

From Fields to Classrooms: The Impact of Droughts on Child Labor and School Performance in Brazil*

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Abstract

This paper investigates the short-term impacts of droughts and dry spells on elementary students Brazil. Using student-level microdata (2013–2019) and a robust difference-in-differences estimator, we find that these climatological shocks increase 5th-grade Mathematics proficiency by an average of 3.99 points (0.15 SD). This cognitive gain is accompanied by improved school flow, including higher promotion rates and reduced dropout and age-grade distortion. Heterogeneity analyses reveal these effects are entirely driven by male students, who exhibit a 5.19-point proficiency gain and a 3 to 4 percentage point reduction in child labor participation; effects for female students are null. Our findings support an "opportunity cost" mechanism: climate-induced agricultural shocks depress local labor demand, reallocating boys' time from economic activities toward educational investment. These results highlight the critical role of labor market dynamics in mediating the impacts of climate shocks on human capital, emphasizing the need for targeted income support and child labor enforcement.

Keywords: Extreme Climate Events; Climatological disasters; Natural Disasters; Student Performance; Child Labor; Brazil.

Resumo

Este artigo investiga os impactos de curto prazo de secas e estiagens sobre estudantes do ensino fundamental no Brasil. Utilizando microdados ao nível do aluno (2013–2019) e um estimador robusto de diferenças em diferenças, encontramos que esses choques climatológicos aumentam a proficiência em Matemática do 5º ano em uma média de 3,99 pontos (0,15 DP). Esse ganho cognitivo é acompanhado por uma melhora no fluxo escolar, incluindo taxas de aprovação mais altas e redução no abandono escolar e na distorção idade-série. Análises de heterogeneidade revelam que esses efeitos são totalmente impulsionados por estudantes do sexo masculino, que apresentam um ganho de proficiência de 5,19 pontos e uma redução de 3 a 4 pontos percentuais na participação no trabalho infantil; os efeitos para estudantes do sexo feminino são nulos. Nossos achados apoiam um mecanismo de "custo de oportunidade": choques agrícolas induzidos pelo clima reduzem a demanda por mão de obra local, realocando o tempo dos meninos de atividades econômicas para o investimento educacional. Esses resultados destacam o papel crítico da dinâmica do mercado de trabalho na mediação dos impactos dos choques climáticos no capital humano, enfatizando a necessidade de suporte de renda direcionado e de fiscalização do trabalho infantil.

Palavras-chave: Eventos Climáticos Extremos; Desastres Climatológicos; Desastres Naturais; Desempenho Escolar; Trabalho Infantil; Brasil.

Código JEL: I2, Q5, Q54

Área: Economia Social e do Trabalho

*The authors are grateful to CAPES, FAPEMIG, and CNPq for financial support.

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1 Introduction

Climate change has intensified the frequency and severity of natural disasters on a global scale, with relevant consequences for well-being, productive structures, and income distribution. In Brazil, this process has manifested itself particularly strongly in the incidence of droughts and dry spells, whose frequency has increased over recent decades, with effects concentrated among socially vulnerable populations. Given the central role of education in human capital formation and long-term economic development, the relationship between climate shocks and educational outcomes constitutes a relevant dimension of the literature on human capital and inequality. Despite the recent expansion of this literature, the direction of these effects and the mechanisms that determine them remain subjects of investigation, particularly in contexts characterized by high levels of inequality and social vulnerability.

This paper investigates the short-term effects of climatological disasters. Droughts and dry spells. On the academic performance of elementary school students in Brazil. The central question is whether, and in what direction, the occurrence of these events between consecutive assessments affects indicators of proficiency, promotion, grade repetition, and age-grade distortion in affected municipalities relative to unaffected municipalities. The hypothesis examined is that the reduction in child labor opportunities resulting from the climate shock lowers the opportunity cost of school attendance, generating, under specific conditions, positive effects on educational outcomes, in contrast to the predominantly negative relationship identified in the literature. The article's contribution lies in the application of the difference-in-differences estimator proposed by de Chaisemartin and D'Haultfœuille (2024), which incorporates temporal heterogeneity in treatment adoption, combined with a database integrating educational microdata and systematic records of climatological disasters at the municipal level.

The institutional context of this analysis is defined by the high incidence of natural disasters in Brazil and their documented economic and social costs. According to the *Atlas Digital de Desastres no Brasil* (Atlas Digital, 2024), more than 22,000 disasters were recorded between 2011 and 2019, affecting more than 116 million people and generating estimated economic losses of R\$ 45.8 billion. Beyond these direct costs, the literature documents that natural disasters affect human capital formation through channels related to health, household income, family composition, and school infrastructure (Alderman et al., 2006; Hoddinott and Kinsey, 2001; Baez et al., 2010; Baez and Santos, 2007). This body of evidence positions the investigation of the educational effects of climatological disasters as a relevant dimension for understanding human capital formation trajectories in smaller and socioeconomically more vulnerable municipalities.

The empirical analysis combines microdata from Prova Brasil (SAEB) for the years 2013, 2015, 2017, and 2019 with information on disaster occurrence from the *Atlas Digital de Desastres no Brasil* (SEDEC/CEPED) and educational indicators made available annually by INEP. The database allows the measurement of average proficiency in Portuguese Language and Mathematics for 5th and 9th grade students, as well as promotion, grade repetition, and age-grade distortion rates. The sample comprises 1,494 municipalities, of which 119 were affected exclusively by climatological disasters during the period analyzed and 1,375 recorded no disaster occurrence, composing the control group.

The identification strategy exploits the occurrence of climatological disasters in the interval between consecutive applications of Prova Brasil, classifying municipalities as treated (exposed to a disaster) or control (not exposed). The analysis is implemented using the difference-in-differences estimator proposed by de Chaisemartin and D'Haultfœuille (2024), which accommodates temporal heterogeneity in treatment adoption across units. The validity of the strategy is assessed through placebo tests, which verify the absence of significant effects when treatment is simulated in municipalities not affected by disasters, providing preliminary evidence that spurious trends do not explain the observed results.

The results indicate a positive and statistically significant effect of climatological disasters on 5th-grade Mathematics scores. In affected municipalities, the average Mathematics score increased by 3.99 points relative to control municipalities, corresponding to 0.15 standard deviations. In parallel, increases in promotion rates and significant reductions in age-grade distortion and school dropout rates are observed in the 5th-grade, indicating that the effects of the climate shock are not limited to learning outcomes but also extend to school progression.

The heterogeneity analysis by gender and race shows that the effect on Mathematics performance is concentrated among male students, for whom the average 5th-grade score increases by 5.19 points, equivalent to 0.19 standard deviations. No significant effects are identified for female students or across racial groups. For this same group, a reduction in a proxy for child labor of between 3% and 4% is observed, corresponding to 0.28 and 0.38 standard deviations in the two periods analyzed, with no equivalent significant effects for female students.

The convergence between the concentration of educational effects among male students and the simultaneous reduction in the proxy for child labor for this same group is consistent with an opportunity cost mechanism of child labor, according to which the reduction in work opportunities associated with the climate shock frees up time for school-related activities. This relationship between the opportunity cost of child labor and educational indicators is consistent with evidence documented in other contexts (Rush, 2018; Shah and Steinberg, 2017; Zimmermann, 2020; Nordstrom and Cotton, 2025). The robustness of the main results is corroborated by the placebo tests, which do not indicate significant effects when treatment is assigned in a simulated manner to municipalities not affected by disasters.

This article contributes to the literature in three dimensions. First, it contributes to the literature on natural disasters and human capital, which has predominantly documented negative effects of climate shocks on educational outcomes (López, 2009; Pörtner, 2008; Sigurdson et al., 2011; Yamauchi et al., 2009; Björkman-Nyqvist, 2013; Carneiro et al., 2021; Nilsson, 2009; Sanders, 2012; ?). This article provides evidence for Brazil of a positive short-term effect on Mathematics performance, geographically expanding a body of findings that had previously been concentrated in Asian contexts.

Second, this article contributes to the literature linking agricultural shocks, the opportunity cost of child labor, and school attendance (Ferreira and Schady, 2009; López, 2009; Rush, 2018; Shah and Steinberg, 2017; Skidmore and Toya, 2002; Zimmermann, 2020; Nordstrom and Cotton, 2025). Shah and Steinberg (2017) show that children's exposure to drought in India was associated with improved Mathematics performance and higher school attendance, partly due to a reduction in participation in labor activities, while Rush (2018) documents an increase in school enrollment in Indonesia following disasters that reduced agricultural labor opportunities. Similarly, Zimmermann (2020) shows that negative rainfall shocks (droughts) increase school enrollment, whereas positive rainfall shocks reduce it, attributing this relationship to the opportunity cost of agricultural labor. This article extends this literature by jointly analyzing performance indicators, school progression outcomes, and a proxy for child labor in the Brazilian case, identifying gender heterogeneity in this mechanism.

Third, this article makes a methodological contribution by applying, in the context of climatological disasters and education in Brazil, the difference-in-differences estimator proposed by de Chaisemartin and D'Haultfœuille (2024), which accommodates temporal heterogeneity in treatment adoption. This approach differs from the traditional difference-in-differences specifications that predominate in the literature on disasters and human capital, offering an additional identification strategy for contexts in which treatment exposure occurs non-simultaneously across units.

The remainder of the article is organized as follows. Section 2 presents the data and the empirical strategy. Section 3 presents the main results and explores heterogeneity and mechanisms. Section 4 discusses the robustness tests. Section 5 concludes.

2 Methodology

2.1 Data

2.1.1 Educational Data

The educational data used in this study come from Prova Brasil, a nationwide standardized assessment conducted and published by the National Institute for Educational Studies and Research Anísio Teixeira (INEP). Since 2007, the assessments have been administered biennially to 5th- and 9th-grade classes in public schools that report a minimum enrollment of 20 students in those grades. This assessment, promoted by the Brazilian Federal Government, aims to measure students' cognitive skills throughout the national territory.

For the publication of results from schools participating in the Basic Education Assessment System

(SAEB), compliance with the following criteria is mandatory: (i) recording a minimum of 10 students present at the time of test administration; and (ii) achieving a participation rate of at least 80% of enrolled students, based on data reported by the educational institution in the Basic Education Census, also conducted by INEP.

The assessment instruments measure proficiency in Portuguese Language and Mathematics and, simultaneously, collect information regarding students' home, family, and school environments, as well as institutional infrastructure. INEP administers a set of questionnaires directed at students, teachers, and principals in order to obtain a comprehensive diagnosis of the educational context.

In this study, microeducational data from the 2013, 2015, 2017, and 2019 editions of Prova Brasil are used. The data were aggregated at the municipal level, considering the average proficiency scores in Mathematics and Portuguese Language. Standardization consists of converting students' proficiency scores to the unified SAEB scale, characterized by a mean of 250 points, a standard deviation of 50, and a range varying from 0 to 500 points.

Additionally, control variables and supplementary outcomes at the municipal level were incorporated, such as the total number of enrolled students, the number of participants in each edition of Prova Brasil, and information regarding child labor status. The latter was defined based on engagement in activities outside the household for at least one hour, as well as the performance of domestic work. The dates on which these tests were administered are reported below:

Table 1: Prova Brasil Test Administration Dates

Prova Brasil Edition	Test Administration Dates
2013	2013/11/11 to 2013/11/21
2015	2015/11/03 to 2015/11/13
2017	2017/10/23 to 2017/11/03
2019	2019/10/21 to 2019/11/01

Source: Author's elaboration based on SAEB data.

To obtain promotion rates at the municipal level, data from the Basic Education Development Index (IDEB), made available by INEP, were used. IDEB is calculated concurrently with the editions of Prova Brasil, since its methodological formulation combines school performance rates (promotion), derived from the School Census, with the average performance scores obtained in SAEB. Consequently, promotion rates from public educational institutions for 5th- and 9th-grade elementary school students were extracted.

2.1.2 Climatological Disaster Data

Data on natural disasters were obtained from the National Secretariat for Protection and Civil Defense (SEDEC), from the *Atlas Digital de Desastres no Brasil (ATLAS)*. Additionally, it quantifies human, material, and environmental damages, public and private economic losses, and identifies the reporting institution responsible for the record.

In Brazil, most natural disasters are closely related to precipitation and temperature anomalies, reflecting complex interactions between climatic and geographical factors. According to the Brazilian Disaster Classification (COBRADE) adopted by SEDEC, occurrences are divided into five major categories¹:

- I. Climatological: Droughts, dry spells, among others;
- II. Hydrological: Flooding, flash floods, and inundations;
- III. Meteorological: Storms and extreme temperatures;
- IV. Geological: Erosive processes and mass movements/earthquakes;
- V. Biological: Epidemics and infestations/pests.

According to the statistics of the *ATLAS*, between 2011 and 2019, climatological shocks accounted for 55.09% of recorded occurrences, followed by hydrological events, with 24.01%. The remaining categories (meteorological, geological, and biological) totaled approximately 23.90% of notifications. In sum, climatological and hydrological disasters constitute the core of environmental shocks in the country, concentrating approximately 79.01% of the total number of occurrences during the analyzed period.

¹For more details on the Brazilian Disaster Classification and Coding System (Cobrade): <https://www.defesacivil.rs.gov.br/upload/arquivos/202105/04095316-cobrade-classificacao-e-codificacao-brasileira-de-desastres.pdf>, accessed on 2024/10/15.

This study focuses on analyzing the impacts generated by the most frequent environmental shocks in Brazilian territory: climatological disasters. Henceforth, the definitions, classifications, and typical manifestations of these events in the national context are presented.

Climatological disasters arise from anomalies in the atmospheric conditions of a specific region, encompassing everything from severe moisture deficits to prolonged dry spells. The main observed typologies include:

- I. Drought: A phenomenon characterized by a prolonged period of precipitation substantially below the climatological average, or by its absolute absence, in which the evapotranspiration rate and the consequent loss of soil moisture exceed hydrological replenishment. This disturbance exerts a direct negative impact on agricultural productivity and regional hydrological reserves.
- II. Dry spell: Although related to the concept of drought, a dry spell is characterized by a delay or absence of precipitation during periods in which rainfall is seasonally expected. Its consequences generate severe hydrological imbalances that compromise public water supply, food security, and energy provision for affected populations.

In order to isolate the causal effect of climatological shocks on educational indicators, this study adopts an impact evaluation design in which the treatment group is composed strictly of municipalities that experienced exclusively disasters of this nature. In contrast, the control group consists of municipalities that recorded no occurrences of natural disasters throughout the defined time horizon (non-switchers). For matching and estimation purposes, the interval of environmental shock occurrence is delimited between January 19, 2011, and October 20, 2019.

The subsequent section reports four thematic maps at the municipal level, distinguishing the spatial distribution of occurrences during the analyzed period: the first map spatially represents climatological disasters; the second maps hydrological events; the third illustrates the regions affected by the remaining categories of shocks (meteorological, geological, and biological); and the fourth quadrant represents the municipal units that remained free of natural disaster records during the investigated time interval.

Figure 1: Thematic Maps Showing the Distribution of Municipalities by Disaster Occurrence and Their Respective Types



Source: Author's elaboration based on the *ATLAS*.

The time window for identifying the climatological shocks that define the treatment status of municipalities was delimited between the final date of application of one edition of Prova Brasil and the first day of application of the subsequent edition. Thus, the disaster occurrences incorporated into this study are strictly confined to these inter-period intervals. Subsequent events that coincided with the period of Prova Brasil administration entail the automatic exclusion of the affected municipalities, mitigating potential confounding biases in the estimates.

To ensure the internal consistency of the identification strategy, municipalities that recorded disasters between January 19, 2011, and November 21, 2013, were excluded from the sample. This restriction is necessary because such localities would be unsuitable as treatment units in the initial round of Prova Brasil considered in this study, corresponding to the 2013 edition.

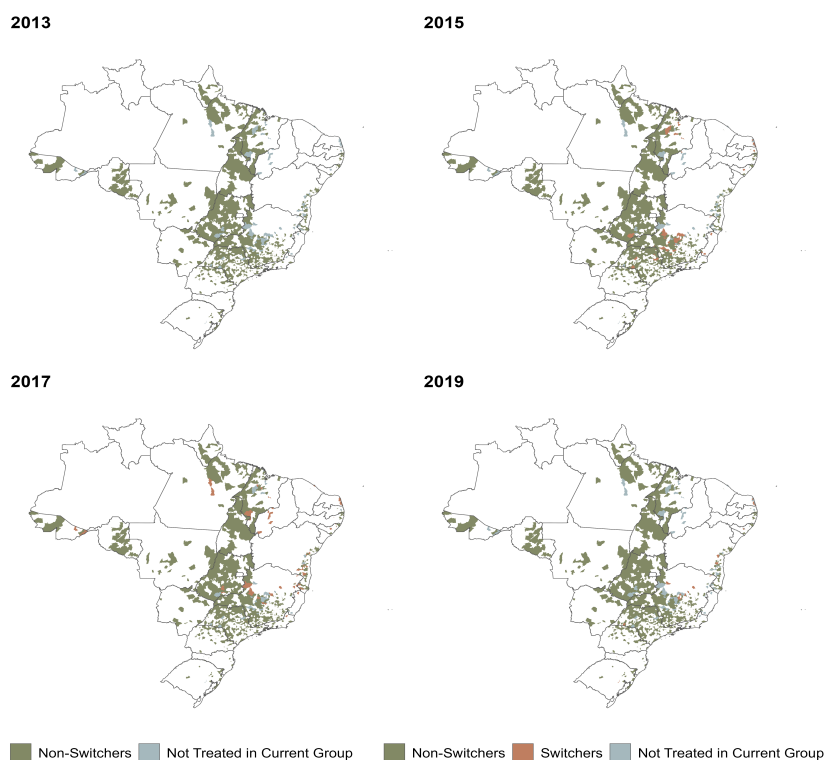
Table 2: Definition of Treated and Control Groups

Groups	Treatment Period	Specific Dates
2015	1	2013/11/22 to 2014/12/31
	2	2015/01/01 to 2015/11/02
2017	3	2015/11/14 to 2016/12/31
	4	2017/01/01 to 2017/10/22
2019	5	2017/11/04 to 2018/12/31
	6	2019/01/01 to 2019/10/20
Control	Never Treated	2011/01/19 to 2019/10/20

Source: Author's elaboration based on SAEB data and the *ATLAS*.

Accordingly, the sample was structured such that the treatment group comprised exclusively municipalities affected by climatological disasters, whereas the control group consisted of municipalities that recorded no adverse event of this nature throughout the investigated time horizon. In total, 118 municipalities were identified as eligible for the treatment group.

Figure 2: Thematic Maps Showing the Classification of Municipalities According to the Identification Strategy



Source: Author's elaboration based on the *ATLAS*.

In contrast, 1,375 municipalities did not present any notifications of natural disasters within the interval considered, thereby composing the control group. Consequently, the final analytical sample totals 1,493 municipalities, while 4,077 municipalities were excluded from the panel as a result of the criteria established by the identification strategy described above.

The term switchers refers to municipalities that received treatment within the specific time windows stipulated for each cohort in Table 2. The expression not treated in the current group applies to units that were exposed to treatment at some point during the macro-analytical period, but outside the strict interval determined for the group under current analysis. In turn, the control group, referred to as non-switchers,

encompasses localities with no record of natural disasters between January 19, 2011, and October 20, 2019.

2.1.3 Others

To validate the impacts on municipal rural production, data from the Brazilian Institute of Geography and Statistics (IBGE) are used. Specifically, the share of agriculture in the municipality's value added is employed as the variable of interest in order to analyze how disasters affect the opportunity cost of rural employment. The objective is to investigate whether this share in value added exhibits a contraction in the post-disaster period in treated municipalities vis-à-vis the control group.

2.2 Empirical Strategy

The method employed in this research follows the approach proposed by de Chaisemartin and D'Haultfœuille (2024), which is based on the estimation of difference-in-differences. The DID_ℓ estimator compares the evolution of outcomes between groups that transition from untreated to treated status (*Switchers*) and those that have not yet changed status (*Non-Switchers*) in the ℓ -th period following the initial change. To support the validity of the parallel trends assumption, placebo estimators will be assessed. Under the assumption of parallel trends, the estimator is consistent and robust to treatment effect heterogeneity.

One advantage of this estimator over that proposed by Callaway and Sant'Anna (2021) is its applicability in settings where treatment adoption varies over time, allowing for multiple treatment status transitions across groups. Moreover, compared to the method proposed by Sun and Abraham (2021), its key advantage lies in the use of not-yet-treated groups as the control group.

Based on the estimator of de Chaisemartin and D'Haultfœuille (2024), let $Y_{g,t}$ represent the outcome (SAEB test scores in Portuguese and Mathematics), and $D_1, \dots, D_t$ indicate treatment status over time. Let F_g denote the first period in which municipality g transitions from control to treatment. The expected difference between the actual outcome of group g in period $F_g - 1 + \ell$ and the counterfactual outcome that would have been observed had g remained untreated between period 1 and period $F_g - 1 + \ell$, is defined as:

$$\delta_{(g,\ell)} = \mathbb{E} \left(Y_{g,F_g-1+\ell} - Y_{g,F_g-1+\ell}(D_{g,1}, \dots, D_{g,1}) \right) \quad (1)$$

To estimate $\delta_{g,\ell}$, the authors propose a DID_ℓ estimator that compares the change in outcomes between periods $F_g - 1$ and $F_g - 1 + \ell$ for group g , with the change observed in groups whose treatment status has not yet changed in the same period. This estimator accommodates group-varying effects, enabling a more accurate analysis of treatment effect heterogeneity.

To isolate the effect of climatological disasters on educational performance, only municipalities that experienced exclusively this type of disaster during the analyzed period were considered as treated. Municipalities that never faced natural disasters composed the control group. Those who experienced more than one type of disaster were excluded from the analysis.

The research design follows the estimator proposed by de Chaisemartin and D'Haultfœuille (2024), which is suitable for situations in which the frequency of treatment exceeds that of the outcome. This is the case for natural disasters, which are recorded annually, while the Portuguese and Mathematics assessments from Prova Brasil occur only every two years. To address this asymmetry, the dataset was divided into two subsamples:

- I. First subsample: Includes all groups and periods in which the treatment status remained constant from the beginning until the observation of the outcome (*Non-Switchers*). Additionally, it includes only the groups that switched from untreated to treated exactly in the year of the Prova Brasil application, i.e., the even-numbered periods presented in Table 2.
- II. Second subsample: Also composed of *Non-Switchers*, but includes only the groups that switched from untreated to treated in the year prior to the Prova Brasil application, corresponding to the odd-numbered periods in Table 2.

This approach allows the identification of treatment effects both in the year when the proficiency tests were administered and in the preceding periods. As such, it enables a comprehensive analysis of the effects of climatological disasters on educational performance across all relevant periods.

3 Results

3.1 Descriptive Statistics

To understand the behavior of the sample exposed to climatological shocks on educational indicators, a descriptive analysis was conducted based on the microdata made available by INEP (SAEB), *ATLAS*, and the Municipal Agricultural Survey (PAM/IBGE). This stage investigates the trajectories and socioeconomic characteristics of the treatment and control groups at baseline and in subsequent periods.

For descriptive tabulation purposes, municipalities eligible for treatment are segmented into two dynamic categories: switchers and not-yet-treated. Switchers correspond to municipalities effectively exposed to the climatological shock within the time window stipulated for each cohort in Table 2. Not-yet-treated represent municipalities that experienced disasters at some point during the macro-analytical horizon, but in a period subsequent to the specific interval under current analysis.

In the 2013 edition of Prova Brasil, which marks the baseline of the study, only municipalities in the control group and those classified as not-yet-treated present records, given the absence of treated municipalities up to that point. In contrast, in the 2019 edition, the descriptive scope encompasses switchers and the control group. At this terminal point, all treatment units in the sample had already been exposed to the environmental shock, reducing the number of municipalities in the not-yet-treated condition to zero. This longitudinal approach makes it possible to examine the temporal evolution of the

Table 3: Descriptive Statistics of Educational Indicators for 5th Grade - Climatological Sample

Variable	2013			2015					2017					2019		
	Mean Not-yet treated (2)	Mean Non Switchers (3)	Diff (5) (2) – (3)	Mean Switchers (1)	Mean Not-yet treated (2)	Mean Non Switchers (3)	Diff (4) (1) – (3)	Diff (5) (2) – (3)	Mean Switchers (1)	Mean Not-yet treated (2)	Mean Non Switchers (3)	Diff (4) (1) – (3)	Diff (5) (2) – (3)	Mean Switchers (1)	Mean Non Switchers (3)	Diff (4) (1) – (3)
Math Proficiency	203.15	215.68	-12.53***	214.92	205.90	221.41	-6.49*	-15.51***	207.20	224.79	226.59	-19.39***	-1.8	215.04	229.56	-14.51***
Portuguese Proficiency	186.41	196.41	-10***	199.43	194.31	206.93	-7.5***	-12.62***	197.57	214.03	214.68	-17.51***	-0.65	201.54	213.73	-12.18***
Age-Grade Distortion Rate	29.11	20.98	8.13***	22.25	29.02	17.87	4.38**	11.15***	27.49	16.48	15.88	11.61***	0.6	20.60	14.19	6.41*
Promotion Rate	89.75	93.86	-4.11***	92.23	88.71	94.21	-2.18*	-5.51***	89.35	93.55	94.89	-5.54***	-1.34	91.05	95.74	-4.69***
Failure Rate	8.07	5.24	2.84***	6.61	9.11	5.02	1.58*	4.09***	8.83	5.69	4.47	4.36***	1.22	7.70	3.82	3.89***
Dropout Rate	2.17	0.90	1.27***	1.36	2.18	0.76	0.6**	1.42***	1.82	0.76	0.64	1.18***	0.12	1.24	0.44	0.8**
Black	0.60	0.54	0.05***	0.58	0.62	0.56	0.03*	-0.06***	0.64	0.61	0.55	0.06***	-0.01	0.07	0.03	0.04***
Female	0.48	0.49	-0.01	0.48	0.51	0.49	-0.01	0.02**	0.49	0.49		0.00				
Child Labor	0.20	0.16	0.04***	0.16	0.16	0.14	0.02**	0.02**	0.16	0.13	0.13	0.03	0.00	0.17	0.16	0.01
Work Domestic	0.81	0.81	0.00	0.80	0.81	0.80	0.00	0.01	0.84	0.87	0.84	0.00	0.03	0.74	0.79	-0.05
Enrollment	461.42	224.46	236.95	233.74	588.54	217.43	-16.31	371.11	588.72	242.80	230.34	12.46	328.38	280.54	217.39	63.15
Attendance	412.97	203.38	209.59	234.24	575.53	212.55	21.69	362.97	520.14	227.50	209.46	310.68	18.04	189.08	191.02	1.94
Attendance Rate	0.88	0.92	-0.04***	0.91	0.90	0.92	-0.01	-0.02*	0.91	0.92	0.93	-0.02**	-0.01	0.94	0.95	0.01
Agric. Share of VA	0.24	0.24	0.00	0.21	0.22	0.23	-0.01	-0.02	0.23	0.20	0.23	0.00	-0.03	0.20	0.21	-0.01

Source: Author's elaboration based on SAEB data and the *ATLAS*. Statistical Significance: *** = 1%, ** = 5%, and * = 10%.

indicators and provides descriptive evidence for assessing the causal impact of disaster exposure on students' cognitive performance and school flow.

Table 3 presents the educational indicators for the 5th grade of elementary school in the climatological sample. With respect to proficiency scores in Mathematics, it is observed that, in 2015, the switcher municipalities exhibited higher performance than the not-yet-treated municipalities. The average difference relative to the control group was -6.49 points for switchers and -15.51 points for the not-yet-treated. However, in 2017, this pattern was reversed: the not-yet-treated municipalities began to exhibit a higher average than the switchers, with differences relative to the control group of -19.39 and -1.80 points, respectively. In 2019, the switchers maintained lower performance than the control group, with a difference of -14.51 points.

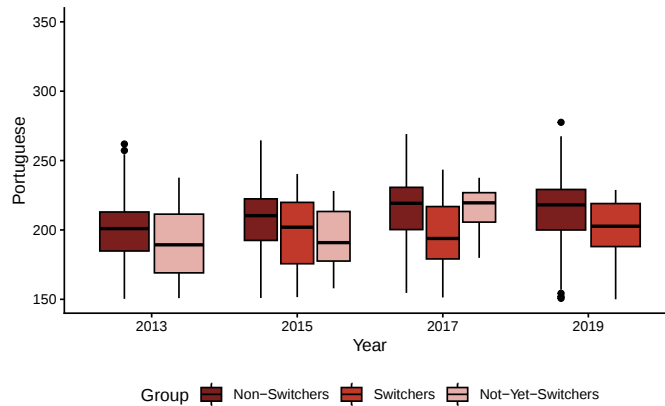
This dynamic is repeated in the results of the Portuguese Language proficiency tests, indicating a common trend across both subjects. In 2015, switchers exhibited better relative performance than the not-yet-treated, with differences of -7.50 and -12.62 points relative to the control group, respectively. In 2017, the not-yet-treated began to outperform the switchers, with a difference of only -0.65 points relative to the control group, while switchers remained -17.51 points below. In all evaluated periods, the control group (non-switchers) recorded the highest average scores.

Figure 3 complements this analysis through boxplots. In Panel A, referring to Portuguese Language, it is observed that, in 2017, the median of the not-yet-treated municipalities exceeds that of the control group, although the latter presents a higher mean due to larger values in the upper quartiles. In this context, the not-yet-treated municipalities outperformed the switchers across all evaluated parameters. In 2015, by contrast, in both Panel A and Panel B, the switchers exhibited better performance than the not-yet-treated, as

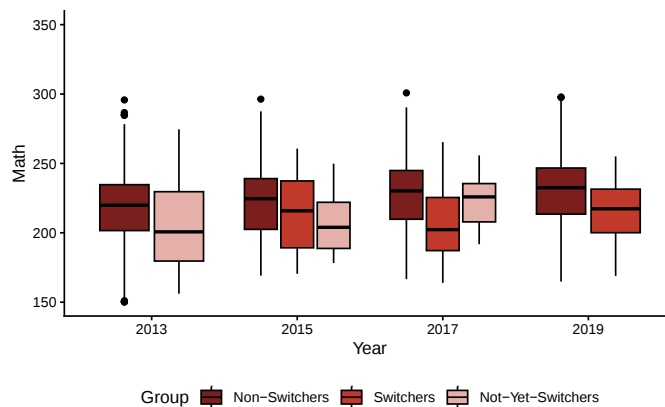
evidenced by a higher median.

The indicators of Promotion, School Dropout, Age-Grade Distortion, and Grade Repetition follow a pattern analogous to that of the proficiency scores: in 2015, switchers exhibit relatively better outcomes, whereas in 2017 the situation is reversed in favor of the not-yet-treated. This set of results reinforces the reversal in dynamics between the groups of treated municipalities over time, highlighting the complexity of the effects of natural disasters on educational performance.

Figure 3: Distribution of 5th Grade Scores – Climatological Sample (Box-Plot)
Panel A – Portuguese Proficiency Test



Panel B – Mathematics Proficiency Test



Source: Author's elaboration based on SAEB data and the *ATLAS*.

Table 4 replicates the previous structure for 9th-grade students in the climatological sample. For the Mathematics and Portuguese Language proficiency tests, the non-switcher and not-yet-treated municipalities exhibit a similar upward trend over time. The non-switchers start with average scores of 250.62 and 243.38 points in Mathematics and Portuguese Language, respectively, in 2013, and evolve consistently until 2019. The not-yet-treated follow this trajectory, with performance close to that of the control group throughout the entire period.

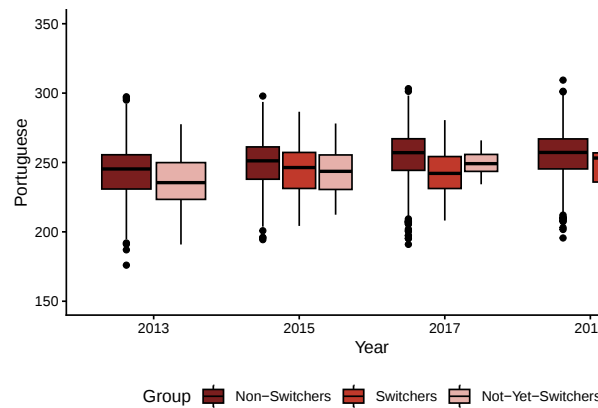
The switchers, in turn, exhibit a deterioration in performance, especially in 2017, when the difference relative to the control group reaches -13.80 points in Mathematics and -11.32 points in Portuguese Language, representing the largest gaps recorded over the entire period analyzed. In 2019, this difference declines to -7.87 and -8.04 points, respectively, suggesting a partial recovery after the period of exposure to treatment.

Table 4: Descriptive Statistics of Educational Indicators for 9th Grade – Climatological Sample

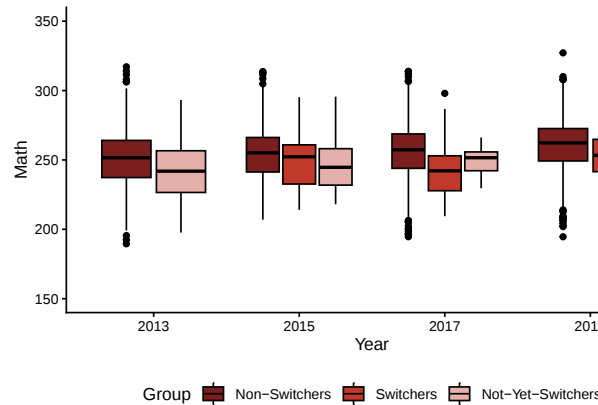
Variable	2013			2015					2017					2019		
	Mean Not-yet Treated (2)	Mean Non Switchers (3)	Diff (5) (2) – (3)	Mean Switchers (1)	Mean Not-yet Treated (2)	Mean Non Switchers (3)	Diff (4) (1) – (3)	Diff (5) (2) – (3)	Mean Switchers (1)	Mean Not-yet Treated (2)	Mean Non Switchers (3)	Diff (4) (1) – (3)	Diff (5) (2) – (3)	Mean Switchers (1)	Mean Non Switchers (3)	Diff (4) (1) – (3)
Math Proficiency	242.15	250.62	-8.47***	248.77	246.60	254.46	-5.68***	-7.86***	242.15	249.35	255.95	-13.80***	-6.60	252.75	260.62	-7.87**
Portuguese Proficiency	236.19	2243.38	-7.19***	244.41	244.10	249.43	-5.03*	-5.33**	243.72	249.45	255.05	-11.32***	-5.60	247.72	255.76	-8.04***
Age-grade Distortion Rate	29.59	23.75	5.84***	26.80	31.93	22.95	3.85*	8.99***	33.14	26.76	22.96	10.17***	3.8	28.70	20.20	8.49**
Approval Rate	87.64	90.76	-3.23***	88.84	87.82	90.07	-1.22	-2.24***	87.78	89.11	90.55	-2.77**	-2.44	87.61	93.13	-5.52***
Failure Rate	7.70	5.91	1.79***	6.87	7.80	6.61	0.27	1.19*	7.11	7.64	6.42	0.69	1.22	8.37	5.03	3.33***
Dropout Rate	4.66	3.33	1.33***	4.28	4.38	3.33	0.96*	1.05**	5.11	3.25	3.04	2.07***	0.21	4.05	1.84	2.19*
Black	0.65	0.57	0.07***	0.64	0.67	0.60	0.04**	0.07***	0.68	0.65	0.58	0.10***	0.06	0.72	0.64	0.08***
Female	0.54	0.52	0.02***	0.53	0.54	0.51	0.03***	0.02***	0.53	0.51		0.02**				
Child Labor	0.20	0.23	-0.03***	0.16	0.16	0.14	0.02**	0.02**	0.16	0.13	0.13	0.03***	0.00	0.17	0.16	-0.01
Work Domestic	0.80	0.82	-0.02**	0.82	0.82	0.83	-0.01	0.00	0.84	0.88	0.85	-0.01	-0.03*	0.85	0.88	0.03***
Enrollment	405.20	228.88	176.32	234.24	575.53	212.55	21.69	362.97	520.14	222.50	209.46	310.68	18.04	189.08	191.02	1.94
Attendance	333.61	190.21	143.40	192.33	492.85	177.70	14.62	315.14	460.24	194.00	177.38	282.86	16.62	169.67	172.50	2.83
Attendance Rate	0.83	0.85	-0.02***	0.82	0.84	0.85	-0.03***	-0.01	0.84	0.83	0.86	-0.02*	-0.03	0.91	0.91	0.00
Agric. Share of VA	0.24	0.24	0.00	0.21	0.22	0.23	-0.01	-0.02	0.23	0.20	0.23	0.00	-0.03	0.20	0.21	-0.01

Source: Author's elaboration based on SAEB data and the *ATLAS*. Statistical Significance: *** = 1%, ** = 5%, and * = 10%.

Figure 4: Distribution of 9th Grade Scores – Climatological Sample (Box-Plot)
Panel A Portuguese Proficiency Test



Panel B Mathematics Proficiency Test



Source: Author's elaboration based on SAEB data and the *ATLAS*.

Figure 4 reinforces this pattern: all groups follow comparable trajectories throughout the analyzed periods, except for the switchers in Panel A, who consistently exhibit lower performance than both the non-switchers and the not-yet-treated. This difference becomes particularly pronounced in 2017 and is not observed in the other years. The school flow indicators. Promotion, Grade Repetition, School Dropout, and Age-Grade Distortion. Follow the same direction, with switchers recording the worst outcomes in 2017, which corroborates the hypothesis that exposure to climatological disasters imposes relevant negative impacts on the educational trajectory of 9th-grade students.

3.2 Main Results

This section presents the results of the estimations based on the method proposed by de Chaisemartin and D'Haultfoeuille (2024), as discussed in the previous section. The analyzed outcome variables comprise Portuguese Language and Mathematics scores of 5th and 5th-grade elementary school students, as well as educational indicators at the municipal level, such as enrollment, school dropout, age-grade distortion, and grade repetition rates, in order to capture the effect of climatological disasters on Brazilian education.

Table 5 and Figure 5 report the estimates related to the proficiency tests administered to 5th and 5th-grade elementary school students.

Table 5: Estimation Results for the Climatological Disaster Sample

Period	5 th Grade				9 th Grade			
	N	Switchers	Portuguese	Mathematics	N	Switchers	Portuguese	Mathematics
-3	2621	17	-4.53 (2.48)	-2.67 (2.89)	2628	17	-5.42*** (1.59)	-3.43* (1.96)
-2	2636	32	0.24 (2.52)	-0.11 (2.63)	2643	32	0.68 (1.86)	0.16 (1.76)
1	4094	63	0.42 (1.41)	3.99** (1.68)	4106	66	0.62 (1.41)	2.18 (1.46)
2	4095	37	1.64 (1.64)	0.19 (1.49)	4103	37	1.07 (1.51)	-0.04 (1.32)
3	2728	51	-2.09 (1.68)	-1.73 (1.98)	2722	51	-0.73 (1.62)	0.65 (1.85)
4	2725	26	-0.19 (2.35)	-1.36 (2.48)	2719	26	-0.13 (2.31)	-0.97 (1.95)
ATE	4229	67	0.59 (2.93)	-0.32 (3.14)	4224	67	0.58 (2.97)	-1.00 (2.77)
SUB1	4267	160	-3.87 (3.25)	2.17 (3.94)	4264	160	-1.12 (2.65)	0.70 (3.04)

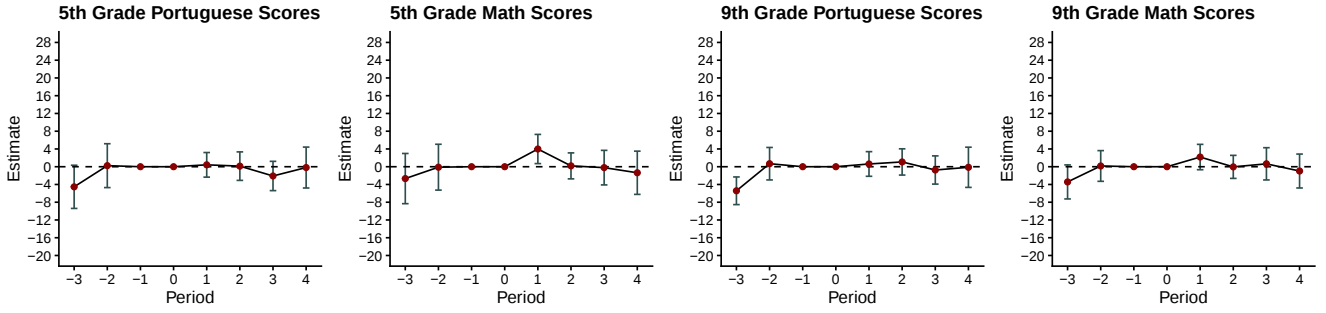
Source: Author's calculations based on data from SAEB and the ATLAS.

Notes: N = Total Observations; Statistical significance: *** = 1%, ** = 5%, * = 10%. Values in parentheses are Standard error. SUB 1 = Subsample 1 and SUB 2 = Subsample 2

The results indicate that only Mathematics proficiency among 5th-grade students presented a statistically significant effect, registering an increase of 3.99 points, equivalent to 0.15 standard deviations relative to the overall distribution of scores in this subject. This pattern provides evidence of an immediate positive impact in Period 1 resulting from climatological disasters. Thus, municipalities affected by such shocks exhibited a significant increase in their average 5th-grade Mathematics scores when compared to the group of untreated municipalities. To gauge the economic magnitude of this finding, the order of magnitude of this effect is comparable to that found Menezes-Filho and Pazello (2004), who evaluated the FUNDEF reform and found that a 20% increase in public school teachers' salaries vis-à-vis private school teachers resulted in a gain of 2.89 points in overall average proficiency (Mathematics and Portuguese Language).

On the other hand, the estimated impact is smaller than that reported Oshiro et al. (2015), who measured the effect of the performance-based bonus policy implemented in 2008 in the state school system of São Paulo, identifying an increase of 6.3 points (0.4 standard deviations). Although the average effect of the climatic shock is smaller than that generated by the São Paulo bonus program, it closely approaches the magnitude reported in the heterogeneity analysis for the male subgroup (Figure 12), validating the expressiveness and economic relevance of the results obtained. This finding converges with the empirical evidence of (Shah and Steinberg, 2017; Rush, 2018; Zimmermann, 2020; Nordstrom and Cotton, 2025), which documents higher performance in Mathematics tests among school-aged children exposed to climate-related disasters. The proposed causal mechanism suggests that, in years marked by adverse climatological shocks, there is a reduction in the labor supply of mothers and children, given the contraction in the opportunity cost of labor, particularly in the rural sector. Consequently, a reallocation of time occurs, favoring greater dedication to school-related activities.

Figure 5: Results for Climatological Disaster Sample



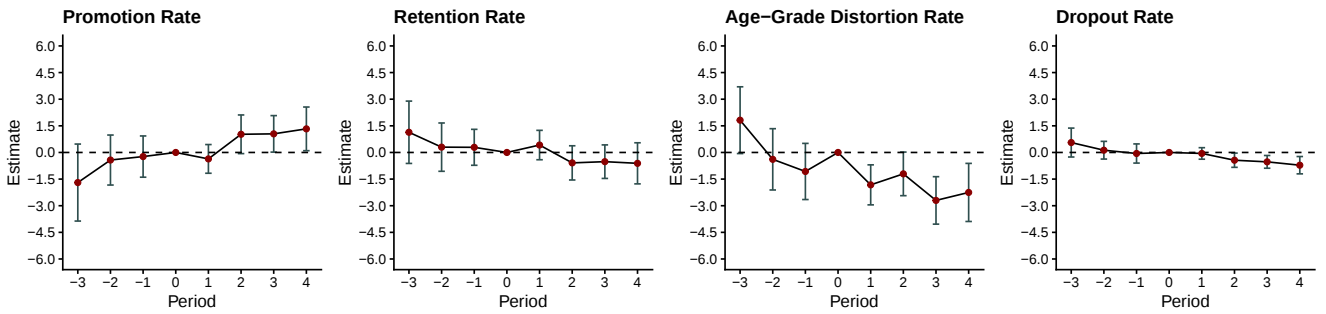
Source: Author's calculations based on data from SAEB and the *ATLAS*. Confidence intervals based on a 5% level of significance.

This finding converges with the empirical evidence of (Shah and Steinberg, 2017; Rush, 2018; Zimmermann, 2020; Nordstrom and Cotton, 2025), which documents higher performance in Mathematics tests among school-aged children exposed to climate-related disasters. The proposed causal mechanism suggests that, in years marked by adverse climatological shocks, there is a reduction in the labor supply of mothers and children, given the contraction in the opportunity cost of labor, particularly in the rural sector. Consequently, a reallocation of time occurs, favoring greater dedication to school-related activities.

In contrast, no statistically significant effects were observed for Portuguese Language scores or for 9th-grade Mathematics performance, suggesting the specificity of the positive impact on 5th-grade Mathematics proficiency.

Finally, Figure 6 reports the estimates for other additional outcome variables, namely school dropout, promotion, age-grade distortion, and grade repetition rates for the 5th grade of elementary school.

Figure 6: Results for Climatological Disaster Sample – 5th Grade



Source: Author's elaboration based on SAEB and *ATLAS* Confidence intervals based on 5% level of significance.

With respect to the promotion rate, considerable variability is observed in the results. This effect is statistically significant at the 5% level for municipalities affected by climatological events in post-disaster Periods 3 and 4, registering average increases of 1.05 and 1.33 percentage points (p.p.), respectively. These magnitudes correspond to increases of 0.14 and 0.18 standard deviations relative to the control group, indicating a substantial impact on promotion rates.

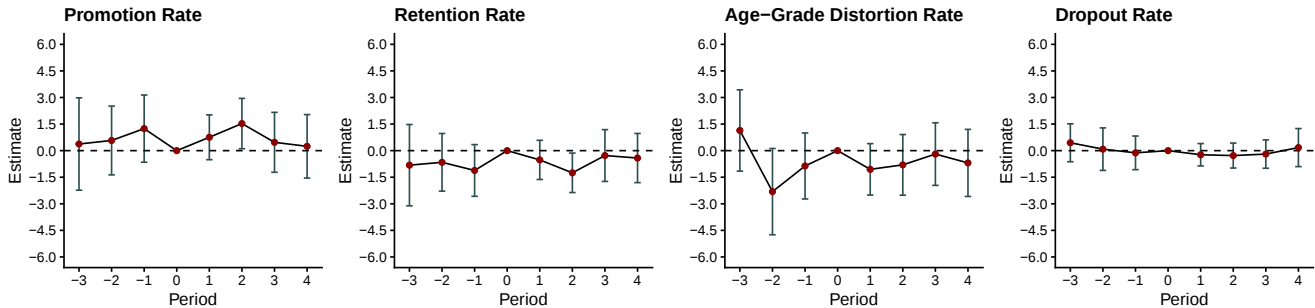
The estimates also point to a reduction in the 5th-grade school dropout rate of approximately 0.43 p.p., which represents a contraction of 0.27 standard deviations relative to the overall distribution of dropout rates. This declining trend persists in Periods 3 and 4, with reductions of 0.52 and 0.71 p.p., respectively. The total average effect is statistically significant, accumulating a reduction of 0.77 p.p. (or 0.48 standard deviations), which suggests a persistent improvement in educational outcomes following treatment.

Regarding age-grade distortion, contemporaneously with the improvement observed in 5th-grade Mathematics scores, a reduction of 1.82 p.p. in this indicator was identified (equivalent to 0.13 standard deviations), signaling a lower proportion of students in a situation of educational delay. This effect remains persistent in subsequent periods, demonstrating the continuity of the impact after the disasters. The total average effect is significant, exhibiting a decline of 3.8 p.p., which represents 0.28 standard deviations. These results suggest an improvement in school flow in treated municipalities vis-à-vis the control group, mitigating the incidence

of students in a situation of grade delay (resulting from grade repetition or late entry) after the occurrence of climatological shocks.

In sum, the results demonstrate an improvement in the educational performance of 5th-grade students, in line with the evidence reported in Figure 4, which indicated gains in Mathematics and improvements in school indicators following the occurrence of climatological disasters.

Figure 7: Results for Climatological Disaster Sample – 9th Grade



Source: Author's elaboration based on SAEB and ATLAS. Confidence intervals based on 5% significance.

Figure 7 reports the estimates for the same outcome variables discussed previously. Greater variability is observed in the promotion rate for the treated group, with an increase of approximately 1.52 percentage points (p.p.) in Period 2, which is statistically significant. Similarly, a reduction of 1.25 p.p. in the grade repetition rate was identified in Period 2. This result is equivalent to a contraction of 0.19 standard deviations relative to the overall distribution of the grade repetition rate, indicating a substantial reduction in repetition among treated municipalities. In contrast, no statistically significant effects were observed for school dropout and age-grade distortion rates.

3.3 Mechanisms

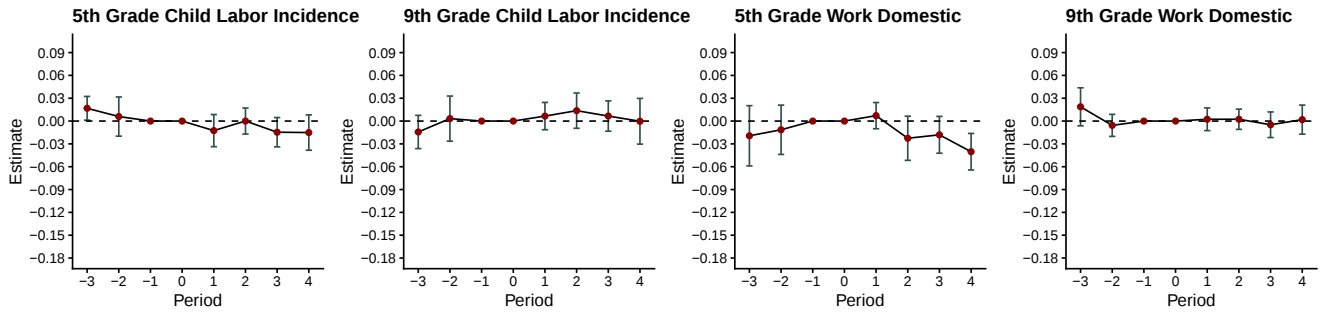
As documented in the literature, particularly in the studies by Shah and Steinberg (2017); Rush (2018); Zimmermann (2020); Nordstrom and Cotton (2025), climatological disasters may exert a positive impact on the Mathematics proficiency of school-aged children by reducing the opportunity cost of child labor, especially in the rural sector. Consistent with this empirical evidence, the main results of this study pointed to a significant increase in the Mathematics scores of 5th-grade students in municipalities affected by climatological disasters.

To investigate the causal mechanism underlying this effect, the percentage of children working outside school hours at the municipal level is proposed as an alternative outcome variable. The central hypothesis assumes that the contraction in child labor opportunities, resulting from climatological shocks, contributed to the observed increase in Mathematics performance. Additionally, in order to measure the reduction in the opportunity cost of rural labor, the share of agricultural value added relative to total value added is examined. This metric provides a diagnosis of the dynamics of the municipal agricultural sector, enabling an indirect assessment of the rural labor market.

To empirically test this hypothesis, the impacts for the climatological disaster sample are estimated using information from the student questionnaire, specifically the question asking whether the student works at least one hour outside the household.

This variable is employed as a proxy for child labor, comparing the percentage of children in this condition in treated municipalities vis-à-vis the control group. The estimation strategy is based on the Difference-in-Differences (DiD) approach detailed in the methodological section, here adapted for this alternative outcome variable.

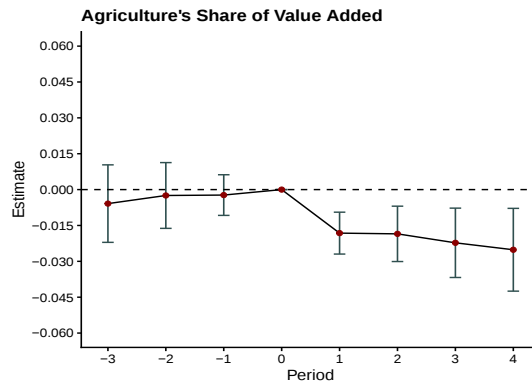
Figure 8: Estimation of the Child Labor and Work Domestic Mechanisms with Treatment as Climatological Disasters



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level.

Figure 8 indicates that, for the overall sample of municipalities affected by climatological disasters, no statistically significant impacts on child labor were detected. Consequently, the subsequent section analyzes the heterogeneity of these effects by race and gender. The only result in which the increase in 5th-grade Mathematics scores persisted was concentrated in the male subgroup, which is associated with a reduction of approximately 4% in child labor during the same period in which the increase in proficiency is observed. This finding suggests a potential and close association between the opportunity cost of child labor and indicators of school performance.

Figure 9: Estimation Agriculture's Share of Value Added Mechanisms with Treatment as Climatological Disasters



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level.

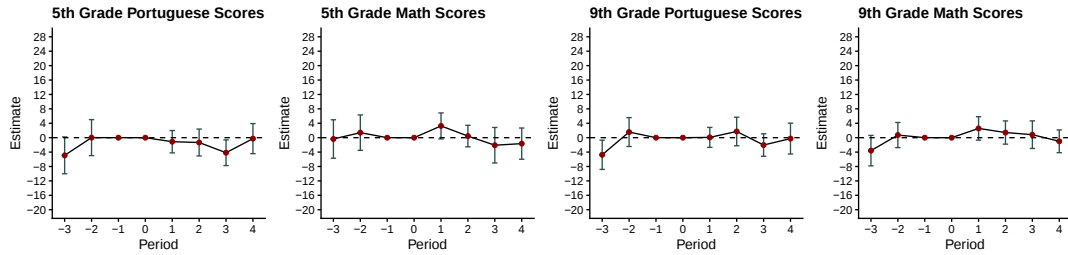
The results reported in Figure 9 indicate that the share of agriculture in municipal value added presents a negative effect. This evidence signals a potential contraction in agricultural activity in the regions affected by treatment relative to the control group. This pattern suggests a reduction in the opportunity cost of rural labor, constituting a possible transmission channel for the observed increase in Mathematics proficiency. Moreover, this adverse shock in the agricultural sector may explain the contraction in child labor identified for the male subgroup in the subsequent section.

3.4 Heterogeneity

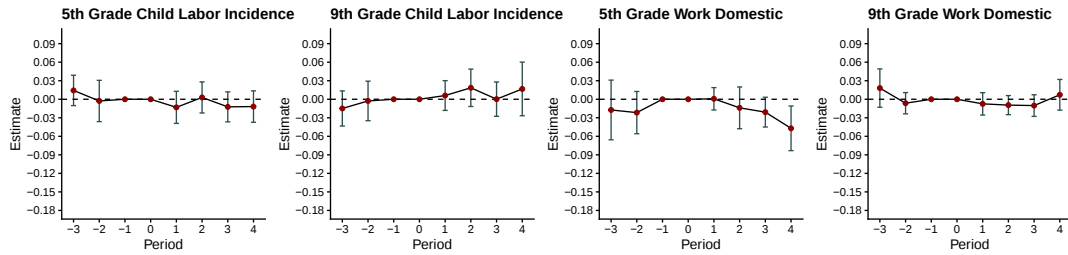
This section investigates the heterogeneity of the main effects and transmission channels (mechanisms), evaluating whether the impacts differ according to race (white and Black individuals) and gender (female and male). The purpose is to examine whether the treatment induces asymmetric responses across distinct groups of individuals. To this end, the graphical representations are structured into two panels:

- I. Panel A: Reports the results associated with educational performance, comprising proficiency in Mathematics and Portuguese Language (5th and 9th grades).
- II. Panel B: Examines the impacts on the mechanisms of child labor and domestic work, observed for students in the same educational stages (5th and 9th grades).

Figure 10: Estimation for the sample of Black students
Panel A – Main Results



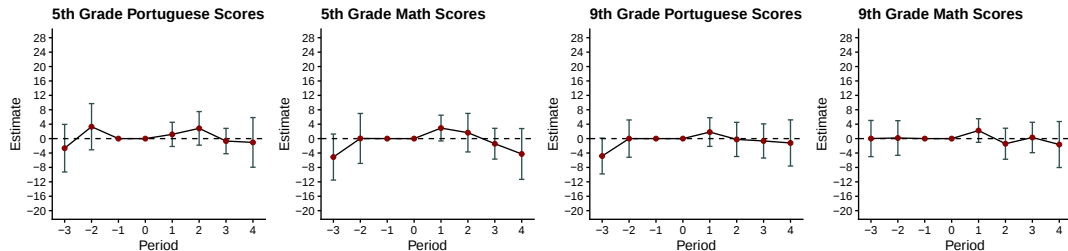
Panel B – Mechanisms



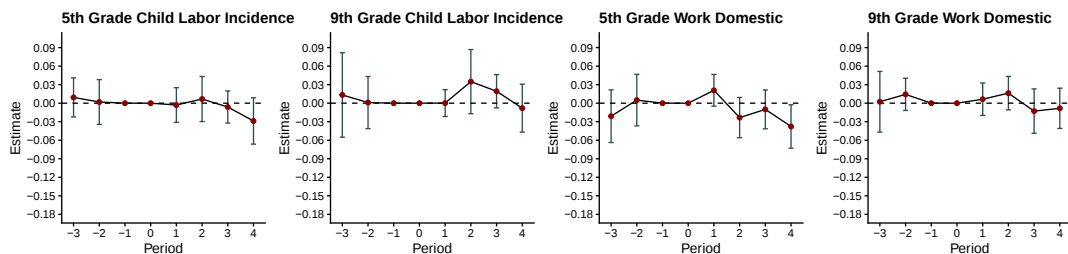
Source: Author's elaboration based on SAEB data and the *ATLAS*.

Initially, the estimates obtained exclusively for the subsample of Black individuals are explored. Figure 10 reports the specific results for this population stratum. With respect to educational performance, a statistically significant effect is identified for Portuguese Language in the 5th grade in the third post-disaster period, specifically in the subsample of municipalities that received treatment one year prior to the application of the assessment. However, the analytical relevance of this finding is mitigated by the fact that, in the pre-treatment period -3, the impact was already significant at the 6% level, indicating a violation of the parallel trends assumption. Additionally, the heterogeneity analysis focused on the child labor mechanism did not reveal statistically significant effects.

Figure 11: Estimation for the sample of White students
Panel A – Main Results



Panel B – Mechanisms



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level

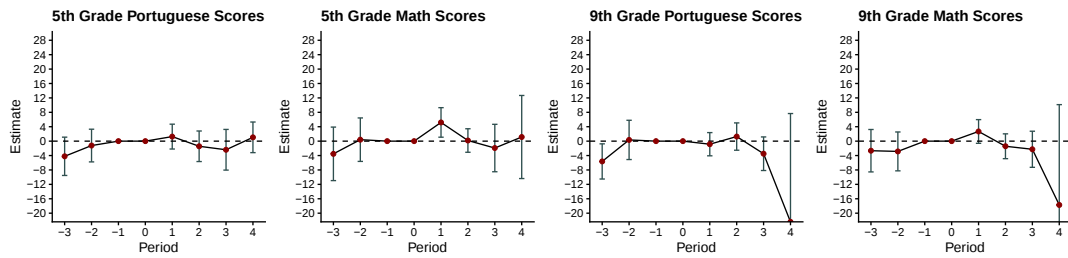
Finally, the results for the subsample of white individuals are analyzed. As illustrated in Figure 11, there are no statistically significant coefficients for this group, indicating that the treatment effect identified in the main sample is not driven by this population stratum.

Proceeding with the analysis, gender heterogeneities are examined. Due to the absence of the question regarding student gender in the 2019 Prova Brasil questionnaire, there is a reduction in the number of observations available for estimation. Consequently, for Period 4, the sample contains only 3 switchers,

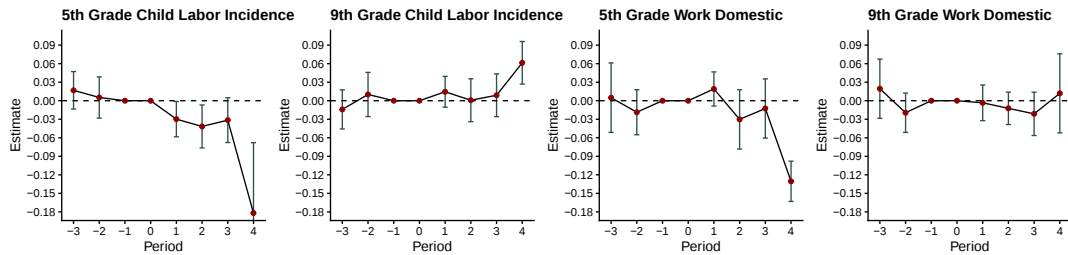
which justifies the presence of substantially wide confidence intervals.

Figure 12: Estimation for the sample of Male students

Panel A – Main Results



Panel B – Mechanisms



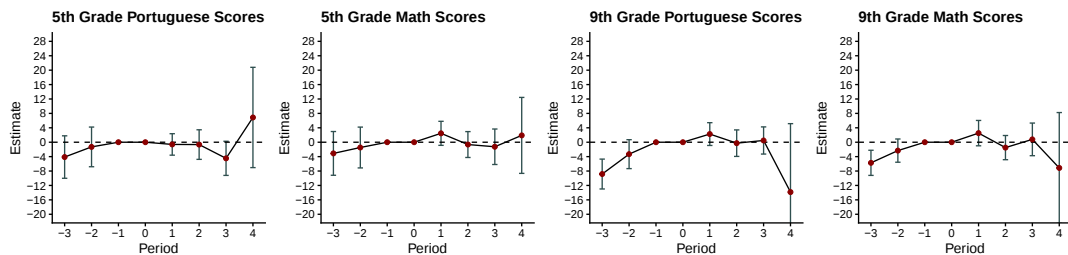
Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level

The results reported in Panel A indicate an increase of 5.19 points in the 5th-grade Mathematics score in Period 1, which represents an increase of 0.19 standard deviations. This impact temporally coincides with the result observed for the aggregated sample, providing evidence that the effect on Mathematics proficiency is driven by the male subgroup, in contrast to the pattern observed in the race heterogeneity analysis. Moreover, consistent with the previous estimations, no statistically significant impacts were identified for 9th-grade students.

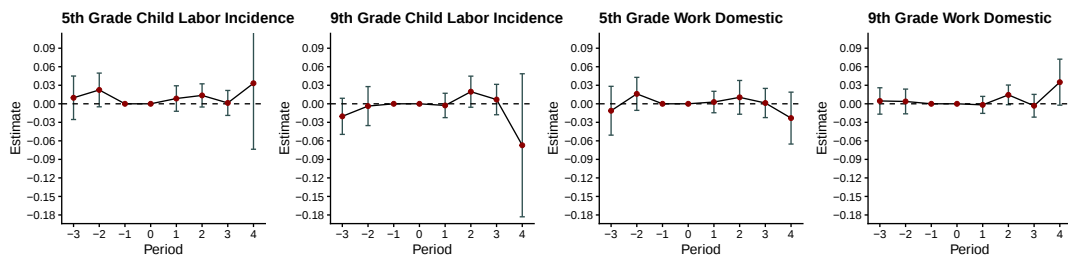
In Panel B, the estimated coefficients point to a contraction in child labor among 5th-grade students, with effects concentrated in Periods 1 and 2. This reduction amounted to 3% and 4% (equivalent to 0.28 and 0.38 standard deviations, respectively) in treated municipalities vis-à-vis the control group. In addition, a reduction in the total average effect (ATE) is observed for both subsamples, with declines of 6% in subsample 1 and 4.5% in subsample 2. This scenario reflects greater school attendance among students, demonstrating the empirical alignment between the transmission channels (mechanisms) and the main result of the study.

Figure 13: Estimation for the sample of Female students

Panel A – Main Results



Panel B – Mechanisms



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level

In Figure 13, which reports the estimates exclusively for the female subsample, a pattern of results entirely distinct from that observed for the male subgroup and for the aggregated sample is identified. Unlike the substantial increase found among male students, the impact on 5th-grade Mathematics scores was not statistically significant for female students. With respect to the 9th-grade, consistent with the previous analyses, no statistically significant impacts were detected under any specification.

Consequently, the estimates of the transmission channels reported in Panel B corroborate this asymmetry across genders. In contrast to the pattern observed for the male subgroup, the coefficients associated with child labor for the female subgroup did not exhibit statistical significance in any of the analyzed periods. This divergence reinforces the evidence that child labor operates as a direct transmission mechanism affecting educational performance, converging with the theoretical and empirical literature addressing the opportunity cost of time allocation (Shah and Steinberg, 2017; Rush, 2018; Zimmermann, 2020; Nordstrom and Cotton, 2025).

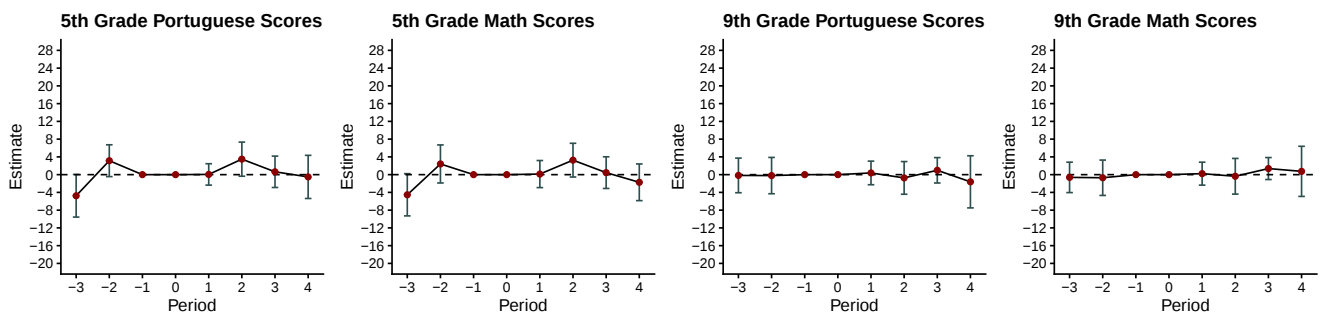
In summary, the heterogeneity analysis reveals that both the increase in Mathematics proficiency and the contraction in child labor in the 5th grade are driven predominantly by the male subgroup. Moreover, the absence of statistically significant results in the race-stratified analysis reinforces that the impact of the climatological shock prevails among male individuals. From a microeconomic perspective, these individuals face a more severe contraction in employment opportunities resulting from the shock, which induces greater school attendance and, consequently, improves Mathematics performance and correlated educational indicators. This mechanism supports a recent strand of the literature documenting how climatic shocks (such as droughts), by reducing the demand for child labor, generate positive externalities on human capital indicators.

3.5 Robustness Check

The placebo test was conducted through the construction of a fictitious treatment variable, randomly assigned to the observations belonging to the control group. The draw of this simulated treatment was calibrated annually to replicate exactly the same proportion observed between treatment and control municipalities in the original specification. To ensure the internal validity of this robustness exercise, all municipalities that were effectively treated at any point during the investigated time horizon were excluded from the estimation.

Consequently, the subsample used in the placebo test is composed exclusively of municipalities remaining in the exogenous control group, that is, localities that were never exposed to the actual treatment throughout the sample period considered.

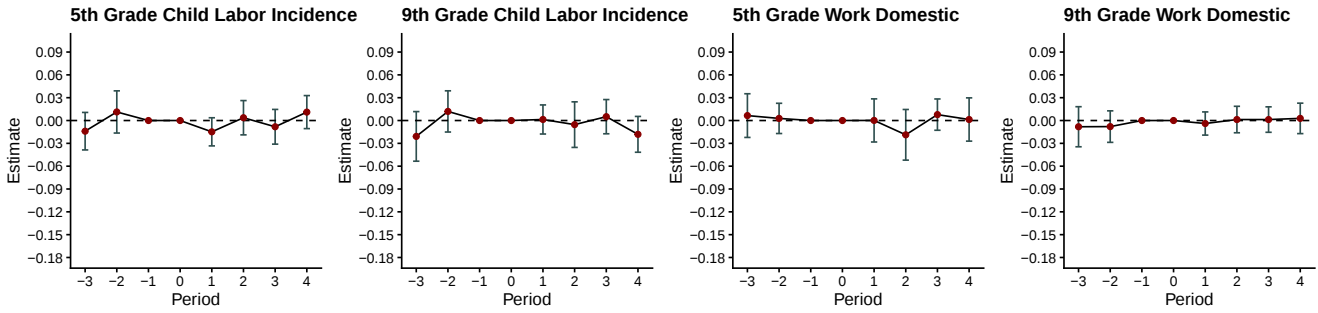
Figure 14: Robustness Estimates for the Main Results



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level

The results obtained from the placebo test indicate that the coefficients associated with the fictitious treatment are not statistically significant, providing evidence of the absence of differentiation in the Mathematics performance of 5th-grade students between the municipalities in the control group randomly assigned to treatment and those that remained strictly in the control condition. This null pattern contrasts with the main finding of this study, which identified a statistically significant increase in Mathematics scores in Period 1 (Figure 5). This divergence corroborates the robustness of the conclusions presented and validates the consistency of the causal identification strategy.

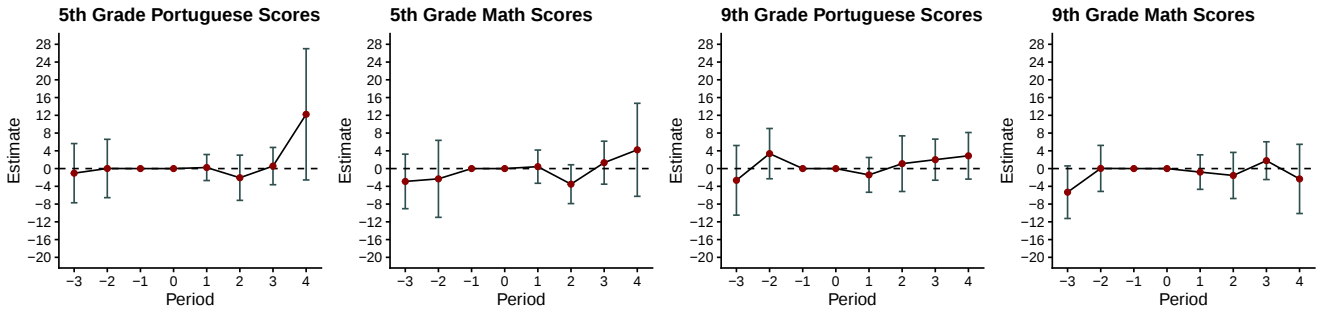
Figure 15: Robustness Robustness Estimates for the Mechanism Analysis



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level

Similarly, the estimates related to the incidence of child labor did not exhibit statistical significance in the subsample subjected to the fictitious treatment. Additionally, in order to validate the reported heterogeneous effects and provide robustness to the empirical evidence, the estimates for the male subgroup under placebo assignment are explored. This step is necessary given that the results of the main specification simultaneously indicate an increase in 5th-grade Mathematics proficiency and a contraction in child labor restricted to this economic subgroup, allowing for an assessment of the internal consistency of the causal mechanism.

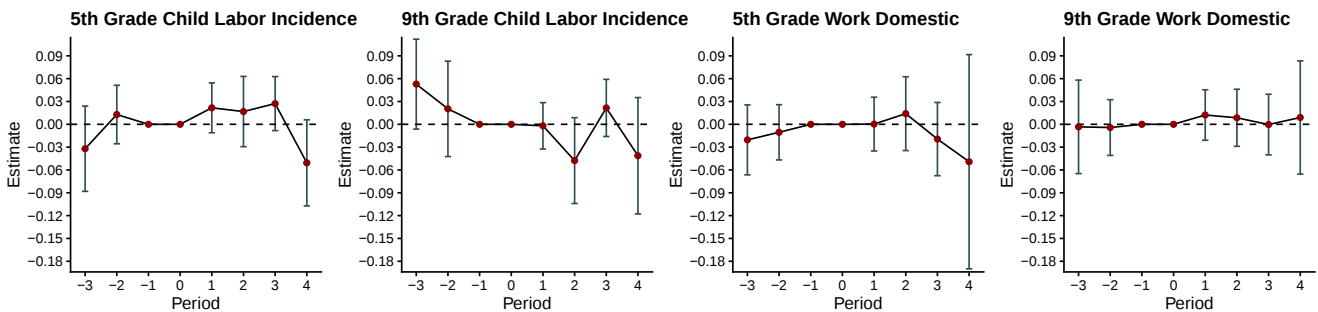
Figure 16: Robustness Analysis of the Main Results for the Male Sample



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level

It is evident that, under the imposition of the fictitious treatment in the control sample, the previously observed effect on Mathematics proficiency disappears entirely. This result mitigates the existence of divergent pre-trends or specification failures in the sample design, validating the exogeneity of the identification strategy. Similarly, when testing the robustness of the transmission mechanism focused on the male subgroup, based on the reduction in the opportunity cost of labor and the consequent contraction in child labor, it is observed that the coefficient associated with the placebo effect loses statistical significance and does not persist. In sum, the absence of spurious effects in both dimensions confirms the internal consistency and robustness of the empirical conclusions of the article.

Figure 17: Robustness Estimates for the Mechanism Analysis for the Male Sample



Source: Author's elaboration based on data from SAEB and the *ATLAS*. Confidence intervals based on 5% significance level

In sum, the placebo exercises restricted to the control sample corroborate the robustness of the original estimates. Under placebo assignment, the positive effect on Mathematics proficiency disappears both in the aggregated sample and in the male subgroup. Similarly, the investigated transmission mechanism, grounded

in the reduction of the opportunity cost of labor and the consequent contraction in the incidence of male child labor, loses statistical significance, with the coefficient being entirely mitigated. The absence of spurious effects in these simulated specifications demonstrates that the main results do not stem from pre-existing trends or spurious correlations, thereby validating the empirical design.

4 Conclusion

This study investigated the contemporaneous effect of extreme climatological events on academic performance in Brazilian basic education. The research contributes to the literature by examining the impact of climatological shocks on the country's human capital, employing a recent and robust econometric identification strategy.

The results indicate a positive impact of climatological disasters on Mathematics proficiency in the 5th-grade of elementary school, particularly in subsample 2, which comprises municipalities exposed to disasters during the period immediately preceding the administration of Prova Brasil. In this specification, treated municipalities exhibited an average increase of 3.99 points in Mathematics scores vis-à-vis the control group. This effect is statistically significant and corresponds to an increase of 0.15 standard deviations relative to the overall distribution of scores. However, this impact is restricted to the edition of the exam that temporally coincides with the shock. Additionally, improvements were observed in correlated school flow indicators, such as higher promotion rates and lower school dropout and age-grade distortion rates, which provides internal consistency to the proficiency test results.

The heterogeneity analysis reveals that this pattern is driven exclusively by the male subgroup, whose increase in Mathematics scores reached 5.19 points (0.19 standard deviations) in the period subsequent to the disaster, differing from the null pattern observed for the female subgroup. From a microeconomic perspective, the transmission channel underlying this asymmetry is grounded in the dynamics of the opportunity cost of time allocation. A statistically significant contraction in the incidence of child labor was identified, restricted to male individuals, with declines of 3% and 4% (equivalent to 0.28 and 0.38 standard deviations) in Periods 1 and 2, respectively. For the remaining race disaggregations and for the female subgroup, the statistical significance of both the effect on scores and on labor market outcomes dissipates. These findings converge with the empirical literature documenting improvements in school performance following adverse climatic shocks (such as droughts), driven by the contraction in the demand for child labor, which increases school attendance and academic performance among male students in relative terms. It is noteworthy that no effects were found for 9th-grade classes in elementary school.

Although the educational gains manifest immediately, the contraction in child labor tends to generate cumulative effects over time. Thus, the set of evidence suggests that the reduction in the supply of child labor resulting from climatic shocks constitutes one of the main mechanisms driving school performance in this cohort.

The placebo tests conducted reinforce the validity of the empirical strategy adopted in this study. By restricting the analysis to never-treated municipalities and randomly simulating treatment assignment, the estimated effects on Mathematics proficiency and the incidence of child labor proved to be statistically null. This result contrasts with the significant impacts identified in the main specification, corroborating the robustness of the identification strategy and providing additional evidence that the estimates do not stem from specification biases or spurious trends in the data.

In terms of policy implications, these results highlight the relevance of public interventions focused on the enforcement of child labor regulations and the strengthening of determinants of school retention. Income transfer mechanisms directed at vulnerable families and the expansion of school feeding programs may mitigate the need for early labor market engagement, consolidating an environment conducive to learning regardless of exogenous shocks.

Finally, this research fills a gap in the existing literature by providing evidence on the contemporaneous effects of natural disasters on Brazilian education, a field that remains underexplored in the country. Moreover, our results challenge the conventional consensus that environmental disasters universally degrade human capital in the short term, providing rare evidence of educational reallocation in a Latin American context.

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