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The Effect of Heat Waves on Economic Activity:

Evidence from Latin America

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Abstract

We document that extreme heat has an economically and statistically significant negative effect on economic growth in Latin America. In particular, we find that the magnitude of the negative impact is increasing in both the intensity and the duration of heat. Further, we find that the effect is driven by absolutely hot days (days above a given threshold in degrees Celsius) as opposed to days that are relatively hot for a given location (above a given number of standard deviations above the region's monthly mean temperature).

JEL classifications: Q5, Q54, Q51

Keywords: extreme heat, heat waves, economic activity, Latin America

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1 Introduction

A longstanding literature documents a negative relationship between average annual or seasonal temperature and economic activity (Dell et al., 2012; Burke et al., 2015; Colacito et al., 2019; Acevedo et al., 2020), particularly in areas with hotter climates (Burke et al., 2015; Colacito et al., 2019). However, climate change is also expected to change the distribution of temperature in ways that are not well captured by changes in mean annual and seasonal temperatures. In particular, climate change is expected to increase the intensity, duration, and frequency of heat waves. Due to the bell shape of the temperature distribution, a small increase in the mean coupled with an increase in variance flattens the bell curve and shifts it rightward, leading to a large increase in the number of extremely hot days.

Because extreme heat impacts physical and cognitive performance, heat waves could have a particularly large impact on economic activity. We use a panel regression framework at the sub-national (i.e., regional) level to identify the effect of extreme heat on economic growth in Latin America. We use an unbalanced panel of region-level (i.e., sub-national) data on gross regional product for 15 countries in Latin America from 1970 to 2010 from Gennaioli et al. (2014) and merge these data with hourly temperature, humidity, and precipitation data from ERA5 aggregated to the region level.

We document that extreme heat has an economically and statistically significant negative effect on economic growth. In particular, we find that the magnitude of the negative impact is increasing in both the intensity and the duration of heat. Further, we find that the effect is driven by absolutely hot days (days above a given threshold in degrees Celsius) as opposed to days that are relatively hot for a given location (above a given number of standard deviations above the region's monthly mean temperature).

Our primary results demonstrate that extreme heat reduces aggregate economic growth and that the magnitude of the effect is increasing in the intensity and duration of heat are consistent and robust across alternative specifications.

While several papers have documented a negative effect of extreme heat on worker productivity (Somanathan et al., 2021; Zhang et al., 2018), there is only one other paper that studies the effect of extreme heat on aggregate economic activity (Miller et al., 2021). Our paper differs from Miller et al. (2021) in three key ways. First, we study a more easily interpretable measure of extreme heat and heat waves. Second, in contrast to Miller et al. (2021) who focus on relative measures of extreme heat, we focus on absolute measures of extreme heat, which more closely reflect the physical effects of extreme heat. Third, we use high-frequency weather and economic data at the sub-national level to reduce the risk of masking incidents of extreme heat by averaging across time and space. This is especially important for geographically large nations and those with several distinct climate zones.

The remainder of the paper is structured as follows. Section 2 describes the data used in the analysis and Section 3 describes the empirical strategy. Section presents the results and Section 5 concludes.

2 Data

We use annual per-capita gross regional product (GRP) as a measure of economic activity at the region level (highest sub-national administrative level) from Gennaioli et al. (2014). The per-capita GRP is in current purchasing power ($US).[1] From these data, we use an unbalanced panel of 15 Latin American countries from 1970 to 2010. Specifically, the 15 countries in our sample are Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, Uruguay, and Venezuela. Brazil, Bolivia, Chile, Colombia, Ecuador, El Salvador, Honduras, Mexico, Nicaragua, Peru, Venezuela, and Uruguay have data covering a

[1] Gennaioli et al. (2014) convert GRP data into per-capita (current purchasing power) US$ values by multiplying national GDP in PPP terms by each region's share of national GDP and then dividing by the regional population.

subset of their regions. Appendix Table A1 describes the number of region-year observations in the sample for each country.

We use hourly temperature (degrees Celsius), humidity, and precipitation data from ERA5,[2] which provides time series reanalysis data at a high spatial resolution (0.25 degree x 0.25 degree grid cells). We use geospatial data from the Database of Global Administrative Areas (GADM, 2012) to aggregate the ERA5 gridded data to the region level by computing area-weighted averages. GADM is a high-resolution database of administrative areas that seeks to provides spatial data for all countries and sub-divisions. We use information on administrative borders at the highest-level below the nation state (level 1) to map ERA5 grid cells to administrative units.

We merge the weather data with the economic data at the region level, with a few exceptions in Brazil and Peru. As described in Appendix 5, there are some regions in Brazil and Peru that are aggregated together in the economic data. In these cases, we aggregated the weather data to the level of the economic data.

We create several sets of variables for the empirical analysis. First, we create variables for the annual mean temperature and seasonal mean temperatures by averaging all hourly temperatures within the year or the season at the region level. For all countries except El Salvador and Mexico, we define seasons as January-March (summer), April-June (fall), July-September (winter), October-December (spring). For Mexico and El Salvador, we define summer and winter as the reverse. Next, we create a variable for monthly precipitation by averaging the hourly precipitation across each calendar month at the region level.

Second, we use bins of the temperature distribution to investigate the impact of temperature on economic growth across the full distribution of temperature. Appendix Figure A1 shows the distributions of mean daily temperature and hourly temperature. We create two sets of five variables representing the number of hours or days in that year that fall into each bin of the hourly temperature distribution and of the mean daily temperature distribution. For hourly temperature, we define the five bins as follows. Bin 1 contains temperatures up to 7C, bin 2 ranges from 7C up to 15C, bin 3 ranges from 15C up to 22C, bin 4 ranges from 22C up to 30C, and bin 5 contains temperatures 30C and above. Because the mean daily temperature averages out the extreme values of the distribution of hourly temperature, the range of the mean daily temperature is not as wide. Therefore, for mean daily temperature, bin 1 contains temperatures up to 9C, bin 2 ranges from 9C up to 15C, bin 3 ranges from 15C up to 21C, bin 4 ranges from 21C up to 27C, and bin 5 contains temperatures 27C and above.

Third, we create a set of variables to focus on days with extreme hot temperature and to investigate the impact of increasing heat intensity. We create annual measures of the number of days with at least one hour above various thresholds (20C to 33C). Table 1 shows the number of region-days above each temperature threshold from 20C to 33C by country and shows that there is significant variation in the number of extreme hot days across countries.

Fourth, we create a set of variables to focus on heat waves and to investigate the impact of increasing duration of heat. We define a heat wave as consecutive days with at least one hour above a given temperature threshold. For each level of heat intensity (29C to 33C), we create annual measures of the number of heat waves of various durations (1 single day to 7 consecutive days). Figure 1 shows the number of heat waves in our sample of each duration (1 single day to 7 consecutive days) for each level of heat intensity (29C to 33C). The number of heat waves is decreasing in both the intensity and the duration, reflecting that more extreme heat waves are less frequent.

Fifth, we use each region's hourly temperature distribution to create a set of variables containing the annual number of days in which the maximum temperature falls 1.5, 1.75, or 2 standard deviations above the region's mean temperature to make a distinction between days that are relatively hot for a location and days that are hot in the absolute sense (i.e., above a specified degree C threshold).

We also calculate the heat index, which is a measure of how temperature feels to the human body when temperature is combined with relative humidity. We compute the relative humidity as in Alduchov and Eskridge (1996), and we compute the heat index as in Anderson et al. (2013)

[2]ERA5 is the fifth generation reanalysis for the global climate and weather for the past 8 decades from the European Centre for Medium-Range Weather Forecasts (ECMWF).

following the procedure from the National Weather Service.[3] There is a direct relationship between air temperature and relative humidity and the heat index, in which the heat index increases with increases in air temperature and/or relative humidity. Using the heat index, we create analogous variables capturing the average annual level of the heat index, the number of hours or days within each bin of the distribution of the heat index, measures of hot days, and measures of heat waves. Appendix Figure A1 shows the distributions of the mean daily heat index and the hourly heat index.

3 Empirical Strategy

We estimate panel regressions at the region level with region and year fixed effects and controlling for monthly precipitation. This allows us to isolate the plausibly exogenous effect of temperature changes within a region over time on economic growth while controlling for determinants of economic growth that are common across regions within a year.

In our first specification, we estimate the effect of annual temperature and annual heat index on the annual growth rate of GRP.

$$\Delta y_{i,t} = \alpha + \beta T_{i,t} + \gamma_i + \nu_t + \eta \sum_{m=1}^{12} \eta_m p_{i,m,t} + \lambda \Delta y_{i,t-1} + \epsilon_{i,t} \tag{1}$$

where $\Delta y_{i,t}$ is the growth rate of GRP in region i between year t and $t-1$, $T_{i,t}$ is the mean annual temperature or mean annual heat index in region i in year t, γ_i and $+\nu_t$ denote region and year fixed effects, $p_{i,t}$ is precipitation in region i in month m of year t, and $\Delta y_{i,t-1}$ is the lagged growth rate of GRP in region i, i.e., the growth rate of GRP in region i between year $t-1$ and $t-2$. Because growth rates of GRP are autocorrelated, we include the lagged dependent variable to control for autocorrelation in economic growth rates. The region fixed effects control for unobserved, time-invariant characteristics at the region level that affect economic growth and the year fixed effects control for determinants of economic growth that are common across regions within a year. We cluster standard errors by region.

In our second specification, we replace the annual temperature or heat index in equation (1) with five bins that contain the number of hours or days in each range of the distribution of mean daily temperature, mean daily heat index, hourly temperature, or hourly heat index.

$$\Delta y_{i,t} = \alpha + \sum_{k=1,2,4,5} \beta_k B_{i,t,k} + \gamma_i + \nu_t + \sum_{m=1}^{12} \eta_m p_{i,m,t} + \lambda \Delta y_{i,t-1} + \epsilon_{i,t} \tag{2}$$

We omit the third (middle) bin so we interpret the coefficients on the other four bins relative to the third bin. In particular, the coefficients, β_k represent estimates of the effect on GRP growth rates of replacing a day or hour with temperature (or heat index) in the middle (third) bin with a day or hour with temperature (or heat index) in another bin.

In our third specification, we replace annual temperature or heat index in equation (1) with the annual count of hot days or a specific intensity or the annual count of heat waves of a specific intensity and duration. We consider hot days and heat waves as defined by temperature and by the heat index. Because an extremely hot day will increase the average seasonal temperature, to isolate the effect of extreme heat on economic growth, we also control for mean seasonal temperatures.

$$\Delta y_{i,t} = \alpha + \beta C_{i,t} + \gamma_i + \nu_t + \sum_{m=1}^{12} \eta_m p_{i,m,t} + \sum_{s=1}^{4} \phi_s T_{i,s,t} + \lambda \Delta y_{i,t-1} + \epsilon_{i,t} \tag{3}$$

where $C_{i,t}$ is the number of hot days of a specific intensity or heat waves of a specific intensity and duration in region i in year t and $T_{i,s,t}$ is the mean temperature in region i in season s in year t.

[3] https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml

In our fourth specification, we add the annual count of the number of days 1.5, 1.75, or 2 standard deviations above the region's mean temperature to equation 3 to make a distinction between relative heat and absolute heat:

$$\Delta y_{i,t} = \alpha + \beta C_{i,t} + \beta R_{i,t} + \gamma_i + \nu_t + \sum_{m=1}^{12} \eta_m p_{i,m,t} + \sum_{s=1}^{4} \phi_s T_{i,s,t} + \lambda \Delta y_{i,t-1} + \epsilon_{i,t} \tag{4}$$

where $C_{i,t}$ is the number of hot days of a specific intensity and $R_{i,t}$ is the annual count of days on which the maximum temperature is 1.5, 1.75, or 2 standard deviations above the region's mean temperature.

Finally, we show that our results are robust to alternative specifications. In particular, due to the possibility of dynamic panel bias when including the lagged dependent variable in a regression (Nickell, 1981), we show that our results are robust to the exclusion of the lagged dependent variable. Further, we show that our main results are robust to more flexibly controlling for region trends by replacing the region fixed effects with quadratic regional trends in our regression specification.

4 Results

We begin by documenting that a higher mean annual temperature reduces the rate of economic growth. Column (1) of table 2 shows that increasing a region's annual mean temperature by 1 degree Celsius reduces the region's growth rate of GRP by 0.012 on average. Column (4) shows that the result for the annual mean heat index is consistent and of larger magnitude. Appendix Table A2 shows that this result is robust to the exclusion of the lagged dependent variable from the empirical specification.

Next, we investigate the effects of temperature across the full range of the temperature distribution on the growth rate of GRP. We find a negative and significant effect of extreme hot temperature on GRP that is consistent and robust to using bins defined by the distributions of mean daily temperature, hourly temperature, mean daily heat index, and hourly heat index. Column (2) of Table 2 shows that replacing a day with a moderate mean temperature between 15C and 21C with a day with mean temperature above 21C reduces the region's growth rate of GRP on average. Specifically, replacing a day with moderate mean temperature with a day with mean temperature between 21C and 27C reduces the growth rate of GRP by 0.00015, and replacing a day with moderate mean temperature with a day with mean temperature above 27C reduces the growth rate of GRP by 0.000369. Column (3) uses the distribution of hourly temperature and shows that the coefficients are very similar. However, because there are a greater number of hours in each bin per year than the number of days in a bin per year, the same magnitude coefficient reflects a much larger effect. Columns (5) and (6) show that the effects of the heat index on the growth rate of GRP are similar in magnitude and statistical significance to those of temperature. Appendix Table A2 shows that these results are robust to the exclusion of the lagged dependent variable from the empirical specification.

Because we find an economically and statistically significant effect of hot days, we focus on extreme heat in the rest of the analysis. First, we show that increasing the intensity of heat increases the magnitude of the negative effect of heat on the growth rate of GRP. Increasing the threshold used to define a single day as a hot day from 20C to 33C, we find a negative relationship between the intensity of heat and economic output, with a statistically significant negative effect starting at a maximum daily temperature of 28C (see Figure A6).[4] These results are robust to defining hot days based on the heat index (see Figure A3), including regional trends in the empirical specification (see Figure A4), controlling for annual mean temperature instead of seasonal mean temperatures (see Figure A5), and excluding the lagged dependent variable (see Figure A6). Second, in Figure 3, we investigate the impact of heat waves or consecutive hot days. Increasing the duration threshold used to define a heat wave from a single hot day to 7 consecutive days, we find a negative relationship between the duration of the heat wave and economic output. This result is robust to

[4]The results of each regression are shown in Appendix Table A3.

using a threshold of 29C, 30C, 31C, 32C, or 33C to define extreme heat.[5] The results are similar if we define a heat wave as consecutive hot days connected by a hot night. Specifically, Appendix Table **??** shows the results for a maximum day-time temperature of at least 32C and a minimum night-time temperature of at least 22C. Further, this result is robust to defining heat waves based on the heat index (see Figure A7), including regional trends in the empirical specification (see Figure A8), controlling for annual mean temperature instead of seasonal mean temperature (see Figure A9), and excluding the lagged dependent variable (see Figure A10).

Finally, we document that the negative effect of extreme heat on economic growth is primarily due to absolutely hot days as opposed to relatively hot days for a given region and month. Table 3 documents the results defining an absolutely hot day as a day with maximum temperature above 30C (column (1)), 31C (column (2)), 32C (column (3)), 33C (column (4)) and a relatively hot day as a day with maximum temperature above 1.5 standard deviations (Panel A), 1.75 standard deviations (Panel B), and 2 standard deviations (Panel C) above the region's monthly mean temperature. Across all panels and columns, there is a statistically significant negative effect of absolute hot days on the growth rate of GRP while there is no significant effect of relatively hot days on the growth rate of GRP.[6]

5 Conclusion

Extreme heat has a significant negative effect on economic growth. The magnitude of the negative effect is increasing in both the intensity and duration of heat. The effect is primarily due to absolutely hot days as opposed to days that are abnormally hot for a location and time. These results suggest that adapting to extreme heat is challenging and that the negative impact of extreme heat on economic growth is likely to persist.

[5] The results of each regression are shown in Appendix Table A4.

[6] Appendix Table **??** shows the effects of including only absolutely hot days or only relatively hot days in the empirical specification. In contrast to the negative effect of absolutely hot days in columns (1)-(4), columns (5)-(7) show that relatively hot days have no significant effect on the growth rate of GRP.

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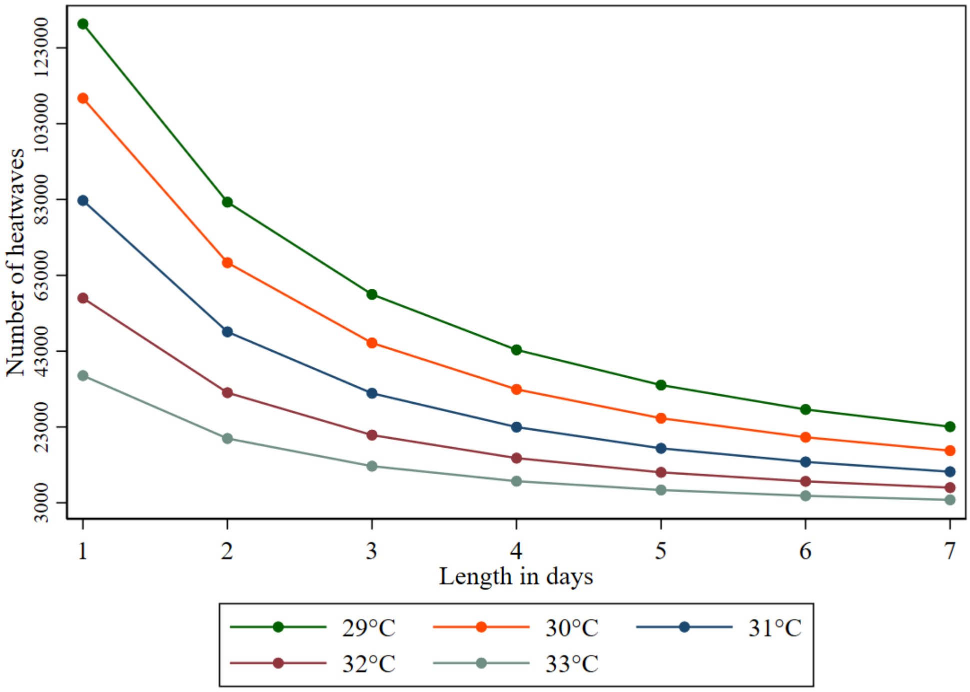
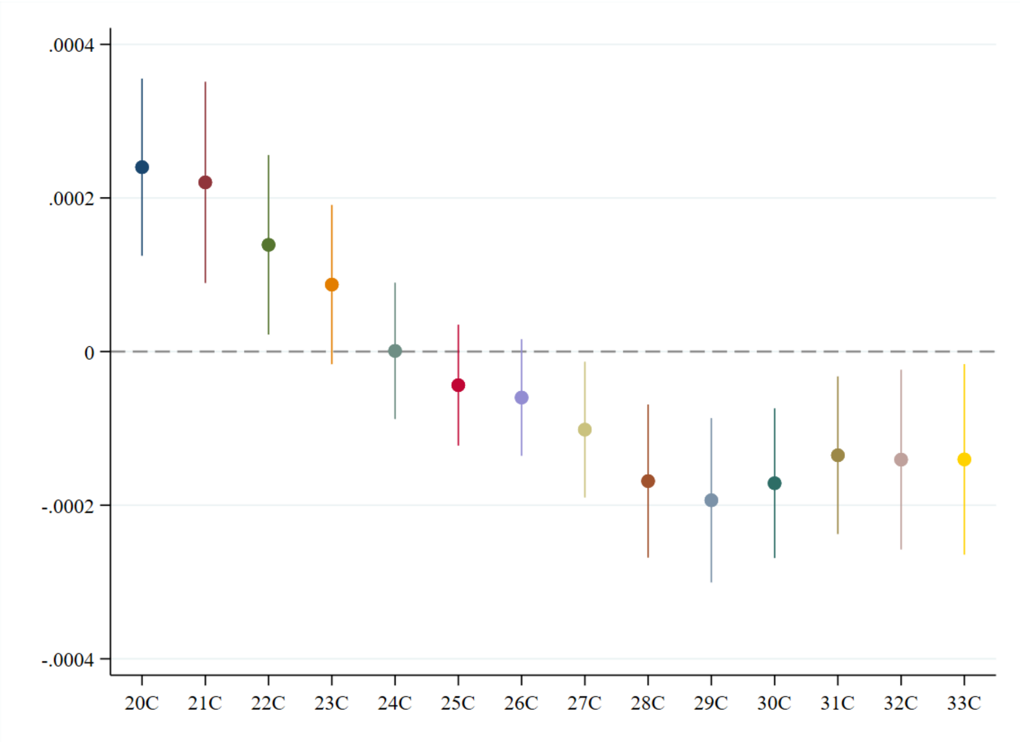
Figures

Figure 1: Number of Heatwaves by Intensity and Duration



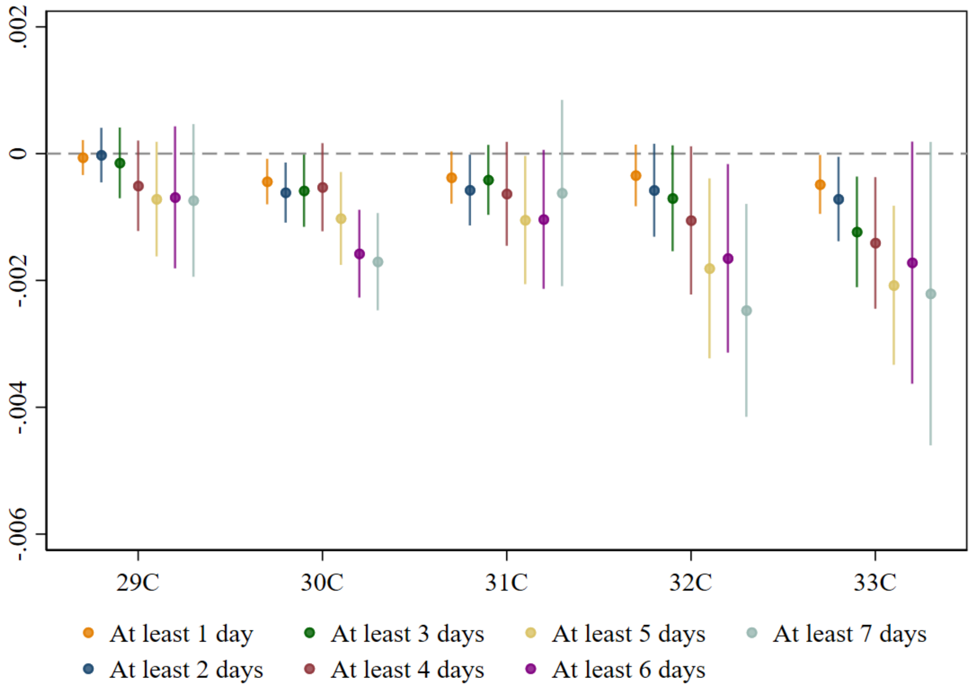
Notes: The figure shows the number of heatwaves of each intensity and duration present in the data for the 272 regions from 1970 to 2010. A heatwave is defined as consecutive days with at least 1 hour above the threshold (in degrees Celsius).

Figure 2: Effect of Hot Days on the Growth Rate of GRP



Notes: Each dot represents the coefficient from a separate regression of the annual count of days with at least 1 hour above the threshold (in degrees Celsius) on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable, and includes year and region fixed effects. Standard errors are clustered by region.

Figure 3: Effect of Heatwaves on the Growth Rate of GRP by Intensity and Duration



Notes: Each dot represents the coefficient from a separate regression of the annual count of heatwaves of each intensity and duration on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable, and includes year and region fixed effects. Standard errors are clustered by region.

Tables

Table 1: Number of Region-Days above Each Temperature Threshold (degrees Celsius)

Panel A							
	20C	21C	22C	23C	24C	25C	26C
Argentina	4,635	4,218	3,810	3,412	3,020	2,640	2,265
Bolivia	2,229	2,052	1,849	1,642	1,458	1,314	1,192
Brazil	7,012	6,926	6,816	6,674	6,490	6,232	5,864
Chile	930	619	382	226	128	64	26
Colombia	7,889	7,511	6,947	6,164	5,309	4,569	3,964
Ecuador	4,240	3,944	3,666	3,275	2,779	2,218	1,604
El Salvador	5,113	5,113	5,112	5,109	5,095	5,062	4,997
Guatemala	7,699	7,412	6,956	6,306	5,460	4,617	3,839
Honduras	5,766	5,708	5,616	5,468	5,241	4,868	4,306
Mexico	10,243	9,847	9,363	8,778	8,094	7,306	6,403
Nicaragua	2,557	2,557	2,556	2,553	2,540	2,500	2,390
Panama	3,287	3,285	3,275	3,237	3,158	3,031	2,855
Peru	3,683	3,263	2,912	2,614	2,296	1,937	1,570
Uruguay	4,242	3,863	3,470	3,073	2,671	2,277	1,899
Venezuela	7,611	7,514	7,390	7,293	7,174	6,884	6,411
Panel B							
	27C	28C	29C	30C	31C	32C	33C
Argentina	1,908	1,566	1,254	975	732	528	366
Bolivia	1,080	948	793	612	420	249	136
Brazil	5,356	4,679	3,818	2,855	1,944	1,175	579
Chile	9	3	1	0	0	0	0
Colombia	3,421	2,853	2,173	1,410	727	297	101
Ecuador	1,027	549	243	98	38	12	3
El Salvador	4,858	4,547	3,938	3,089	2,195	1,410	816
Guatemala	3,108	2,339	1,583	962	540	286	146
Honduras	3,556	2,764	2,011	1,372	887	520	278
Mexico	5,430	4,440	3,512	2,690	1,978	1,369	876
Nicaragua	2,139	1,715	1,264	904	614	370	201
Panama	2,571	1,998	1,216	562	236	101	32
Peru	1,229	886	528	252	96	29	6
Uruguay	1,532	1,193	886	626	420	264	156
Venezuela	5,680	4,756	3,682	2,582	1,634	947	526

Notes: Number of days in each country (summing all regions) with at least one hour above each threshold averaged across the years 1970-2010.

Table 2: Effects of Temperature and Heat Index on the Growth Rate of GRP

	Temperature			Heat Index		
	(1) Annual Mean	(2) Daily Mean	(3) Hourly	(4) Annual Mean	(5) Daily Mean	(6) Hourly
Annual Mean	-0.0118***			-0.00722***		
	(0.00271)			(0.00141)		
Bin 1		-0.0000453	0.00000553		0.0000312	0.0000129*
		(0.0000936)	(0.00000742)		(0.0000995)	(0.00000777)
Bin 2		-0.0000396	0.00000487		0.0000963	0.00000942*
		(0.0000586)	(0.00000567)		(0.0000653)	(0.00000535)
Bin 4		-0.000153***	-0.0000135***		-0.000148***	-0.0000152***
		(0.0000553)	(0.00000514)		(0.0000542)	(0.00000431)
Bin 5		-0.000351***	-0.0000341***		-0.000355***	-0.0000347***
		(0.0000851)	(0.00000752)		(0.0000815)	(0.00000749)
Lag of the GRP growth rate	0.0946***	0.0934***	0.0913***	0.0934***	0.0922***	0.0910***
	(0.0318)	(0.0316)	(0.0317)	(0.0317)	(0.0316)	(0.0316)
Observations	7416	7416	7416	7416	7416	7416
R^2	0.132	0.138	0.139	0.133	0.139	0.140

Notes: Columns (1) and (4) present the effect of the average annual temperature and heat index, respectively, on the growth rate of per capita GRP. The independent variables in Columns (2) and (5) correspond to the number of days that the daily mean temperature and the daily mean heat index fall into a given range. In Column (2), the bins are: below 9C (Bin 1), equal to 9C and up to 15C (Bin 2), equal to 21C and up to 27C (Bin 4), or above 27C (Bin 5). In Column (5), the bins are: below 7C (Bin 1), equal to 7C and up to 14C (Bin 2), equal to 21C and up to 28C (Bin 4), or above 28C (Bin 5). The independent variables in Columns (3) and (6) correspond to the number of hours that the temperature and the heat index fall into a given range. In Column (3), the bins are: below 7C (Bin 1), equal to 7C and up to 15C (Bin 2), equal to 22C and up to 30C (Bin 4), or above 30C (Bin 5). In Column (6), the bins are: below 5C (Bin 1), equal to 5C and up to 14C (Bin 2), equal to 23C and up to 32C (Bin 4), or above 32C (Bin 5). All regressions control for monthly precipitation and the lagged dependent variable and include year and region and year fixed effects. Standard errors in parentheses are clustered by region. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$.

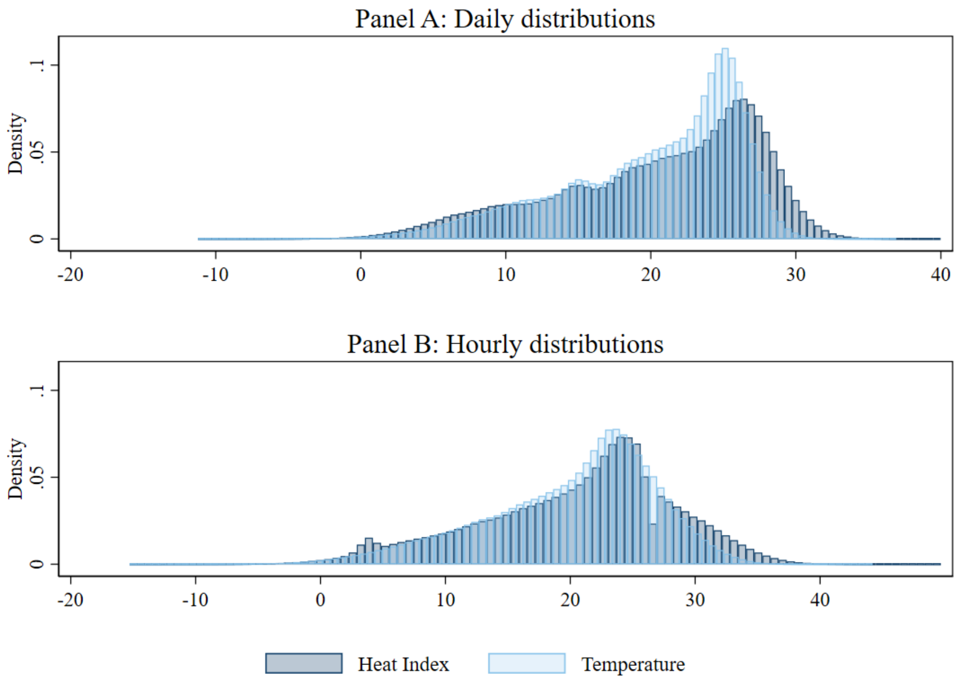
Table 3: Effect of Relative and Absolute Hot Days on the Growth Rate of GRP

	30C	31C	32C	33C
	(1)	(2)	(3)	(4)
Panel A : Maximum daily temperature 1.5 standard deviations above the monthly mean				
Relative hot days	-0.0000266	0.00000889	-0.000113	-0.000154
	(0.000245)	(0.000229)	(0.000214)	(0.000209)
Absolute hot days	-0.000170***	-0.000128**	-0.000150**	-0.000168**
	(0.0000581)	(0.0000609)	(0.0000725)	(0.0000778)
Days both relatively and absolutely hot	-0.000101	-0.000234	0.000230	0.000618
	(0.000360)	(0.000414)	(0.000427)	(0.000374)
Lag of the GRP growth	0.0910***	0.0917***	0.0923***	0.0930***
	(0.0316)	(0.0316)	(0.0316)	(0.0316)
Observations	7416	7416	7416	7416
R^2	0.140	0.140	0.139	0.139
Panel B : Maximum daily temperature 1.75 standard deviations above the monthly mean				
Relative hot days	0.0000953	0.000186	0.0000514	0.0000191
	(0.000374)	(0.000380)	(0.000368)	(0.000323)
Absolute hot days	-0.000171***	-0.000133**	-0.000143**	-0.000149*
	(0.0000589)	(0.0000616)	(0.0000711)	(0.0000767)
Days both relatively and absolutely hot	-0.0000472	-0.000300	0.000176	0.000516
	(0.000509)	(0.000576)	(0.000745)	(0.000746)
Lag of the GRP growth	0.0911***	0.0919***	0.0923***	0.0928***
	(0.0316)	(0.0316)	(0.0316)	(0.0316)
Observations	7416	7416	7416	7416
R^2	0.140	0.140	0.139	0.139
Panel C : Maximum daily temperature 2 standard deviations above the monthly mean				
Relative hot days	-0.000369	-0.000189	-0.000266	-0.000536
	(0.000563)	(0.000537)	(0.000519)	(0.000478)
Absolute hot days	-0.000171***	-0.000135**	-0.000142**	-0.000151**
	(0.0000592)	(0.0000621)	(0.0000703)	(0.0000743)
Days both relatively and absolutely hot	0.000560	0.000173	0.000590	0.00247**
	(0.000914)	(0.000899)	(0.000980)	(0.00112)
Lag of the GRP growth	0.0911***	0.0920***	0.0922***	0.0926***
	(0.0315)	(0.0315)	(0.0315)	(0.0315)
Observations	7416	7416	7416	7416
R^2	0.140	0.140	0.139	0.140

Note: Each panel and column represents a separate regression of the annual count of relatively hot days, the annual count of absolutely hot days, and the annual count of days that are both relatively and absolutely hot on the growth rate of per capita GRP. A relative hot day is defined as a day in which the maximum temperature was 1.5 standard deviations above the monthly temperature mean (in Panel A), 1.75 standard deviations above (in Panel B), and 2 standard deviations above the mean (in Panel C). Absolute hot days are defined as days in which the maximum temperature was above 30C (in column (1)), 31C (in column (2)), 32C (in column (3)), and 33C (in column (4)). Regressions control for monthly precipitation and mean seasonal temperatures and include year and region fixed effects. Standard errors in parentheses are clustered by region. * p < 0.1, ** p < 0.05, *** p < 0.001.

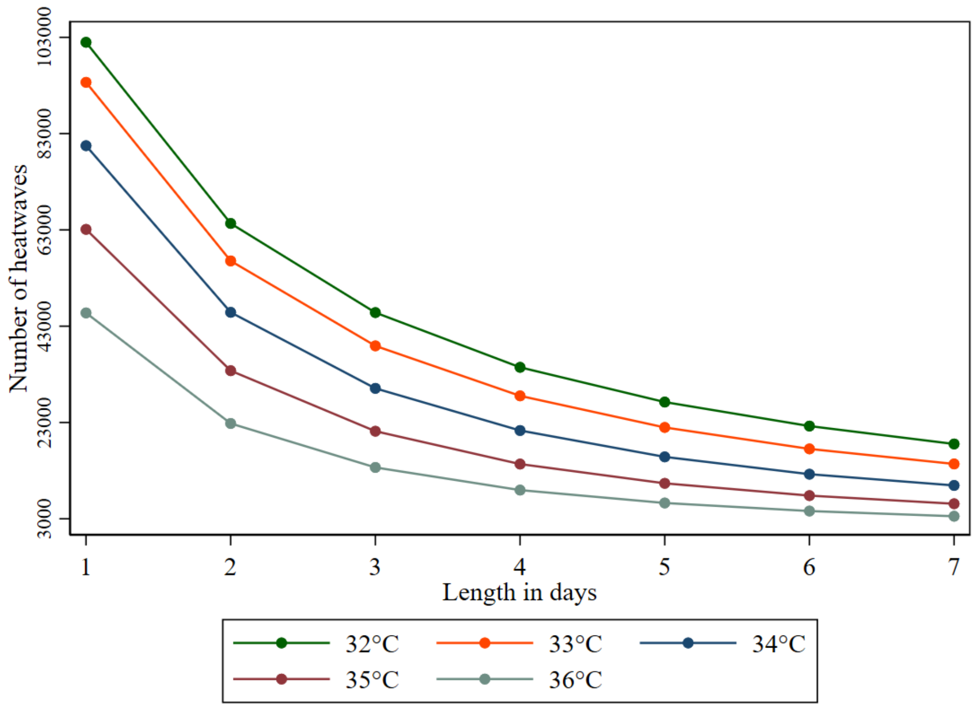
Appendix Figures

Figure A1: Distributions of Daily Mean and Hourly Temperature and Heat Index



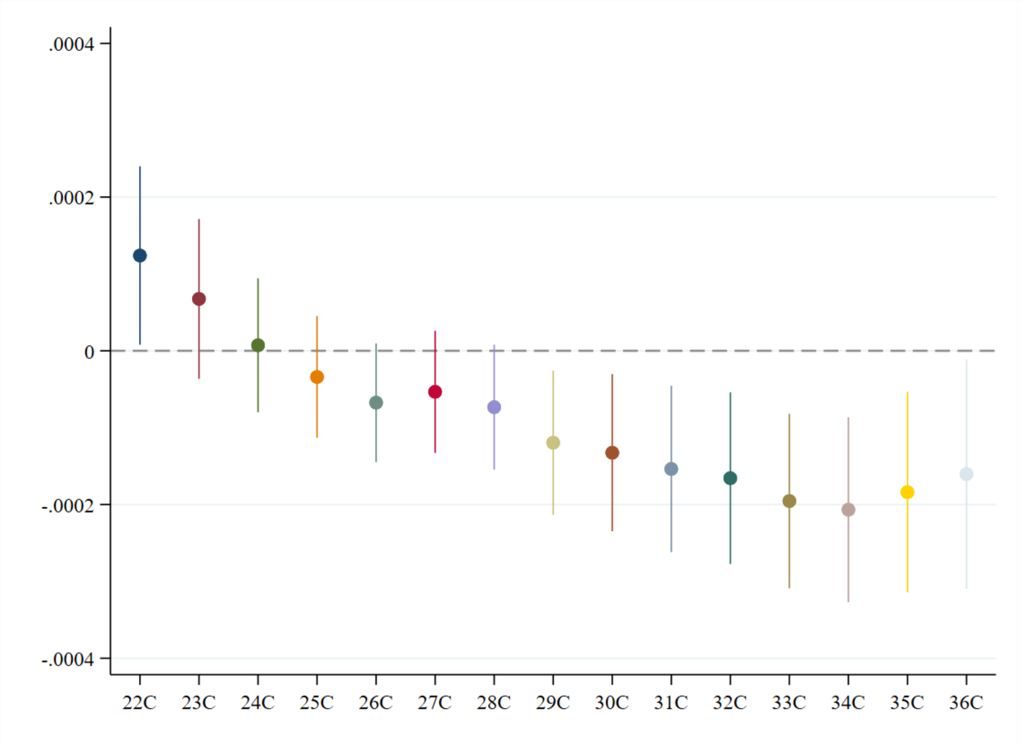
Notes: Panel A shows the distributions of the daily mean temperature and the daily mean heat index from 1970-2010. Panel B shows the distributions of the hourly temperature and the hourly heat index from 1970-2010.

Figure A2: Number of Heatwaves by Heat Index Intensity and Duration



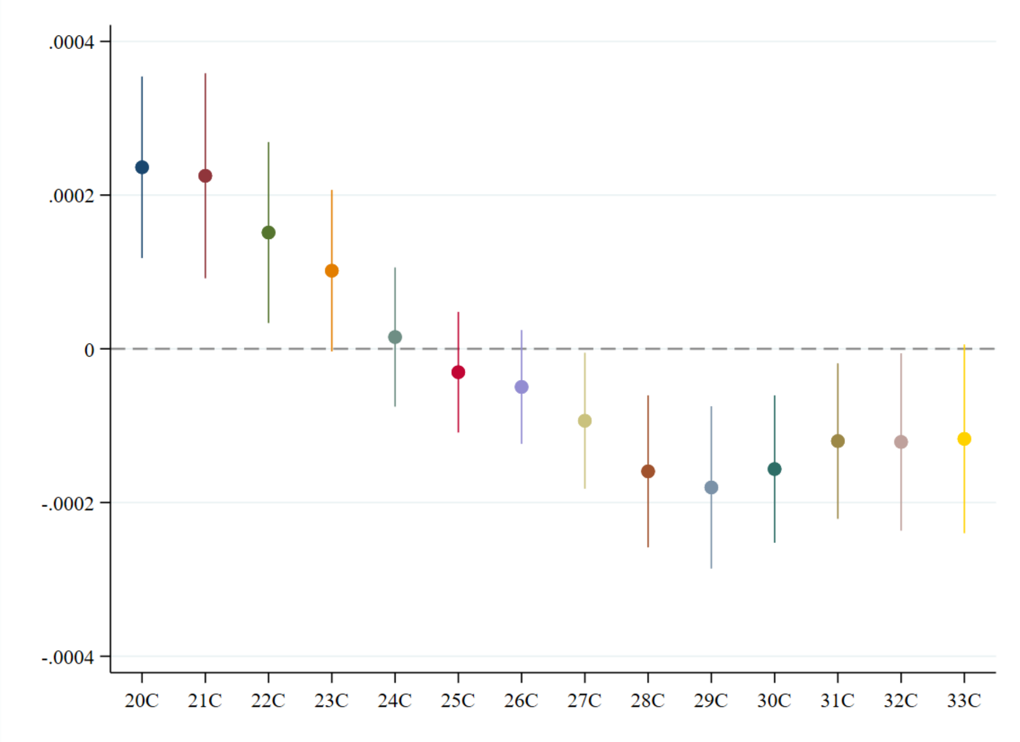
Notes: The figure shows the number of heatwaves of each heat index intensity and duration present in the data for the 272 regions from 1970 to 2010. A heat wave is defined as consecutive days with at least 1 hour of heat index above the threshold (in degrees Celsius).

Figure A3: Effect of Hot Days (defined by the heat index) on the Growth Rate of GRP



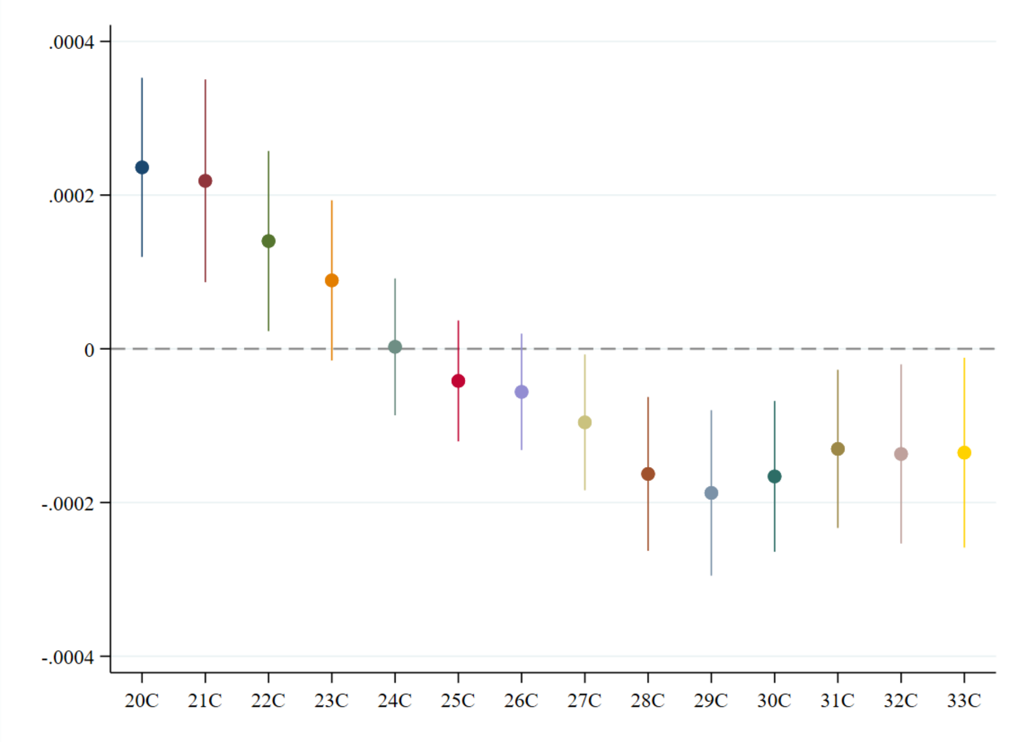
Notes: Each dot represents the coefficient from a separate regression of the annual count of days with at least 1 hour of heat index above the threshold (in degrees Celsius) on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable and includes year and region fixed effects. Standard errors are clustered by region.

Figure A4: Effect of Hot Days on the Growth Rate of GRP Including Regional Trends



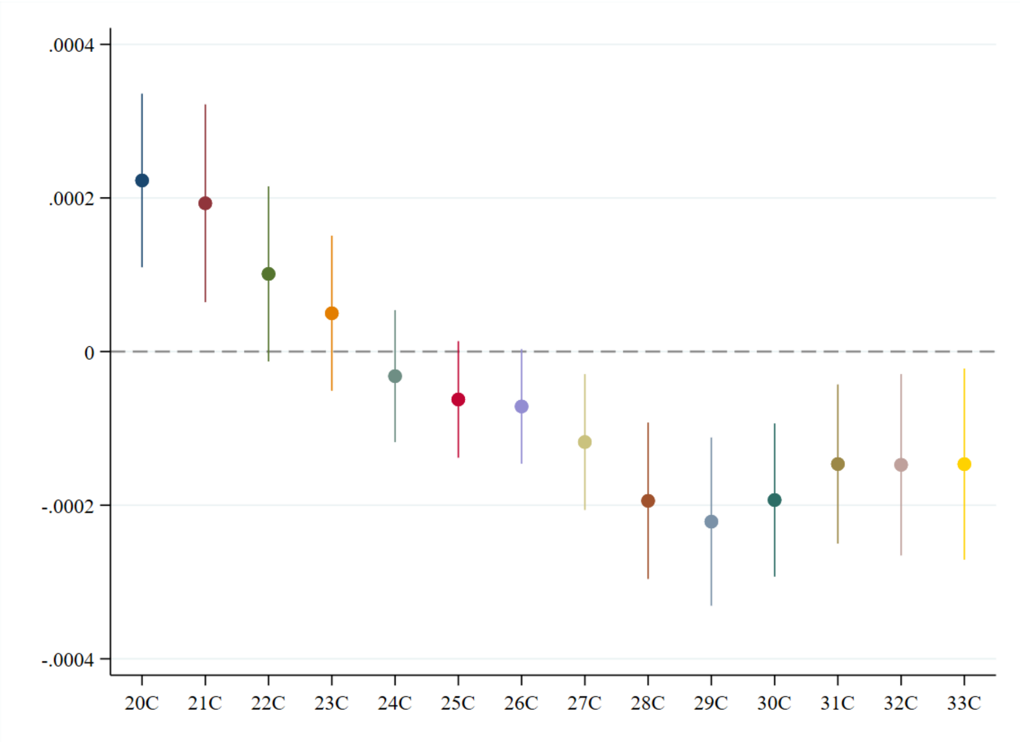
Notes: Each dot represents the coefficient from a separate regression of the annual count of days with at least 1 hour of temperature above the threshold (in degrees Celsius) on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable and includes year and region fixed effects and linear and quadratic region trends. Standard errors are clustered by region.

Figure A5: Effect of Hot Days on the Growth Rate of GRP Controlling for Annual Temperature



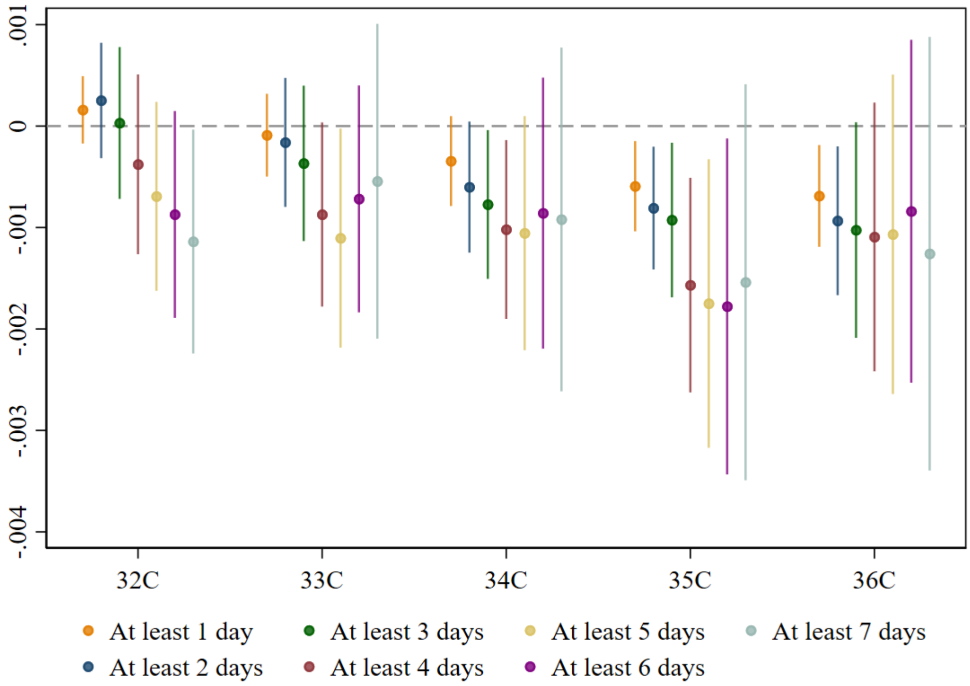
Notes: Each dot represents the coefficient from a separate regression of the annual count of days with at least 1 hour of temperature above the threshold (in degrees Celsius) on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean annual temperature, and the lagged dependent variable and includes year and region fixed effects. Standard errors are clustered by region.

Figure A6: Effect of Hot Days on the Growth Rate of GRP



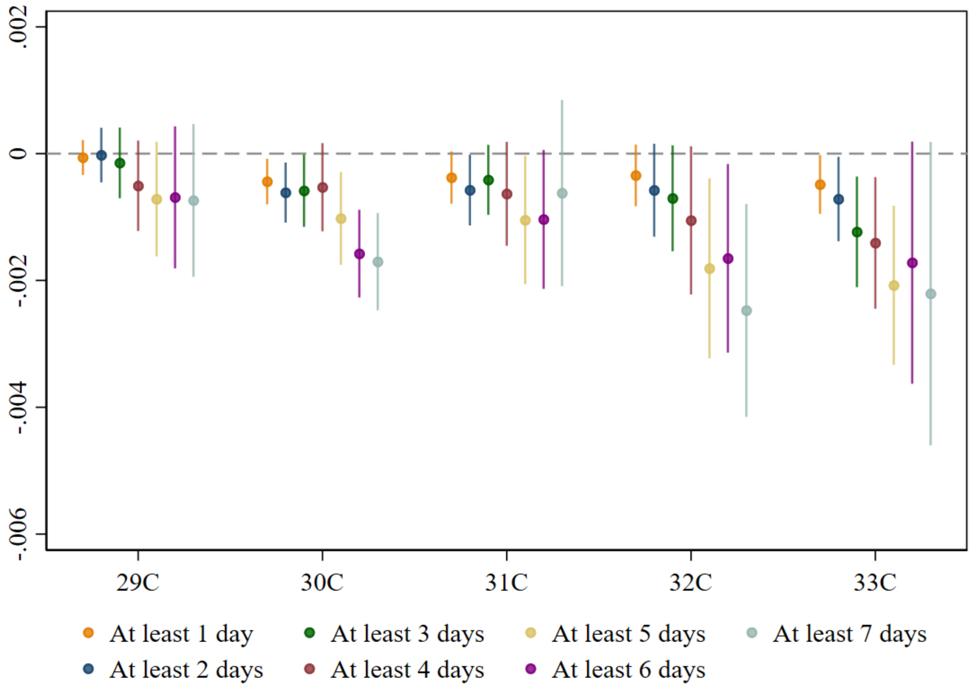
Notes: Each dot represents the coefficient from a separate regression of the annual count of days with at least 1 hour above the threshold (in degrees Celsius) on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean seasonal temperatures, and includes year and region fixed effects. Standard errors are clustered by region.

Figure A7: Effect of Heatwaves Defined by the Heat Index on the Growth Rate of GRP by Intensity and Duration



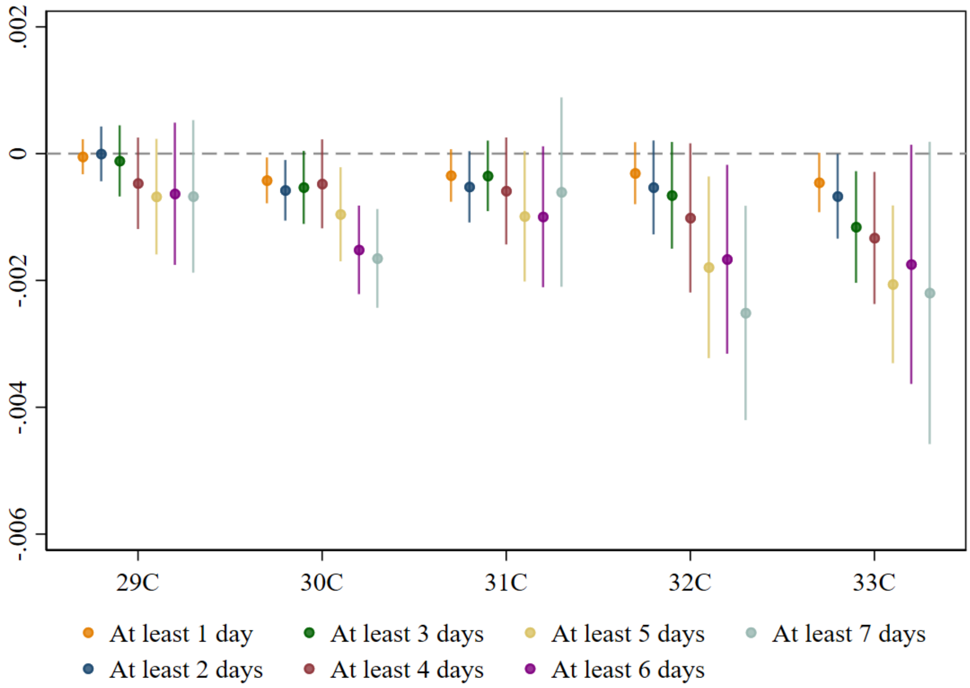
Notes: Each dot represents the coefficient from a separate regression of the annual count of heatwaves defined by the heat index of each intensity and duration on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable and includes year and region fixed effects. Standard errors are clustered by regions.

Figure A8: Effect of Heatwaves on the Growth Rate of GRP by Intensity and Duration Controlling by Regional Trends



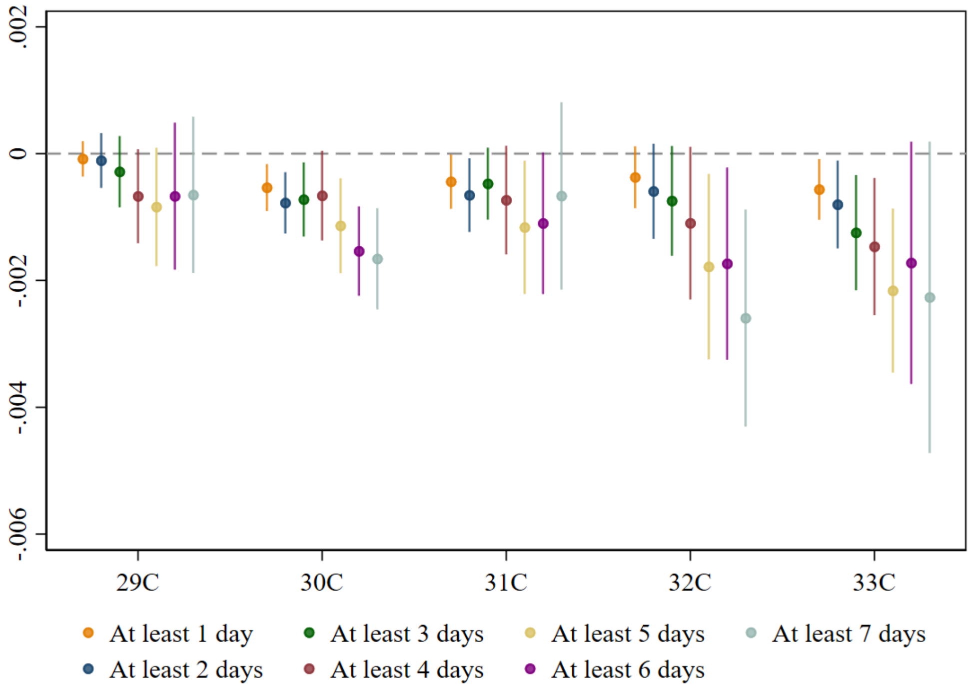
Notes: Each dot represents the coefficient from a separate regression of the annual count of heatwaves of each heat index intensity and duration on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable and includes year and region fixed effects and linear and quadratic region trends. Standard errors are clustered by regions.

Figure A9: Effect of Heatwaves on the Growth Rate of GRP by Intensity and Duration Controlling for Annual Temperature



Notes: Each dot represents the coefficient from a separate regression of the annual count of heatwaves of each intensity and duration on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation, mean annual temperature, and the lagged dependent variable and includes year and region fixed effects. Standard errors are clustered by regions.

Figure A10: Effect of Heatwaves on the Growth Rate of GRP by Intensity and Duration without Controlling for the Lag of the GRP Growth Rate



Notes: Each dot represents the coefficient from a separate regression of the annual count of heatwaves of each intensity and duration on the growth rate of per capita GRP. 90% confidence intervals are shown. Each regression controls for monthly precipitation and mean seasonal temperatures and includes year and region fixed effects. Standard errors are clustered by regions.

Appendix Tables

Table A1: Description of the Sample

	Observations	Regions in the sample	Regions in the country
Argentina	840	24	24
Bolivia	270	9	9
Brazil	819	20	27
Chile	455	13	16
Colombia	932	23	32
Ecuador	286	21	24
El Salvador	154	14	14
Guatemala	242	22	22
Honduras	240	16	18
Mexico	1,271	31	32
Nicaragua	217	7	17
Panama	108	9	9
Peru	782	23	25
Uruguay	627	19	19
Venezuela	399	21	23
Total	7,642	272	302

Notes: Brazil, Chile, Colombia, Ecuador, Honduras, Mexico, Nicaragua, Venezuela, and Uruguay have economic data for a subset of their regions. In addition, Brazil has economic data covering 26 of its 27 regions, but 8 regions are aggregated into 2. Peru has data covering all of its 25 regions, but 4 regions are aggregated into 2.

Table A2: Effects of Temperature and Heat Index on the Growth Rate of GRP without Controlling for the Lag of the GRP Growth Rate

	Temperature			Heat Index		
	(1) Annual Mean	(2) Daily Mean	(3) Hourly	(4) Annual Mean	(5) Daily Mean	(6) Hourly
Annual Mean	-0.0120***			-0.00731***		
	(0.00273)			(0.00143)		
Bin 1		-0.0000725	0.00000181		0.000000179	0.00000865
		(0.0000916)	(0.00000719)		(0.000103)	(0.00000770)
Bin 2		-0.0000295	0.00000588		0.000103	0.00000925*
		(0.0000564)	(0.00000555)		(0.0000676)	(0.00000518)
Bin 4		-0.000158***	-0.0000139***		-0.000153***	-0.0000157***
		(0.0000540)	(0.00000513)		(0.0000530)	(0.00000430)
Bin 5		-0.000360***	-0.0000352***		-0.000366***	-0.0000358***
		(0.0000844)	(0.00000754)		(0.0000808)	(0.00000766)
Observations	7642	7642	7642	7642	7642	7642
R^2	0.126	0.133	0.135	0.127	0.134	0.136

Notes: Columns (1) and (4) present the effect of the average annual temperature and heat index, respectively, on the growth rate of per capita GRP. The independent variables in Columns (2) and (5) correspond to the number of days that the daily mean temperature and the daily mean heat index fall into a given range. In Column (2), the bins are: below 9C (Bin 1), equal to 9C and up to 15C (Bin 2), equal to 21C and up to 27C (Bin 4), or above 27C (Bin 5). In Column (5), the bins are: below 7C (Bin 1), equal to 7C and up to 14C (Bin 2), equal to 21C and up to 28C (Bin 4), or above 28C (Bin 5). The independent variables in Columns (3) and (6) correspond to the number of hours that the temperature and the heat index fall into a given range. In Column (3), the bins are: below 7C (Bin 1), equal to 7C and up to 15C (Bin 2), equal to 22C and up to 30C (Bin 4), or above 30C (Bin 5). In Column (6), the bins are: below 5C (Bin 1), equal to 5C and up to 14C (Bin 2), equal to 23C and up to 32C (Bin 4), or above 32C (Bin 5). All regressions control for monthly precipitation and include year and region and year fixed effects. Standard errors in parentheses are clustered by region. * p < 0.1, ** p < 0.05, *** p< 0.001.

Table A3: Effect of Hot Days on the Growth Rate of GRP

Panel A : Growth rate of GRP							
	20C	21C	22C	23C	24C	25C	26C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Hot days	0.000240***	0.000220***	0.000139*	0.0000872	0.000000896	-0.0000437	-0.0000598
	(0.0000699)	(0.0000794)	(0.0000708)	(0.0000628)	(0.0000538)	(0.0000477)	(0.0000460)
Lag of the GRP growth	0.0933***	0.0941***	0.0942***	0.0940***	0.0934***	0.0933***	0.0932***
	(0.0316)	(0.0315)	(0.0316)	(0.0316)	(0.0316)	(0.0316)	(0.0316)
Observations	7416	7416	7416	7416	7416	7416	7416
R^2	0.140	0.140	0.139	0.139	0.139	0.139	0.139
Panel B : Growth rate of GRP							
	27C	28C	29C	30C	31C	32C	33C
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Hot days	-0.000102*	-0.000169***	-0.000194***	-0.000171***	-0.000135**	-0.000141**	-0.000140*
	(0.0000536)	(0.0000604)	(0.0000648)	(0.0000590)	(0.0000622)	(0.0000709)	(0.0000751)
Lag of the GRP growth	0.0930***	0.0919***	0.0910***	0.0911***	0.0919***	0.0923***	0.0926***
	(0.0316)	(0.0316)	(0.0317)	(0.0315)	(0.0315)	(0.0315)	(0.0315)
Observations	7416	7416	7416	7416	7416	7416	7416
R^2	0.139	0.140	0.141	0.140	0.140	0.139	0.139

Notes: Each column represents a separate regression of the annual count of days with at least 1 hour above the threshold (in degrees Celsius) on the growth rate of per capita GRP. Each regressions controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable and includes year and region fixed effects. Standard errors are clustered by region.

Table A4: Effects of Heatwaves on the Growth Rate of GRP by Intensity and Duration

	29C	30C	31C	32C	33C
Panel A: Growth rate of GRP					
Single day	-0.000062	-0.000440**	-0.000377	-0.000343	-0.000486*
	(0.000167)	(0.000217)	(0.000250)	(0.000294)	(0.000282
Observations	7416	7416	7416	7416	7416
R^2	0.139	0.139	0.139	0.139	0.139
Panel B: Growth rate of GRP					
2 consecutive days	-0.000023	-0.000614**	-0.000575*	-0.000578	-0.000716*
	(0.000261)	(0.000287)	(0.000338)	(0.000444)	(0.000403
Observations	7416	7416	7416	7416	7416
R^2	0.139	0.139	0.139	0.139	0.139
Panel C: Growth rate of GRP					
3 consecutive days	-0.000146	-0.000585*	-0.000414	-0.000704	-0.001234**
	(0.000338)	(0.000345)	(0.000334)	(0.000506)	(0.000528
Observations	7416	7416	7416	7416	7416
R^2	0.139	0.139	0.139	0.139	0.139
Panel D: Growth rate of GRP					
4 consecutive days	-0.000507	-0.000530	-0.000633	-0.001053	-0.001408**
	(0.000432)	(0.000421)	(0.000497)	(0.000708)	(0.000629
Observations	7416	7416	7416	7416	7416
R^2	0.139	0.139	0.139	0.139	0.139
Panel E: Growth rate of GRP					
5 consecutive days	-0.000717	-0.001022**	-0.001047*	-0.001810**	-0.002077***
	(0.000548)	(0.000444)	(0.000613)	(0.000860)	(0.000760
Observations	7416	7416	7416	7416	7416
R^2	0.139	0.139	0.139	0.139	0.139
Panel F: Growth rate of GRP					
6 consecutive days	-0.000689	-0.001577***	-0.001036	-0.001651*	-0.001719
	(0.000678)	(0.000419)	(0.000664)	(0.000901)	(0.001157
Observations	7416	7416	7416	7416	7416
R^2	0.139	0.140	0.139	0.139	0.139
Panel G: Growth rate of GRP					
7 consecutive days	-0.000738	-0.001704***	-0.000621	-0.002472**	-0.002208
	(0.000730)	(0.000465)	(0.000889)	(0.001017)	(0.001450
Observations	7416	7416	7416	7416	7416
R^2	0.139	0.140	0.139	0.139	0.139

Notes: Each column represents a separate regression of the annual count of heatwaves of each intensity (specified in columns) and duration (specified in rows) on the growth rate of per capita GRP. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable and includes year and region fixed effects. Standard errors are clustered by region.

Table A5: Effect of Heatwaves (defined by day-time and night-time temperatures) on the Growth Rate of GRP by Duration

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Single day	-0.0000522						
	(0.000124)						
2 consecutive days		-0.000650					
		(0.000453)					
3 consecutive days			-0.000950*				
			(0.000563)				
4 consecutive days				-0.00157**			
				(0.000750)			
5 consecutive days					-0.00268***		
					(0.000867)		
6 consecutive days						-0.00210**	
						(0.000939)	
7 consecutive days							-0.00370***
							(0.00112)
Lag of the GRP growth	0.0932***	0.0930***	0.0929***	0.0926***	0.0921***	0.0926***	0.0919***
	(0.0316)	(0.0315)	(0.0315)	(0.0314)	(0.0314)	(0.0315)	(0.0315)
Observations	7416	7416	7416	7416	7416	7416	7416
R^2	0.139	0.139	0.139	0.139	0.140	0.139	0.140

Notes: Each column represents a separate regression of the annual count of heatwaves of each duration (specified in rows) on the growth rate of per capita GRP. A heat wave is defined as consecutive days with maximum day-time temperature above 32C and minimum night-time temperature for the preceding night above 22C. Each regression controls for monthly precipitation, mean seasonal temperatures, and the lagged dependent variable and includes year and region fixed effects. Standard errors are clustered by region.

Table A6: Effect of Relative and Absolute Hot Days on the Growth Rate of GRP

	(1) 30C	(2) 31C	(3) 32C	(4) 33C	(5) 1.5 SD	(6) 1.75 SD	(7) 2 SD
Absolute hot days	-0.000171***	-0.000135**	-0.000141**	-0.000140*			
	(0.0000590)	(0.0000622)	(0.0000709)	(0.0000751)			
Relative hot days					-0.0000638	0.0000880	-0.000147
					(0.000196)	(0.000297)	(0.000474)
Lag of the GRP growth	0.0911***	0.0919***	0.0923***	0.0926***	0.0933***	0.0934***	0.0934***
	(0.0315)	(0.0315)	(0.0315)	(0.0315)	(0.0316)	(0.0316)	(0.0316)
Observations	7416	7416	7416	7416	7416	7416	7416
R^2	0.140	0.140	0.139	0.139	0.139	0.139	0.139

Notes: each column represents a separate regression of the annual count of hot days on the growth rate of per capita GRP. Columns (1) to (4) define a hot day as a day in which the maximum temperature was above 30C, 31C, 32C, or 33C respectively. Columns (5) to (7) define a hot day a day in which the maximum temperature was 1.5, 1.75, or 2 standard deviations above the regional monthly mean, respectively. Regressions control for monthly precipitation, mean seasonal temperatures, and the lag of the dependent variable and include year and region fixed effects. Standard errors are clustered by region.

Data Appendix

The economic data contain the following departures from the region (highest sub-national) level.

- Brazil: Ten regions (states and federal district) are aggregated into three areas with data reported for three aggregates.
  - Amazonas, Mato Grosso, Mato Grosso do Sul, Rondonia, and Roraima
  - Goias, Distrito Federal, and Tocantins
  - Pará and Amapa
- Peru: Four regions are aggregated into two areas with economic data reported for two aggregate areas.
  - Lima and Callao
  - Loreto and Ucayali

In addition, the Database of Global Administrative Areas provides geospatial data for Nicaragua at a level of aggregation below the highest sub-national level (i.e. level 2). Therefore, the geospatial data must be aggregated to the highest sub-national administrative level before aggregating the weather data to the region level using area weighted averages. Specifically, the following level 2 areas are aggregated into seven regions:

- Atlántico Norte & Sur
- Pacífico Central : Managua, Masaya, Granada and Corazo
- Pacífico Sur: Rivas
- Pacifico Norte: León and Chinandega
- Interior Central: Boaco and Matagalpa
- Interior Norte: Nueva Segovia, Madriz, Estelí and Jinoteca
- Interior Sur: Chontales