Prolonged Droughts and Education

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Abstract

This paper examines the effects of an extended drought on education in a developing nation, highlighting how prolonged drought exposure influences both the supply and demand for education. We utilize weekly satellite data on vegetation health, temperature, and moisture to assess drought severity in the semi-arid region of Northeast Brazil during one of its most severe droughts in history. We employ a difference-in-differences approach that accounts for dynamic treatment effects to evaluate the cumulative impacts of weather shocks. On the supply side, we observe an 8% reduction in the number of public school teachers in affected municipalities. Additionally, municipalities experiencing more extreme drought months saw a 14% decrease in elementary school teachers over the years, with low-skilled teachers being the most impacted. The drought also led to school closures, particularly in areas lacking drinkable water. We do not observe similar effects in private schools. On the demand side, we find that droughts decreased student learning and increased grade progression in the long term, consistent with previous research findings.

JEL Codes: I25, Q54, O13, O15

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1 Introduction

Human capital formation has been at the center of development for nations, and economists have documented its importance in rigorous way for decades, with a key role performed by education through schooling (Mankiw et al., 1992). In recent years, the advent of climate change has brought light to the vulnerability of human capital investments to weather shocks, especially because of their increase in frequency and intensity[1]. However, applied research on this topic tends to focus on the demand side of education (Dell et al., 2014; Venegas Marin et al., 2024b), usually with a short-term perspective like how weather shocks affect exam performance (Graff Zivin et al., 2020), or how it affects schooling decisions (Soares et al., 2012; Shah and Steinberg, 2017). Fewer attention has been paid to the consequences on the supply side, such as schools and teachers[2].

In this paper, we study the impacts of a prolonged drought episode on education in a developing country. We evaluate potential consequences on both the demand and the supply side of education, with a focus on elementary schools. Our focus is on a drought episode that occurred in the Northeast region of Brazil. It was considered one of the worst droughts in history and lasted six years, from 2012 to 2017 (Marengo et al., 2017). We run a difference-in-differences specification by De Chaisemartin and d'Haultfoeuille (2024) that allows the presence of dynamic treatment effects to document cumulative impacts of a drought event that lasted for more than one period. In addition, we focus on municipalities in the semi-arid part of the Northeast region, due to the region's high vulnerability to climate change and its high share of rural population[3].

[1] A 10-year-old in 2024 will experience three times more river floods, twice as many tropical cyclones and wildfires, four times more crop failures, five times more droughts, and 36 times more heat waves over their lifetimes in a 3°C global warming pathway compared to a 10-year old in 1970. Already, the population affected by climate shocks annually has more than doubled in the past 40 years (Thiery et al., 2021).

[2] A recent report by the World Bank states that schools were closed in at least 75% of extreme weather events in the past 20 years. For example, in Malawi, 42% of primary schools were closed due to a drought in 2015, forcing more than 130,000 boys and girls to drop out of school (Venegas Marin et al., 2024a).

[3] According to the World Bank (2008), one-third of the world's rural population lives in arid and semi-arid regions, and these regions are usually ranked among the poorest. Moreover, recent studies by climatologists have documented increases in both the frequency and intensity of drought episodes over the years (Dai, 2013;

We use weekly satellite data from the NOAA Centre for Satellite Applications and Research (2019) and measure drought intensity with the Vegetation Health Index (VHI). The VHI is a well-established way to assess droughts through a combination of vegetation coloring and temperature anomalies through thermal images, which produces a more precise picture of droughts, one that considers not only rainfall but also moisture, temperature and ground vegetation (AghaKouchak et al., 2015).

On the supply side, we find that municipalities experiencing more drought weeks lost on average 8% of their contingent of public elementary school teachers (grades 1-9). Effects are stronger for schools located in places subjected to more extreme drought periods, with a total negative effect over the years of 14%. For private schools, the effects are less precise, and the coefficients become non-significant some periods after the first year of drought. In addition, we do not find significant results for private schools in places exposed to extreme droughts. Most of the reduction in public schools is concentrated on low-skill teachers with only a high school degree and with a temporary job contract, although we still see significant negative effects for tenured teachers. We also document that municipalities exposed to more periods of drought tend to experience more school closures and that the impacts are primarily driven by schools reporting a lack of water supply. We show that most of the drop in the total number of teachers comes from these public schools. Finally, we also show that being exposed to years of drought significantly decreased municipal expenses on education, mainly for elementary school budgets.

We also look at some demand side outcomes, such as school progression and learning. Using data from a large standardized exam administered to ninth-grade students, we find significant negative effects on performance on math and language tests when municipalities are exposed to months of extreme drought, a result consistent with previous literature (Branco and Féres, 2018; Nordstrom and Cotton, 2023). Finally, we find that droughts increased progression rates after 6 years of drought, with retention also decreasing, which

Song et al., 2020; Dai, 2021)

might represent a sort of compensation for the loss in schools in the first years of drought.

Our paper builds on previous literature on the social impacts of climate change (Dell et al., 2014; Carleton and Hsiang, 2016). With regard to its impacts on education, this has been a relatively recent development. A recent study by the *World Bank Research Observer* showed that of 15 review articles on the economic impacts of climate change published since 2010, only three mention the impacts of climate change on education Venegas Marin et al. (2024b). Studies documented the effects of weather shocks on the demand for human capital investments such as schooling and labor decisions. For example, income shocks due to droughts and rainfall variations in rural areas were shown to affect schooling and child labor through opportunity costs and wages (Soares et al., 2012; Björkman-Nyqvist, 2013; Adejuwon, 2016; Shah and Steinberg, 2017; Nübler et al., 2021). Moreover, drought episodes have also been shown to negatively affect learning and school performance (Branco and Féres, 2018; Joshi, 2019; Nordstrom and Cotton, 2023).

Less attention has been given by the literature to the impacts on the supply side, especially on school infrastructure and teachers. Studying the same Brazilian context, Branco and Féres (2018) document negative impacts of droughts on student learning, but do not find evidence of disruptions in school supply and teacher absence. However, they use a shorter window of time than we do in a Two-Way Fixed Effects estimation. Recently, Angrist et al. (2023) built a cross-country dataset showing how climate events caused school closures since 2002. They show that continuing to provide education in times of a natural shock that forced schools to close increases learning and makes education systems more robust to climate change. Our paper focuses on the ways that a weather shock can disrupt education markets, with teachers and schools being affected.

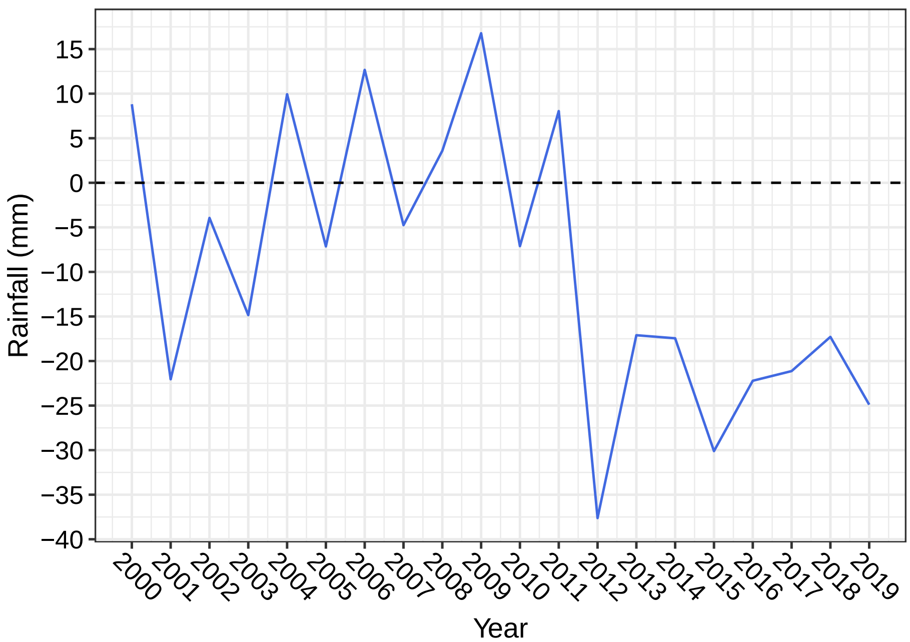
The rest of the paper proceeds as follows. Section 2 provides a brief background on the 2012-2017 drought and the Brazilian semi-arid region. Section 3 presents the data and details on the use of VHI as a drought measure. Section 4 introduces our identification strategy. Section 5 discuss the main results, and Section 6 explores potential mechanisms.

Finally, Section 7 concludes.

2 Background

2.1 The 2012-2017 drought

Figure 1. Precipitation in the semiarid - Deviations from the historic average



Note: The figure plots average precipitation (in mm) in terms of deviations to the historic average for municipalities in northeast's semiarid region, for years 2000-2019. Data on daily precipitation for municipalities comes from the Brazilian National Institute for Space Research (INPE).

Starting in 2012, a prolonged drought episode began in the northeast region of Brazil. Although residents of the region often experience dryer weather compared to other parts of the country, the 2012 drought episode was one of the worst on record (Marengo et al., 2016; Santana and Santos, 2020). This is also evidenced in recent precipitation data, as we can see in Figure 1. It plots the average rainfall in the semi-arid part of the northeast, expressed in deviations from the average between 2000 and 2019. The year 2012 represents the largest drop in precipitation since the start of the time series, not returning to previous levels even after the considered end of the drought in 2017. We follow the official semi-arid delimitation given by the Brazilian Ministry of National Integration[4] (Ministério da Integração Nacional, 2017). Municipalities are considered part of the semi-arid if three climatic conditions are met:

(i) It is within the boundaries of isohyets below 800 mm, i.e., the lines on a map joining points of historical average precipitation below 800 mm (yearly precipitation records from 1981 to 2010);

(ii) It has average Thornthwaite Index below 0.50 (this indicator combines humidity and aridity indexes to determine an area's moisture regime);

(iii) It has an index of risk of drought above 60% (the index is defined as the share of days under hydric deficit, which accounts for daily precipitation and evapotranspiration, also calculated with data from 1981 to 2010).

This definition produces a total of 1,262 municipalities, of which 1,171 are in the Northeast region of Brazil[5]. As already pointed out in previous literature, the semi-arid region of the northeast constitutes an ideal case for studying the impacts of prolonged droughts due to its historic climate, which turns any positive rainfall shock into a beneficial event. Its climate also is representative of one third of the land surface, being also highly susceptible to a changing world climate with more intense events such as the El Niño (Rocha and Soares, 2015; Marengo et al., 2016; Branco and Féres, 2021).

3 Data

We built a municipal panel for the semi-arid Brazilian region that combined administrative data on education and weather variables to measure drought and intensity of drought. We start our sample in 2009 as this was a year of few drought-like conditions in the

[4]Resolution 115 of November 2017.

[5]Appendix Figure B3 shows the geographic location of municipalities in the Northeast region that are also part of the semi-arid region.

whole region, so most places would have the same period-one treatment, important for our identification strategy. We used a natural experiment of prolonged drought that occurred in Brazil's Northeast region in 2012-2017 and was considered one of the worst and longest in its history.

3.1 Drought data

Previous economic literature on droughts commonly uses deviations in average rainfall as a measure of dry weather conditions (Rocha and Soares, 2015; Shah and Steinberg, 2017; Branco and Féres, 2021). However, geographers and climate scientists have long established that drought depends on other conditions in addition to rainfall and that areas with high levels of rainfall can indeed experience a drought (Wilhite and Glantz, 1985; AghaKouchak et al., 2015). Moreover, it must involve deviations in both rainfall and the amount of evaporation from the soil and plants.

In this paper, we rely on recent advances in the technology of weather measurement that allow remote sensing to measure events such as droughts. We used satellite data on vegetation health from the National Oceanic Atmospheric Administration's (NOAA) Center for Satellite Applications and Research (STAR). It consists of weekly observations from a fleet of polar-orbiting satellites collected since 1982 by the Advanced Very High Resolution Radiometer (AVHRR), and since 2013 by the Visible Infrared Imaging Radiometer Suite (VIIRS). Data are at the global level with a spatial resolution of 4 km. This approach combines visible, near-infrared and thermal radiances in a numerical index that characterizes vegetation health and is extremely useful in detecting and monitoring such complex and difficult-to-identify phenomena as drought (Kogan, 1997; NOAA Centre for Satellite Applications and Research, 2019).

3.1.1 Vegetation Health Index (VHI)

Our measure of drought is based on the Vegetation Health Index (VHI), an index ranging from 0 to 100 that is calculated with the satellite observations mentioned above and is a weighted average of two other established measures: the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). The VCI is measured as anomalies in the Normalized Difference Vegetation Index (NDVI), an index of the different portions of the electromagnetic spectrum observed, which can be used to determine how green the vegetation is on the ground (AghaKouchak et al., 2015). NDVI (and VCI) tends to be highly correlated with precipitation and soil moisture and is widely used to measure agricultural droughts (Donohue et al., 2009; Nordstrom and Cotton, 2023). The TCI is measured in anomalies of thermal infrared measures, expressed as deviations from historical average temperatures, also shown to be important for vegetation health (NOAA Centre for Satellite Applications and Research, 2019). This makes the VHI a good tool for measuring droughts, as it combines both soil and air conditions and temperature and is a popular indicator for agricultural droughts (Gidey et al., 2018a,b).

We calculate weekly averages of VHI in municipalities in the semi-arid Brazilian region and count the number of months the VHI was below a certain threshold that constitutes a drought. Following NOAA Centre for Satellite Applications and Research (2019), we define a week of drought in a municipality when its average VHI is below 35[6]. Appendix Table A3 provides values for the VHI and different classification of droughts provided by NOAA and also by the National Drought Mitigation Center from the University of Nebraska[7]. Since our main educational outcomes are measured yearly, we use these variations in the intensity of drought over time and space and build our measure of treatment as a function of the number of months of drought experienced by a municipality in each

[6] NOAA uses a threshold of 40 for the VHI to define drought but considers values below 35 as more intense episodes of drought provide us more variation and also allows us to better explore shocks that are truly unanticipated.

[7] https://droughtmonitor.unl.edu/

year. Although being one of the longest drought episodes (Martins and Magalhães, 2015), the intensity of the drought varied over time in the Northeast region of Brazil, as shown in the appendix Figure B2, providing us with enough variation for our analysis.

3.2 Education data

Data on school transition rates (promotion, retention, and dropout) and school teachers come from the Brazilian School Census. The School Census is the main tool for collecting information on basic education and the most important Brazilian educational statistical survey. It is coordinated by the Ministry of Education and is carried out in collaboration between the state and municipal education departments, with the participation of all public and private schools in the country. This data has been collected annually since 1995. We used years 2009-2019 and municipalities in the semiarid part of Brazil's northeast region. Table A1 displays summary statistics on the number of schools, teachers, and students for the sample, between public and private schools. We also used individual-level data on teachers for the same period to perform a heterogeneity analysis on the impacts of droughts on education supply. Table A2 provides a summary of these data. Our goal is to develop a more comprehensive look at the impacts of droughts on education in developing countries than previously done.

To measure the impact of droughts on school performance, we use data from the Basic Education Assessment System (SAEB)[8]. SAEB is a set of large-scale external evaluations that allows the government to make a diagnosis of basic Brazilian education and factors that can interfere with student performance. Since 1995, the biennial assessment has aimed to provide an overview of Basic Education and has undergone some methodological changes for improvement. In addition to other indicators, the SAEB scores structure the grade of the Basic Education Development Index (Ideb). We use data from the standardized exams conducted after year 2011 when it becomes possible to compare scores. Before

[8]*Sistema de Avaliação da Educação Básica.*

2010, the elementary school in Brazil had two possible systems, but after this year, all Brazilian schools have implemented the law no 11,274/2006. This law institutes the nine-year primary school, with the compulsory inclusion of six-year-old instead of seven-year-old children, and also reorganized school curriculum. Our analysis considers students enrolled in fifth and ninth grades of elementary school.

4 Empirical Strategy

4.1 Drought-year definition

We define the assignment of treatment based on the VHI values as explained in section 3. A year of drought is defined as at least 6 months of VHI values below 35 in a municipality. We use this as our main treatment variable in a binary specification. Formally, for municipality i on year t:

$$D_{it} = \mathbb{1}\left\{ \sum_{k=1}^{12} \mathbb{1}\left[VHI_k \leq 35\right] \geq 6 \right\} \tag{1}$$

We also consider more intense definitions of drought shocks, according to the values provided by the NOAA Centre for Satellite Applications and Research (2019). All specifications are in binary treatment form. For years with at least one month of VHI values below 25, we define a year with severe drought. For VHI values below 15 for at least one month, we define a year of extreme drought. That is,

$$\begin{aligned} \text{Severe}_{it} &= \mathbb{1}\left\{ \sum_{k=1}^{12} \mathbb{1}\left[VHI_k \leq 25\right] \geq 1 \right\} \\ \text{Extreme}_{it} &= \mathbb{1}\left\{ \sum_{k=1}^{12} \mathbb{1}\left[VHI_k \leq 15\right] \geq 1 \right\} \end{aligned} \tag{2}$$

4.2 Dynamic treatment effects

Our main goal is to measure the cumulative impacts that drought years can have on education, with a focus on school supply (i.e., teachers). Assuming deviations in short-term weather are as good as random, the standard approach has been running Two-Way Fixed Effects (TWFE) regressions, controlling for unit and period unobservables, even when the objective was to estimate dynamic treatment effects (Dell et al., 2014). However, recent studies have shown that, in settings with many periods, non-absorbing or non-binary treatment, the usual TWFE estimator is biased. Moreover, TWFE estimators do not account for dynamic treatment effects with treatment heterogeneity, that is, results might be biased when past treatment affects outcomes in the present, which is precisely the case in this study (Roth et al., 2023).

We run a difference-in-differences specification that allows for dynamic treatment effects and for units to enter and leave treatment, with the definitions from equations 1 and 2. De Chaisemartin and d'Haultfoeuille (2024) show that, when this is the case, average treatment effects can be identified, provided that there exist groups with the same period-one treatment. This restriction is satisfied in our setting, where treatment is binary and groups can join and leave treatment. Then, their difference-in-differences estimator is applicable with the usual no anticipation and parallel trends assumptions.

The main difference of this approach is that treatment effects take into account the full history of the outcome over time, and estimators measure a cumulative impact of treatment for a period and its' lags up to the moment when units first switch treatment status. Thus, treatment and control groups are defined based on their treatment path, and comparisons are made among units with the same period-one treatment status, but where the control group consists of units that do not switch over the sample period. The parallel trends assumption, in this case, tells us that these units will have the same expected outcome evolution if treatment status remains the same.

Let F_g be the first time group g changes treatment status, where units in g have the same treatment for period one. For all g, we compare the evolution of the outcomes from period $F_g - 1$ to $F_g - 1 + \ell$. Then, our event-study estimates provide the average effect across all groups for each period ℓ. The following estimator provides this:

$$\text{DID}_\ell = \frac{1}{N_\ell} \sum_g S_g \text{DID}_{g,\ell} \quad (3)$$

where S_g is equal to 1 or -1 for groups whose treatment increases or decreases in F_g relative to baseline. Interpretation of the coefficients, in this case, is the average effect of having been exposed to weakly higher treatment for ℓ periods, relative to units where treatment status has remained the same (De Chaisemartin and d'Haultfoeuille, 2024).

5 Results

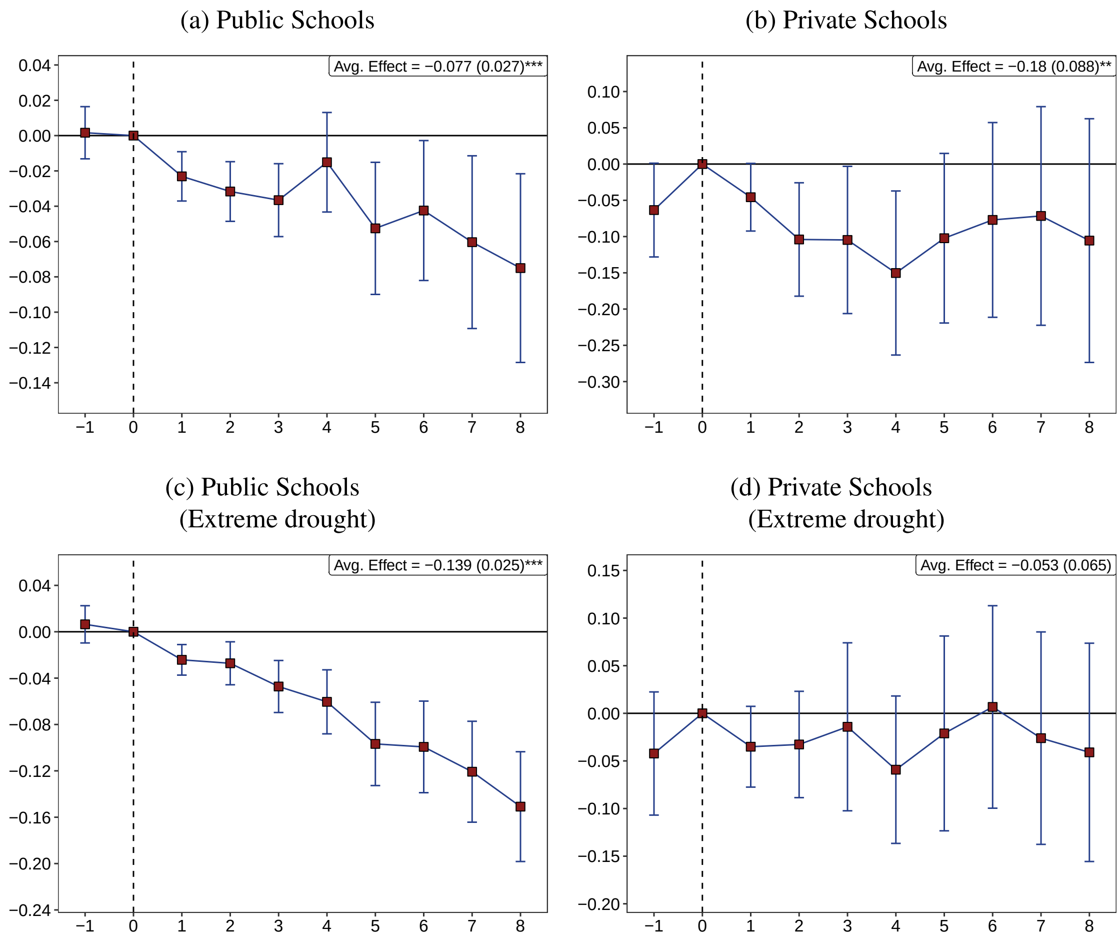
We present results of our main treatment definitions for the cumulative effects of droughts on education over time. Our main contribution is to analyze the impacts these weather shocks have on the supply side, namely schools and teachers. We also show results for students, replicating findings from previous literature on school performance and student progression rates. In all plots, the sample considers only municipalities in the semi-arid portion of the Northeast region, as these are mostly rural, more susceptible to the effects of droughts and also similar in characteristics such as population and average income.

5.1 Impacts on school teachers

Figure 2 shows the impacts of drought on the total number of school teachers in a municipality. We first consider elementary school teachers (grades 1-9) and separate the results between public and private schools. In Appendix Figure B6 we show results for high school teachers with the same specifications as in Figure 2.

Panels (a) and (b) use our more general definition for a year of drought, consisting of experiencing at least 6 months of average weekly VHI values below 35, as noted by Equation 1. Panels (c) and (d) use our more extreme measure of drought, which consists

Figure 2. Total number of teachers (log): Grades 1-9



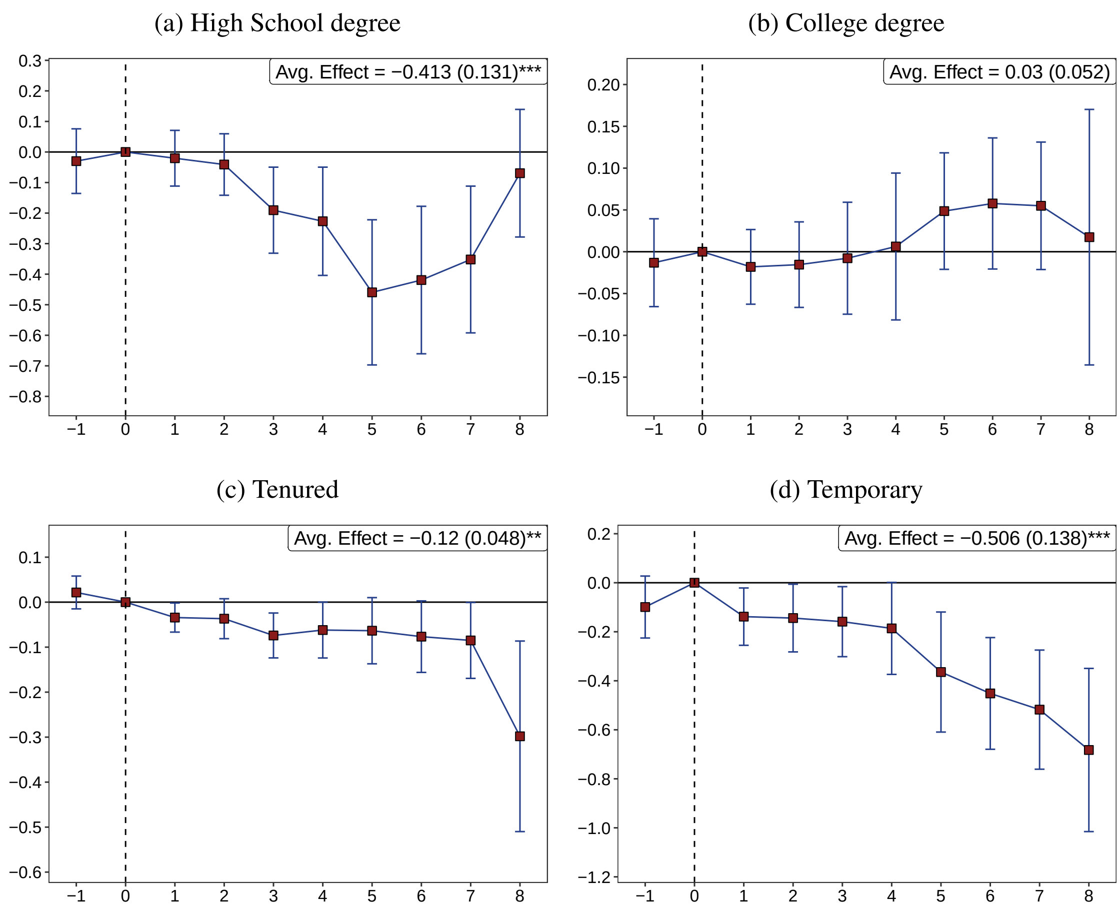
Note: The figure plots event-study coefficients for drought impacts on the log of the total number of school teachers in municipalities in the semi-arid region of the Brazilian Northeast for grades 1-9, separated in public and private schools. Panels (a) and (b) show the results of experiencing at least 6 months of VHI values below 35 in a year (definition 1). Panels (c) and (d) consider municipalities experiencing at least 1 month of VHI values below 15, categorized as extreme drought episodes (definition 2). Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

of having at least 1 month of VHI values below 15 (Eq. 2). From the sample period of 2009-2019, municipalities experiencing more drought weeks lost on average 8% of their contingent of public school elementary teachers. Effects are stronger for schools located in places subjected to more intense drought periods, with a total negative effect over the years of 14%. Although we find larger effects in magnitude for private school teachers, estimated coefficients are noisier, and we cannot rule out the existence of pre-trends in the number of elementary school teachers. The cumulative impacts become nonsignificant after some periods of the first drought experienced. In addition, we do not find significant results for private schools in places exposed to extreme droughts.

Closer analysis of elementary school teachers from public schools tells us that less qualified teachers were more affected by these drought years. We show this in Figure 3, where most of the reduction in the overall number of teachers appears to be concentrated on those with only a high school degree, but no college (panel a). Moreover, effects are much larger for teachers with a temporary job contract, although we still see significant negative effects for tenured teachers.

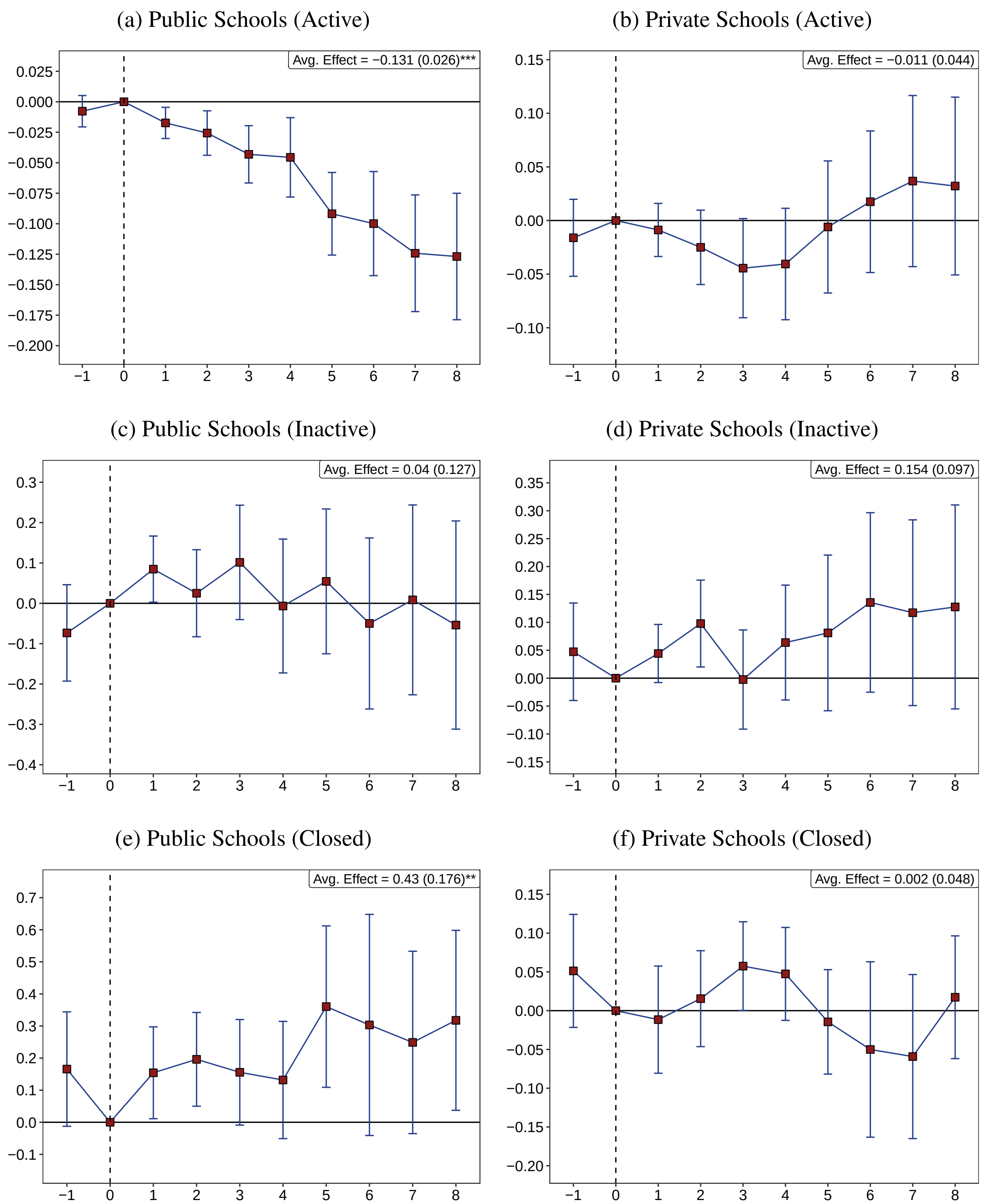
We also document important changes in the total number of schools in municipalities due to droughts. Figure 4 shows the main results for quantity of schools, according to their working status. The school census provides information on whether a school is active, inactive, or permanently closed. Again, we separate between public and private schools in the semi-arid region. The number of active public schools has decreased drastically over the years in municipalities more affected by droughts. Also, this appears to be related to permanent school closures and not simply inactivity, as we can see in panels (c) and (e). We do not find a similar decrease for private schools.

Figure 3. Public school teachers by characteristics: Grades 1-9



Note: The figure plots event-study coefficients for drought impacts on the log of the total number of public school teachers in municipalities in the semi-arid region of the Brazilian Northeast for grades 1-9. All panels consider experiencing at least 6 months of VHI values below 35 in a year (definition 1). Panels (a) and (b) show the results by the level of teacher education. Panels (c) and (d) consider their employment contract. Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

Figure 4. Number of schools by activity (log)



Note: The figure plots event-study coefficients for drought impacts on the log of the total number of schools in municipalities in the semi-arid region of the Brazilian Northeast, separated in public and private schools by their level of activity. Panels (a) and (b) show results for schools that were active in census years. Panels (c) and (d) consider schools that were inactive (temporarily) in census years. Panels (e) and (f) consider schools that were permanently closed. All panels consider a year of drought experiencing at least 6 months of VHI values below 35 in a year (definition 1). Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

5.2 Impacts on students

We now present results for some student outcomes, such as performance on standardized math and language exams and progression rates for public and private schools.

In Figure 5, we show the effects of drought on student performance in a large standardized exam administered by the Brazilian government to assess the quality of basic education (SAEB). This exam is administered every two years, consisting of Math and Language tests, and we use results from exams done between years 2011-2019 as those were made by the Ministry of Education to be comparable over the years. We find significant negative effects on performance for 9th graders when municipalities are exposed to months of extreme drought (VHI $\leq$ 15), although the effects are not statistically significant for our preferred definition of drought shock (panel a). We also control for individual student characteristics such as race, gender, mother's education, and whether a student dropped out in previous years.

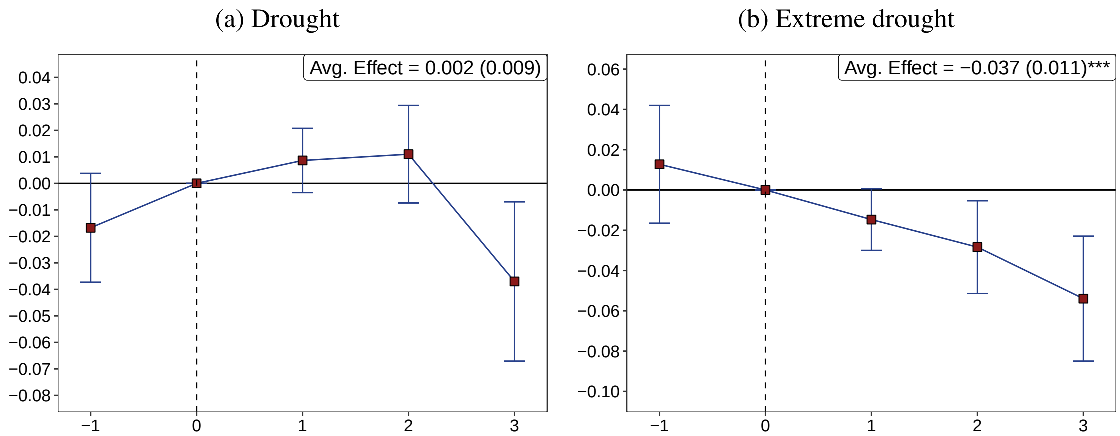
For cases of more intense drought episodes, we find that the cumulative effects on learning are in line with previous studies, where extreme droughts have been shown to negatively impact droughts (Branco and Féres, 2018; Nordstrom and Cotton, 2023). For replication purposes, we run a TWFE specification with this performance data for 9th graders also to find negative results, and to display the results in Appendix Table A4

5.2.1 School progression

In this section, we present results on municipal schooling transition rates. These are calculated for municipalities in the semi-arid northeast based on the School Census. We report impacts for progression (students advance to the next grade), retention (students are held back a grade) and dropout rates.

Previous literature has encountered a somewhat ambiguous effect of weather shocks on schooling levels. A drought can affect rural households through a direct income effect, where it represents an increase in poverty and health, thus reducing schooling (Soares et al., 2012; Nordstrom and Cotton, 2023). However, the literature also documents the presence of substitution effects when a drought changes local labor market conditions. In this case, the opportunity cost of schooling decreases as wages decrease due to weather shock, resulting in an increase in overall schooling (Shah and Steinberg, 2017; Colmer, 2021). Which of these dominates will depend on local market conditions.

Figure 5. School performance: 9th graders



Note: The figure plots event-study coefficients for provides results for the impact of at least 6 months of drought on ninth grade students' performance on *Prova Brasil* administered by SAEB every two years. Proficiency in math and language exams for the period 2011-2019 and students in municipalities of the semi-arid northeast were considered. Individual controls included are the gender, age, mother's education, race, and a dummy to determine whether the student has dropped out in previous years. Extreme drought considers VHI values below 15. Standard errors are clustered at municipal level.

Figure 6 plots the results for these transition rates, considering students in elementary school (grades 1-9). In the short term, the progression coefficients are negative, and the dropout rates increase (not statistically significant) for public schools in the semi-arid region. However, this seems to be offset in the longer run, with retention rates decreasing and an average negative effect of -1.2 p.p. We also break these rates for elementary school students by initial years (grades 1-5) and end years (grades 6-9) in the appendix figures B4 and B5, respectively. We also show in Figure 7 decreases in the teacher/student ratio for elementary private schools, in line with these transition results and what could mean a worsening of working conditions for those who stay during a drought.

6 Possible mechanisms

The 2012-2017 drought had widespread effects on the water supply of municipalities in the semi-arid northeast. At the height of the drought in 2015, nearly 1,000 municipalities declared a state of emergency[9]. The loss of teachers in municipalities affected by prolonged droughts could be due to many possible factors, not mutually exclusive. For public schools that depend on state transfers and municipal budgets, prolonged drought is a negative income shock, especially in rural areas that depend on crop yields (Dell et al., 2012). But droughts also worsen working conditions for teachers and students due to the lack of clean water and the spread of diseases (Rocha and Soares, 2015; Branco and Féres, 2018). In the following, we try to unravel a couple of these mechanisms.

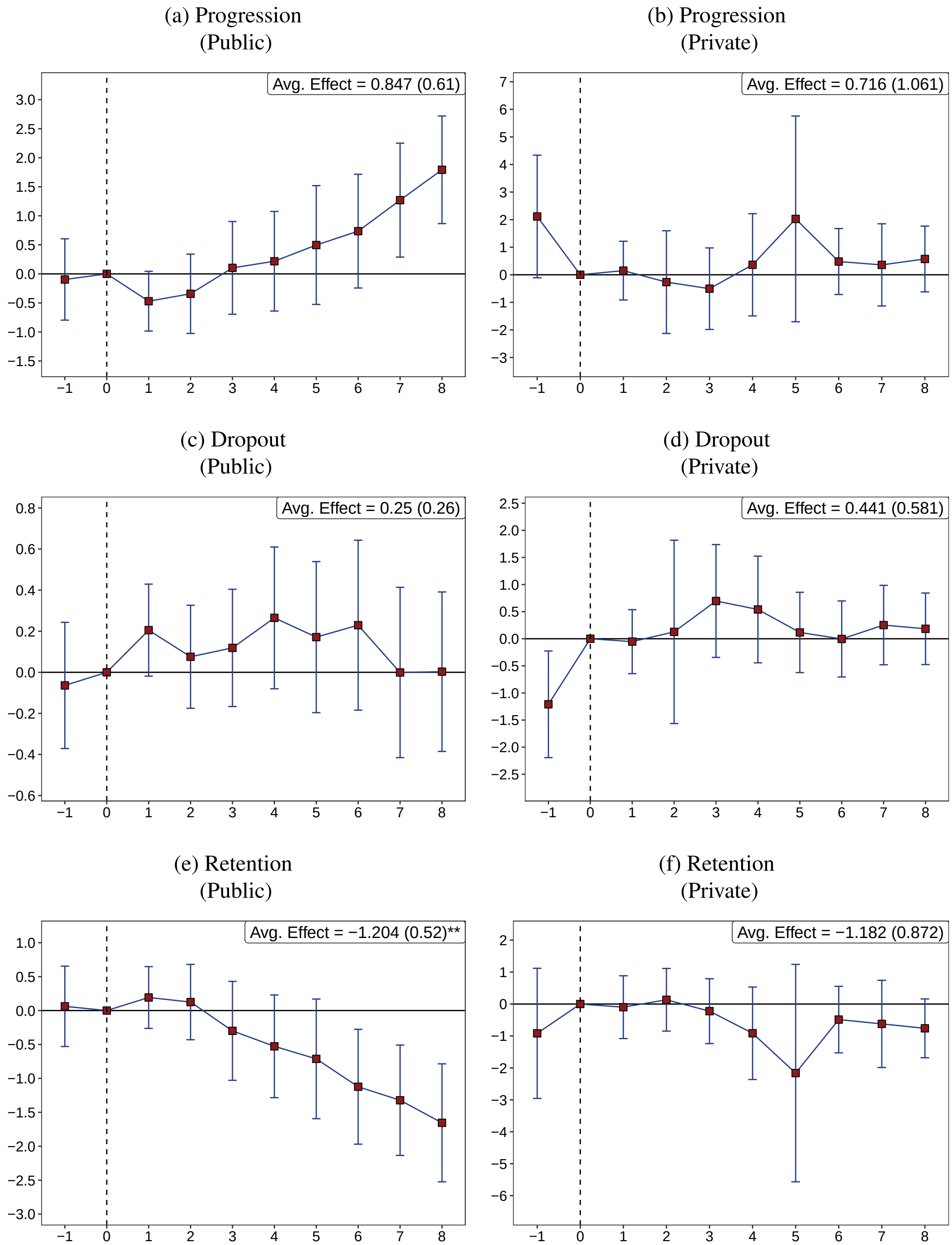
6.1 Municipal and school resources

Figure 9 runs our drought measures on the number of elementary school teachers in public schools according to their reported water supply situation in the School Census. This data captures information on whether a school has a steady supply of drinkable water and if it provides it to students. We see that the main decrease in the number of teachers comes mainly from those schools where water supply is deficient. In addition, public schools providing water have even seen an increase in the number of elementary school teachers. We also provide results for private schools in the Appendix Figure B7. Together with the results in Figure 4, intense droughts appear to increase the probability that schools suspend activities, with impacts that persist with the duration of the drought.

We also provide evidence on how droughts can affect municipal budgets. Figure 8

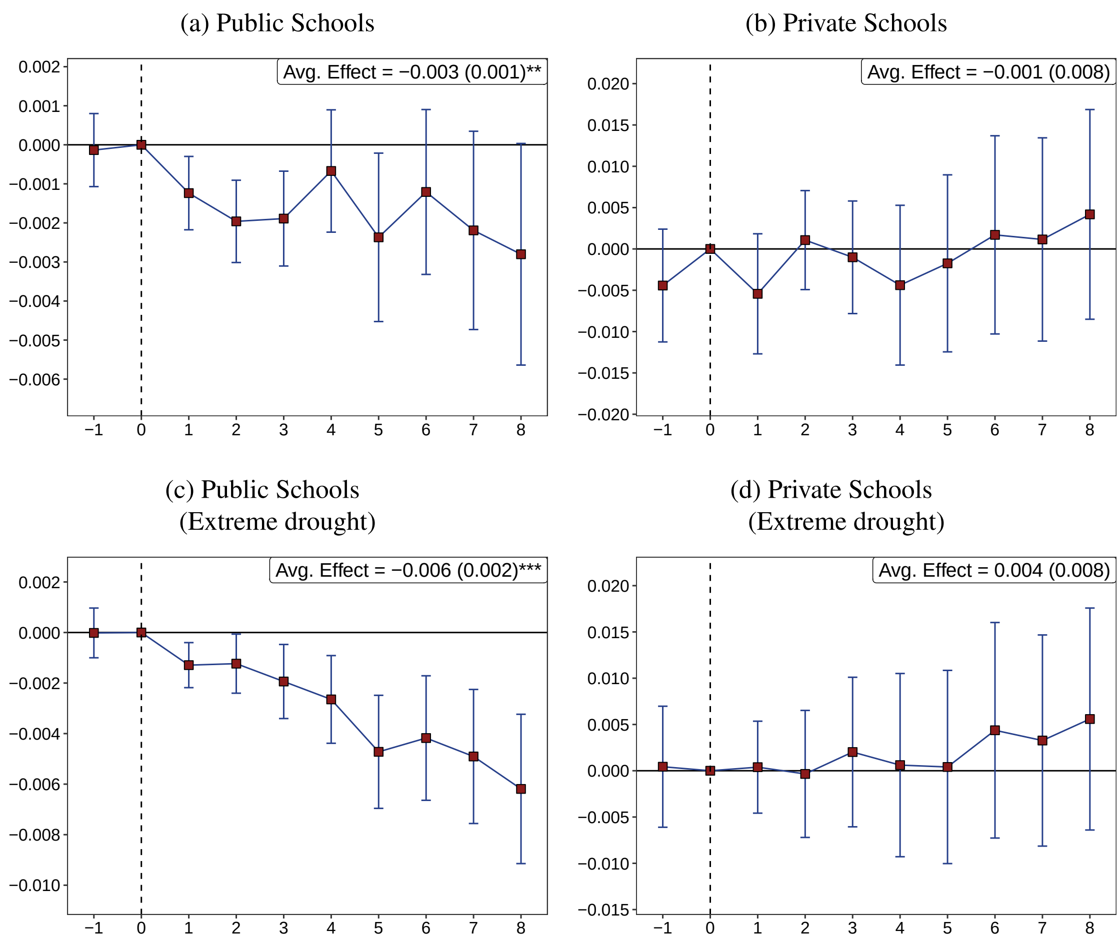
[9] https://g1.globo.com/jornal-nacional/noticia/2015/10/seca-deixa-quase-mil-cidades-do-nordeste-em-situacao-de-emergencia.html

Figure 6. Transition rates: Grades 1-9



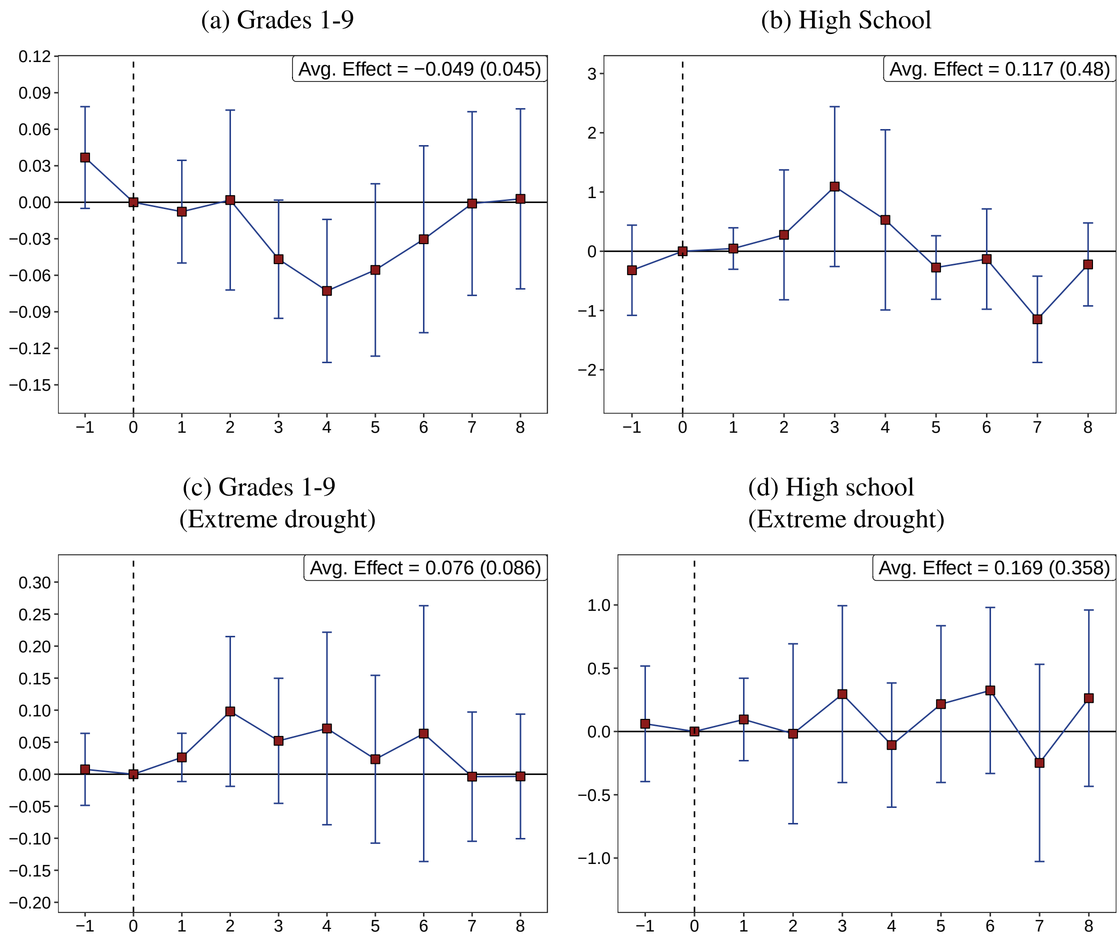
Note: The figure shows the event-study coefficients for the impacts of drought on school transition rates. A year of drought is defined as having at least 6 months with VHI below 35. Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

Figure 7. Ratio of teachers per student: Grades 1-9



Note: The figure plots event-study coefficients for drought impacts on the ratio of teachers per student in municipalities in the semi-arid region of the Brazilian Northeast for High School teachers, separated in public and private schools. Panels (a) and (b) show the results of experiencing at least 6 months of VHI values below 35 in a year (definition 1). Panels (c) and (d) consider municipalities experiencing at least 1 month of VHI values below 15, categorized as extreme drought episodes (definition 2). Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

Figure 8. Municipal expenses on education



Note: The figure plots event-study coefficients for drought impacts on the log of municipal expenses in 2019 values. It shows expenses in elementary schools and high schools. Panels (a) and (b) show the results of experiencing at least 6 months of VHI values below 35 in a year (definition 1). Panels (c) and (d) consider municipalities experiencing at least 1 month of VHI values below 15, categorized as extreme drought episodes (definition 2). Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

considers yearly municipal planned expenses on education (in logs) in 2019 values[10]. We use data from FINBRA, a national database in which municipalities are required to report their financial statements. It also provides data on expenses by categories such as Health, Education, Transport, etc. From the figure, we see a decrease in municipal expenses specifically in elementary schools, after being exposed to periods of drought.

7 Conclusion

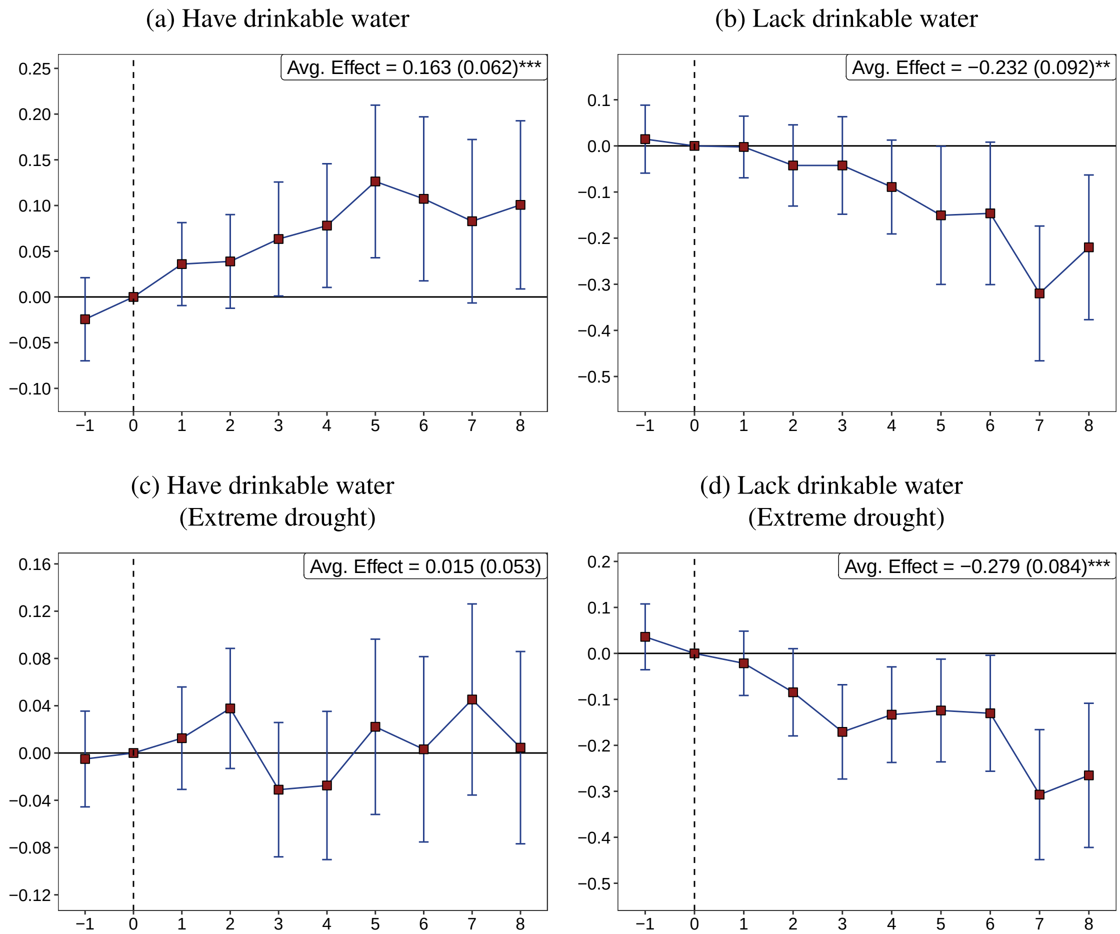
Droughts are one of the most pervasive and far-reaching extreme events, with consequences for agriculture, water availability, livestock breeding, ecosystems, and food supply (Wilhite and Pulwarty, 2017). This paper builds on existing evidence of how extreme weather affects human capital formation through a school supply channel. Consistent with previous literature, we find negative effects of droughts on learning for children in Elementary School years, but we also document that droughts negatively impact the supply of basic education.

Severe and extreme droughts have had prolonged dynamic effects on the number of teachers working and the number of schools closing in municipalities, revealing a potential channel through which extreme weather events can affect children's education. Moreover, these negative impacts are concentrated in public schools that lack a steady supply of drinkable water.

The effects are driven by low-skilled teachers, those who have high school degrees but no college education. However, we do not see any evidence of the substitution of these missing workers. We also find significant decreases in municipal expenses in elementary schools and increases in the ratio of students per teacher, pointing to a worsening of working conditions as a potential mechanism.

[10]Planned expenses (*despesas empenhadas*) are written by municipal officials with respect to a specific purpose. Once in that stage, the money is locked and can only be used for this pre-established purpose. It is the first stage in budget execution, the other two being the delivery of the goods/services (*liquidação*) and finally the execution of payment (*pagamento*).

Figure 9. Public school teachers by school water supply: Grades 1-9



Note: The figure plots event-study coefficients for drought impacts on the log of the total number of school teachers in municipalities in the semi-arid region of the Brazilian Northeast for Elementary School teachers, separated school supply of drinkable water, as reported in the School Census. Panels (a) and (b) show the results of experiencing at least 6 months of VHI values below 35 in a year (definition 1). Panels (c) and (d) consider municipalities experiencing at least 1 month of VHI values below 15, categorized as extreme drought episodes (definition 2). Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

These prolonged drought episodes are expected to become more frequent with climate change (Dai, 2013; Song et al., 2020), highlighting the need for more evidence on adaption policies (Kahn, 2016). In Brazil's semi-arid region, initiatives such as the provision of water cisterns to poor households have already been implemented by the government in recent years, with positive results (Da Mata et al., 2023). Scaling up these interventions is essential to counteract the costs to the development of climate change.

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A Appendix Tables

Appendix Table A1. Schools - Semiarid northeast (2007-2019)

School type		N	Mean	SD	Min	Max
	Active Schools	15,223	33.7	39.7	2	714
	Non-active Schools	15,223	9.59	14.3	0	146
Public	Num. Students ES	15,223	3,286	5,048	211	97,089
	Num. Students HS	15,223	868	1,757	0	53,394
	Num. Teachers ES	15,223	175	235	10	4,819
	Num. Teachers HS	15,223	47.6	114	0	3,281
	Student/Teacher ES	15,223	17.5	4.34	5.58	41.6
	Student/Teacher HS	15,223	19.5	9.67	3	546
Private	Num. Students ES	15,223	617	1,972	0	35,443
	Num. Students HS	15,223	101	522	0	12,802
	Num. Teachers ES	15,223	42.3	129	0	2,734
	Num. Teachers HS	15,223	12.5	60.8	0	1,622
	Student/Teacher ES	15,223	12.4	4.91	0.333	143
	Student/Teacher HS	15,223	6.53	5.14	0.143	153

Note: The table provides summary statistics for schools in the Brazilian semiarid northeast region. Data is from the annual school census for years 2007-2019 and includes 1,171 municipalities.

Appendix Table A2. School teacher data

School type		N	Mean	SD	Min	Max
Private	Age	2,135,155	35.4	9.11	14	90
	Black	2,135,155	0.344	0.475	0	1
	Non-declared race	2,135,155	0.417	0.493	0	1
	Woman	2,135,155	0.644	0.479	0	1
	Rural school	2,135,155	0.0119	0.109	0	1
	Diff. municipality	2,135,155	0.12	0.325	0	1
	Schooling ES	2,135,155	0.00754	0.0865	0	1
	Schooling HS	2,135,155	0.308	0.462	0	1
	Schooling Higher	2,135,155	0.685	0.465	0	1
	STEM teacher	2,135,155	0.237	0.426	0	1
	New in school	2,135,155	0.766	0.424	0	1
Public	Age	14,286,302	39	9.55	12	91
	Black	14,286,302	0.337	0.473	0	1
	Non-declared race	14,286,302	0.458	0.498	0	1
	Woman	14,286,302	0.688	0.463	0	1
	Rural school	14,286,302	0.245	0.43	0	1
	Diff. municipality	14,286,302	0.171	0.376	0	1
	Schooling ES	14,286,302	0.00357	0.0597	0	1
	Schooling HS	14,286,302	0.233	0.423	0	1
	Schooling Higher	14,286,302	0.763	0.425	0	1
	STEM teacher	14,286,302	0.256	0.436	0	1
	Tenured public	14,286,302	0.679	0.467	0	1
	Temporary	14,286,302	0.314	0.464	0	1
	New in school in year *t*	14,286,302	0.767	0.423	0	1

Note: The table provides summary statistics for schools in the Brazilian semiarid northeast region. Data is from the annual school census for years 2007-2019 and includes 1,171 municipalities.

Appendix Table A3. Drought intensity classification

Category	Percentile	Index	Possible Impacts
Abnormally dry	30 %tile	$35 < \text{VHI} \leq 40$	Entering drought: short-term dry spell reducing planting, growth of crops or pastures. Exiting drought: some lingering water deficits, pastures or crops not fully recovered.
Moderate Drought	20 %tile	$25 < \text{VHI} \leq 35$	Some damage to crops, pastures; streams, reservoirs, or wells with low levels, some water shortages developing or imminent; voluntary water use restrictions requested.
Severe Drought	10 %tile	$15 < \text{VHI} \leq 25$	Likely crop or pasture losses; water shortages common; water-use restrictions imposed.
Extreme Drought	5 %tile	$5 < \text{VHI} \leq 15$	Major crop/pasture losses; widespread water shortages or restrictions.
Exceptional Drought	2 %tile	$0 \leq \text{VHI} \leq 5$	Exceptional and widespread crop/pasture losses; water shortages in reservoirs, streams, and wells leading to emergency situations.

Note: The table shows drought categories according to different values of the Vegetation Health Index (VHI) provided by NOAA Centre for Satellite Applications and Research (2019). The possible impacts considered for each drought type were taken from the National Drought Mitigation Center of the University of Nebraska and the Brazilian Drought Monitor (*Monitor de Secas do Brasil*) at monitordesecas.ana.gov.br.

Appendix Table A4. Effects of droughts on student performance - 9th grade

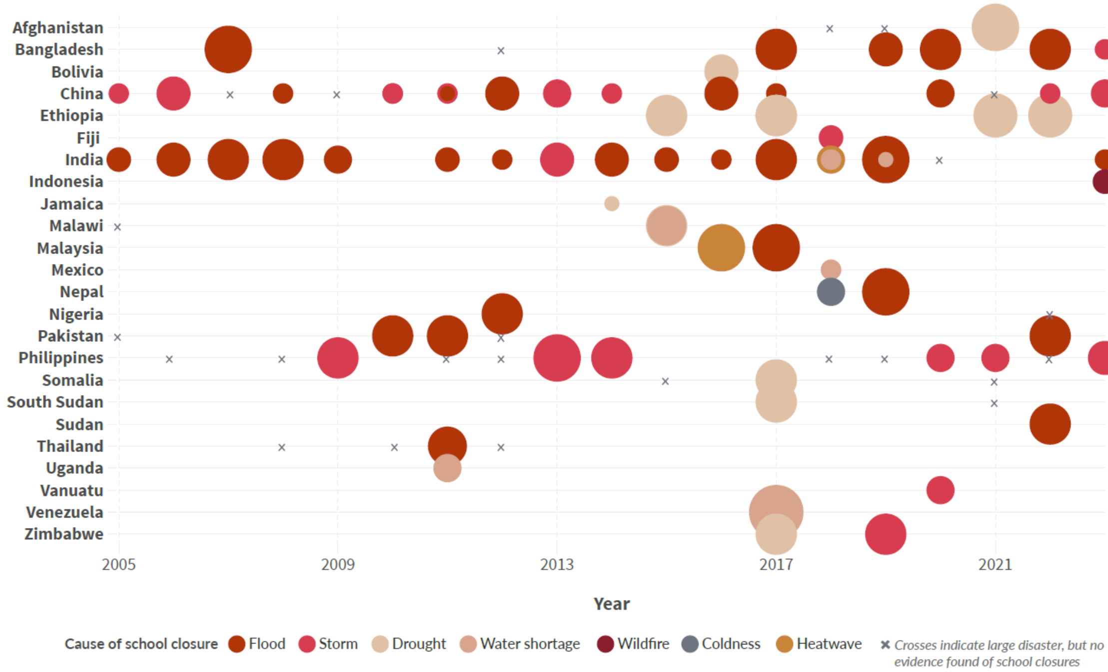
Dependent Variable:	Standardized score					
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
Drought	-0.024***			-0.016**		
	(0.007)			(0.007)		
Severe drought		-0.010			-0.008	
		(0.009)			(0.009)	
Extreme drought			-0.008			-0.010
			(0.037)			(0.025)
Controls				Yes	Yes	Yes
Fixed-effects						
Municipal FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Exam FE	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	2,576,413	2,576,413	2,576,413	1,802,528	1,802,528	1,802,528
R^2	0.11335	0.11328	0.11327	0.18559	0.18556	0.18556
Within R^2	8.44×10^{-5}	7.55×10^{-6}	2.75×10^{-7}	0.09504	0.09501	0.09500

Clustered (Municipal FE) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Note: The table provides results for the impact of at least 6 months of drought on ninth grade students' performance on *Prova Brasil* administered by SAEB every two years. Proficiency in Math and Language exams for period 2011-2019 and students in municipalities of the semiarid northeast were considered. Individual controls included are students' gender, age, mother's education, race, a dummy for whether the student has ever dropped out in previous years and a dummy for whether the student has ever repeated a grade. Severe drought considers VHI values below 25. Extreme drought considers VHI values below 15.

B Appendix Figures

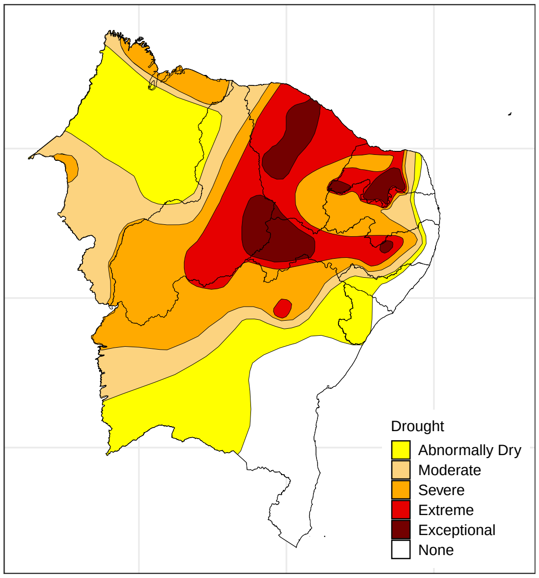
Appendix Figure B1. School closures and climate-change 2002-2021



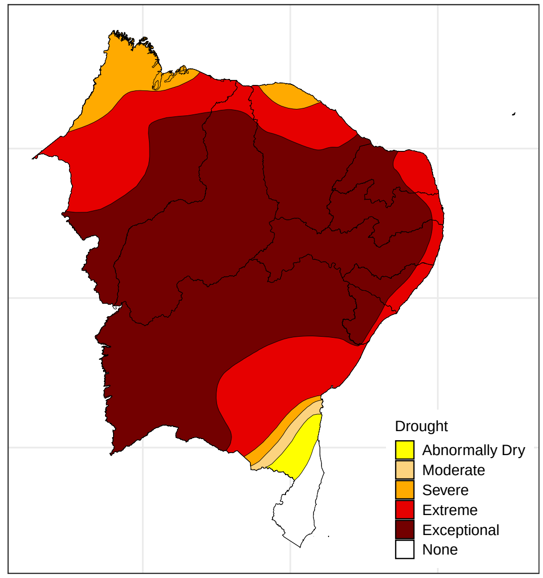
Note: Reproduced from Angrist et al. (2023). The figure plots an index of the length of school closures and number of people affected by shocks that have disrupted schooling by country and year. The larger the bubble the larger either the length of school closure or the number of people affected, or both.

Appendix Figure B2. Drought intensity - Brazil's northeast region

(a) December 2014



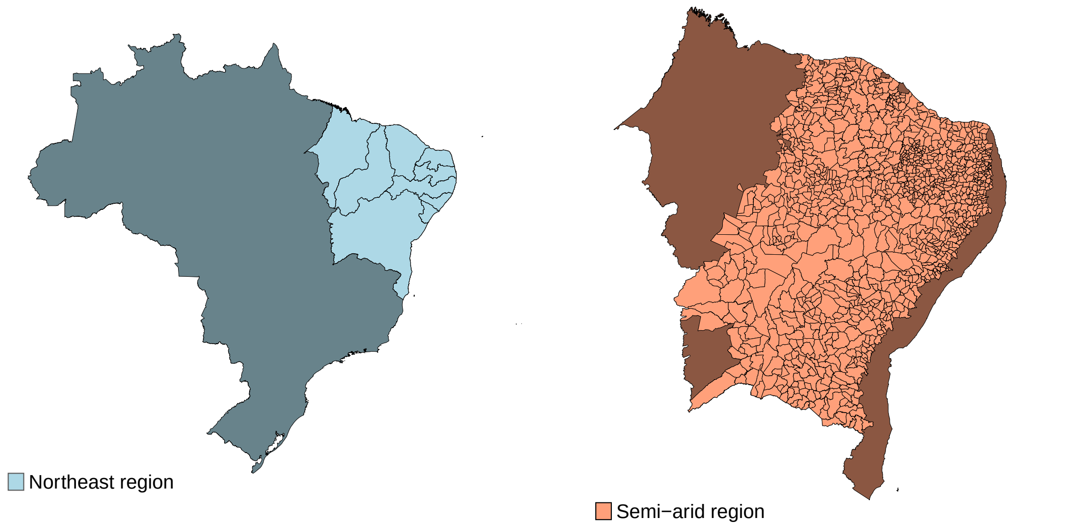
(b) December 2016



The figure plots drought conditions over Brazil's northeast region in two moments in time. Panel (a) considers December 2014 and panel (b) considers December 2016. Drought categories are defined according to Appendix Table A3. Data was taken from the Brazilian Drought Monitor (*Monitor de Secas*), compiled by the National Water Agency (ANA) at monitordesecas.ana.gov.br.

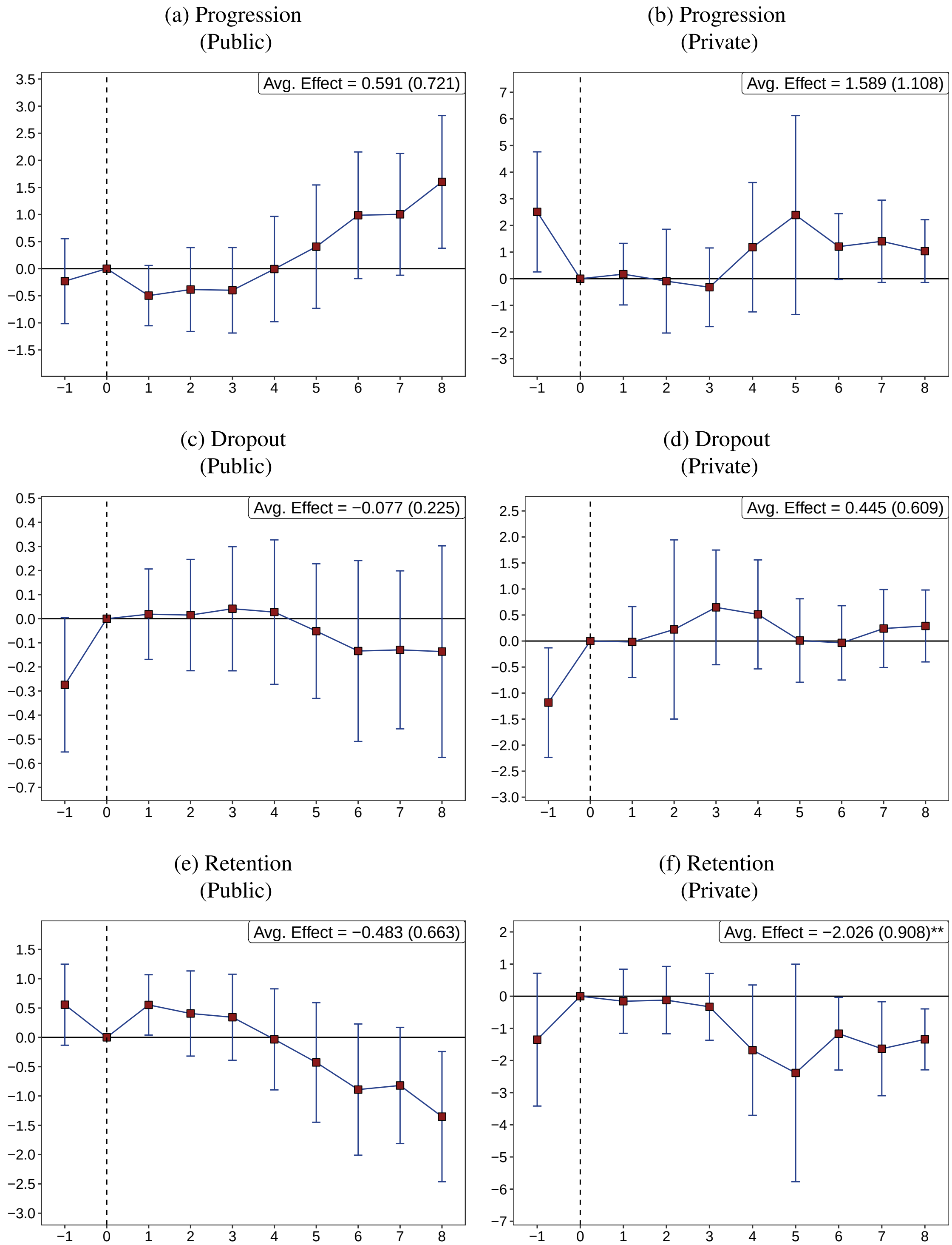
Appendix Figure B3. Northeast and semi-arid regions in Brazil

(a) Northeast region (b) Semi-arid municipalities



Note: The figure displays maps of Brazil and its Northeast region with state lines (panel A) and the municipalities in the northeast also belonging to the semi-arid region (panel B).

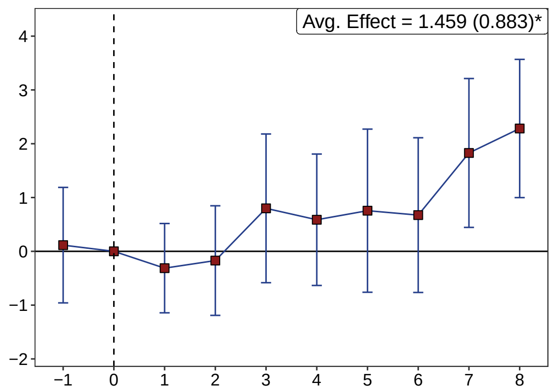
Appendix Figure B4. Transition rates: Grades 1-5



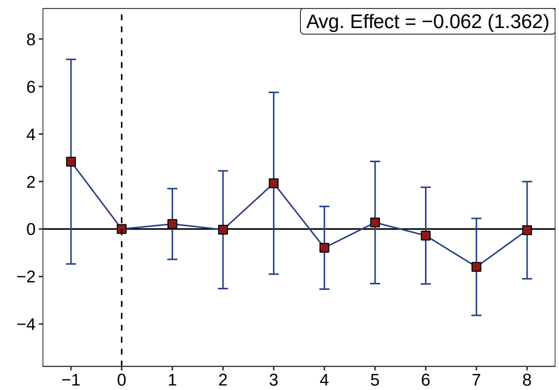
Note: The figure shows the event-study coefficients for the impacts of drought on school transition rates. A year of drought is defined as having at least 6 months with VHI below 35. Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

Appendix Figure B5. Transition rates: Grades 6-9

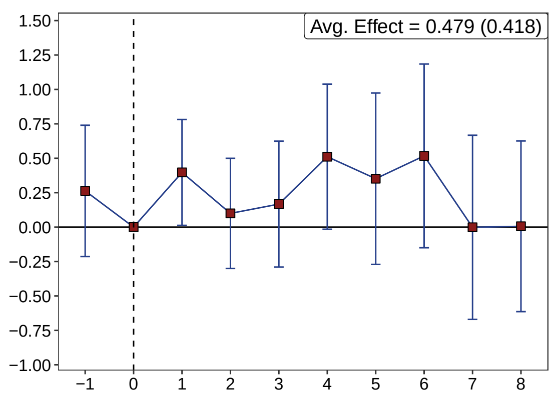
(a) Progression
(Public)



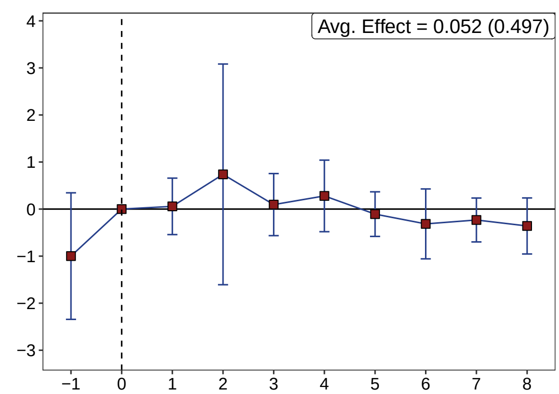
(b) Progression
(Private)



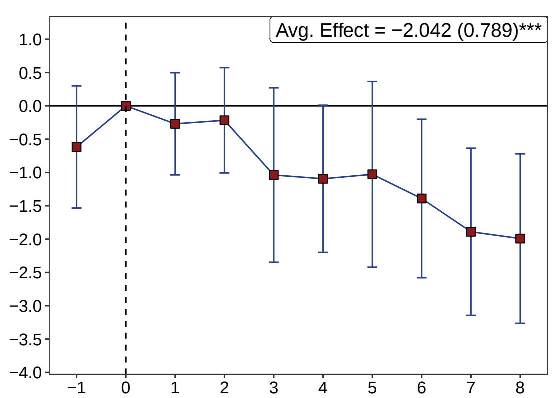
(c) Dropout
(Public)



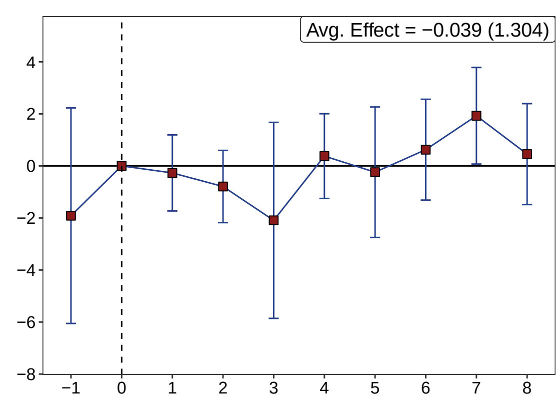
(d) Dropout
(Private)



(e) Retention
(Public)

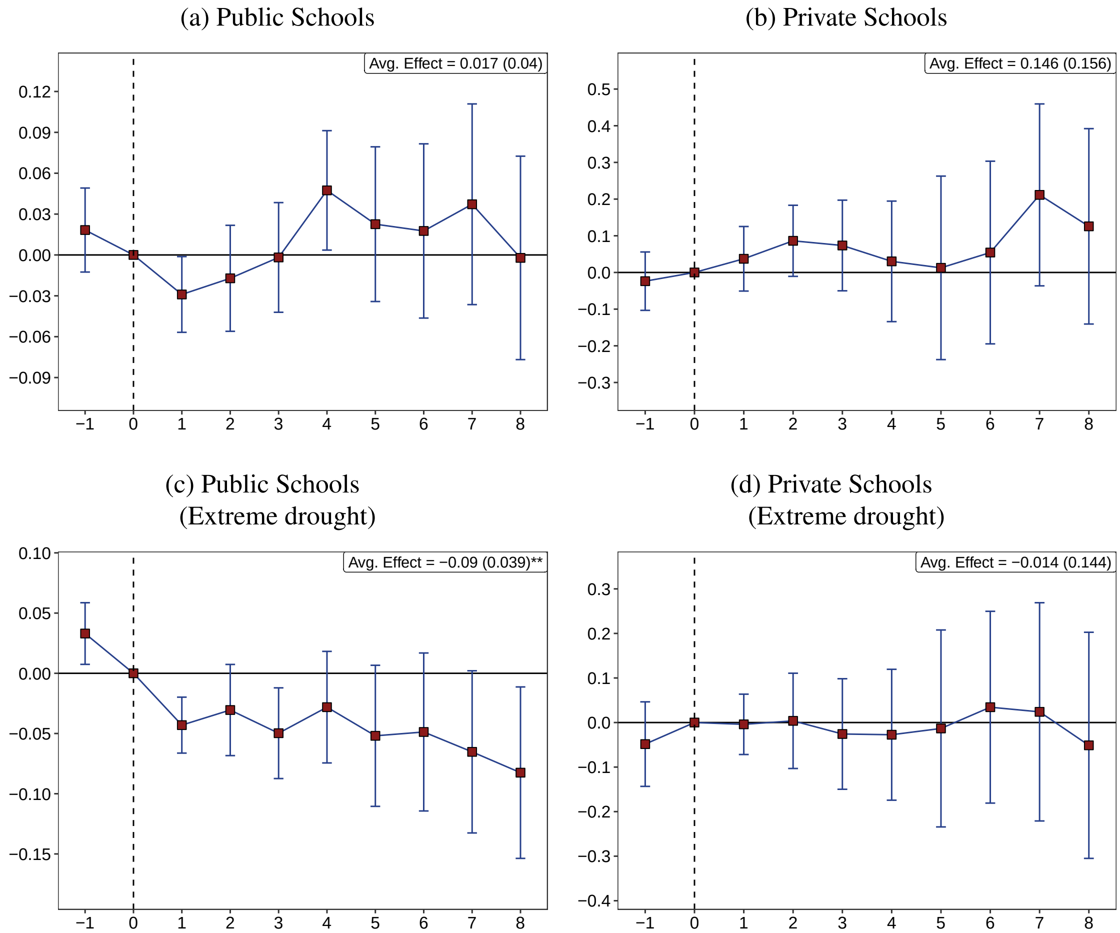


(f) Retention
(Private)



Note: The figure shows the event-study coefficients for the impacts of drought on school transition rates. A year of drought is defined as having at least 6 months with VHI below 35. Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

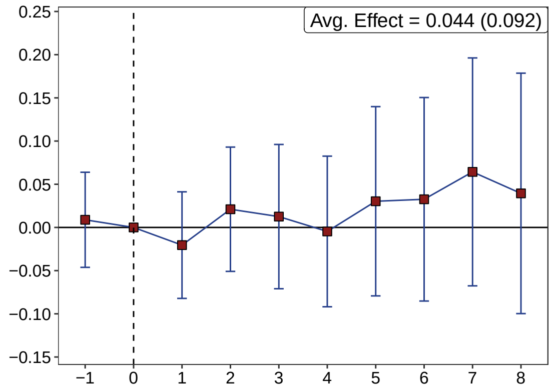
Appendix Figure B6. Total number of teachers (log): High School



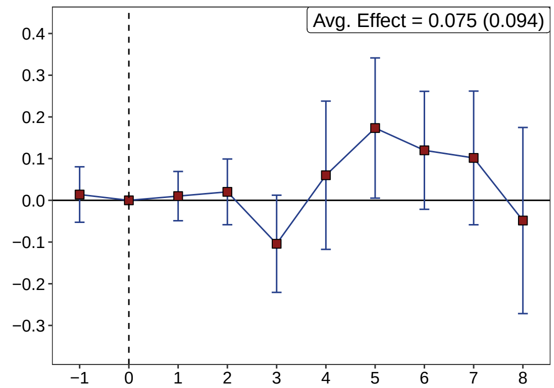
Note: The figure plots event-study coefficients for drought impacts on the log of the total number of school teachers in municipalities in the semi-arid region of the Brazilian Northeast for High School teachers, separated in public and private schools. Panels (a) and (b) show the results of experiencing at least 6 months of VHI values below 35 in a year (definition 1). Panels (c) and (d) consider municipalities experiencing at least 1 month of VHI values below 15, categorized as extreme drought episodes (definition 2). Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.

Appendix Figure B7. Private school teachers by school water supply: Grades 1-9

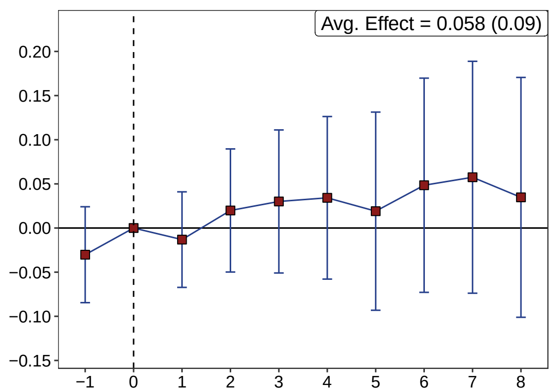
(a) Have drinkable water



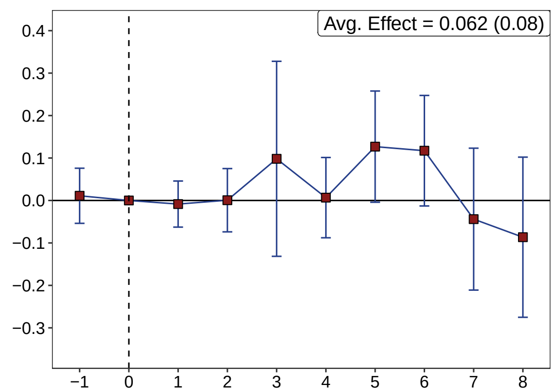
(b) Lack drinkable water



(c) Have drinkable water
(Extreme drought)



(d) Lack drinkable water
(Extreme drought)



Note: The figure plots event-study coefficients for drought impacts on the log of the total number of school teachers in municipalities in the semi-arid region of the Brazilian Northeast for Elementary School teachers, separated school supply of drinkable water, as reported in the School Census. Panels (a) and (b) show the results of experiencing at least 6 months of VHI values below 35 in a year (definition 1). Panels (c) and (d) consider municipalities experiencing at least 1 month of VHI values below 15, categorized as extreme drought episodes (definition 2). Standard errors are clustered by municipal level, and the standard error of the average effect is in parentheses.