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

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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 as likely to kill people in the bottom half of the income distribution. Finally, we show causal evidence that the Seguro Popular, a universal health care policy, has saved at least 1,600 lives per year from cold weather since 2004. (*JEL* I12, I13, I14, O13, O15, Q54)

Climate change is a major threat for human health in the twenty-first 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 United States (Braga et al. 2001; Deschênes and Moretti 2009; Deschênes and Greenstone 2011; Barreca 2012), but recent evidence from developing countries suggests much greater impacts (Burgess et al. 2017; Carleton et al. 2021). 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

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has been observed in the United States over time (Barreca et al. 2016; Heutel, Miller and Molitor 2020), 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-income 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 program targeted at low-income households—the *Seguro Popular*—to analyze the impact that extending universal health care 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's 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 favor 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. By contrast, extremely hot days—over 32°C—trigger a comparably small amount of additional deaths (around 500 annually).[2]

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 affect the poorest income groups. Analyses by causes of death show that the higher vulnerability of the poor comes, to a large extent, from respiratory diseases and circulatory system diseases.[3] By 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 health care 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 should 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 health care (particularly for vulnerable groups) may significantly reduce vulnerability to weather. During our study period, Mexico implemented a nationwide policy, the *Seguro Popular*, to increase access to health care 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]

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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 (6.6°C, on average) 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., Deschênes 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 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 health care is a major issue in Mexico: according to the 2000 Mexican census, over 80 percent of people in the first income quartile do not have access to social security.

We assess whether 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 enrollment 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 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 health care 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 the 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, particularly when they become older. Furthermore, these households are at risk over longer time periods during the year than richer households, since they appear to be vulnerable to even mildly cold temperatures. We show that access to universal health care 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 health care 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 online Appendix A1, but we summarize the most important results of this literature in this section. To quantify heat-related 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-shaped relationship between temperature and mortality at the daily level (Curriero et al. 2002; Hajat et al. 2006; Hajat,

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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), and 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.

Kovats, and Lachowycz 2007; McMichael et al. 2008). Human beings face the lowest 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-related and cold-related mortalities. This is in line with medical evidence that the human body starts to be at risk outside a comfort zone that 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 (Deschênes and Greenstone 2011). With temperature bins, the impact between temperature and mortality is evaluated separately 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, Deschênes and Moretti 2009 and Deschênes and Greenstone 2011), possibly 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's 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 is strongly influenced by ambient air temperature and humidity (Lipsitch and Viboud 2009; du 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 during 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; Deschênes and Moretti 2009).[6] Recent developments in epidemiology show that the impact of cold weather on human health is in fact much stronger than the impact of hot weather (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). 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 percent of all deaths are attributable to cold while only 0.42 percent 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 percent of total mortality.

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

However, uncertainty remains regarding the true mortality impact of hot days because extreme weather events may not only directly affect human physiology, they may also reduce agricultural output, the availability of drinkable water, and household income. These impacts may, in turn, affect health or access to health care 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 (Deschênes 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 incomes of populations located in rural areas. In Mexico, 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 United States (see, for example, Deschênes and Moretti 2009 and Deschênes and Greenstone 2011).

The existence of such economic factors in addition to the standard epidemiological 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 declining heat-related mortality that has been observed in the United States over time and the gradual deployment of air conditioning. Heutel, Miller, and Molitor (2020) similarly argue that the deployment of air conditioning explains regional differences in the health impact of heat on the elderly in the United States. Deschênes and Greenstone (2011) predict that climate change in the United States would lead to a 3 percent increase in age-adjusted mortality by the end of the twenty-first 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 (Deschênes 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

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[7] See Basu (2009) and Deschênes (2014) for thorough literature reviews.

[8] Another possibility is that some of our mortality impacts are for people who 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).

mortality across twelve cities in medium-income and low-income countries. Using long-term climate change scenarios, Barreca (2012) finds a very small reduction in mortality for the United States as a whole (–0.08 percent), but this hides significant heterogeneity: mortality would decrease in the coldest states, whereas it would increase significantly (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—12 to 46 percent— by the end of the century.

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 nontransmissible diseases have long been the leading causes 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 health care 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).

A. *Mortality Data*

Our mortality data comes from the Mexican general mortality records (*defunciones generales*) from 1990 onward as assembled by INEGI. The microdata 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 online 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

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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.

Table 1—Summary of Death Statistics

		Average daily municipal mortality rate (deaths per 100,000 inhabitants)			
Group	Average pop. per mun.	All causes	Respiratory diseases	Circulatory diseases	Metabolic diseases
Panel A					
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)

	Average daily municipal mortality rate (deaths per 100,000 inhabitants)			
Group	Infectious diseases	Neopl.	Violent and accidental	All other
Panel B				
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 parentheses 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.

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 nonlinearly until it reaches 21.3 deaths 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 tenth 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 accounts 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 have 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.

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, on average, were operative in any given year 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 are 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 temperatures 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

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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 within a 20 km radius. In this case, we match each municipality with the 5 closest stations within a maximum radius of 50 km. 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 2008a).

[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).

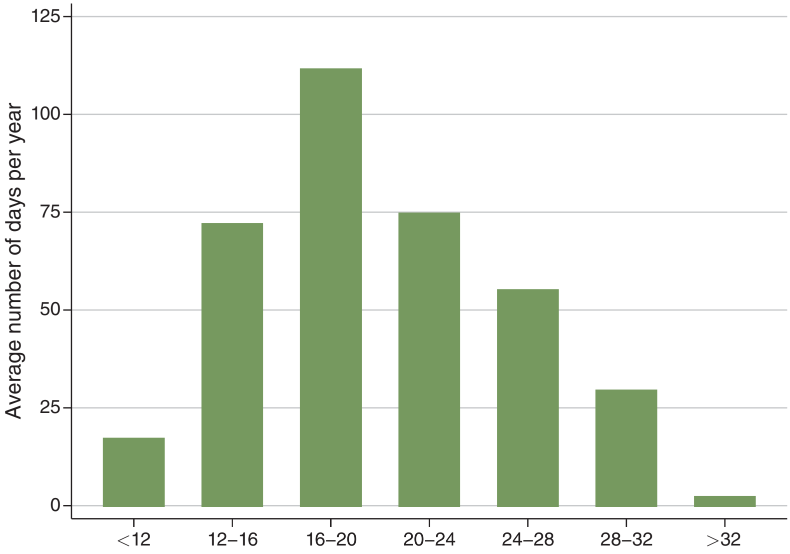

Figure 1. Population-Weighted Number of Days per Year Falling within Each Temperature Bin (in °C) for Historical Data (1998–2017)

Notes: The figure shows the distribution of daily mean temperatures across seven 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.

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 of 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 United States, featuring fewer days below 12°C and many more days above 32°C.[13] The distribution is also more spread out in the United States.

C. *Socioeconomic Data*

Information from the 2000 Mexican 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.

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[13] Deschênes and Greenstone (2011) provide a distribution of daily mean temperatures in the United States 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).

We extract socioeconomic information on income, educational attainment, social insurance coverage, profession, age, etc. This data source is described in detail in online 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 health care coverage of the very poor: more than 80 percent of the people in the first income quartile have no social security.

III. The Effect of Temperatures on Mortality in Mexico

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 the monthly level in online Appendix A4. The results obtained from these regressions at the 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 (January 1 to December 31) fixed effects to control for differences in mortality rates due to seasonal phenomena at 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., January 1, 2006; January 2, 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 locations to estimate differences in effects across temperature bins.[14]

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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 highest and lowest 10 percent of temperatures recorded within the same calendar day and municipality and a 10°C difference between the highest and lowest 1 percent. 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.

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

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

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]

$T_{i,d,m,t}$ includes our climatic variables of interest. One issue of importance is to account for nonlinearity (Dell, Jones and Olken 2014). A conservative approach consists in using temperature bins to specify the relationship between temperature and mortality (Deschênes 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 online 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, Deschênes 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 nonlinearities in the temperature-mortality relationship and for dynamic effects, Deschênes 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,

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[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 mortality of 0. 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 online Appendix A4). Monthly data naturally includes fewer 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., June 28, 1999 in Tijuana and the December 3, 2006 in Bahía de los Ángeles.

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

since all effects seem to fade out after 15–20 days. The expression for the distributed lag model is as follows:

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

The subscript s stands for the various temperature bins, and $B_{s,d-k,i}$ is a dummy variable equal to 1 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.

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 2 bins above 28°C, suggesting that hot days (28–32°C) and extremely hot days (>32°C) displace death by more than 1 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 people 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., Deschênes 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 online Appendix A6.)

Furthermore, we find statistically significant and strong impacts on mortality for all temperature 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

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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.

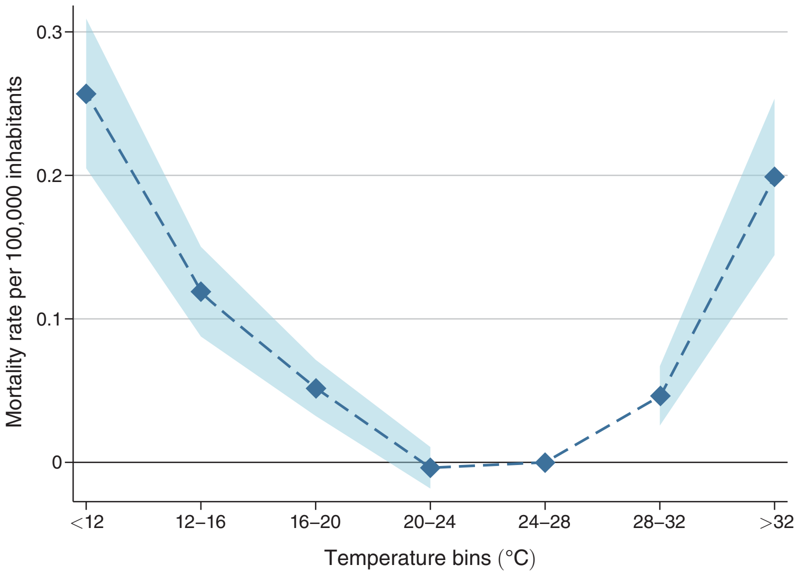

Figure 2. Impact of Temperature Bins on 31-Day Cumulative Mortality, in Deaths per 100,000 Inhabitants

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 (January 1 to December 31) fixed effects, and municipality-by-year fixed effects.

by around 0.26 deaths per 100,000 inhabitants compared with a day falling in the 24–28°C bin. Therefore, 2 mildly cold days between 12°C and 16°C convey nearly the same mortality impact as 1 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 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. (The 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

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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.

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 parentheses. 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°C.

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.

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 types 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 make up 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. By 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 3 causes of death are estimated to concentrate more than 80 percent of the deaths induced by suboptimal weather exposure.[22]

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[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 United States, where two-thirds of

Table 3—Mortality and Death Estimates by Age Group and Type of Disease

	Mortality per 100,000 inhabitants				
Sample	<12°C	12–16°C	16–20°C	>32°C	Deaths per year
Panel 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)
Panel 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, and the regressions control for the daily precipitation level and include day-by-month-by-year fixed effects, municipality-by-calendar-day (January 1 to December 31) fixed effects, and municipality-by-year fixed effects. Standard errors are in parentheses and clustered at the municipality level. The first 4 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 causes of death 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.

We provide estimates of years of life lost in online Appendix A7. Most years of life lost are due to cold weather effects on people over age 55. Moreover, we can use our model to simulate the impact that climate change may have on mortality in

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cold-related deaths have a cardiovascular origin and around 20 percent are caused by respiratory diseases, while diabetes and infectious diseases account for only about 3 percent and 2 percent, respectively, of cold-related deaths (Deschênes 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 diseases (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 United States is likely due to differences in the classifications 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.

Mexico. This is only a partial effect of climate change, since our model only identifies short-term responses to cold and heat waves within a reduced time frame. The details of this analysis are provided in online 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.

C. *Robustness*

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

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 online 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 death 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 health care. We also include municipality by rural or urban area fixed effects to separate rural from urban areas within the same municipality, since we expect people living in the city center 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, noncomparable nomenclature from 2013 onward, we performed the analysis with data from 1998 to 2012 only. The output of this estimation is presented in online 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 in vulnerability to cold at unusual and mild levels between the first two and last two quartiles. For example, an unusually cold day below 12°C conveys 0.37 deaths per 100,000 inhabitants for the first quartile of income versus 0.20 deaths for the last quartile. By 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.

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 first 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 in 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 2 quartiles of predicted income compared to the third and fourth quartiles.[25]

Panels B to D of Table 4 provide a series of robustness checks confirming these findings. First, 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 constitute the most vulnerable

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[23] With this method, we are able to assign an income quartile to 81.6 percent 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 to which no income quartile could be attributed.

[24] We run a joint regression estimating the coefficients for the first and fourth 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 and 180 numerator and 2281 denominator degrees of freedom.

[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 in Table 4 are based on the results of the regressions reported in Figure 3, while the estimates in 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.

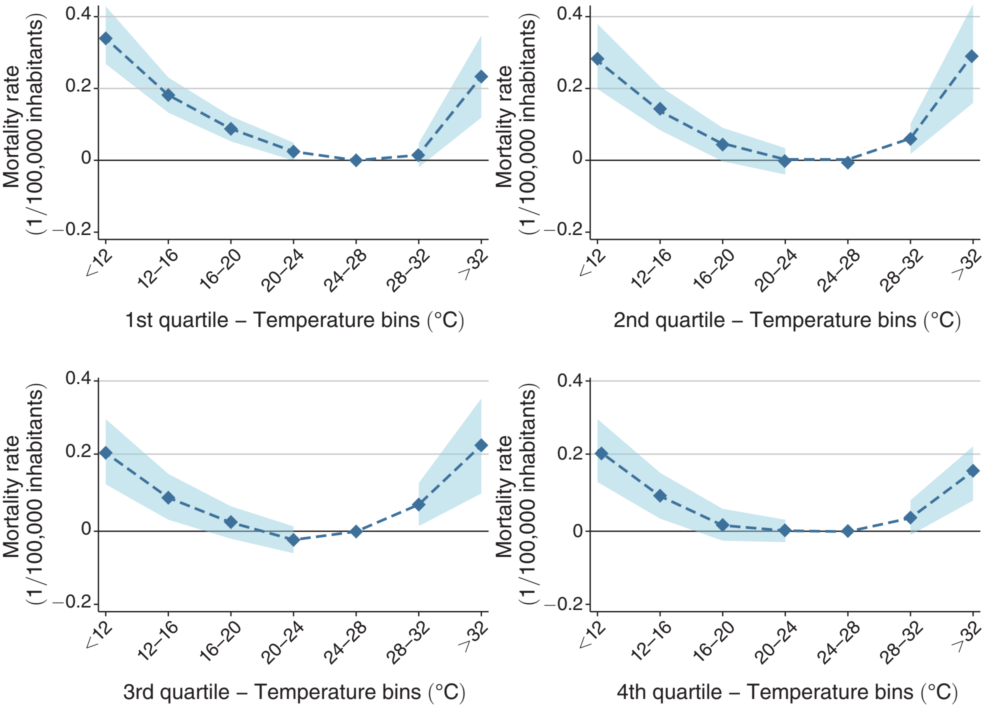

Figure 3. Impact of Temperature on Cumulative 31-Day Mortality by Income Quartile

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 include 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 percent of the deaths could not be attributed to any quartile using the data on the death certificates.

group by far. 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 online Appendix C1.) Correcting for age does not affect our conclusion: the first 2 quartiles of income are about 35 percent more vulnerable to mildly cold days compared to the last 2 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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[26] An *F*-test between the first and fourth quartiles of income suggests that the coefficients for the temperature bins are statistically different at 1 percent.

TABLE 4—IMPACT OF COLD TEMPERATURES BY PREDICTED INCOME QUARTILE

Model	Percent change in average daily mortality			Average deaths per year		
	<12°C	12–16°C	16–20°C	<12°C	12–24°C	>28°C
Panel 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)
Panel 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)
Panel 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)
Panel 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 parentheses (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, normalized to 1 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 percent 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°C. The estimates for the average number of deaths are based on the coefficients displayed in the first four columns and the frequency of cold days provided in Figure 1.

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, panel 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 of Mexican households in the 2000 census. The answers to this set of questions are not as easy to for respondents to manipulate. 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 online 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 online 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, but 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 online 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 percent of housing units are equipped with some form of heating equipment.

V. Weather-Related Mortality and Universal Health Care

The analysis of Sections III and IV shows a 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 health care 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 of restricting the population of recipients to vulnerable groups. They can also restrict the range of

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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.

[28] Formerly, low-income families working in the informal sector did not have access to health care insurance, and the country still suffers from chronic underfinancing of free public hospitals. Mexico is the OECD country with the lowest budget dedicated to health: in 2019, current expenditure per capita in purchasing power parity was \$1,133, compared to \$4,166 on average in other OECD countries and \$10,949 in the United States (see OECD 2022).

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 percent) 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 health care. Access to the *Seguro Popular* was open to all. In practice, it focused on people who were not eligible for employment-based health insurance, i.e., low-income households working in the informal sector. Enrollment 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, those 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. By contrast, a long list of varied pathologies and treatments 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 homoderivatives, and 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* was been replaced after January 1, 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 who 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 onward.

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[29] Furthermore, additional protection has been provided to children under 5 years of age born after December 1, 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, unfortunately, we do not have this exact piece of information.

The evidence so far suggests that there have been clear benefits from the rollout of the *Seguro Popular*. King et al. (2009) and Ávila-Burgos et al. (2013) find that out-of-pocket health expenditure and catastrophic health expenditure was 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 centers.

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 health care 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 ten months of implementation, possibly because health effects could require more time to materialize. By contrast, other studies have identified health benefits. Knox (2008) find effects of the program on the utilization of health care services. Parker, Saenz, and Wong (2018) find similar effects of higher health care utilization among the elderly. Likewise, Servan-Mori et al. (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 third and fourth years of implementation. We reproduce the relevant figure from Cohen (2020) in online 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.

A. *Method*

We aim to assess whether 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 for the *Seguro Popular*, i.e., those without 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

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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 has been stable since 2010, with only a few additions and subtractions.

certificates report the cause of death and whether the deceased was affiliated with an insurance scheme. People without standard health insurance are those who report having either no health insurance, the *Seguro Popular*, or a scheme called *IMSS Oportunidades* (for vulnerable, low-income households) as health insurance. To construct mortality rates, we use population estimates that account for the share of people with no affiliation with 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 health care 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]

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

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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 the 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 the 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 errors, 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 online Appendix D2: we simply rerun the model after excluding all municipalities with less than 10,000 inhabitants. The results are very similar.

[34] We are only interested in the interaction terms, since the *Seguro Popular* variable 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 online 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 can still assess the impact of the interaction terms. Results lose precision but are similar to our baseline results, however.

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 6×30 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 the 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 III) are reported in online Appendix A4 and are very close to our general results in Figure 2 for the impact of weather on mortality.

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 for the *Seguro Popular* because they do not have any standard health insurance, such as the IMSS and ISSSTE, and they died from a pathology covered by the *Seguro Popular*. Columns 1 to 4 are for the whole population; columns 5 and 6 focus 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 causes of death (excluding infectious and parasitic diseases, 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

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

Table 5—Impact of the *Seguro Popular* on the Eligible Population

Age group	All age groups				55 and over	
Cause of death	Weather-sensitive			All	Weather-sensitive	All
	(1)	(2)	(3)	(4)	(5)	(6)
Seguro Popular:						
× 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)
× 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)
× 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)
× 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)
× 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)
× 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)
Interacted fixed effects						
Temperature bins and precipitation:						
× month by year	X	X	X	X	X	X
× municipality by month	X			X	X	X
× state			X			

Notes: Weather-sensitive causes of death are all causes of death 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 causes of death. The dependent variable is the monthly mortality rate per 100,000 inhabitants for 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 or absence of the *Seguro Popular*. The specifications also control for the interaction between the *Seguro Popular* and precipitation (in millimeters). 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 parentheses 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°C.

bin implies that the *Seguro Popular* saved around 1,600 lives (95 percent confidence interval is 334–2,850) every year since 2004.[36]

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 bin becomes statistically significant at 10 percent. The estimates for this bin would correspond to an additional 1,350 lives saved every year.[37]

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[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 percent 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 percent would have no access to any other health insurance: $0.031/100{,}000 \times 72.6 \times 129{,}000{,}000 \times 0.92 \times 0.60 \approx 1{,}600$.

[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): $0.017/100{,}000 \times 112.5 \times 129{,}000{,}000 \times 0.92 \times 0.60 \approx 1{,}350$.

TABLE 6—EFFECTS OF THE *SEGURO POPULAR* ON OTHER GROUPS

Health insurance status	Without		With			With and without
Cause of death (weather-sensitive)	Covered and not (1)	Not covered (2)	Covered and not (3)	Covered (4)	Not covered (5)	Covered and not (6)
Seguro Popular:						
× 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)
× 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)
× 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)
× 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)
× 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)
× 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: Weather-sensitive causes of death are all causes of death 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 causes of death.The dependent variable is the monthly mortality rate per 100,000 inhabitants from the selected population (with and without access to standard health insurance) and pathologies (covered or not by the *Seguro Popular*) for all causes of death 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 or absence of the *Seguro Popular*. The specifications also control for the interaction between the *Seguro Popular* and precipitation (in millimeters). 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 parentheses are clustered at the level of municipalities. Reference day is 24–28°C.

Furthermore, our baseline model (columns 1–3) excludes 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, cause of death, and income quartiles are presented in online Appendix D2.

So far, we have used specifications that focus on the population that was eligible for 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 have had spillover 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 causes of death.) 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 who 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 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 spillover effects on this group of the population. Column 3 includes all diseases, while columns 4 and 5 focus on pathologies covered (column 4) and not covered (column 5) by the *Seguro Popular*, respectively. Coefficients are mostly insignificant, suggesting that the policy mainly had an effect on people without traditional health insurance. An exception is days below 12°C for people with 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 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 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 evidence suggesting that other groups also could have benefited from the policy due to spillover effects.

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, 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 and extremely hot days (>32°C) kill around 500 people 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 twenty-first century, even in the absence of any adaptation. This illustrates the vast heterogeneity in the impact of climate change 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 that they are also more vulnerable at relatively mild temperatures. Therefore, protecting low-income households from cold 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. Health care 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 health care coverage caused by the deployment of the *Seguro Popular* to assess its contribution to reducing vulnerability to the weather. Applying the historical distribution of temperature in Mexico to our estimates, we find that the scheme saved around 1,600 lives per year from exposure to mildly cold temperature (12°–16°C) since 2004. 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-income and middle-income countries are very large: in the 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 health care 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.

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