# Here Comes the Rain: Lasting Effects of Weather Shocks on Higher Education*

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**Abstract**

This paper examines how one-day rainfall shocks can have persistent effects on education in Brazil. I use panel data on millions of college applicants taking the high stakes National High School Exam (ENEM) and its widespread use in admissions by universities to estimate the effects of extreme weather variation on exam attendance and, in the following years, university enrollment at the municipal level. First, I show that a rainfall shock of more than one standard deviation of local average increases absenteeism in the exam by 3.6%, using municipal and exam date fixed effects. Second, heavy rain on exam days is significantly correlated with a decrease in total college enrollment of affected municipalities a year later. This effect is totally drawn by students using ENEM score on their application. I find significant negative effects on enrollment on private, but not public, institutions. Overall this suggest a persistence of seemingly random one-day shocks on educational decisions.

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# 1 Introduction

Climate change has substantially increased the frequency of extreme weather events[1], with variations in daily temperatures and precipitation increasing the probability of natural disasters such as floods and cyclones[2]. Although economists saw the emergence in the last decade of a rich literature exploring the effects of weather exposure on an array of outcomes, less attention has been devoted to how weather *shocks* might affect variables in the medium to long term.

This paper examines how one-day rainfall shocks can have persistent effects on education in Brazil. I use data on millions of college applicants taking the high stakes National High School Exam (ENEM) and its widespread use as entrance exam by universities to estimate the effects of extreme weather variation on exam attendance and, in the following years, university enrollment. Relying on the assumption that a rainfall shock on the day of the exam is not correlated with other municipal characteristics affecting education, one can use panel methodologies to recover a causal estimate of the effects of a shock on exam attendance, after controlling for municipal and exam date fixed effects.

If weather affects everyone equally and if those missing the national exam due to heavy rain are already less likely to enroll in college (e. g. less motivated, low ability), then a one-day shock should not have significant effects on college enrollment in a municipality as it would not change their distribution. If, however, the most affected group consists of students that would do well (and consequently enroll in college) but have a high cost of attending, then missing the exam might turn out to have persistent consequences on their educational path.

[1]The Third National Climate Assessment reported increases in the amount of precipitation falling in extreme events (defined as the top 1% of all daily events) of up to 71% for some regions in the United States in the 1958-2012 period (Melillo et al., 2014).

[2]In Brazil, studies also show an increase in probability of natural disasters over the years. Dalagnol et al. (2022) points out that an event similar to the 2020 floods in the south-eastern Minas Gerais region is made 70% more likely to occur due to climate change. In northeast Brazil, Rudorff et al. (2022) found flooding events of the Parnaiba River in 2018, 2019 and 2020 were made approximately 30% more likely.

The Brazilian ENEM context offers useful means for examining if these seemingly random shocks persist over time (affecting decisions), for a number of reasons. First, it is the largest college entrance exam in the country and the second largest in the world, only after China's National College Entrance Examination, with millions taking it every year. Moreover, since 2008 a growing number of universities have adopted ENEM scores as single entrance criteria, increasing exam stakes. Second, ENEM happens only once a year in two consecutive days on the last quarter[3], making selection on test days impossible. Also, this makes retaking the exam a costly exercise. Finally, many private universities use ENEM scores for awarding scholarships and complement the selection process, so the impacts might go beyond public markets.

For high school seniors less than 20 years old, rainfall on the day of the exam of more than 1 standard deviation relative to the local (historical) average reduces attendance by 0.54 percentage points, controlling for municipal and exam date fixed effects, and this is equivalent to an increase in the average municipal absenteeism share by approximately 3.6%. One potential concern is that richer, more developed, municipalities in Brazil tend to be in places where rainfall is low, thus generating omitted variable bias. However, while a number of studies have indeed shown that rainfall correlates with income and other outcomes over time, it is reasonably plausible to assume that a one-day rainfall *shock* is independent of municipal characteristics, at least in this very short run. Still, controlling for covariates such as GDP per capita, population and infant mortality do not alter results.

I also investigate individual characteristics of exam takers to reveal the varying effects of extreme rainfall on attendance. This exploration allows me to identify the profile of students most significantly impacted by such weather disruptions. Black women from public high schools have a probability of attending the exam that is 0.5 percentage points lower, on average, than white men from private schools, when exposed to heavy rain on

[3]The exam always takes place in the months of October, November or December on two days: Saturday and Sunday. After 2017, exams started to be administered only on Sundays, in consecutive weeks.

exam day. The effect is even larger for those who do not live in the same municipality as their exam location. With respect to performance, using the fact that the exam takes place in two consecutive days, I also explore within-individual variation to find that, controlling for exam subject and individual fixed effects, this extreme rainfall shock is associated with an increase in student's standardized score by 4.1% of a standard deviation, suggesting that low-achieving students are more likely to miss the exam.

ENEM is a high stakes college entrance exam, so a natural question is if these weather shocks affect college enrollment. In theory, the effect is ambiguous. If those more likely to miss the exam are also the ones who would not achieve a minimum score to be admitted, then being exposed to extreme weather should have negligible effects beyond the exam. If, however, affected students would do well had they attended the exam, this one-day shock might persist in time. I test this with data from the Brazilian Higher Education Census on the universe of students enrolled in college every year. After controlling for municipal and ENEM date fixed effects, I observe a 2% decrease in higher education enrollment by students from municipalities experiencing a rainfall shock on exam day. I do not find significant effects in enrollment for universities that do not use ENEM as admission criteria. Moreover, I find significant effects on enrollment for private, but not public, universities. Lastly, I do not find significant effects on total college enrollment two years after the weather shock.

Overall, these estimates provide evidence on another important way single-event standardized exams can be jeopardised by outside random shocks. Transportation and building infrastructure investments can be a traditional and efficient way of mitigating this channel of negative impacts of increasing weather shocks in the economy, for those who come from unprivileged backgrounds.

I contribute to the recent new wave of empirical research that uses panel methodologies to identify the effects of temperature, precipitation and other climatic variables on the economy.[4] These studies can be divided into two main groups. First, a large literature explores the effects of weather *exposure* on a wide range of outcomes such as child labor and human capital investment (Shah and Steinberg, 2017; Colmer, 2021), voting turnout (Fujiwara et al., 2016), health and mortality (Rocha and Soares, 2015; Deschênes and Greenstone, 2011; Barreca, 2012), conflict and income (Dell et al., 2012; Baylis, 2020; Hidalgo et al., 2010), crime (Moreno-Medina, 2022), and education (Graff Zivin et al., 2018; Park, 2022). Whether studying the effects of climate per se or in an instrumental variables framework, they measure medium or long term effects of being exposed to weather (or weather shocks) for days, months or years.

The second group, closer to this research, focus on the impacts of a single shock on outcomes in the short run, but do not go beyond the shock. Most of them also deal with the sensitivity of standardized tests to quasi-random shocks (Borghans et al., 2016; Ebenstein et al., 2016; Reardon et al., 2018; Graff Zivin et al., 2020). Graff Zivin et al. (2020) provided the first evidence on how higher temperatures affect cognitive performance of students in a high-stakes environment. In a setting similar to mine, Melo and Suzuki (2023) and Li and Patel (2021) study the effects of high temperatures on the ENEM exam performance, with the first documenting how changing exam stakes mitigate the negative effects through increased effort.

The rest of the paper proceeds as follows. Section 2 describes the institutional setting. Section 3 describes the data sources. Section 4 illustrates our empirical strategy for identification. Section 5 provides results and 6 concludes.

## 2 Institutional Background

In 1998 the Brazilian Ministry of Education launched the National High School Exam or *Exame Nacional do Ensino Médio* (ENEM) to evaluate the performance of students enrolled

[4] For good literature reviews see Carleton and Hsiang (2016) and Dell et al. (2014).

in public high schools across the country. The exam was meant to be an assessment tool, to be administered every year and its results were to drive policy implementation. From then on ENEM began to increase its importance and exceed the role of policy tool, being used for the first time as admission criteria by public universities in 2004.

Following an expansion of new federal public universities in Brazil during the 2000s, the federal government created the Unified Admissions System, *Sistema de Seleção Unificada* (SISU). This would serve as a centralized platform where public universities could access applications and use student's performance in ENEM as an admission criteria. This move markedly changed the stakes of the exam, as more universities joined SISU in the 2010s (Melo and Suzuki, 2023). The number of ENEM takers also grew considerably. In 2014 roughly 8 million individuals were registered to take the exam, making it the largest in the country and the second largest college entrance exam in the world, only after the National College Entrance Examination (NCEE) in China[5].

The exam is always administered on weekends, Saturday and Sunday for 2010-2016 and, after 2017, in two consecutive Sundays. Moreover, throughout our sample period, the exam happened in one of three months: October, November or December. After being reformulated in 2008, questions consisted of four modules, with 180 items, plus one essay. The final score is calculated using Item Response Theory for allowing comparisons over the years.

## 3 Data

I am leveraging information from three large data sources, two of them comprising administrative data. The following are described in more detail below: (i) individual-level data on the National High School Exam (ENEM); (ii) individual-level data on all entrants in higher education in Brazil (Higher Education Census); (iii) municipal-level data on weather.

[5] https://oglobo.globo.com/brasil/educacao/vestibular-chines-tem-2-milhoes-de-candidados-mais-do-que-enem-10540014.

Table 1 presents a summary in some key characteristics.

Table 1. Data Summary

| | Mean | St. Dev. | Min | Max |
|---|---|---|---|---|
| **ENEM data** | | | | |
| Women | 0.60 | 0.09 | 0.00 | 1.00 |
| Whites | 0.43 | 0.27 | 0.00 | 1.00 |
| Married | 0.11 | 0.28 | 0.00 | 1.00 |
| Private HS | 0.07 | 0.09 | 0.00 | 1.00 |
| Regular HS | 0.96 | 0.04 | 0.25 | 1.00 |
| Attendance | 0.84 | 0.09 | 0.00 | 1.00 |
| Average municipal score | 485.99 | 37.29 | 301.65 | 763.80 |
| **Weather** | | | | |
| Precipitation (mm/day) | 3.68 | 8.20 | 0.00 | 173.00 |
| Temperature (°C) | 24.65 | 3.36 | 12.78 | 33.65 |
| Humidity (%) | 75.62 | 14.17 | 29.00 | 100.00 |
| Rainfall | 0.44 | 0.50 | 0 | 1 |
| Extreme rainfall | 0.10 | 0.30 | 0 | 1 |
| **Higher Education** | | | | |
| Entered public institution | 0.25 | 0.23 | 0.00 | 1.00 |
| Financial aid (FIES) | 0.29 | 0.30 | 0.00 | 1.00 |
| ENEM only at admission | 0.19 | 0.21 | 0.00 | 1.00 |
| *Vestibular* only at admission | 0.68 | 0.24 | 0.00 | 1.00 |
| Total entrants | 166.08 | 1,396.68 | 1 | 77,434 |

**Note:** The table shows a summary of the three main data sources used in this research. Data on the universe of ENEM exam takers comes from Ministry of Education's INEP. Daily weather variables for every municipality were provided by SISAM-INPE. Data on students enrolled in higher education is taken from the Higher Education Census, conducted also by the Brazilian Ministry of Education.

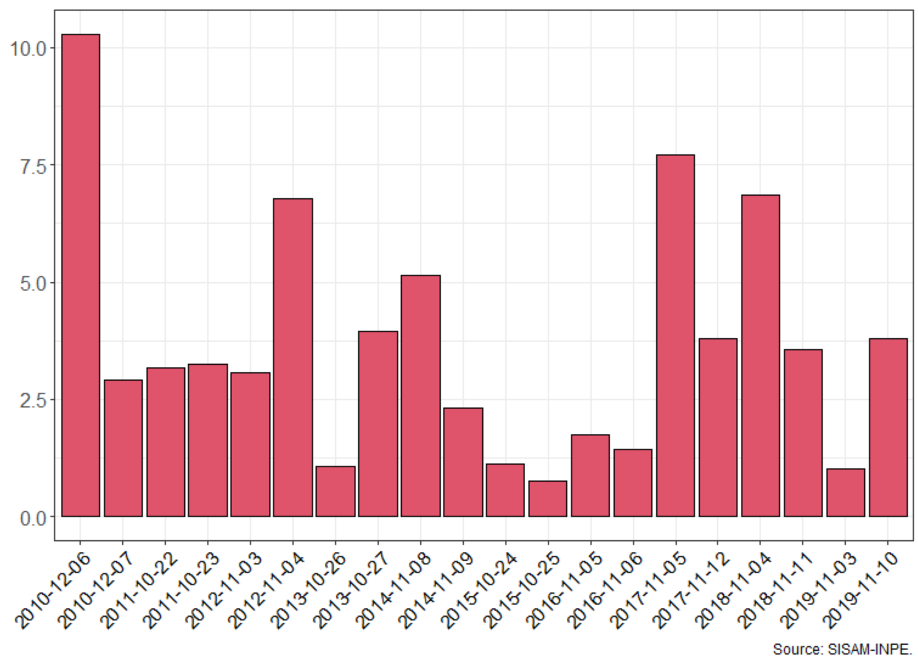
### 3.1 National High-School Exam data

Micro data from the universe on ENEM takers is made publicly available by the Brazilian Ministry of Education's Research Institute (INEP)[6]. These include, for each exam taker, information on scores, attendance, exam location, as well as individual characteristics such as race, gender, place of residence and high school information. The exam is administered on four subjects: Natural Sciences, Social Sciences, Portuguese and Mathematics - plus an

[6] *Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira.*

essay. We follow Melo and Suzuki (2023) and restrict our population to students in their last year of high school and of age between 16 and 20 years old, also removing students that were eliminated from the exam.[7] This guarantees a more homogeneous sample of students, leaving out cases of older exam takers with higher cost of attending ENEM, or that are applying for the second or third time. The resulting sample has roughly 14.5 million high-school seniors taking the exam from 2010 to 2019. Moreover, the exam is administered in approximately 1,800 municipalities, which means that many students have to travel to take the exam.[8]

Figure 1. Average precipitation on ENEM days




**Note:** The figure plots average precipitation (in mm) for municipalities across Brazil at all ENEM exam days for years 2010-2019.

### 3.2 Weather data

Data on Brazilian weather comes from the Environment Information System (SISAM), a project lead by the National Institute for Space Research (INPE) in partnership with

[7]Students can be eliminated if they are caught cheating.
[8]There are 5,570 municipalities in Brazil.

other organizations, including the Pan-American Health Organization[9]. The SISAM dataset compiles daily variables from different sources, also including information on wild fires and air quality measures such as $CO_2$ concentration. All variables are aggregated at the municipal level for the period 2000-2019 and include precipitation, temperature, relative air humidity and wind speed.

#### 3.2.1 Rainfall data

Daily precipitation comes from two main sources and are then aggregated at the municipality level by SISAM. The first are measures taken by the Climate Prediction Center, of the National Ocean and Atmospheric Administration (NOAA). These are collected with a spacial resolution of 0.5° (approximately 50 km) and interpolated for a spacial resolution of 12.5 km.[10] SISAM also relies on their own climate measurement center, their Weather Research and Forecasting model, conduced by the Center for Weather Forecast and Climate Studies from INPE. These are also collected on a resolution of 0.05° and then resampled for a resolution of 12.5 km to match NOAA data.[11]

Figure 1 plots the average rainfall across municipalities during each of ENEM exam dates for the 2010-2019 period.

### 3.3 Higher Education Census

Data from Brazilian higher education institutions are provided by the Higher Education Census, realized every year by the Ministry of Education to assess the universe of students enrolled in College degrees, including graduate and undergraduate programs. The census provides information on students enrolled, on schools (whether private or state-owned), its infrastructure and also on programs and courses available, as well as professors and

[9] *Sistema de Informações Ambientais Integrado à Saúde Ambiental*.
[10] See Xie et al. (2010).
[11] Details of their climate model are provided in Skamarock et al. (2019).

researchers. This allow the government to follow the evolution in time of higher education and on the elaboration of policy.

I gather information on all students entering higher education in Brazil from 2010-2019. The census also makes available a student's place of birth and the principal criteria used in her admission process. Institutions use mainly an entrance exam (*vestibular*) in admission, usually this being the only criteria. Most universities owned by the Federal Government however, use the ENEM exam as sole criteria, through a centralized system (SISU). I keep in my sample students which ENEM was the only admission criteria used or a specific exam was the only one used. Excluding cases where a combination of both was considered. I also keep only those enrolling in regular schools for a college degree, dropping those in military institutions, as their admission process involves different criteria besides the entrance exam.

## 4 Empirical Strategy

We want to measure the impact of extreme climatic events (rainfall shocks) on attending ENEM and if this potential shock persists. That is, if a student misses the exam because of a negative rainfall shock, will she apply again next year for college? Or is this particular student's marginal cost of doing a high stakes exam like ENEM already high, with the shock providing the necessary increase for her to drop and pursue her outside option? These are important policy questions for the objective of understanding who will be the most affected by climate change in future.

We explore weather variation over time within a municipality to assess the effects of rainfall shocks on exam attendance and on higher education access. Let $Y_{mdit}$ be an outcome variable for municipality $m$ at day $d$ of month $i$ and year $t$. I define as a rainfall *shock* as a dummy variable $\text{D}_{mdit}$, such that:

$$\text{D}_{mdit} = \mathbb{1}\left\{ \frac{r_{mdit} - \bar{r}_{mi}}{\sigma^r_{mi}} \geq 1 \right\} \tag{1}$$

where $r_{mdt}$ is precipitation in millimeters for municipality $m$ on day $d$ of month $i$ and year $t$, and $\bar{r}_{mi}$ and $\sigma^r_{mi}$ are daily average and standard deviation of rainfall for month $i$ during years 2000-2019. I define an extreme rainfall event when precipitation in a particular day was greater or equal than 1 standard deviation of the historical daily average for that place and month.

With this I announce my main specification:

$$Y_{mdit} = \mu_m + \delta_{dit} + \beta \cdot \mathrm{D}_{mdit} + \gamma \mathbf{X}_{mt} + \varepsilon_{mdit} \tag{2}$$

where $\mathrm{D}_{mdit}$ is the dummy variable in 1, $\mu_m$ and $\delta_{dit}$ represent municipal and date fixed effects and variables in $\mathbf{X}_{mt}$ are covariates that change over time at the municipal level.

Our main identification assumption is that rainfall extreme events (at the day of exam) are uncorrelated with municipal characteristics which may determine if a student attends ENEM. This can be a potential problem since in recent years rainfall shocks have been demonstrated to affect an array of economic variables from violence to income (Dell et al., 2014), which may in turn impact attendance. Moreover, if places with higher precipitation tend also to have higher rates of absenteeism, spurious correlations might arise. I exclude these possibilities by leveraging on two facts: first, the fact that I am exploring a contemporaneous *daily* shock, that is, what is the effect of raining on day $t$ on attendance on that same day. Thus, due to the limited time window, it becomes less plausible that rainfall is affecting attendance through an omitted channel such as municipal income or crime levels, as these would take longer to realize. The second potential source of endogeneity is mitigated by the inclusion of municipal and exam date fixed effects, which control for both time-invariant municipal unobservables and policies implemented nationally in specific years, which could affect presence in ENEM.

Table 2. Effects of rainfall on municipal ENEM attendance

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Rainfall | -0.007*** | -0.003*** | -0.002*** | | | |
| | (0.001) | (0.001) | (0.001) | | | |
| Extreme rainfall | | | | -0.013*** | -0.005*** | -0.005*** |
| | | | | (0.001) | (0.001) | (0.001) |
| Num.Obs. | 222,560 | 222,560 | 167,804 | 222,560 | 222,560 | 167,804 |
| R2 | 0.002 | 0.417 | 0.497 | 0.002 | 0.417 | 0.498 |
| R2 Adj. | 0.002 | 0.402 | 0.480 | 0.002 | 0.402 | 0.480 |
| Controls | | | X | | | X |
| FE: Municipal | | X | X | | X | X |
| FE: Exam date | | X | X | | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Clustered (municipal level) standard errors in parentheses.

**Note:** The table shows results of main specification for the effects of rainfall and extreme rainfall on the share of students attending ENEM from a particular municipality. Columns 1 and 4 display simple OLS results. Columns 2 and 5 include municipal and exam date fixed effects. Control variables included in columns (3) and (6) are: yearly population and GDP per capita (in logs), infant mortality rate and the share of high school students enrolled at a full-time high school program. The student sample considers only high school seniors aged 16-20 who were not eliminated from the exam.

# 5 Results

## 5.1 Effects of extreme rainfall on ENEM attendance

Estimation of Equation 2 produces the results displayed in Table 2. The main outcome is the share of registered students from a particular municipality who actually attended ENEM exam. I also consider in columns (1) to (3) results for when treatment is purely a positive precipitation at a municipality ($r_{mdt} > 0$, above). This is represented by the coefficients of variable ”Rainfall”.

Results for the preferred specification of treatment (i.e., an extreme rainfall *shock*) are presented in columns (4) to (6) of Table 2. A rainfall shock of more than one standard deviation of the historical average is associated with a reduction in ENEM attendance by $0.54$ percentage points. Putting in real terms, it represents on average $7,820$ less students each year. But is this purely a random shock, affecting every student the same way, or can this represent a potentially damaging economic shock? As the consequences of global warming become more apparent, this represents a fair question as to how much ”damage” should we expect, since these negative shocks begin to occur more often (Willett et al., 2008).

From the point of view of a student taking the exam, we ask how this can affect her cost of attending and, more importantly, seeking a vacancy in a Higher Education Institution. If weather shocks affect only the students with higher marginal cost of attending (this means those from low socially and economic background, from lower quality high schools and more time and financial constraints to academic life), then missing ENEM might be the push needed to keep them from attending university altogether, even if they have the chance to re-take the exam in the following year.

Table 3. Interaction terms between extreme rainfall indicator and share of students by individual characteristics

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Extreme rainfall | -0.001 | -0.023*** | 0.031*** | -0.002** |
| | (0.002) | (0.008) | (0.008) | (0.001) |
| Extreme rainfall × Non-whites | -0.008** | | | |
| | (0.003) | | | |
| Extreme rainfall × Women | | 0.030** | | |
| | | (0.014) | | |
| Extreme rainfall × Public High School | | | -0.037*** | |
| | | | (0.008) | |
| Extreme rainfall × Different municipality | | | | -0.005*** |
| | | | | (0.001) |
| Num.Obs. | 222,560 | 222,560 | 222,540 | 222,560 |
| R2 | 0.420 | 0.417 | 0.417 | 0.418 |
| R2 Adj. | 0.405 | 0.402 | 0.402 | 0.403 |
| FE: Municipal | X | X | X | X |
| FE: Exam date | X | X | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Clustered (municipal level) standard errors in parentheses.

**Note:** This table shows the estimated coefficients of the interaction terms between the share of students according to their individual characteristics and an indicator of an extreme rainfall event during ENEM exam, grouped by student's municipality of residence. Columns (1) and (2) consider race and gender, column (3) considers whether a student goes to a public high school and column (4) considers the share of students who do not live in the same municipality where they take the exam.

Table 3 provides some insights on who are the most affected students by these adverse events. It displays coefficients for the interaction between the share of students taking the exam, by their individual characteristics, and our indicator of weather shock. Columns (1) and (2) consider the share of non-white and female students applying, respectively. Columns (3) and (4) consider the share of students from a public high school and those who do not live in the same municipality where they take the exam. Overall, coming from an unprivileged background (non-white, from public school and who live far) make students more vulnerable to single day shocks, increasing their probability of missing the exam due to a rainfall shock.

ENEM is administered every year, so it is fair to ask what are the effects of this shock in the following year, that is, does the students retake the exam, after missing in the first year? We show this in Table 4. Here we present results for extreme rainfall (on exam days in year $t$) on the log of total registered students in the following year (columns 1 and 2) and attendance in $t+1$ (columns 3 and 4). Two things are worth noticing in Table 4. First, if students are in fact just delaying their college entrance a year (thereby being exposed to weather shocks would not have any meaningful consequence) then we would expect an increase in the total number of students registering for ENEM in the following year. In fact, what we observe is the opposite. Columns (1) and (2) of table 4 considers only students with ages between 17 and 22 and who already finished high school. This restriction aims to capture only the group of students who are potentially doing the exam for the second time. Moreover, as a robustness test we run extreme rainfall in $t$ on attendance in $t+1$ and do not find significant effects (columns 3 and 4).

Table 4. Rainfall shock in $t$ on exam outcomes in $t+1$

| | Attendance | Total not in HS | Concluded HS | Total HS seniors |
|---|---|---|---|---|
| Extreme rainfall | 0.001 | -0.010*** | -0.018*** | -0.014*** |
| | (0.001) | (0.003) | (0.003) | (0.003) |
| Num.Obs. | 142,858 | 142,854 | 142,842 | 142,858 |
| R2 | 0.523 | 0.973 | 0.972 | 0.967 |
| R2 Adj. | 0.504 | 0.972 | 0.971 | 0.966 |
| Controls | X | X | X | X |
| FE: Municipal | X | X | X | X |
| FE: Exam date | X | X | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Clustered (municipal level) standard errors in parentheses.

We also look into what are the municipal characteristics that may be more correlated with this negative effect. In Table 5 I show coefficients for the interaction terms between my extreme rainfall dummy and an indicator for when a municipality is below the median in three dimensions: Column (1) considers extreme weather for those municipalities with population below the median ($\approx 11,379$). In column (2) I consider those with below-median land area ($\approx$ 417 km$^2$). Finally, column (3) keeps those municipalities that had a share of roads paved that was less the national median ($\approx$ 78%)[12].

Table 5. Extreme rainfall on exam attendance - municipal characteristics

| | (1) | (2) | (3) |
|---|---|---|---|
| Extreme rainfall | -0.005*** | -0.003** | -0.005*** |
| | (0.001) | (0.001) | (0.001) |
| Extreme rainfall × Small population | 0.000 | | |
| | (0.002) | | |
| Extreme rainfall × Share of paved roads in 2010 | | -0.007*** | |
| | | (0.002) | |
| Extreme rainfall × Small land area | | | 0.000 |
| | | | (0.002) |
| Num.Obs. | 222,560 | 222,400 | 222,560 |
| R2 | 0.417 | 0.417 | 0.417 |
| R2 Adj. | 0.402 | 0.402 | 0.402 |
| FE: Municipal | X | X | X |
| FE: Exam date | X | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Clustered (municipal level) standard errors in parentheses.

**Note:** The table display the coefficients for the interaction terms between extreme rainfall during ENEM exam days and a dummy indicating if a municipality is below the median in one of three dimensions: Population (column 1), share of paved roads (column 2) and land area (column 3).

### 5.2 Effects of rainfall on exam performance

Figure **??** suggest that students from socially vulnerable backgrounds are receiving a larger in magnitude shock from these random weather events. Table 6 show results for the impact of rainfall on average student performance. For this, we slightly change our main specification to account for student and exam subject fixed effects, as follows:

$$Y_{imst} = \phi_i + \eta_s + \beta \cdot \mathrm{D}_{mt} + \varepsilon_{imst} \tag{3}$$

[12] We consider share of roads paved in 2010 since this is the only available information at a national level.

where $Y_{imst}$ is a measure of student $i$'s performance at ENEM subject $s$, from municipality $m$ in year and day $t$. $\phi_i$ and $\eta_s$ represent student and exam subject fixed effects. What this means is that we are now leveraging on the variation provided by the fact that ENEM is administered in two days

We show results in Table 6 for both the absolute score of student $i$ in subject $s$ (columns 1 and 3) and on her standardized score (columns 2 and 4). It seems that rainfall of one historic standard deviation (on average $7.69$ mm) increases exam scores by $4.1\%$ of a standard deviation.

Table 6. Rainfall effects on ENEM score

| *Outcome:* | Absolute score (1) | $Z_{\text{score}}$ (2) | Absolute score (3) | $Z_{\text{score}}$ (4) |
|---|---|---|---|---|
| Rainfall | 0.470 | 0.003*** | | |
| | (0.675) | (0.001) | | |
| Extreme rainfall | | | 0.269 | 0.005*** |
| | | | (1.166) | (0.001) |
| Num.Obs. | 49,776,596 | 49,776,390 | 49,776,596 | 49,776,390 |
| R2 | 0.711 | 0.708 | 0.711 | 0.708 |
| R2 Adj. | 0.612 | 0.609 | 0.612 | 0.609 |
| FE: Subject | X | X | X | X |
| FE: Individual | X | X | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Clustered (municipal) standard errors in parentheses

**Note:** The table shows OLS results for rainfall at ENEM exam days on individual test scores. Individual and exam subject fixed effects are included. Columns 2 and 4 consider an individual's standardized score with respect to subject and home municipality.

### 5.3 Effects on access to Higher Education

As discussed by Melo and Suzuki (2023), ENEM is considered a high-stakes exam, due to many respected universities using it as single admission criteria. Moreover, it is also a necessary condition for applying for government financing, if you plan to enroll in a private institution.[13] Missing ENEM could then have larger consequences for a student's life, as it seems to be an important factor in the short-term decision process to apply for higher education. From tables 5 and 6, we consider two hypothesis: first, the effects of this weather event is concentrated on lower performing students (i.e., those from less favorable economic backgrounds). For these students, attending ENEM (and applying for college) has a higher cost, as they usually face more challenges throughout life. Applying for college might be a one time only event for some, due to the high level of effort required. A negative shock would then prevent some students from accessing higher education altogether. This leads us to the second hypothesis, based on tables 4 and 5, that students are not retaking ENEM in the following year, after missing the first time. If that is the case, we would expect a negative effect of raining in ENEM on the number of enrollments at universities in the following year, of students that are from those municipalities that received the shock.

[13] The Student Financing Fund (Fies) is a government program created in 2001 and provides financing for low-income students who wish to enroll in a private higher education institution. Since 2015, taking the ENEM exam and achieving a minimum average score is a necessary condition for applying (portalfies.mec.gov.br).

Table 7. Effects of rainfall on access to higher education

| *Outcome:* | log(Total entrants) | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Extreme rainfall | $-0.021$*** | $-0.020$*** | | |
| | (0.005) | (0.005) | | |
| Precipitation (mm/day) | | | $-0.001$*** | $-0.001$*** |
| | | | (0.000) | (0.000) |
| Control mean | 174 | 174 | 174 | 174 |
| Num.Obs. | 123,482 | 123,258 | 123,482 | 123,258 |
| R2 | 0.949 | 0.949 | 0.949 | 0.949 |
| R2 Adj. | 0.947 | 0.947 | 0.947 | 0.947 |
| Controls | | X | | X |
| FE: Municipal | X | X | X | X |
| FE: Exam date | X | X | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Robust standard errors in parentheses

**Note:** The table shows the results of rainfall in a municipality at ENEM exam days on the log of the total number of students, from that same municipality, enrolling in a higher education institution the following year.

We use data from the Brazilian Higher Education Census to test if a municipality that was exposed to heavy rain on ENEM in year $t$ enrolls less students in college in $t + 1$. The Census does not provide information on a student's home municipality, however, it provides the birthplace of the students. To merge this with our ENEM sample, we keep only those students that finished high school in the same municipality where they were born. ENEM only started providing information on student's place of birth after 2013, so our sample will consider this new time window of 2013-2019.[14]

Table 7 provide our main estimation results. As shown, in years exposed to an extreme rainfall shock (more than one standard deviation of average), municipalities sent fewer students to college. We use again specification 2 but now the main outcome is the log of the total number of students who enrolled in higher education in $t + 1$ (considering

[14] I run the same regressions using the full sample with students birthplace being a proxy for residence in the Appendix to no change in results.

the weather shock happens in year $t$). Columns (1) and (2) show the coefficients for our preferred definition for rainfall shock. In columns (3) and (4) we consider results for the raw measure of precipitation (mm per day) for a sense of magnitude. Columns (3) and (4) tell us that 10 mm of rainfall is associated with 1% less students (from municipalities that experience the shock) enrolling in college.

We also disentangle enrollments by admissions criteria. Census data informs us if a student was admitted to a Higher Education Institution (HEI) using their ENEM score, a college-specific entrance exam (*vestibular*) or a combination of both. Moreover, we also look at the type of HEI students are enrolling. Columns (1) and (2) of Table 8 consider the same specification as Table 7 classified by type of institution (columns 1 and 2) and admission criteria used by students (columns 3 and 4).

To support our story that students who miss ENEM exam due to heavy rain are not accessing higher education, Table 8 shows a significant decrease in enrollment by students using their ENEM score in the selection process. I do not find significant effects for students using another type of entrance exam (*vestibular*). Moreover, this effect is concentrated on those entering private, but not public, universities.

Overall, black women students, from usually poor municipalities (those below the median in share of roads paved) appear to be the most affected by this negative random weather shock. Once they miss ENEM, Tables 7 and 8 shows that they might not be accessing college. Column (1) of Table 8 shows that there could be some substitution effect, that is, students that missed ENEM are now applying through *vestibular* and still entering public universities. However, it is also possible that equilibrium effects might be at play. If those from lower socioeconomic backgrounds are being denied access (because they missed the exam), it is possible that public institutions now have more vacancies, that are being taken by students from higher social backgrounds. Public universities are widely perceived in Brazil to be of higher quality than their private counterparts (Machado and Szerman, 2021) which could mean that the effect in those entering via specific exams might constitute a selection in those top students not affected by rainfall.

Table 8. Composition effects of weather shocks in college access

| *Outcome:* | log(Entered Private)<br>(1) | log(Entered Public)<br>(2) | log(Entrance exam only)<br>(3) | log(ENEM only)<br>(4) |
|---|---|---|---|---|
| Extreme rainfall | −0.034***<br>(0.005) | 0.008<br>(0.006) | −0.005<br>(0.005) | −0.063***<br>(0.006) |
| Num.Obs. | 120, 338 | 101, 322 | 118, 674 | 101, 190 |
| R2 | 0.944 | 0.918 | 0.941 | 0.912 |
| R2 Adj. | 0.941 | 0.914 | 0.939 | 0.908 |
| FE: Municipal | X | X | X | X |
| FE: Exam date | X | X | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Robust standard errors in parentheses

**Note:** The table shows the effects of extreme rainfall in a municipality, at ENEM exam days, on the number of students enrolling in higher education by their main admission criteria (columns 1 and 2) and by individual characteristics (columns 3-5), in logs of the total coming from that particular municipality.

We also note that students do not seem to be trying to get into university again in the following year, as we have seen in Table 4. Now, we run the same specification for college entrants in Table 9. Here consider if heavy rainfall affects the number of students entering college two years after the shock during ENEM. If students are simply retaking ENEM next year, we would expect an increase in the share of those from municipalities exposed to bad weather. However, Table 9 shows otherwise. We find no effects on the total number of students, or the share of those using specific exams. We do however still find a decrease in the share of students that used ENEM as sole admission criteria.

Table 9. Effects of rainfall on college access in $t + 2$

| *Outcome:* | log(Total entrants) (1) | Total entrants (2) | ENEM only (3) | Entrance exam only (4) |
|---|---|---|---|---|
| Extreme rainfall | 0.003 | 1.185 | −0.004* | −0.001 |
| | (0.006) | (4.378) | (0.002) | (0.003) |
| Num.Obs. | 60819 | 60819 | 60819 | 60819 |
| R2 | 0.963 | 0.989 | 0.587 | 0.587 |
| R2 Adj. | 0.959 | 0.988 | 0.546 | 0.546 |
| FE: Municipal | X | X | X | X |
| FE: Exam date | X | X | X | X |

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Robust standard errors in parentheses

**Note:** The table shows the effects of extreme rainfall in a municipality, at ENEM exam days, on the number of students enrolling in higher education two years after the shock. Columns 3 and 4 present uses outcomes as a share of the total.

## 6 Conclusion

This paper provides new evidence on the way weather shocks can have lasting impacts on individual outcomes in education. We use individual administrative data on a National High School Exam in Brazil (ENEM) and find that weather shocks related to rainfall decrease student participation in the exam, after controlling for municipal and exam date fixed effects. We define extreme rainfall at a student's home municipality as having precipitation on the days of ENEM that is more than one standard-deviation from the monthly historical average for that location. Using panel data regressions, we show that extreme rainfall decreases the individual probability of attending by 0.3 percentage points. Moreover, aggregating data at the municipal level, we show that attendance (defined as the number of students that were present divided by total students registered at ENEM) decrease by approximately 0.54 p.p. if there was extreme rainfall on that location. This means that roughly 7,820 students miss the exam each year due to rainfall shocks.

Our heterogeneity analysis shows that the most affected group is formed by female black students from public high schools, which might indicate disadvantage backgrounds as we also find significant positive effects of extreme rainfall on exam scores. Also, municipalities that with less than 70% of roads paved are affected by extreme rainfall almost two times as large as our baseline specifications.

We then provide evidence that missing ENEM can have lasting impacts fora municipality concerning educational outcomes. Extreme rainfall on ENEM days decreases the total number of students that access higher education coming from those locations. Also, we find significant negative effects for students that use ENEM in their admission process, but not for those using *Vestibular* and we also find negative effects in the total number of students that go to private institutions.

Taken together, we believe our results provide one possible channel of how weather shocks might be amplifying inequalities, since access to higher education is highly correlated with future income. As rainfall shocks tend to happen often due to climate change, our paper has a number of policy implications on how to prepare cities to deal with it, whether it is by providing better road and facilities infrastructure or public transportation. Additionally, we also highlight the downsides of how university admissions based solely on two-day standardized exams might treat candidates from poorer backgrounds unfairly, hence increasing already large inequalities.

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# A Appendix Tables and Figures