Heat and Humidity on Early-life Outcomes: Evidence from Mexico

- Online Appendix -

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A North American Regional Reanalysis (NARR)

The North American Regional Reanalysis (NARR) is a comprehensive meteorological model created by the National Centers for Environmental Prediction (NCEP). This enhanced model and assimilation process result in significant improvements in the accuracy of temperature, winds, and precipitation data, compared to previous global reanalysis datasets. The NARR provides output that includes data eight times daily, covering a range of variables for the years 1979 to the present, including daily mean air temperature at the surface level (Kelvin degrees), daily total precipitation (kg/m^2, equivalent to mm), daily mean pressure (Pascals), and daily mean specific humidity (kg/kg).

The NARR dataset is particularly suitable for constructing wet-bulb temperatures in Mexico, as it includes essential parameters such as temperature, air pressure, and specific humidity. Specific humidity, which is the mass of water vapor per unit mass of air (including water vapor), is crucial for calculating relative humidity. Relative humidity, in turn, is a key component for determining wet-bulb temperature. The dataset's comprehensive coverage of these variables allows for the accurate application of the Stull method formula, which is used to calculate wet-bulb temperature in the equation. This capability makes the NARR dataset highly valuable for detailed climatic analysis in the Mexican region.

$$T_{wb} = T_{db} * atan\{0.151977 * (RH + 8.313658)^{\frac{1}{2}}\} + atan(T_{db} + RH) - atan(RH - 1.676331) + 0.00391838 * RH^{\frac{3}{2}} * atan(0.023101 * RH) - 4.686035 \tag{A.1}$$

where relative humidity (RH) is defined as

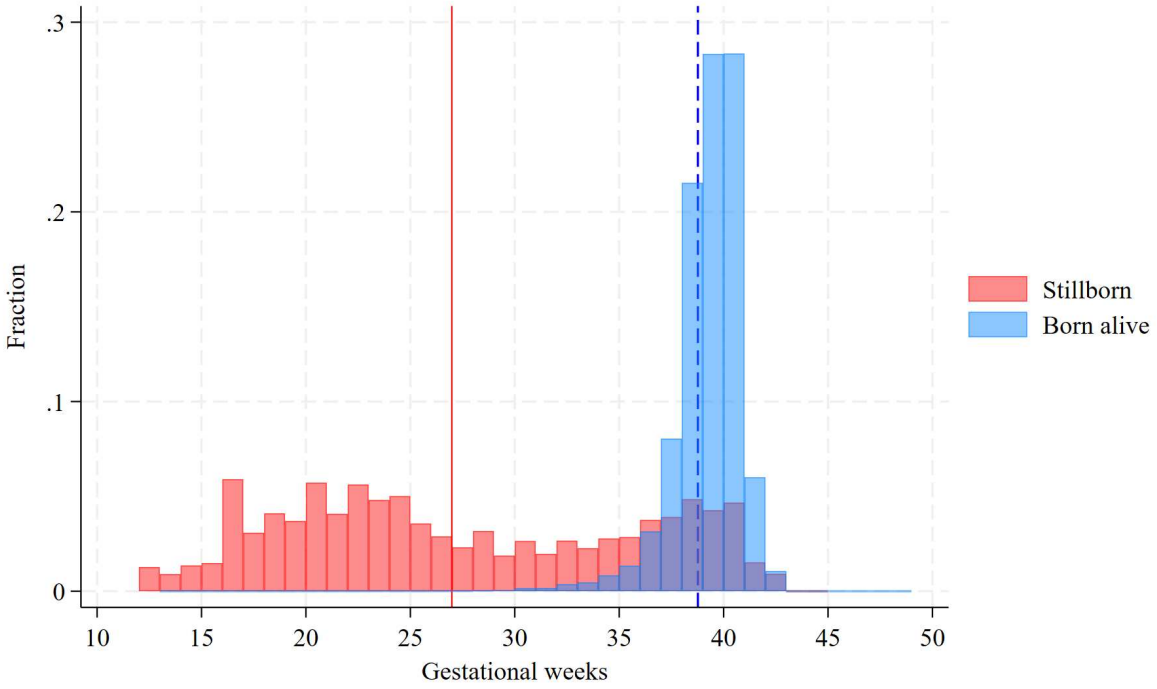
$$RH = 0.263 * PRES * SH * \{exp(\frac{17.67 * (T_{db} - 0.01)}{T_{db} - 243.5})\}^{-1} \tag{A.2}$$

and wet-bulb (T_{wb}) and dry-bulb (T_{db}) temperatures are in degrees in Celsius (°C), RH is in %, and air pressure ($PRES$) is in Pacals (Pa).

Within the framework of the Stull formula for constructing the wet-bulb temperature, two principal insights emerge. Firstly, the wet-bulb temperature, by definition, is the lowest temperature that can be reached through the process of evaporative cooling and is, therefore, always lower than the corresponding dry-bulb temperature. This characteristic reflects the wet-bulb temperature's role as a measure of the cooling potential of the air. Secondly, the relationship between wet-bulb and dry-bulb temperatures is not a straightforward linear one. This non-linearity means that a simple one-to-one comparison between the two temperature readings is not possible. Instead, this relationship is influenced by a complex set of atmospheric conditions including relative humidity, air pressure, and the thermal properties of water vapor, all of which affect the rate of evaporation and the consequent cooling effect.

B Supplementary Tables and Figures

Figure A1: Distribution of gestational age for live and stillbirths



Notes: This histogram depicts the distribution of gestational weeks at birth for two groups: stillbirths (red) and live births (blue). The x-axis represents the number of gestational weeks, while the y-axis represents the fraction of births in each group. The vertical red line indicates the rounded mean gestational age for stillbirths (39 weeks or 271 days), and the vertical blue dashed line indicates the rounded mean gestational age for live births (27 weeks or 189 days).

Table A1: Summary Statistics: Weather Variables

	Mean	SD	Min	5th	25th	Median	75th	95th	Max
Wet-bulb	15.36	4.90	-0.48	7.99	11.92	14.83	18.66	24.36	28.31
Dry-bulb	21.19	5.27	2.84	13.14	17.32	20.82	24.91	30.24	39.31
Relative humidity	56.14	16.76	9.04	25.57	44.31	58.00	69.33	80.71	91.44
Precipitation	2.49	2.89	0.00	0.01	0.22	1.33	4.05	8.21	26.15

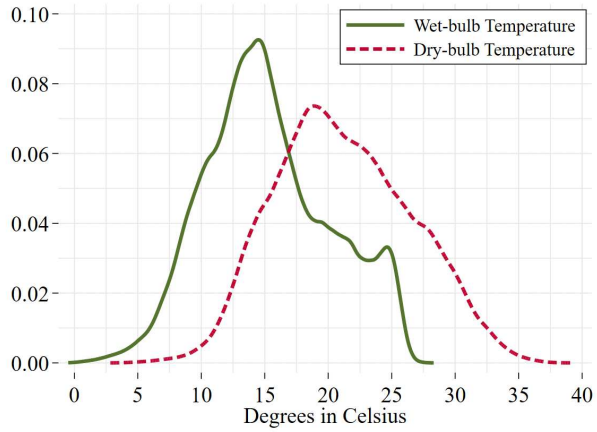
Notes: This table summarizes the descriptive statistics of the historic municipality by year-month climate measures for all the Mexico municipalities, from January 2007 to December 2022. Relative humidity is in % and precipitation is in millimeters (mm). Wet-bulb temperatures depicted are derived using the Stull formula, which is presented in Appendix A. The temperatures and relative humidity are calculated from daily mean values, aggregated at the municipality by year-month level. Precipitation is calculated from daily maximum values, aggregated at the municipality by year-month level. The terms 5th, 25th, Median (50th), 75th, and 95th represent each percentile, respectively.

Table A2: Heterogeneity by Demographic Characteristics of Newborn and Mother

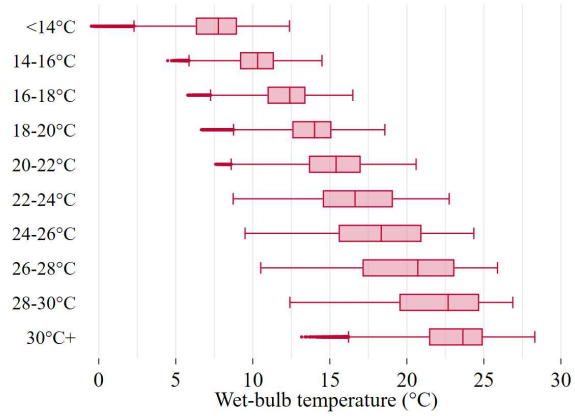
	Pooled	Gender (ref: Male)	Birth Order (ref: later-born)	Mother's Educ. (ref: < MS)	Mother's Age (ref: < 20 y.o.)
	(1)	(2)	(3)	(4)	(5)
24˚C+	-4.050***	-4.307***	-4.291***	-4.283***	-3.453***
	(0.552)	(0.633)	(0.597)	(0.742)	(0.766)
22-24˚C	-2.740***	-2.857***	-2.923***	-3.313***	-2.174***
	(0.520)	(0.569)	(0.545)	(0.671)	(0.720)
A. By Child's Gender					
24˚C+ x Female		0.536			
		(0.498)			
		[0.2818]			
22-24˚C x Female		0.245			
		(0.402)			
		[0.5422]			
B. By Child's Birth Order					
24˚C+ x First-born			0.545		
			(0.533)		
			[0.3067]		
22-24˚C x First-born			0.410		
			(0.489)		
			[0.4017]		
C. By Mother's Education Attainment					
24˚C+ x Less than HS [a]				0.181	
				(0.711)	
				[0.7993]	
22-24˚C x Less than HS				0.738	
				(0.634)	
				[0.2446]	
24˚C+ x HS or equiv. [b]				-0.0984	
				(0.869)	
				[0.9099]	
22-24˚C x HS or equiv.				0.413	
				(0.878)	
				[0.6381]	
24˚C+ x College+ [c]				0.892	
				(1.068)	
				[0.4038]	
22-24˚C x College+				1.283	
				(0.893)	
				[0.1511]	
D. By Mother's Age Group					
24˚C+ x Aged 20-34 y.o. [e]					-0.671
					(0.612)
					[0.2735]
22-24˚C x Aged 20-34 y.o.					-0.769
					(0.671)
					[0.1191]
24˚C+ x Aged 34 y.o.+ [f]					-1.615
					(1.035)
					[0.3095]
22-24˚C x Aged 34 y.o.+					-1.96
					(1.176)
					[0.2522]
$H_0 : a = b = c = 0$				[0.6220]	
$H_0 : e = f = 0$					[0.6662]
Obs.	24,947,124	24,944,461	24,944,703	24,958,076	24,942,510

Notes: The dependent variables presented in this table are birth weight (in grams). Column (1) show estimation results for the preferred specification in equation (1), while Columns (2) through (5) present estimation results with all the regressors interacted with a binary indicator for indicated child- or maternal characteristics. The interaction variables are child being female (ref.=male; Column (2)); child's birth order is the first (ref.=second or later; Column (3)); mother's education level categorized as less than high school ("Less than HS"), high school or equivalent ("HS or equiv."), college or above ("College+") (ref.=less than middle school ("< MS"); Column (4)); and mother's age at her child's birth being less than 20 to 34 years old, or 35 years or above (ref.=less than 20 y.o.; Column (5)). All specifications include birth municipality-conception month and birth state-birth year fixed effects, rainfall exposure during pregnancy, and the remaining mother and child characteristics. Temperatures are in wet-bulb metrics. While the table reports coefficients for only the two highest temperature bins, all the same bins used in equation (1) are included as regressors. Standard errors clustered at the birth municipality level are reported in parentheses, and p-values for testing the hypothesis that the corresponding coefficient is zero are reported in brackets unless a specific null hypothesis is indicated. $^{***}p < 0.01$,$^{**}p < 0.05$,$^{*}p < 0.1$.

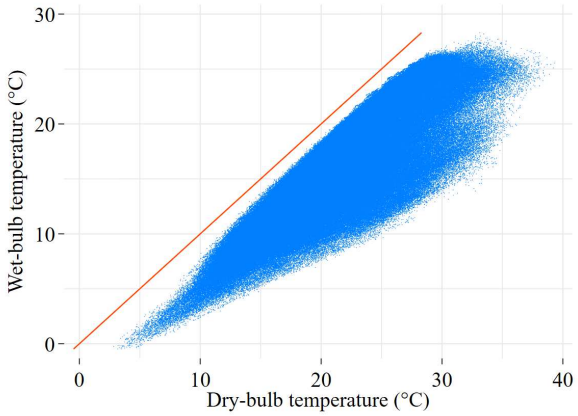
Figure A2: Sample Distribution of Wet-bulb and Dry-bulb Temperatures



(a) Distribution of wet-bulb Temperatures (horizontal) by dry-bulb temperature bins (vertical)



(b) Monthly mean degrees in Celsius by municipalities, 2000-2021



Notes: Observations depicted are the average wet-bulb temperature and dry-bulb temperatures, calculated monthly in each year for each municipality in Mexico, covering a period from 2000 to 2021.

Figure A3: Cross-municipality Variation in Wet-bulb Temperature

(**a**) August, 2008 (**b**) August, 2021

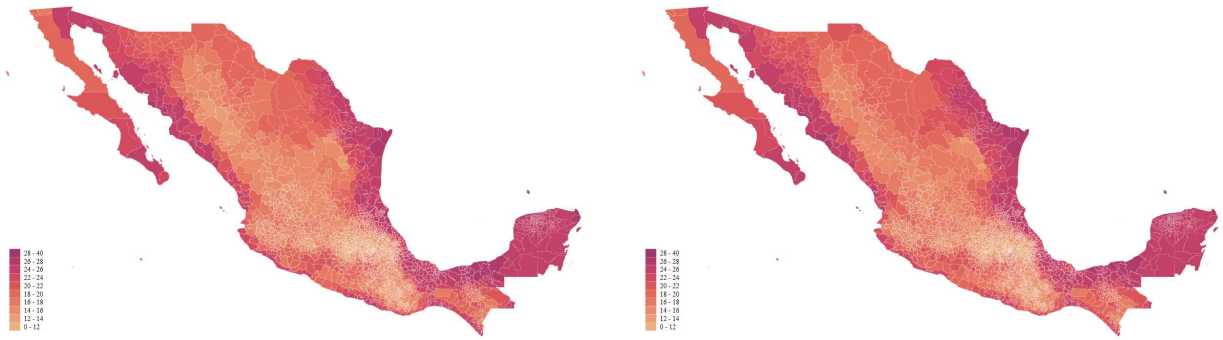
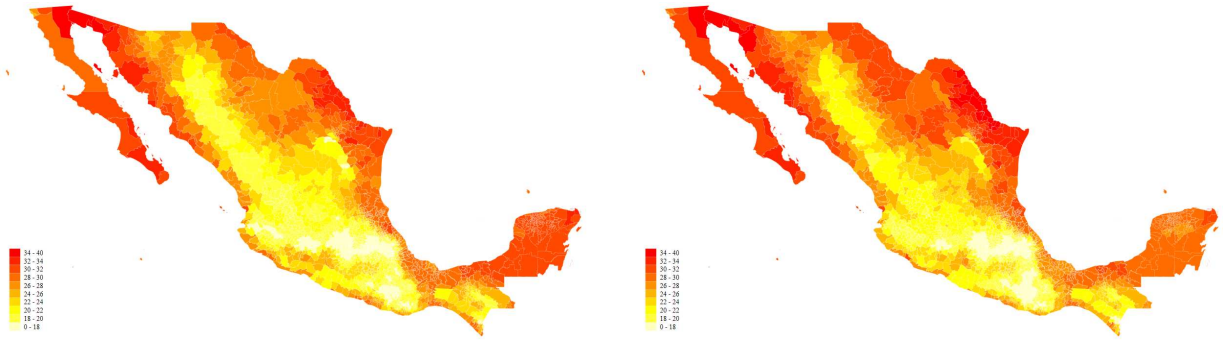


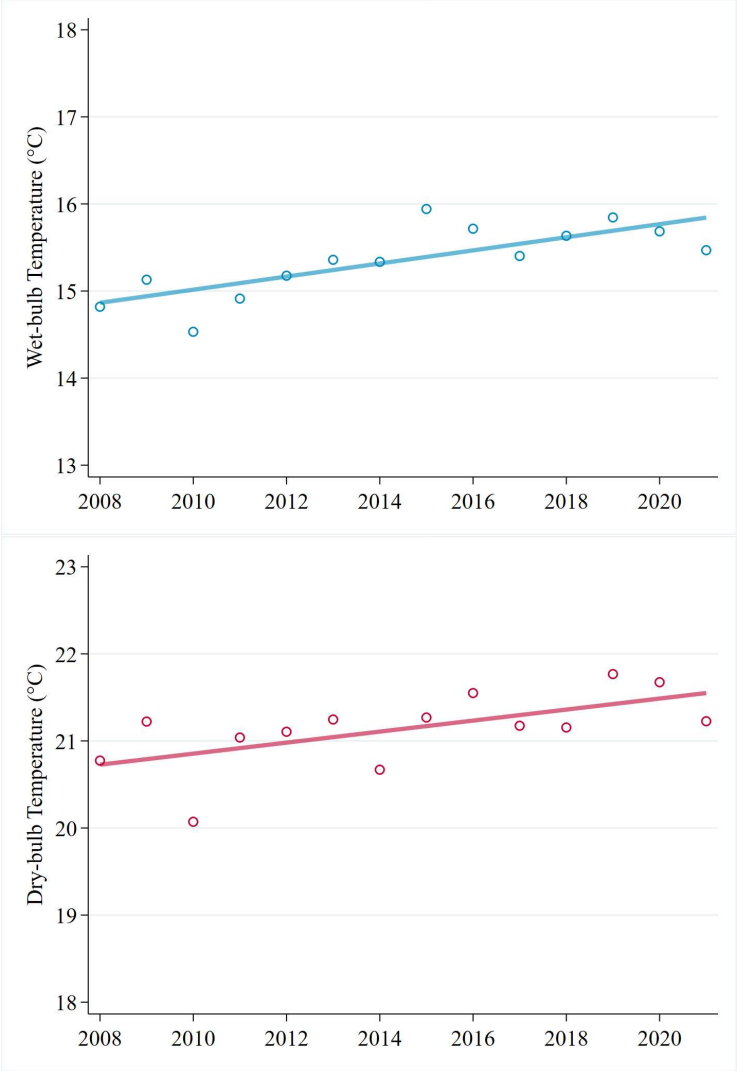
Figure A4: Cross-municipality Variation in Dry-bulb Temperature

(**a**) August, 2008 (**b**) August, 2021



Notes: Observations depicted are the average wet-bulb temperature and dry-bulb temperatures, calculated monthly in each year for each municipality in Mexico, comparing 2008 August and 2021 August.

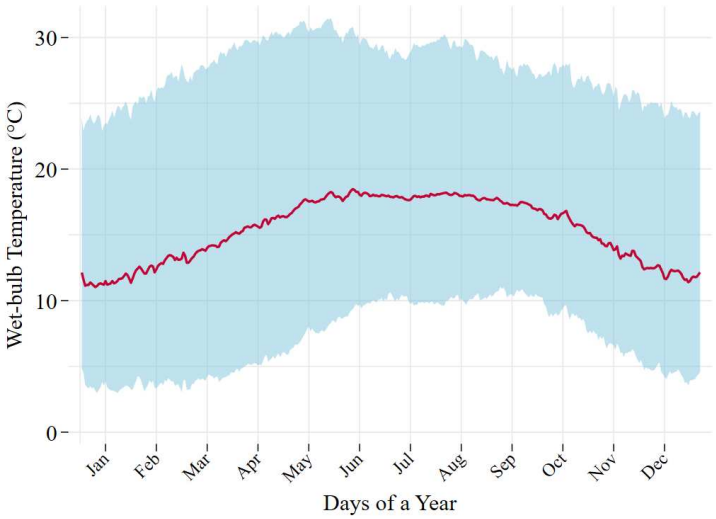
Figure A5: Annual variation in temperatures (2008-2021)



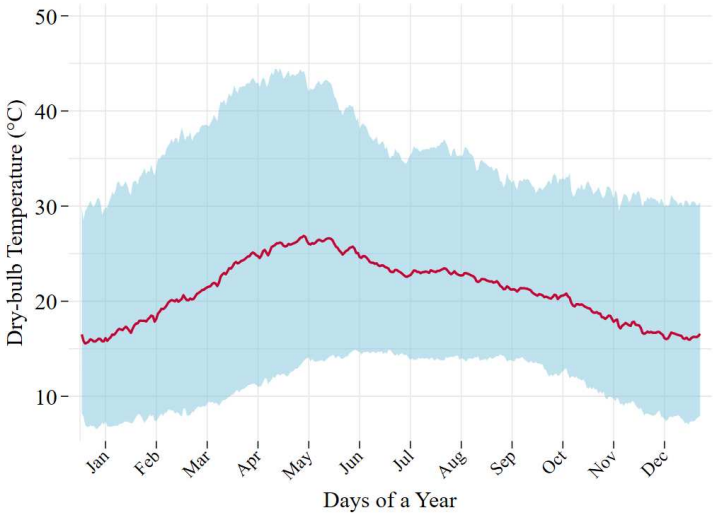
Notes: The figures display the annual variation in wet-bulb temperature (top) and dry-bulb temperature (bottom) in Mexico from 2008 to 2021. Circles represent the state-level aggregated annual temperatures, while the lines depict the linear trend.

Figure A6: Inter-annual variation in temperatures

(a) Wet-bulb temperature

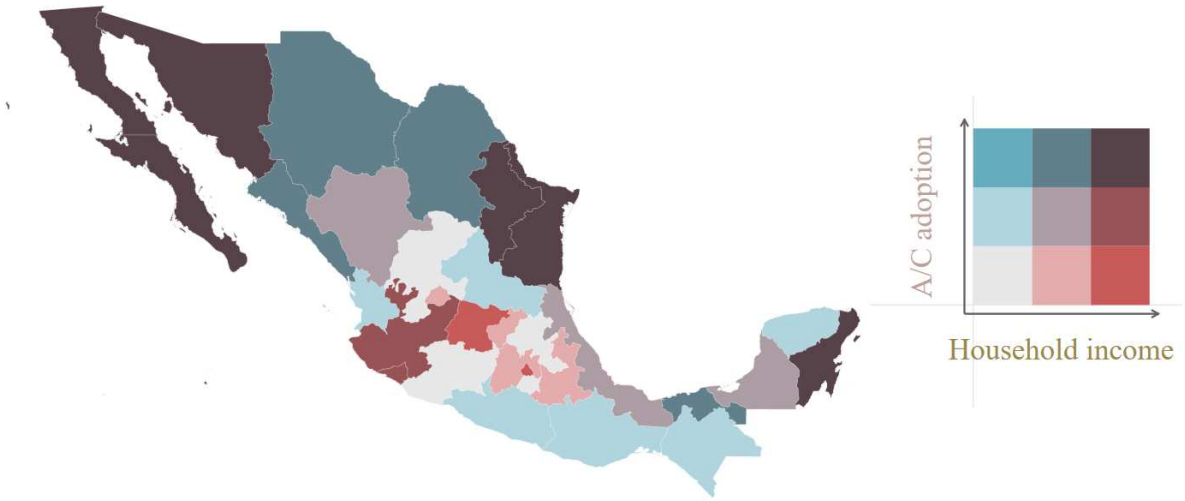


(b) Dry-bulb temperature



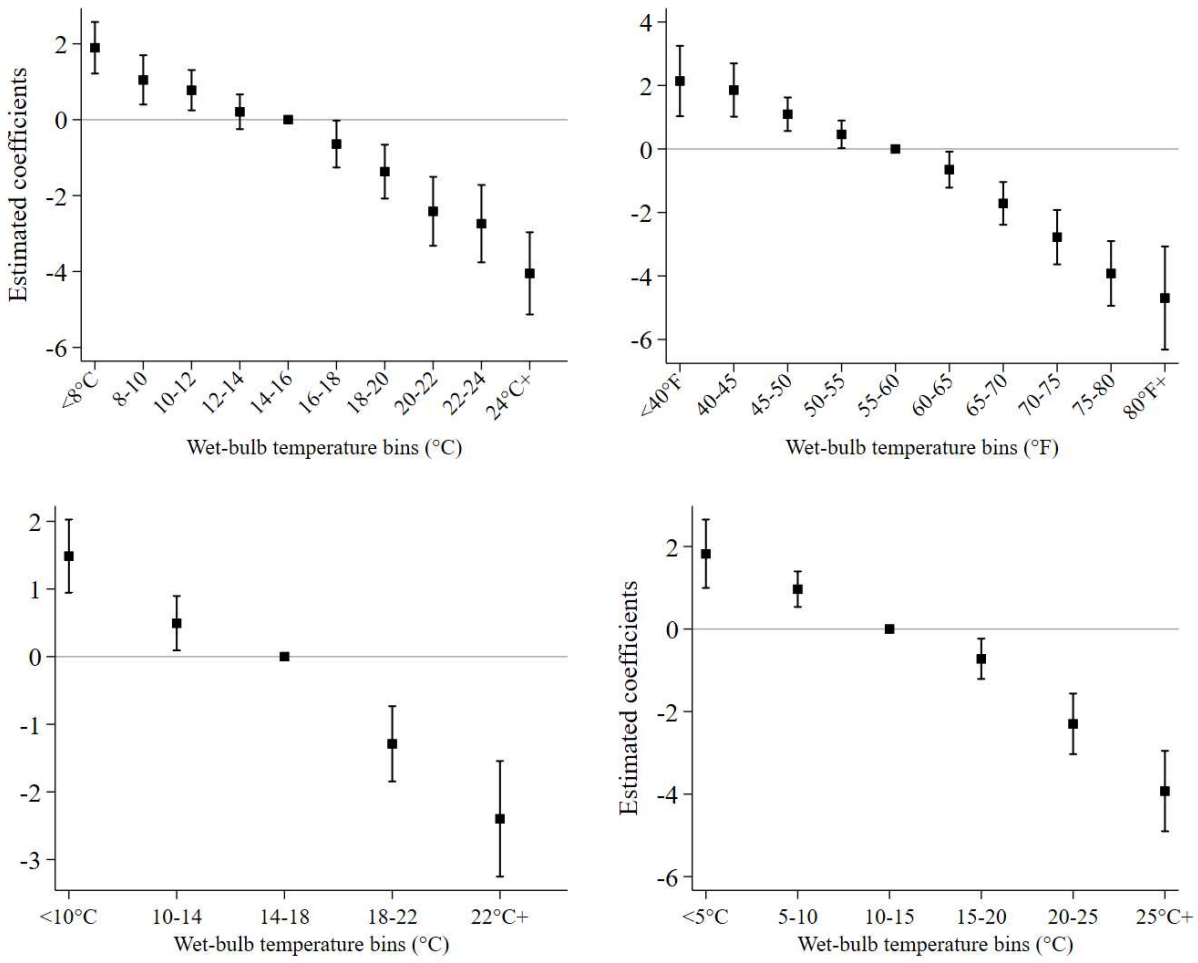
Notes: The figures show the inter-annual variation in wet-bulb temperature (top) and dry-bulb temperature (bottom) for each day of the year in Mexico, from January 1st to December 31st, averaged over the sample years from 2008 to 2021. The red line represents the average wet-bulb (or dry-bulb) temperature for each day, while the blue shaded area indicates the temperature range, with the top of the shaded area showing the maximum and the bottom showing the minimum temperatures observed for each day over the sample years.

Figure A7: Correlation between household income and air conditioning adoption



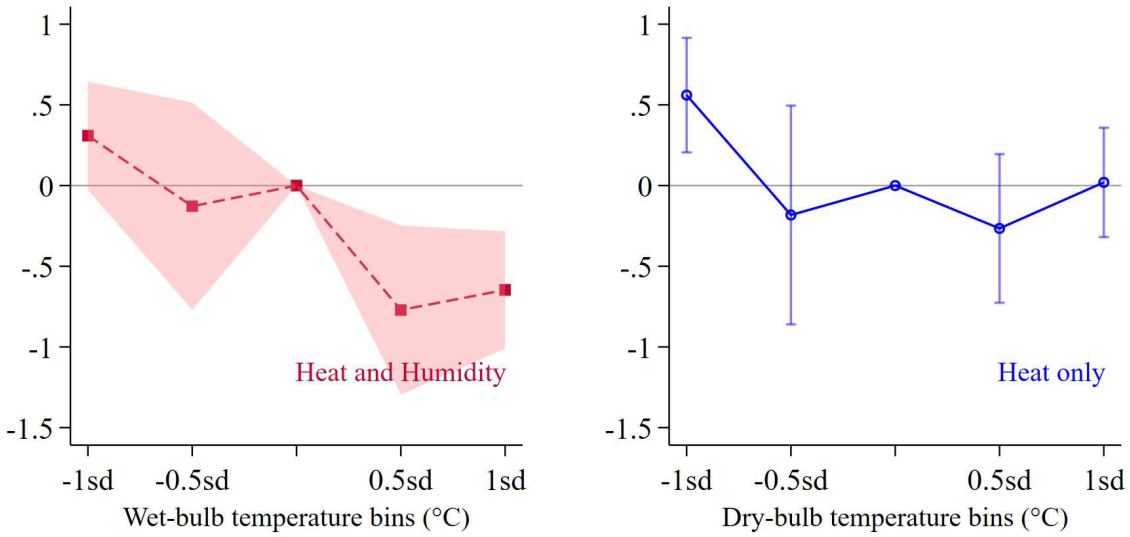
Notes: Each color shade corresponds to a distinct combination of two variables at the state level in Mexico: average household income (x-axis) and share of households equipped with air conditioning (y-axis), segmented into terciles to help comparison. The terciles divide the data into three equal parts for each variable at the state level. Data points are adjusted using survey weights to ensure representativeness. The source is 2016 ENIGH.

Figure A8: Robustness to Alternative Temperature Bins



Notes: These figures plot the estimated coefficients and the 95 percent confidence intervals using standard errors clustered at the birth municipality level. The dependent variable in all panels is birth weight (in grams). Temperature measures are in wet-bulb metrics, while the bins vary. Reference categories are presented without confidence intervals in each figure, as they are the omitted categories in each specification. All specifications include birth municipality-conception month and birth state-birth year fixed effects, as well as rainfall exposure during pregnancy and maternal and child characteristics.

Figure A9: Effects of Temperature Deviations from the Normal on Birth Weight: A Robustness Check



Notes: Temperature bins are constructed to capture the average number of days within each bin per month during pregnancy, with a total of five bins. The bins include days with temperatures less than -1 standard deviation from the normal, between -1 and -0.5 standard deviations from the normal, the middle temperature between -0.5 and 0.5 standard deviations (the omitted category), between 0.5 and 1 standard deviation, and greater than 1 standard deviation. The historical normal (mean value) and standard deviation of the temperatures are computed for each municipality and month-of-the-year over the sample years from 2007 to 2021. The left panel uses the wet-bulb temperature measure, capturing the combined effects of heat and humidity, while the right panel uses the conventional dry-bulb temperature measure, focusing on heat effects alone. The dependent variable in both panels is the birth weight (in grams). All specifications include birth municipality-conception month and birth state-birth year fixed effects, as well as rainfall exposure during pregnancy and maternal and child characteristics. The estimated coefficients and the 95 percent confidence intervals using standard errors clustered at the birth municipality level are plotted.

Table A3: Robustness to Alternative Specifications for Local Seasonality, Alternative Sample, and Mother's Migration Responses

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
24'C+	-4.050***	-4.406***	-4.048***	-3.288***	-4.275***	-3.756***	-2.626***
	(0.552)	(0.400)	(0.552)	(0.397)	(0.563)	(0.556)	(0.491)
22-24'C	-2.740***	-2.800***	-2.738***	-2.124***	-2.934***	-2.618***	-1.571***
	(0.520)	(0.355)	(0.520)	(0.387)	(0.533)	(0.520)	(0.442)
Municipality-Month FE	X		X		X	X	X
State-Year FE	X		X	X	X	X	X
Residential Municipality-Month FE		X					
Residential State-Year FE		X					
Municipality-Week FE				X			
Week polynomials			X				
Rainfall	X	X	X	X	X		X
Maternal / Child Demog.	X	X	X	X	X	X	X
Per Capita Public Expenses					X		
Full-term Babies Only							X
Obs.	24,947,124	25,335,149	24,947,124	24,938,713	22,371,792	24,947,124	23,396,809

Notes: The dependent variable is birth weight in grams. Column (1) presents the preferred specification in equation (1). Per capita public expenses, controlled for in Column (5), are at the municipality by year level, with prices adjusted by Mexico's annual CPI (base year=2018). Temperatures are in wet-bulb metrics. While the table reports coefficients only for the two highest temperature bins, all the same bins used in equation (1) are included as regressors. Standard errors are in parentheses, which are clustered at the birth municipality level. Significance levels are indicated as follows: $^{***}p < 0.01$,$^{**}p < 0.05$,$^{*}p < 0.1$.

Table A4: Correlation between Temperature Exposure and Mother's Characteristics

	Higher Educ.	Age	Indigenous	Partnered
	(1)	(2)	(3)	(4)
24°C+	-0.0000859	0.0586*	-0.00460	0.00428
	(0.00322)	(0.0328)	(0.00385)	(0.00295)
22-24°C	-0.000230	0.0552*	-0.00380	0.00420
	(0.00322)	(0.0334)	(0.00394)	(0.00291)
20-22°C	-0.00146	0.0517	-0.00458	0.00401
	(0.00320)	(0.0333)	(0.00409)	(0.00291)
Municipality-Month FE	X	X	X	X
State-Year FE	X	X	X	X
Other Controls				
Rainfall	X	X	X	X
Mother's education	X	X	X	
Mother's age	X		X	X
Child's sex	X	X	X	X
Child's birth order	X	X	X	X
Mean (Dep. Var.)	0.4331	25.48	0.0698	0.8945
Obs.	26,314,989	26,314,989	11,654,895	25,845,516

Notes: The dependent variable is birth weight in grams. Column (1) presents the preferred specification used in equation (1), which controls for birth municipality by conception month-of-the-year fixed effects and birth state by birth year fixed effects. Column (2) includes a control for the public expense variable, representing the yearly total expenses of each municipality. Temperatures are in wet-bulb metrics. While the table reports coefficients for only the two highest temperature bins, all the same bins used in equation (1) are included as regressors. Standard errors are in parentheses, which are clustered at the birth municipality level. Significance levels are indicated as follows: $^{***}p < 0.01$,$^{**}p < 0.05$,$^{*}p < 0.1$.

Table A5: Alternative Temperature Measure: Maximum Temperatures

	Weight	LBW(%)	Gestational age	Preterm(%)	Height	APGAR
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Wet-bulb Maximum						
34°C+	-0.273	-0.000823	0.00178	-0.00935	0.00473*	0.00126
(0.293)	(0.293)	(0.0127)	(0.0111)	(0.0153)	(0.00275)	(0.00161)
32-34°C	-0.237	0.0106	-0.00432	-0.00812	0.000588	0.00258
(0.325)	(0.325)	(0.0154)	(0.0127)	(0.0195)	(0.00308)	(0.00180)
Panel B. Dry-bulb Maximum						
45°C+	0.185	-0.0156*	0.0145*	-0.00549	-0.000268	0.000212
(0.182)	(0.182)	(0.00810)	(0.00784)	(0.0100)	(0.00174)	(0.00103)
42-45°C	-0.107	-0.00359	-0.0116	0.00603	0.00124	0.000297
(0.252)	(0.252)	(0.0108)	(0.0121)	(0.0187)	(0.00265)	(0.00134)

Notes: The dependent variables are defined as follows for each column: (1) birth weight (in grams), (2) incidence of low birth weight (less than 2,500 grams, multiplied by 100), (3) gestational age (in days), (4) incidence of preterm birth (less than 37 weeks, multiplied by 100), (5) birth height (in centimeters), and (6) APGAR score (ranging from 0 to 10). Panel A categorizes temperature exposure based on the monthly mean number of days with daily wet-bulb maximum temperatures falling within nine bins: <20°C, 20-22°C, 22-24°C, 24-26°C, 26-28°C, 28-30°C, 30-32°C, 32-34°C, and 34°C+. The reference category, which is excluded from each specification, is the 26-28°C bin. Panel B adopts a similar approach for daily dry-bulb maximum temperatures with nine bins: <24°C, 24-27°C, 27-30°C, 30-33°C, 33-36°C, 36-39°C, 39-42°C, 42-45°C, and 45°C+. Here, the reference category omitted is the 33-36°C bin. Controls include birth municipality-conception month-of-the-year and birth state-birth year fixed effects, as well as rainfall exposure during pregnancy, and mother and child characteristics. Standard errors are clustered at the birth municipality level. Significance levels are indicated as follows: $^{***}p < 0.01$,$^{**}p < 0.05$,$^{*}p < 0.1$.