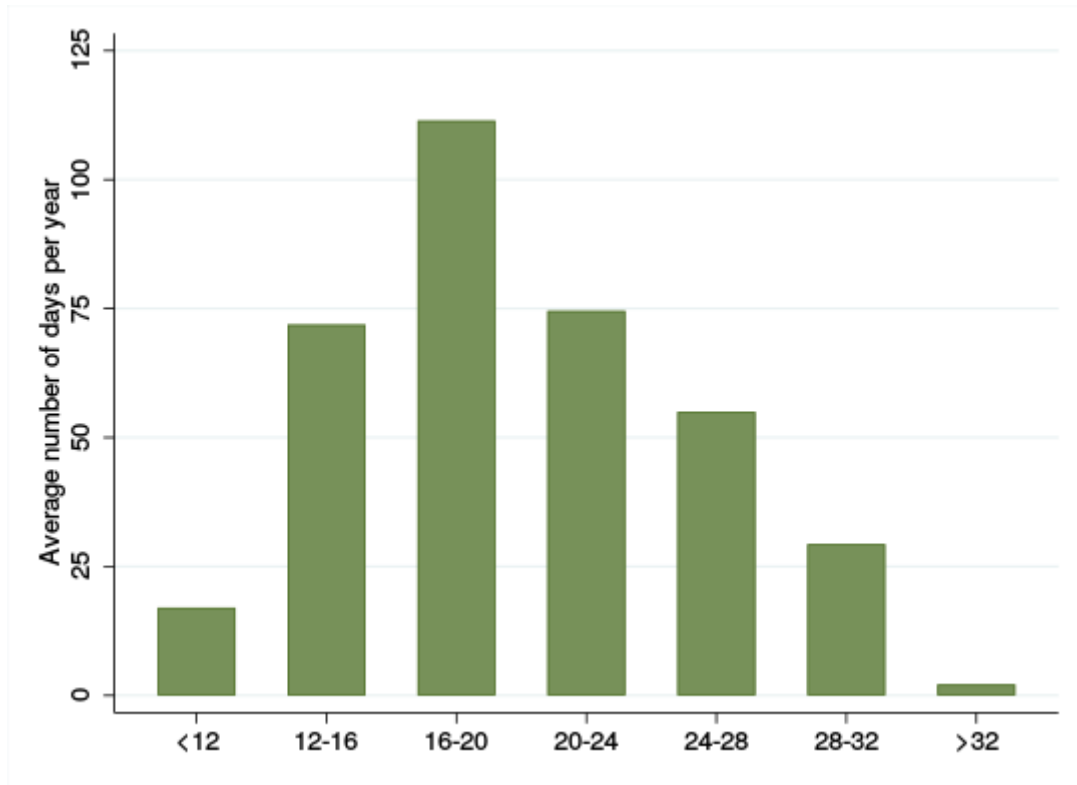
Notes: The figure shows the distribution of daily mean temperatures across 7 temperature-day bins (in °C). Each green bar represents the historical average number of days in each temperature category during a year (calculated over 1998-2017). Municipality averages have been weighted by total population in a municipality.

Figure 2: Impact of temperature bins on 31-day cumulative mortality, in deaths per 100,000 inhabitants
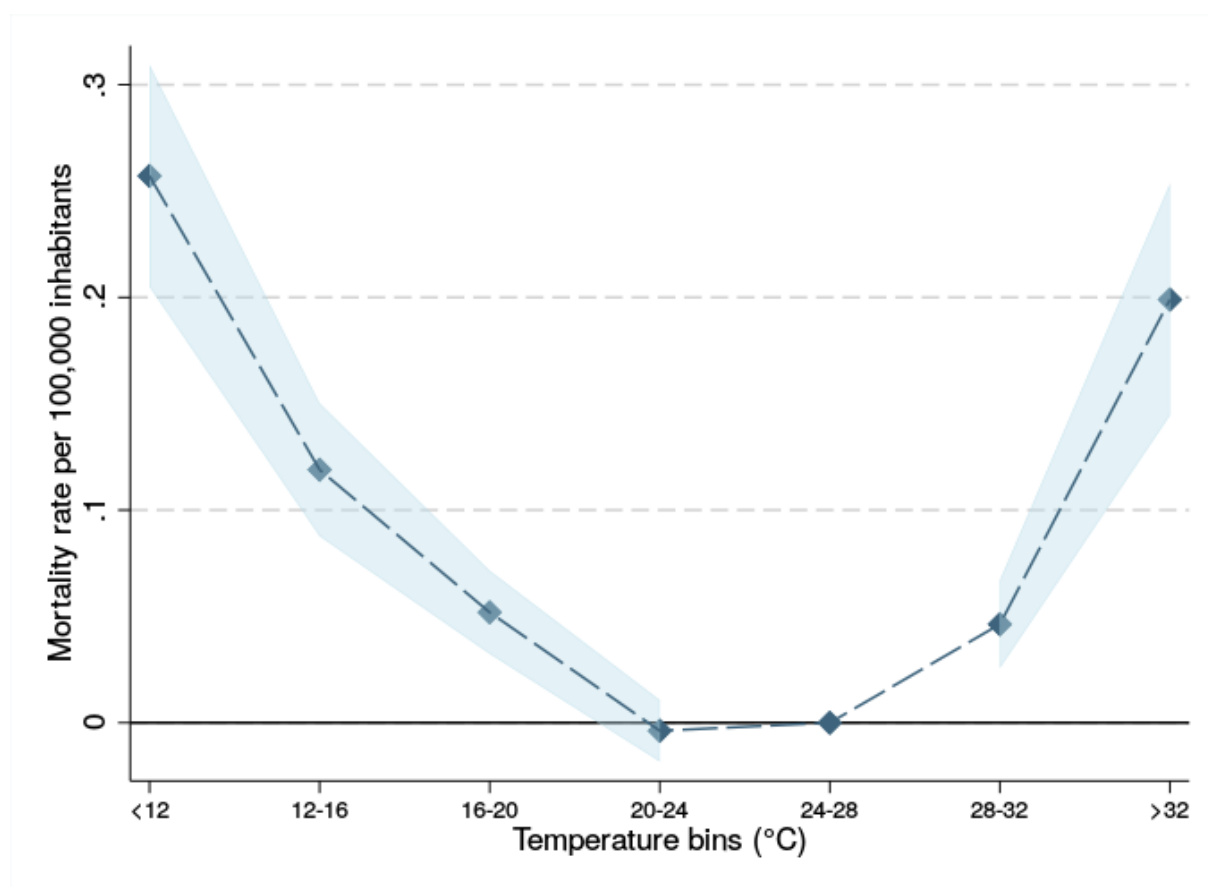
Notes: The graph shows the cumulative effect of a day with a temperature within each bin (relative to the 24°C-28°C category) obtained from a dynamic model with 30 lags. The diamonds show the sum of the coefficients on these thirty lags in each category. The shaded area corresponds to the 95 percent confidence interval (clustered at municipality level). The dependent variable is the daily mortality rate at the municipality level. 14,231,164 observations. The regression controls for the daily precipitation level and includes day-by-month-by-year fixed effects, municipality-by-calendar-day (1st January to 31st December) fixed effects, and municipality-by-year fixed effects.

Figure 3: Impact of temperature on cumulative 31-day mortality by income quartile
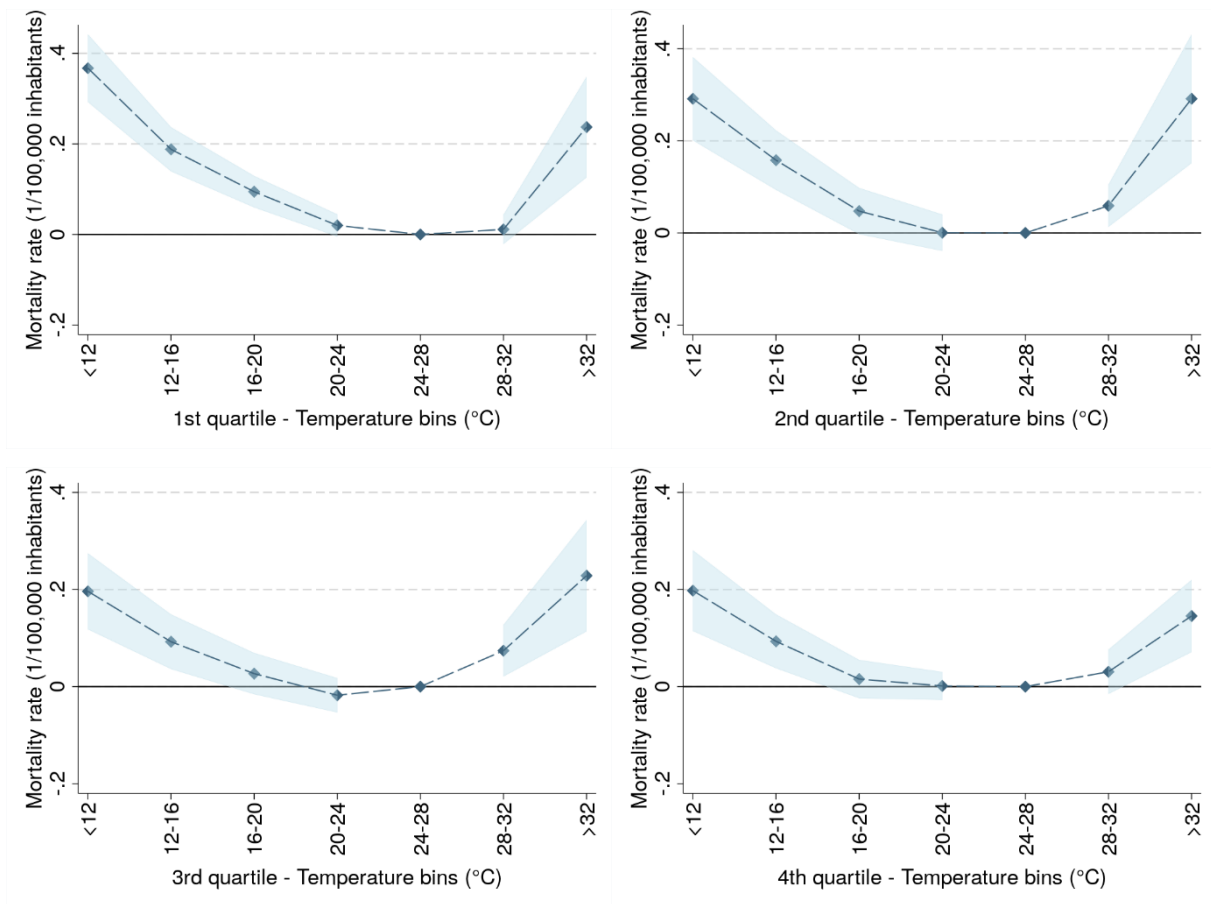
Note: The results for each quartile are taken from separate regressions. The dependent variable is the mortality per 100,000 inhabitants belonging to the quartile. The y-axis is mortality per 100,000 inhabitants and the x-axis corresponds to the cumulative impact after 31 days for each of the 4°C temperature bins in the regressions. The reference bin is 24-28°C. The regressions control for the daily precipitation level and includes day-by-month-by-year fixed effects, municipality-by-calendar day (1-365) fixed effects, and municipality-by-year fixed effects. The shaded areas represent the 95 percent confidence interval for each estimated set of coefficients. Note that all coefficient values have been augmented by a factor of $1/(1-0.184)$ because 18.4% of the deaths could not be attributed to any quartile using the data on the death certificates.