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Extreme temperatures and school performance of the poor: Evidence from Mexico

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ABSTRACT

As the risks associated with climate change intensify, understanding its impacts on human capital development is crucial. In this paper, we analyze the causal effects of temperature on the academic performance of students in Mexico, a middle-income country facing significant climate risks and socioeconomic challenges. Using panel data on over 5.5 million students, our results show that a 1 °C increase in annual average temperature leads to a 0.07 and 0.08 standard deviation decrease in Spanish and math test scores, respectively. Moreover, a one standard deviation (0.93 °C) increase in the long-term municipal temperature average is associated with 0.04 and 0.03 standard deviation declines in those scores. The effects are context-dependent - students in historically colder municipalities actually benefit from hotter temperatures, likely due to improved learning conditions in under-insulated schools and homes. However, the detrimental impacts appear consistent across urban, rural, and socioeconomically disadvantaged areas, underscoring the vulnerability of marginalized populations to the academic consequences of climate change. Overall, our findings highlight the urgency of addressing the educational dimensions of the global climate crisis through targeted interventions and adaptive policies, particularly in low- and middle-income countries.

1. Introduction

As the risks associated with climate change have become more salient, researchers have turned their attention to understanding the impacts that higher temperatures have on human activities and behavior. In this paper, we analyze the effect of extreme temperatures on the performance of students on a national standardized examination in Mexico, a medium-income economy with high poverty, inequality, and climate risk (Eckstein et al., 2019).

Specifically, we examine the causal effects of annual temperature exposure, defined as the mean average temperature during the 365 days before the exam was taken, on scores from the ENLACE (for its Spanish acronym) examination, a low-stakes but nationally representative standardized test taken by students aged 11 to 15 years old. ENLACE scores have been shown to be predictive of important long-term outcomes like secondary school graduation, college enrollment, and future wages (De Hoyos, Estrada, and Vargas 2021). As such, understanding how temperature impacts these test scores can provide insight into the potential effects of climate change on the educational and economic prospects of vulnerable populations in Mexico.

Using panel data at the individual student level, we estimate the causal effects of annual temperature exposure on ENLACE scores under the assumption that within-student annual temperature variations are as good as random. Our results show that exposure to an increase of 1 °C in the annual average temperature leads to a 0.07 and 0.08 standard deviation decrease in the Spanish and mathematics test scores, respectively. These findings are context-dependent, as we also observe that students in colder municipalities actually benefit from higher temperatures.

2. Data

2.1. Test score data

ENLACE evaluated two main subjects: Spanish and math. In this data, we observe students' test scores from 2007 to 2013 for Progresa-

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Oportunidades-Prospera (POP) beneficiaries.[1] We have information on almost 5.5 million students (Table A1 in the appendix presents the summary statistics). We use the dates of the exams (appendix Table A.3) to link our test scores data to the weather data.[2]

2.2. Weather data

Using the month-year in which the students took the exam, we linked ENLACE data to the ERA-Interim weather data.[3] Using information from 1979 to 2013, we created different measures of temperature to capture cumulative exposure, as well as anomalies with respect to long-term trends. For cumulative exposure, we created a variable that captures, at the municipality level, the mean average temperature during the 365 days before the exam was taken. We use cumulative precipitation during the same period as a covariate in the analysis. Using data from 1979 to 2000 we calculated mean monthly average temperature; this allowed us to estimate Long-Term Temperature (LTT) for the month before the test.[4] We then estimated temperature anomalies as the standardized difference between the temperature during the month before the test and the LTT.

3. Empirical approach

We use three models to estimate the impact of temperature on learning among school-age children. In the first model, we estimate the effect that the average temperature during the 365 days before taking the exam has on Spanish and math test scores:

$$Scores_{imt} = \alpha_i + \beta AvgTemp_{mt} + \delta PrecAcum_{mt} + \mu_t + \epsilon_{imt} \quad (1)$$

where $Scores_{imt}$ are Spanish or math test scores of student i in municipality m at time t; α_i are student-level fixed effects; β measures the effect of average temperature ($AvgTemp_{mt}$) in municipality m during the 365 days previous to taking the exam at time t; $PrecAcum_{mt}$ is the accumulated precipitation in the 365 days prior to taking the exam; and, μ_t are year fixed effects which control for national shocks (e.g., the effect of the Great Recession on the budget destined to education). Identification of our student fixed effects model relies on within-student year-to-year variation in test scores and temperatures.[5]

Following Park et al. (2020), our second approach controls for the number of days that the temperature fell on several temperature intervals or bins. This allows us to identify potential non-linearities in the effect of temperature on test scores:

$$Scores_{imt} = \alpha_i + \sum_{j=1}^{4} \beta_j DaysBinj_{mt} + \delta PrecAcum_{mt} + \mu_t + \epsilon_{im} \quad (2)$$

where $DaysBinj_{mt}$ are the number of days that the temperature fell on bin j, and $j = \{[0,17],(21,25],(25,29],[29,\infty)\}$. The base category for the interpretation of β_j is the interval where the average temperature $\in (17, 21]$.

Our final approach considers temperature anomalies ($TempAnom_{mt}$) with respect to the long-term municipal average of temperature (LTT_m) from 1979 to 2000. The anomalies are standardized so that we can interpret the parameters of interest as the effect of a one standard deviation anomaly. Furthermore, we interact this anomaly with the long-term average to see if the effect of the anomaly varies with the base long-term level:

$$Scores_{imt} = \alpha_i + \beta_1 TempAnom_{mt} + \beta_2 TempAnom_{mt} \times LTT_m + \delta PrecAcum_{mt} + \mu_t + \epsilon_{imt} \quad (3)$$

The identification assumption in all these specifications is that within-student, year-to-year temperature and precipitation variations are as good as random, or, using Hsiang's (2016) terminology, we assume unit homogeneity: each student is a good control of themself across the years.

4. Results

Estimating the first model (Eq. (1)) shows that experiencing a year that is on average 1 °C hotter decreases the Spanish score by 0.07 standard deviations, and the math score by 0.08 standard deviations (columns (1) and (4) in Table 1). Results from the second model (Eq. (2)) are presented in columns (2) and (5) of Table 1. A clear pattern emerges regarding the relationship between temperature exposure and test performance. Compared to the reference bin (number of days with temperature in the range 17–21 °C), experiencing an additional cooler day (temperature below 17 °C) increases tests scores in both Spanish (0.0013) and math (0.0016). On the other hand, experiencing an additional hot day decreases performance. For Spanish, an additional day in the 21–25 °C or 25–29 °C ranges reduces the score by 0.0005 standard deviations, while an extra day above 29 °C is associated with a decrease of 0.0007 standard deviations. The effects are even larger for math performance, except for an extra day in the 21–25 °C bin.

Our final model (Eq. (3)) examines the impact of temperature anomalies relative to the long-term municipal average (LTT). Columns (3) and (6) of Table 1 show that a one standard deviation increase in temperature anomaly in the month before the test decreases Spanish scores by 0.0395 standard deviations and math scores by 0.0331 standard deviations. As the coefficients of the interaction between the anomaly and LTT show, the effect of temperature anomalies is not homogenous across LTT levels. As illustrated in panel A of Fig. 1, the negative effect of temperature anomalies on test scores decreases as the LTT increases. In municipalities with an LTT of 30 °C or more, the effect of a temperature anomaly becomes statistically indistinguishable from zero.

To further explore heterogeneity, we re-estimated the first model (Eq. (1)) for different subgroups based on student sex, rural/urban location, municipality marginalization level,[6] and historical temperature.[7] The results of this analysis are shown in panel B of Fig. 1. The size and significance of the estimated coefficients are stable across most dimensions, with two exceptions. First, the coefficients are not statistically

[1] POP is a well-known conditional cash transfer program which was implemented from 1997 to 2018 in Mexico.

[2] The ENLACE data includes a variable that identifies the possibility that a particular student might have cheated in the exam. We decided to exclude those observations from our analysis. Additionally, to minimize problems of misattribution of weather variables at the municipal level, we excluded students living in the top 1% Mexican municipalities in terms of size. As a robustness check, we estimated all the models without excluding these students, the results are qualitatively the same as those presented here.

[3] The data was downloaded from https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim on September 2019.

[4] We used 2000 as the end date when estimating LTT to clearly separate between historic temperature trends and the temperature experienced by the students. Nonetheless, as a robustness check, we repeated the analysis presented here using 2013 as the end date. The results remain qualitatively the same as those presented in section 4.

[5] Appendix tables A.2 and A.4 show that the within-student standard deviation (sd) of the test scores comes to half of the overall test scores' sd, and the within-student sd of annual average temperature amounts to approximately 37% of the overall temperatures sd.

[6] Based on the marginalization index, an indicator of poverty at the municipal level, estimated by Mexico's National Council of Population.

[7] Following Alberto et al (2021), we use the long-term mean temperature (1979-2000) during the hottest months of the year (May-August) to group the municipalities in our sample in three categories: Hot (municipalities in the 90th percentile), Cold (municipalities in the 10th percentile), and Temperate (the rest of the municipalities).

Table 1
Relationship between temperature, temperature bins, temperature anomaly and test grades.

	Spanish			Mathematics		
	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	−0.0715***			−0.0844***		
	[0.0086]			[0.0109]		
≤ 17		0.0013***			0.0016***	
		[0.0001]			[0.0001]	
21–25		−0.0005***			−0.0002	
		[0.0001]			[0.0002]	
25–29		−0.0005**			−0.0009***	
		[0.0003]			[0.0003]	
>29		−0.0007*			−0.0011**	
		[0.0004]			[0.0005]	
Anomaly			−0.0395***			−0.0331***
			[0.0101]			[0.0114]
Anomaly*LTT			0.0013***			0.0009***
			[0.0004]			[0.0005]
Individual FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
N	9960932	9960932	9960932	9960932	9960932	9960932

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Cluster robust standard errors in brackets. All regressions control for precipitation accumulated during the 365 days before the month of the exam. The base level for models 2 and 5 is the number of days with average temperature above 17 and below 21 during the period. LTT is the long-term mean monthly average temperature for the period 1979–2000. Anomaly is the standardized difference between the temperature during the month before the test and the LTT.

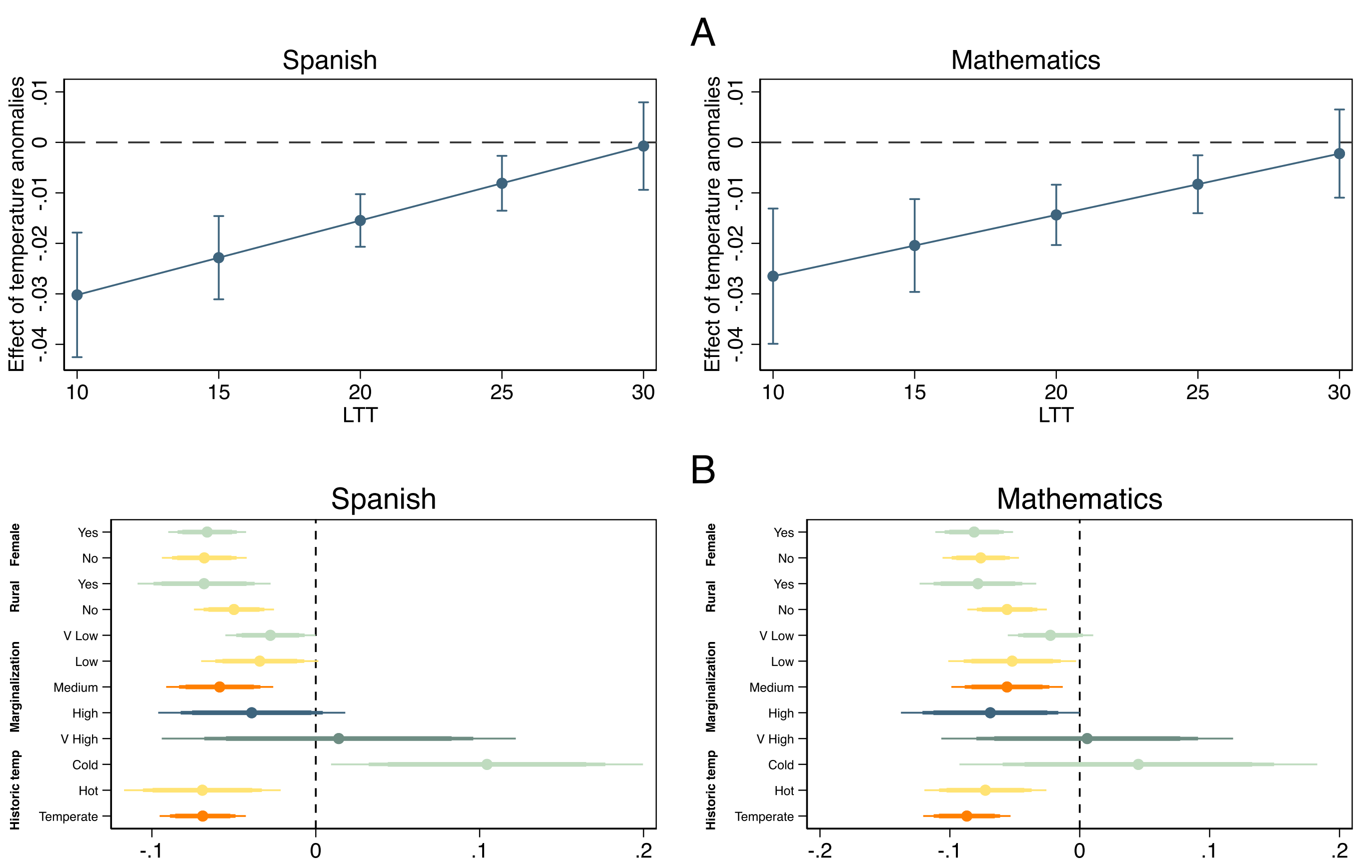

Fig. 1. Effect of anomalies and temperature effects by category. Note: Panel A shows the effects of temperature anomalies at different levels of LTT. Cluster robust confidence intervals at 95% are shown. **Panel B** shows the effects of temperature on grade scores by dividing the student sample in four different categories: sex (female/male), rural/urban, marginalization (very low, low, medium, high, very high), and historical temperature (cold, hot, temperate). Cluster robust confidence intervals at the 90%, 95% and 99% are shown for each one of the estimated effects.

significant for students in very highly marginalized municipalities. Second, the estimates are positive for students in colder municipalities, although only statistically significant for Spanish.

5. Conclusions and discussion

High temperatures and temperature shocks have a negative effect on school performance, as measured by students' scores on Spanish and math tests in a low-stakes national exam in Mexico. The detrimental impacts are similar across urban and rural areas, as well as across the different levels of marginalization. Although at first this might seem surprising, it suggests that since students come from disadvantaged households (all of them are beneficiaries of the anti-poverty program Progresa-Oportunidades-Prospera), the economic characteristics at the municipal level are not relevant.

Interestingly, we find a positive effect of temperature on Spanish test scores for students living in relatively cold municipalities. Poor students are likely to live in dwellings that lack adequate insulation; the same can be expected of the schools that they attend to. Under those circumstances, increases in temperature might lead to better studying and living conditions and hence to improvements in schooling performance.

Finally, we do not find evidence of sex-differentiated effects. This is consistent with other results in the literature, which show that weather events tend to have the same impact on the tests scores of boys and girls (Fruttero et al. 2023).

As climate change continues to drive increases in temperature and temperature shocks become more frequent, school performance in Mexico could be seriously compromised. Policymakers should design and implement policies and interventions that can help mitigate the negative effects of extreme temperatures on students' outcomes.

Suggesting specific policies requires understanding the mechanisms that are behind the negative causal effects of extreme temperatures on test performance. Unfortunately, identifying the transmission mechanisms that might be behind our results requires data that is not currently available. Therefore, this task is left for future research.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.econlet.2024.111700.

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