Heterogeneity in the Educational Impacts of Natural Disasters: Evidence from Hurricane Florence

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This Version: July 11, 2022

Abstract

In September 2018, Hurricane Florence caused widespread and extended school closures throughout North Carolina. Using a difference-in-differences framework, we explore within-school variation in the impact of hurricane-related schooling disruption on students' end-of-grade test scores. Impacts were not concentrated on students performing at the lowest levels in the prior year nor on those from the most disadvantaged backgrounds. Rather, the estimates suggest that most students experienced small declines in test performance irrespective of baseline human capital or demographic group.

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‡Acknowledgements: The authors would like to thank seminar participants at the AEFP Annual Conference 2021 and the SIEPR 2020 Working Group, as well as Sarah Crittenden Fuller and Thayer Morrill for helpful feedback and comments on an earlier version. The authors thank Eleanor Warren for excellent research assistance.

1 Introduction

In light of current climate change-related increases in average sea and air temperatures, scientists predict that extreme weather events and weather-related natural disasters will become more frequent and more severe (Abatzoglou and Williams, 2016; Walsh et al., 2016).[1] These events often result in schools closing for an extended period.[2] Students likely suffer disruptions in both their school and home settings, with those from disadvantaged families potentially bearing the highest costs. To target resources efficiently, it is important to understand which students are at risk of experiencing the largest learning losses following a natural disaster-related school closure. We provide new insights on the heterogeneous impacts of natural disaster-related school closures by studying the aftermath of Hurricane Florence, which caused widespread and extended school closures in North Carolina in the fall of 2018.

School closures may disproportionately impact students who were previously struggling and performing at the lowest levels because it is more difficult for them to catch up on missed material. Similarly, the most disadvantaged students may be less resilient to school closures or experience greater disruptions at home concurrent with school closures. In this paper, we estimate learning losses by prior achievement levels and by measures of economic disadvantage, racial/ethnic group, gender, and limited English proficiency status. Further, middle school students may be more capable of independent learning and could, theoretically, make up missed material outside of classroom hours. Therefore, we also explore whether elementary school students experienced greater impacts than middle school students.

Using geographic variation in school closures in North Carolina due to Hurricane Florence, we estimate a regression model with school fixed effects to compare end-of-grade (EOG) test performance of elementary (4th and 5th grade) and middle school (7th and 8th grade) students using data spanning AY2014-15 through AY2018-19. We find a small but statistically significant and robust drop, on average, in both reading and mathematics end-of-grade examinations. Importantly, the effect is concentrated near the median of mathematics performance. On the other hand, all but those with the highest performance on prior-year reading exams saw significant reading test score losses. When considering heterogeneity by grade levels, test score declines were similar for elementary and middle school students. We fail to find evidence that economically disadvantaged or racial minority students

[1] For example, Abatzoglou and Williams (2016) estimate that human-caused climate change nearly doubled the number of forest fires in the western United States between 1984 and 2015.

[2] For example, in California between 2002 and 2019, wildfires resulted in over 21,000 cumulative missed school days across from 6,500 schools (Lardieri, 2019). In the last week of October 2019 alone, wildfires and planned power outages in California caused the closure of 1,510 schools, which served over 500,000 students (Lambert, 2019).

experienced larger learning losses. Indeed, nearly every subgroup studied experienced some learning loss due to the school closures.

Our estimates regarding the impact of Hurricane Florence capture learning losses from both missed instruction and disruption that occurred in students' lives outside of school. In fact, by leveraging data from the Federal Emergency Management Agency (FEMA), where available, we find evidence that both effects are present in our setting. It should also be noted that we measure short-run test score declines net of any mitigation actions taken. Furthermore, it is outside the scope of this study to explore persisting impacts of school closures or the effectiveness of remediation strategies. Taken together, the results of this study indicate that the impacts of natural disaster-related school closures are broadly experienced by students in both middle and elementary schools across most demographic groups and throughout the distribution of prior performance levels.

2 Background and Data

2.1 Prior Literature

Natural disasters lead to disruptions in students' lives that are idiosyncratic and extreme, with some students suffering material hardship in addition to any impacts from extended school closure. Arcaya, Raker, and Waters (2020) provide an analysis of the ways disasters affect individuals and communities, while Kousky (2016) provides a review of the literature on natural disasters in developing countries, where displacement and housing damage predominate the risks for children. In the United States, several studies have focused on the impact of Hurricane Katrina, which caused major evacuations and long-term damage in New Orleans in 2005. Sacerdote (2012) tracks the long-term academic performance of evacuees, while Imberman, Kugler, and Sacerdote (2012) consider the impacts of displaced students on peers in receiving schools. One distinct aspect of Hurricane Katrina is that while displacement forced many students to change school districts, student outcomes improved in the long term because many pupils moved to higher-quality schools. In related work, Davis, Cannon, and Fuller (2021) interview school districts following Hurricanes Harvey and Matthew and find that hurricanes constrain instructional time and increase the social-emotional needs of students.[3]

Our research also builds on prior work using weather-related school closings to identify the causal

[3]In a conference presentation, Fuller and Davis (2020) use North Carolina school data to study the effects of Hurricanes Matthew and Florence on student achievement and behavior. Their preliminary findings are mixed but provided suggestive evidence of test score losses in mathematics.

effect of instructional time on student test performance. Marcotte and Hemelt (2008) use snowfall as an instrument to estimate the effect of unexpected school closures on academic performance. Using a similar strategy, Goodman (2014) contrasts school closures with the impact of individual student absences; the former has little impact, but the latter is harmful to test performance.

Our study also contributes to a large literature examining the impact of instructional time on student outcomes through expansion of the school day or school year and through international comparisons of instructional time (e.g., Huebener, Kuger, and Marcus, 2017; Rivkin and Schiman, 2015).[4] Related research explores how instructional time impacts student performance by exploiting random variation in testing dates and within-classroom absences (e.g., Aucejo and Romano, 2016; Fitzpatrick, Grissmer, and Hastedt, 2011; Gershenson, Jacknowitz, and Brannegan, 2016; Hansen, 2011; Sims, 2008).[5] Another strand of literature examines summer learning losses (e.g., Alexander, Entwisle, and Olson, 2001; Fryer and Levitt, 2004) finding test scores do rise over the summer months but at a slower rate relative to the school year. Most similar to our study, Hansen (2011) finds that test score impacts due to weather-related closures are consistent across performance and grade levels.

Our estimates of average learning losses due to Hurricane Florence are consistent with these prior studies. Our main contribution is highlighting that learning losses were not concentrated on a particular demographic group nor among those who were previously performing at the lowest levels.

2.2 Setting and Closure Data

Following Hurricane Florence in September 2018, FEMA declared 34 (out of 100) counties in North Carolina disaster areas.[6] We use published statistics from the North Carolina Department of Public Instruction (NCDPI) on the number of days schools were closed after Florence.[7] These data consist of 1,503 schools for which we have Florence-related closure information.[8]

[4]Huebener, Kuger, and Marcus (2017) exploit a reform in Germany that expanded instructional hours, and find small treatment effects concentrated among the highest performing students. Similarly, using international comparisons, Rivkin and Schiman (2015) find that increased instructional time positively impacts the performance of students in high-quality classroom environments.

[5]Aucejo and Romano (2016) find a small positive effect of instructional days before the testing date, but this impact is considerably smaller than that due to days missed because of student absences. Fitzpatrick, Grissmer, and Hastedt (2011) also find significant learning gains from instructional days with similar impacts across the distribution of student background characteristics. Sims (2008) explores how schools strategically delay testing dates to increase instructional days and finds small positive effects for mathematics but not reading.

[6]See: `https://www.fema.gov/disaster/4393`, [accessed July 2020].

[7]Data are provided at: `https://files.nc.gov/dpi/spg-report2019_final.xlsx`, [accessed June 2020]. These data report the number of school days missed net of makeup days. As described in the Appendix, we gathered supplemental data from newspaper articles and other public data sources on the total number of days school were closed irrespective of makeup days.

[8]The student-level data are described in Section 2.3 and the Data Appendix, where we explain how we construct the sample of 1,503 schools used in the analysis.

Figure 1 illustrates the distribution of school closure duration due to Florence, net make-up days. Approximately 24 percent of the schools in our full sample did not close due to Hurricane Florence, while about 2 percent closed for fewer than one day. The longest school closures (26.5 days) affected 0.13 percent of schools. Although the vast majority of school districts closed all their schools for the same period of time, approximately 10 percent of schools are in districts in which some schools closed longer than others. All but four schools that closed more than 14 days were closed longer than their districts' modal closure length. Our analysis includes school fixed effects to account for any time-invariant school-level characteristics that may be correlated with the propensity for longer closures and student test score gains, such as older buildings or a teacher workforce drawn from larger geographic distances.

2.3 Student Data

The student-level data are derived from restricted-access administrative records from the North Carolina Education Research Data Center (NCERDC). The number of local education authorities (LEAs), schools, and students at each data creation step are reported in Appendix Table A1.[9] In North Carolina there are roughly 112,000 students per grade per year. We assign students to the school they attended at time $(t-1)$ to abstract away from school switching in 2019. Because we focus on elementary grades 4-5 and middle school grades 7-8, we begin with a dataset of 3rd, 4th, 6th, and 7th graders who have valid demographics and EOG test scores in 2015-16 through 2018-19, yielding a sample of 1,394,825 students in 2,081 schools in 284 LEAs. We further restrict the sample to schools with non-missing values for closure days due to Hurricane Florence. Additionally, we remove schools with non-traditional calendars (e.g., year-round schools), three school districts that were severely impacted by Hurricane Matthew in 2018, and schools with grade-span configurations that are incompatible with our identification strategy of assigning students to their t-1 school.[10] Finally, to remove outliers, we retain only those students whose schools reported median days of membership between 150-200 days in year $t-1$, and we remove the roughly 5 percent of students without a valid on-time test score at time t. This yields a dataset of 107 school districts, 1,503 schools, and 1,020,384 students.

[9]The analysis dataset includes 2015-16 through 2018-19, constructed using information for the prior year $(t-1)$. For the small number of duplicate observations, we retain the highest test score and the highest number of membership days (if available). For the analysis, student school characteristics and individual characteristics are all measured as of time $(t-1)$, with only test scores and time t instructional days measured at time t. Therefore, the sample only includes schools where a student in 4th, 5th, 7th, or 8th grade would have been in the same school in year $t-1$.

[10]The data include schools with the following grade spans: PK-5, PK-6, PK-8, PK-9, PK-12, K-5, K-6 (if not 6th grader), K-8, K12, 1-5, 2-5, 3-5, 6-8, 6-9, 6-10, 6-12, and 6-13. The most common configurations are PK-5 (31%), K-5 (14%), and 6-8 (47%).

To estimate the impact of school closures due to Hurricane Florence, we must identify a comparable set of students and schools for which trends in student achievement would have been similar in the absence of the hurricane. Schools that did not experience Florence-related closures are mostly located in areas at low risk of hurricane-related disruptions and may have different test-score trends than schools frequently affected by storms. Indeed, in results not shown, estimates that include students attending schools that did not close due to Hurricane Florence yield a marginally statistically significant coefficient on a pre-trend test, suggesting a potential violation of the parallel trends assumption. Including schools with zero missed days attenuates the main estimates slightly but yields identical patterns in heterogeneity (see Section 4.2.3). Thus, we restrict our sample of schools to only those closed for any duration due to Hurricane Florence, yielding our main analysis sample of 74 school districts, 1,148 schools, and 811,893 students.

Summary statistics for the full dataset and the main analysis sample (Table 1) show that approximately half of the students are male, 25 percent are Black, 19 percent are Hispanic, and 9 percent are another non-White race. About 12 percent of students have a disability, that is, a physical or mental impairment that substantially limits one or more major life activities.[11] Approximately 50 percent are economically disadvantaged, defined as being eligible for free or reduced-price lunch. About 10 percent have limited English proficiency, indicated by participation in North Carolina's English Language Learner program.[12]

The main test scores of interest are EOG examinations in mathematics and reading. We estimate impacts on students in the 4th and 5th grades (elementary school) and 7th and 8th grades (middle school) and always control for prior-year performance and link to prior-year school. Starting in the 2017-18 school year, students enrolled in 8th grade algebra were given a different end-of-grade examination ("MATH1") than the standard 8th grade mathematics EOG. Algebra students are positively selected by prior-year performance. Therefore, we estimate middle school mathematics EOG performance only for 7th graders. We normalize EOG examination scores to a mean of zero and a standard deviation of one within each grade in each academic year, before any sample restrictions. We follow the same procedure for the prior-year mathematics and reading scores before making sample restrictions, so the means here are slightly above zero.

Our data additionally include student-level "membership days," which correspond to the total days

[11] For a formal definition of disability, see: https://www.dpi.nc.gov/students-families/parents-corner/students-disabilities, [accessed October 2020].

[12] See: https://www.dpi.nc.gov/districts-schools/testing-and-school-accountability/testing-policy-and-operations/testing-students-identified-english-learners, [accessed October 2020].

of attendance in school as of the date of EOG examinations.[13] North Carolina's school calendar policies are formalized in 2012 Senate Bill 187 and apply as of the 2013-2014 school year.[14] Typically, testing dates are set before the academic year commences, and school calendars are constructed assuming a small number of missed school days due to inclement weather. North Carolina requires that EOG examinations are held during the final 10 instructional days of the school year. Schools must hold at least 185 days of instruction with at least 5.5 instructional hours per day or at least 1,025 instructional hours in the school year. Schools must start no earlier than the Monday closest to August 26 and end no later than the Friday closest to June 11, unless a weather-related calendar waiver is approved. Following Hurricane Florence, North Carolina allowed districts in counties under federal disaster declarations to waive 20 days of school in 2018-19. However, the 20-day waiver did not dictate anything about the testing window for EOG examinations. Therefore, a priori, days of closure may not translate directly into lost days of instruction either before the EOG (our outcome measure) or for the academic year.

2.4 FEMA Data

To disentangle the school closure and disruption effects of Hurricane Florence on student outcomes, we use data on registrations for FEMA's Individuals and Households Program (IHP) following Hurricane Florence to proxy for damage and disruption in students' home environments.[15] IHP provides financial and direct services to eligible individuals and households that experienced uninsured or underinsured necessary expenses. The data include total valid registrations and the IHP dollar amount awarded aggregated at the county by city by zip code level.[16] To link these measures of hurricane damage to North Carolina students, we match Census Block Group centroids to the zip code tabulation area (ZCTA) in which they are located.[17] When using these data, the sample is restricted to students living in block groups linked to ZCTAs with populations larger than 90.

[13]This variable is missing for less that 0.3% of the sample. Prior to 2018, these data are reported alongside test score information. For 2018 and 2019, the data are only available in attendance files.

[14]See: https://www.dpi.nc.gov/districts-schools/district-operations/financial-and-business-services/school-calendar-legislation.

[15]FEMA provides these data at https://www.fema.gov/openfema-data-page/registration-intake-and-individuals-household-program-ri-ihp-v2, [accessed January 2021]. The data provided by FEMA are raw and unedited. To get more accurate estimates at the Zip Code Tabulation Area (ZCTA) level, we edited obvious typographical errors and then matched the data by zip code to ZCTA. The data were then collapsed to be unique by ZCTA and merged to 2019 ACS 5-Year ZCTA-level population counts. Using the ZCTA-level population data, FEMA IHP registrations and dollar amounts were normalized per 100 people.

[16]More information on IHP can be found at https://www.fema.gov/assistance/individual/program, [accessed February 1st, 2021].

[17]This crosswalk was constructed using 2018 North Carolina Census Block Group and 2010 United States ZCTA TIGER/Line Shapefile data. The unique block group identifier GEOID was then matched to the North Carolina Education Research Data Center (NCERDC) block group identifier BLOCK2010 to link the normalized FEMA data to our sample.

3 Empirical Methods

3.1 Empirical Model

Our empirical strategy relies on the exogenous timing and geographic location of school closures. Our econometric model includes both school and academic-year fixed effects, allowing us to control for time-invariant characteristics of schools and idiosyncratic differences by year that are common across schools. The model includes controls for prior-year test performance so the outcomes of interest can be interpreted as annual test-score gains. All regression equations include grade fixed effects and controls for student gender, race/ethnicity, disability status, LEP, and economically disadvantaged status.

The regression equation takes the following form:

$$(1) \quad Y_{ist} = \alpha + \lambda Y_{is,t-1} + \beta \text{Florence Closure Days}_{st} + X_{is,t-1}\Gamma + \tau_t + \psi_s + \epsilon_{ist}$$

Here, $Y_{i,s,t}$ is the standardized test score of student, i, in school, s, in year t. The coefficient of interest, β, measures how much more the students' standardized test scores changed, on average, as a function of the Florence closure days, holding constant schools' time-invariant characteristics and any idiosyncratic year effects that are common across students. The model includes controls for performance on mathematics and reading EOG examinations in the prior year, $Y_{i,s,t-1}$, so our coefficient estimates are appropriately interpreted as changes from students' baseline performance.

In Appendix Figures A1 and A2, we show a strong negative correlation between Florence closure days and lost days of instruction and also a strong but non-linear correlation between closure days and intensity of storm damage. While the relationship between Florence closure days and the change in instructional days between 2017-18 and 2018-19 is broadly linear, Florence closure days did not always translate one-to-one into lost days of instruction (represented by the dashed 45-degree line), particularly for very extended school closures (see Appendix Figure A1). We also find a strong correlation between average FEMA registrations per 100 people (our proxy for hurricane-related damage) and Florence closure days, but the relationship is non-linear, with the average close to zero for schools closed fewer than five days (see Appendix Figure A2). The estimates of the impact of an additional day of school closure due to Florence should therefore be interpreted with these interrelationships in mind, as our results capture impacts of both lost instructional days and storm-related disruptions.

4 Results

4.1 Average Test Score Losses

We begin by estimating the relationship between the number of school closure days due to Hurricane Florence and students' mathematics and reading EOG test scores. In Table 2 we report estimates of equation (1), in which the key coefficient of interest, β, measures the effect of an additional closure day on student performance. In column (1), the model includes grade and year fixed effects, as well as controls for student gender, race/ethnicity, disability status, LEP status, and economically disadvantaged status. We find that one additional closure day due to Florence is associated with a significant decrease in mathematics and reading scores of 0.0040 and 0.0013 standard deviations, respectively.

Table 2, Column (2) presents estimates that include school fixed effects. The results indicate that an additional school closure day reduces mathematics test scores by 0.0033 standard deviations, which suggests that some of the school closure effect on mathematics is mediated by time-invariant school characteristics. For reading, the estimated impact is larger in magnitude when we include school fixed effects: an additional missed school day leads to a 0.0035 standard deviation lower reading test score. These estimates are consistent with those of Aucejo and Romano (2016) and Sims (2008). Aucejo and Romano (2016) find that one additional calendar day increases mathematics by 0.0017 standard deviations and reading by 0.0008 standard deviations. Similarly, Sims (2008) finds that an additional instruction day leads to 0.0052 standard deviations higher mathematics scores and a statistically insignificant 0.001 standard deviation higher reading scores.

In Table 2, Column (3), the model includes school-level days of instruction. Since instructional days are highly correlated, but not perfectly collinear, with school closure days (see Appendix Table A1), this allows us to disentangle the impacts of missed instructional time and other disruptions due to the storm. We find that for mathematics scores, the average impact of an additional instructional day is a 0.0009 standard deviation increase, and the effect of closure days conditional on instructional days is similar. For reading scores, the main effect of closure days is only a slightly smaller and still statistically significant 0.0030 standard deviation decrease. These results suggest that the impact on students from Hurricane Florence is not entirely explained by missed days of instruction, but rather combines the impacts of missed instructional time and other hurricane-related disruptions.

To further explore the impact of disruptions, we include a proxy for hurricane-related damage to homes in the community. The proxy data are derived from registrations for the IHP, which are not

available for the full sample. We therefore replicate the baseline specification on the subset of students with valid data on ZCTA-level hurricane damage. The results, reported in Table 2, Column (4), show that the effects are slightly smaller, but qualitatively similar and still statistically significant. Column (5) includes both the number of valid registrations per 100 people and the total IHP dollars per 100 people. Again, the impacts differ between mathematics and reading. For mathematics, the number of FEMA claims entirely explains the school closure effect. For reading, the point estimate is actually slightly larger, and the hurricane damage variables do not significantly predict reading test scores.

Table 2, Column 6, includes all measures of the hurricane's impact: net days missed, instructional days, and ZCTA-level property damage. For mathematics, the estimates suggest that both lost instructional days and home disruptions reduce test score performance. In reading, only instructional days are a significant predictor of test scores.

The remainder of the results in this paper focus on the preferred specification in Table 2, Column (2), which includes school fixed effects to account for any time-invariant school-level characteristics that might be correlated with the extent of school days missed due to Hurricane Florence. These results should be interpreted as the net effect of hurricane exposure, as they incorporate the impact of both lost instructional time and potential disruptions in students' home environments.

4.2 Robustness Checks

4.2.1 Attrition

A concern when studying the impacts on students of a natural disaster early in the school year is attrition before testing in the spring: students might be displaced, simply not return to school, or switch schools. For this reason, our main analysis sample consists of students with valid test scores in the prior year, and school closure days are assigned based on the school attended in year $t-1$. The regression estimates thus far constrain the sample to include only students with valid time t test scores in the appropriate grade. To account for differential test-taking rates, we test whether exposure to an additional closure day changes the probability that students have a valid time t test score. We do not detect a statistically significant relationship between closure days and valid year t test scores (Table 3, Column (1)). However, the point estimate is negative, suggesting that exposure to an additional closure day may reduce the probability of test taking. If attritting students are also lower performing, then this type of attrition would cause the estimated impacts on test scores to be biased towards zero.

Among students with valid test scores, school switching is more likely following Hurricane Florence

closures (Table 3, Column (2)). Missing 10 days is associated with a 2 percentage point higher probability of switching schools relative to a baseline school-switching rate of 10 percent. This suggests that school switching, with its associated disruption, may be one potential mechanism whereby Hurricane Florence negatively impacted students.

4.2.2 Parallel Trends

The fundamental identifying assumption in our model is that the extent of closure days due to Hurricane Florence does not correlate with cross-school time-varying differences that are also associated with test scores. We probe the plausibility of this assumption by performing a placebo analysis to test for differential pre- Florence trends in test scores. We estimate a modified version of Equation (1) where we falsely attribute Florence closure days to the 2017-18 school year, one year before Hurricane Florence occurred. We estimate the model for only students in 2016-17 and 2017-18, excluding 2018-19. Significant estimates of the coefficient on the placebo Florence closure days in 2017-18 would suggest differential changes in test scores across schools over time before Florence, violating the parallel trends assumption. However, in Table 3, Columns (3) and (4), we find no evidence that the placebo closure days in 2017-18 were associated with statistically significant changes in math or reading EOG scores, supporting the plausibility of the parallel trends assumption.

4.2.3 Restricting to Positive Days Missed

The main analysis sample includes only students attending schools that experience positive days missed following Hurricane Florence. The motivation for this restriction is that unaffected schools may not be an appropriate counterfactual.[18] Table 3, Columns (5) and (6), replicates the baseline model presented in Table 2, Column (2) for the full sample. The overall estimates of Florence's impact on math and reading scores are qualitatively similar using either the restricted or full samples. Further, as presented in Appendix Table A2, our findings regarding the heterogenous impacts of Florence, described in Section 5 below, are qualitatively similar when estimated on the full sample. Altogether, these results indicate that this sample restriction is not driving our findings.

[18] In results not shown, the estimated coefficient on the placebo 2018 days missed is -0.0012 (0.0007) for the unrestricted sample.

5 Heterogeneity in the Educational Impacts of Hurricane Florence

This study's central question is: for which students are natural disasters most detrimental to learning? To further investigate the impact of natural disasters on student learning, we interact the main results from Table 2, Column (2) with student characteristics to determine whether natural-disaster-related school closures affect student groups differentially.[19] All specifications include year, grade, and time $t-1$ school fixed effects, as well as controls for the students' gender, race/ethnicity, disability status, economic disadvantage, and LEP status. Standard errors are clustered at the time $t-1$ school level.

In Table 4, Column (1), we explore whether effects are larger for middle school versus elementary school students. Middle school students may be more capable of independent learning and have greater ability to make-up missed material independently, but they may not have the same level of parent involvement or supervision. Our reference category is elementary school students (grades 4 and 5). We find that the difference in the impact on performance is not statistically significant for mathematics or reading, but the mathematics estimates suggest that middle school students might experience a larger learning loss relative to elementary school students. These results fail to support targeting either elementary or middle school students for remediation.

In Table 4, Column (2), we present results by students' gender. Heterogeneity by gender may reflect behavioral differences or differences in learning styles. However, it is not clear how this might translate into differential impacts of natural disasters. For both mathematics and reading, boys experience a smaller but still statistically significant impact following school closures. In results not shown, the sum of the coefficients for males is a statistically significant roughly -0.003 standard deviation decrease in both reading and mathematics.

Our data include only a coarse measure of economic disadvantage (see Section 2.3). This measure classifies roughly half of the students in our sample as being from economically disadvantaged families. Along this dimension, we fail to find statistically significant differences in the impact of Hurricane Florence on either mathematics or reading tests (Table 4, Column (3)). Students with LEP status see significantly smaller mathematics and reading test score declines, and no effect overall (Table 4, Column (4)). Recall that these estimates are net of any remediation that occurred prior to the EOG testing dates.

Looking across different racial/ethnic groups (Table 4, Column (5)), we find only limited evidence

[19] Appendix Table A2 presents parallel estimates for the full sample, which includes students who attended schools that did not miss any days due to Hurricane Florence.

that math or reading scores were impacted differentially by race – with notable exceptions. The group "other non-White students," which comprises students from a variety of racial/ethnic backgrounds, shows a decline in mathematics test scores over twice as large as that for White students. However, it is difficult to interpret the estimates for such a heterogeneous group. In contrast, non-White Hispanic students see significantly smaller reading test score declines (with no effect overall) but similar declines in math performance, relative to their White peers. These results point to impacts across a broad range of students.

Finally, in Table 4, Column (6), we explore heterogeneity in prior-year student performance by interacting Florence closure days with indicators for the quintile of performance on the prior-year EOG test.[20] The reference category is the third (i.e., median) quintile. Instead of single control variables for prior mathematics and reading test scores, the regressions include quintile-specific polynomials. The effect of an additional school closure day for students in the third quintile of prior-year mathematics performance is slightly larger than the estimated average effect in Table 2, Column (2). We detect negative impacts on math scores in the first through fourth quintiles. Interestingly, the smallest impacts are in the top and bottom quintiles of prior-year performance. These results suggest that the negative impacts of Hurricane Florence-related school closures on mathematics performance were felt by all but the students highest in the prior-year score distribution and were largest near the median.

In contrast, the impact on reading is strongest for students in the bottom quintile of prior-year reading test score performance. Still, there is a statistically significant impact on reading for all students, including those scoring in the top quintile in the prior year, who saw a small, marginally significant 0.001 standard deviation decline. These results indicate that while, for reading, students who scored poorly in the prior year experienced the most significant learning losses, students from the full distribution had lower reading test scores due to Hurricane Florence.

6 Discussion and Conclusion

It is not clear, a priori, which students might be most able to recover from school closures due to natural disasters. Students who were previously struggling may lose additional ground. Some families may be more directly impacted by storm damage, while others may have the resources to provide supplemental instruction for their children. Understanding which students might be least able to recover following

[20] In results not shown, the patterns are broadly consistent using the five achievement levels used in North Carolina or when dividing into deciles.

an event that causes school closures is key to allocating resources effectively.

The evidence presented here suggests that students from nearly all demographic groups and prior performance levels experienced some learning loss due to Hurricane Florence. Moreover, we fail to find strong evidence that particular demographic groups or students with higher or lower levels of past performance experience disproportionate learning losses. The magnitudes of these estimates are small, representing about a 0.003 standard deviation decline in both mathematics and reading, on average. This magnitude is consistent with prior studies of the impact of instructional days on test scores. When looking at demographic groups, we fail to find evidence that effects are concentrated by racial/ethnic group or by economic disadvantage. For mathematics, students from the second through fourth quintiles in prior achievement experienced the largest test score declines. For reading, students in the bottom quintiles of prior performance saw the largest test score impacts, but the estimates are statistically significant at all levels of prior reading performance.

Note that we interpret the score declines measured here as test score losses net of all efforts to recover following the hurricane. That is, these decreases take into account any efforts that may have been made following Hurricane Florence to mitigate the impacts of the storm on student learning. We cannot say what the test score losses might have been absent these efforts. Furthermore, future work should explore whether school closures due to extreme weather events have compounding effects on students, and whether schools, parents, and students can develop strategies that ameliorate the learning losses experienced due to disaster-related school closures. This study does not address the long-term impacts of school closings, nor the efficacy of distance learning and other strategies to mitigate learning loss. Yet, our results serve to inform how policymakers view the aftermath of extended natural disaster-related school closures as they plan for, and grapple with, the mitigation of consequences for students. Our findings fail to support targeting remediation efforts to the lowest performers and, rather, suggest broad impacts of school closures on student learning.

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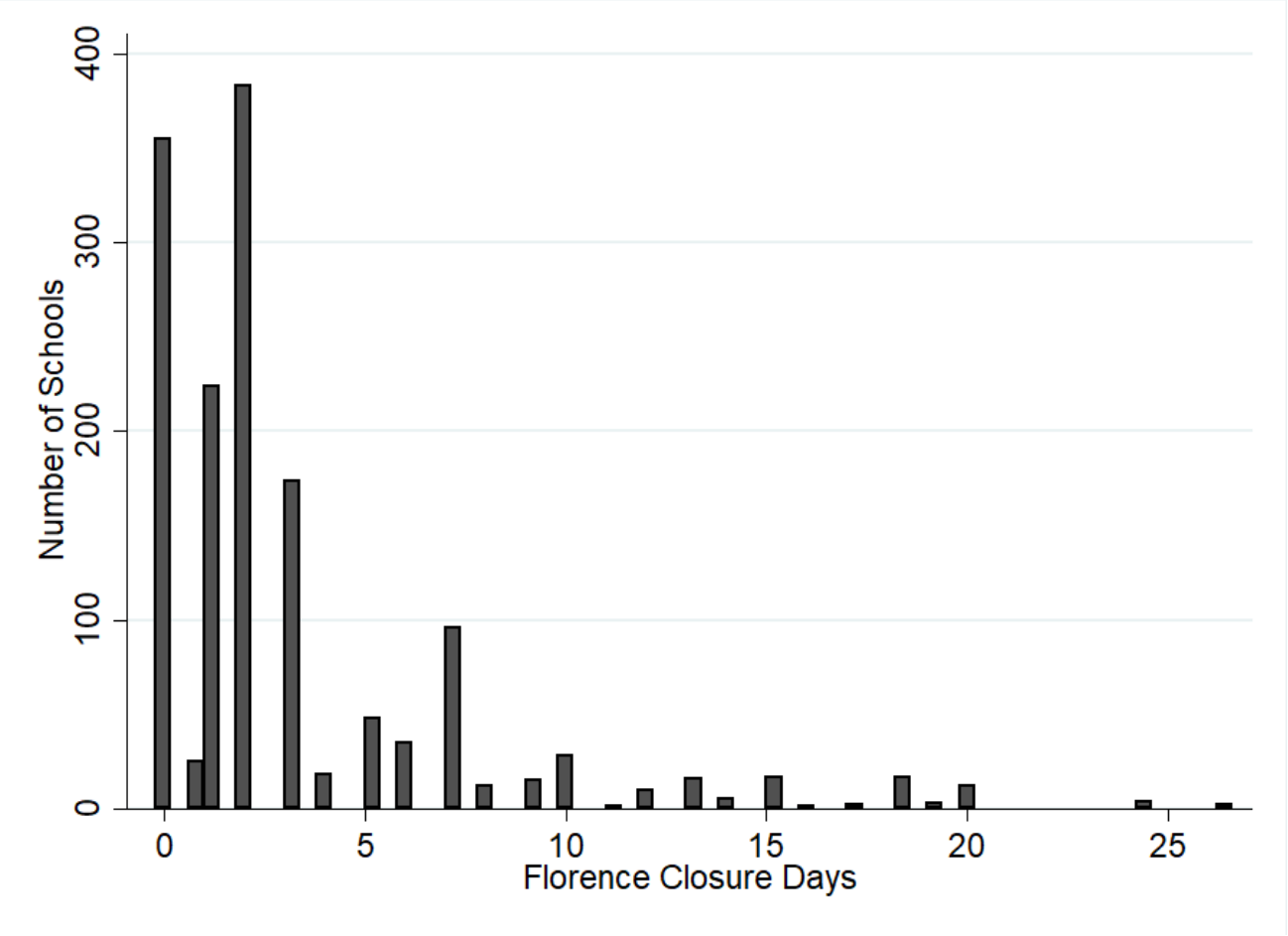
Figure 1: 2019 Hurricane Florence-Related Closure Days for North Carolina Schools



Notes: N = 1,503 schools.

Table 1: Sample Summary Statistics

	Full Sample (1)		Positive Missed Days (2)	
	Mean	Std. Dev.	Mean	Std. Dev.
Student Characteristics, Time $t-1$				
Male	0.51	[0.50]	0.51	[0.50]
Black	0.25	[0.43]	0.26	[0.44]
Hispanic	0.18	[0.39]	0.19	[0.39]
Other (Non-White)	0.08	[0.28]	0.09	[0.28]
Disability	0.12	[0.32]	0.12	[0.32]
Economically Disadvantaged	0.50	[0.50]	0.49	[0.50]
Limited English Proficiency	0.10	[0.31]	0.11	[0.31]
Grade 3 (t-1)	0.26	[0.44]	0.26	[0.44]
Grade 4 (t-1)	0.26	[0.44]	0.26	[0.44]
Grade 6 (t-1)	0.24	[0.43]	0.24	[0.43]
Grade 7 (t-1)	0.25	[0.43]	0.24	[0.43]
Math EOG t-1	0.02	[1.00]	0.04	[1.00]
Reading EOG t-1	0.01	[0.99]	0.02	[0.99]
Observations	1,020,384		811,893	

Notes: Data are derived from the North Carolina Education Research Data Center student-level data. Background characteristics are measured at time $t-1$ (2016-2018). The analysis sample is restricted to students whose school missed at least 0.6 days due to Hurricane Florence. See Section 2.3 and the Data Appendix for a complete list of sample restrictions.

Table 2: School Closures and Test Score Losses

	Linear	+ School FE	Days of Instruction (t)	FEMA Sample	Property Damage	All Measures
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Mathematics EOG						
Florence Days Missed	-0.0040***	-0.0033***	-0.0025***	-0.0027***	-0.0004	0.0002
	(0.0010)	(0.0009)	(0.0009)	(0.0010)	(0.0016)	(0.0016)
Membership Days (t)			0.0009***			0.0009***
			(0.0000)			(0.0001)
FEMA Regs per 100 pop					-0.0039*	-0.0036
					(0.0022)	(0.0022)
IHP Amount per 100 pop					0.0058	0.0051
					(0.0082)	(0.0083)
ZCTA Population				0.0000	0.0000	0.0000
				(0.0000)	(0.0000)	(0.0000)
Observations	613192	613192	610731	424437	424437	422877
Mean of Dep Var	0.0424	0.0424	0.0456	0.0598	0.0598	0.0627
Panel B: Reading EOG						
Florence Days Missed	-0.0013**	-0.0035***	-0.0030***	-0.0028***	-0.0037***	-0.0033***
	(0.0006)	(0.0007)	(0.0007)	(0.0007)	(0.0011)	(0.0011)
Membership Days (t)			0.0006***			0.0006***
			(0.0000)			(0.0000)
FEMA Regs per 100 pop					0.0010	0.0012
					(0.0016)	(0.0016)
IHP Amount per 100 pop					0.0021	0.0020
					(0.0051)	(0.0052)
ZCTA Population				-0.0000	-0.0000	-0.0000
				(0.0000)	(0.0000)	(0.0000)
Observations	811893	811893	808849	563576	563576	561657
Mean of Dep Var	0.0248	0.0248	0.0281	0.0326	0.0326	0.0356

The sample includes 4th, 5th, and 7th grade students (Panel A), and 4th, 5th, 7th, and 8th grade students (Panel B) from AY2016-17 through AY2018-19. The regression specifications include school, grade, and year fixed effects, as well as indicators for student gender, race/ethnicity, disability status, limited English proficiency, and economically disadvantaged status. The dependent variable in Panel A is Mathematics EOG and in Panel B is Reading EOG. In Columns (4) - (6), the sample is further restricted to students living in a Census Block Group that can be linked to a ZCTA with a population size of at least 90. Hurricane damage controls are derived from publicly available FEMA data on the Individuals and Households Program (IHP), described in detail in the text. Standard errors are clustered at the time $t-1$ school level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Specification Checks

	Valid Test Score	Switch Schools	Placebo		Full Sample	
			Math	Reading	Math	Reading
	(1)	(2)	(3)	(4)	(5)	(6)
Florence Days Missed x 2019	-0.0002	0.0020*			-0.0019**	-0.0023***
	(0.0002)	(0.0012)			(0.0008)	(0.0006)
Placebo Days Missed x 2018			-0.0004	-0.0008		
			(0.0010)	(0.0008)		
Observations	856070	811893	405137	536397	768841	1020384
Mean of Dep Var	0.9484	0.1134	0.0409	0.0245	0.0300	0.0146

Notes: The sample in Column (1) is all students who have a valid time $t-1$ test scores, and the dependent variable is having a valid year t reading test score. The dependent variable in Column (2) is having a time t test score at a different North Carolina school than that attended at time $t-1$. The dependent variables in Columns (3) and (4) are mathematics and reading EOG, respectively. Columns (3) and (4) include only pre-2019 data and assign placebo treatment to 2018 – as if the school experienced the days closed due to Hurricane Florence in 2018. Columns (5) and (6) report estimates from a model parallel to Table 2, Column (2) estimated on a sample that includes school that did not close at all due to Hurricane Florence. All specifications include year, grade, and time $t-1$ school fixed effects, as well as controls for the students' gender, race/ethnicity, disability status, economically disadvantaged status, and limited English proficiency status. Standard errors are clustered at the time $t-1$ school level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

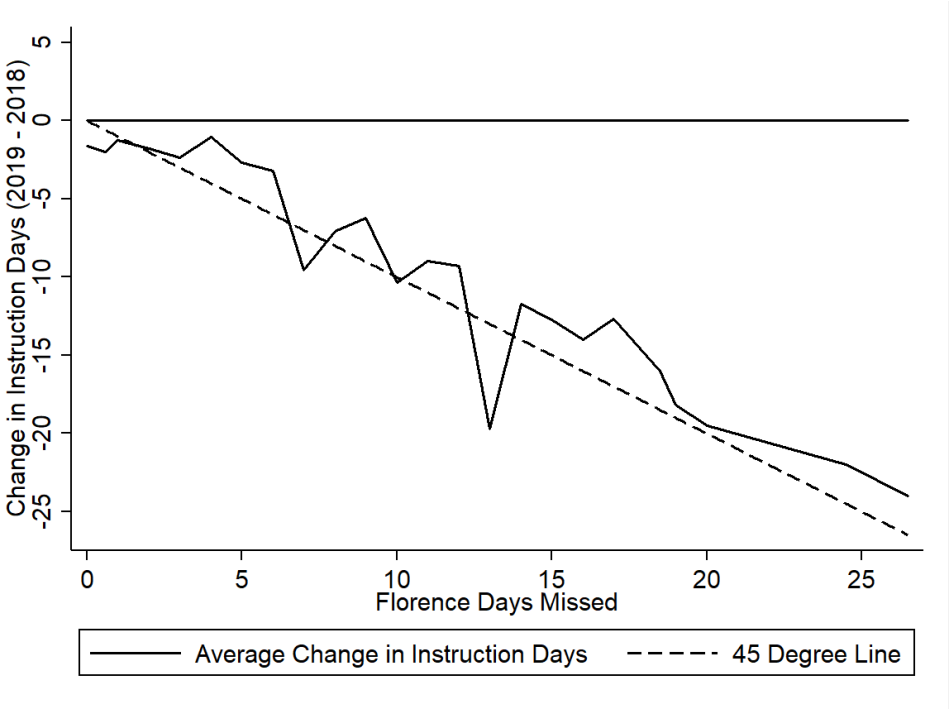
Table 4: Heterogeneity by Grade and Demographic Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Mathematics EOG (N = 613,192)					
Florence Days Missed	-0.0029***	-0.0041***	-0.0033***	-0.0035***	-0.0029***	-0.0050***
	(0.0011)	(0.0010)	(0.0010)	(0.0009)	(0.0010)	(0.0011)
x Middle School	-0.0012					
	(0.0014)					
x Male		0.0015***				
		(0.0004)				
x Econ. Disadvantaged			-0.0000			
			(0.0006)			
x Limited English Proficiency				0.0032***		
				(0.0010)		
x Black					-0.0008	
					(0.0008)	
x Hispanic					-0.0002	
					(0.0008)	
x Other NW					-0.0029***	
					(0.0009)	
x Math (t-1) 1st Quintile						0.0031***
						(0.0008)
x Math (t-1) 2nd Quintile						-0.0004
						(0.0007)
x Math (t-1) 4th Quintile						0.0009
						(0.0006)
x Math (t-1) 5th Quintile						0.0070***
						(0.0009)
	Panel B: Reading EOG (N = 811,893)					
Florence Days Missed	-0.0033***	-0.0040***	-0.0037***	-0.0037***	-0.0037***	-0.0025***
	(0.0008)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0008)
x Middle School	-0.0004					
	(0.0009)					
x Male		0.0009**				
		(0.0004)				
x Econ. Disadvantaged			0.0002			
			(0.0005)			
x Limited English Proficiency				0.0024***		
				(0.0008)		
x Black					-0.0002	
					(0.0006)	
x Hispanic					0.0019***	
					(0.0006)	
x Other NW					-0.0008	
					(0.0007)	
x Reading (t-1) 1st Quintile						-0.0045***
						(0.0007)
x Reading (t-1) 2nd Quintile						-0.0018***
						(0.0006)
x Reading (t-1) 4th Quintile						-0.0005
						(0.0006)
x Reading (t-1) 5th Quintile						0.0014**
						(0.0006)

Notes: All specifications include covariates as described in Table 2, Column (2). Column (6) includes quintile-specific, linear prior test score controls. Standard errors are clustered by $t-1$ school. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

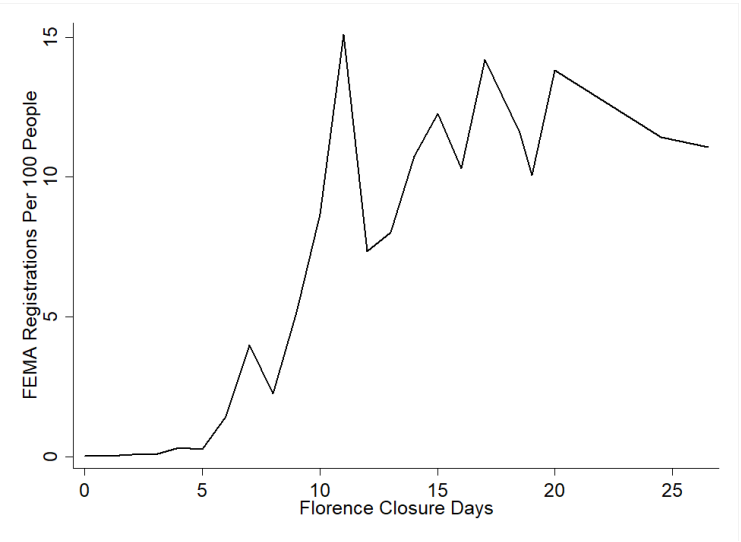
A Online Appendix

Figure A1: Florence Closure Days and Change in Instruction Days



Notes: The y-axis represents the change in median days of instruction at the school level. The x-axis represents the number of Hurricane Florence-related school closure days. The solid line shows the average median number of days of instruction for a given number of Florence closure days. The data are derived from NCERDC student-level records and NCDPI Hurricane Florence closure data.

Figure A2: Florence Closure Days and Storm Damage



Notes: The y-axis represents the number of FEMA registrations per 100 ZCTA population. The x-axis represents the number of Florence school closure days. The line shows the average number of FEMA registrations for a given number of Florence closure days. The data are derived from NCERDC student-level records, FEMA records, and NCDPI Florence closure data.

Table A1: Dataset Construction

	LEA	Schools	Students
Years (t-1) 2016-2018, Grade (t-1) 3rd, 4th, 6th, and 7th, with valid t-1 demographics and test scores	284	2,081	1,394,825
School-level restrictions			
Restrict to regular and non-charter schools	115	1,844	1,294,753
Non-missing values for days missed (NCDPI data)	115	1,807	1,282,256
Restrict to traditional calendar	115	1,684	1,192,995
Remove 3 districts impacted severely by Hurricane Matthew	112	1,633	1,158,494
Remove incompatible grade span configurations	107	1,503	1,074,916
Keep only schools with (t-1) median membership days between 150-200	107	1,503	1,073,442
Restrict to schools with positive Florence closure days	74	1,148	856,070
Time (t) student-level restrictions			
Restrict to valid time (t) reading test scores	74	1,148	811,893
Restrict to valid time (t) mathematics test scores	74	1,147	613,192

Table A2: Heterogeneity by Grade and Demographic Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Mathematics EOG, N = 768,841					
Florence Days Missed	-0.0014	-0.0027***	-0.0019**	-0.0021**	-0.0015*	-0.0040***
	(0.0010)	(0.0009)	(0.0009)	(0.0008)	(0.0009)	(0.0010)
x Middle School	-0.0013					
	(0.0014)					
x Male		0.0015***				
		(0.0004)				
x Econ. Disadvantaged			-0.0000			
			(0.0005)			
x Limited English Proficiency				0.0032***		
				(0.0010)		
x Black					-0.0006	
					(0.0008)	
x Hispanic					-0.0004	
					(0.0008)	
x Other NW					-0.0021**	
					(0.0009)	
x Math (t-1) 1st Quintile						0.0040***
						(0.0009)
x Math (t-1) 2nd Quintile						0.0002
						(0.0007)
x Math (t-1) 4th Quintile						0.0010
						(0.0006)
x Math (t-1) 5th Quintile						0.0069***
						(0.0009)
	Panel B: Reading EOG, N = 1,020,384					
Florence Days Missed	-0.0021***	-0.0027***	-0.0025***	-0.0025***	-0.0026***	-0.0017**
	(0.0007)	(0.0006)	(0.0007)	(0.0006)	(0.0006)	(0.0007)
x Middle School	-0.0005					
	(0.0009)					
x Male		0.0007*				
		(0.0004)				
x Econ. Disadvantaged			0.0004			
			(0.0004)			
x Limited English Proficiency				0.0027***		
				(0.0008)		
x Black					0.0004	
					(0.0006)	
x Hispanic					0.0020***	
					(0.0006)	
x Other NW					-0.0005	
					(0.0007)	
x Reading (t-1) 1st Quintile						-0.0033***
						(0.0007)
x Reading (t-1) 2nd Quintile						-0.0010*
						(0.0006)
x Reading (t-1) 4th Quintile						-0.0003
						(0.0006)
x Reading (t-1) 5th Quintile						0.0014**
						(0.0006)

Notes: This table is parallel to Table 4 but estimated on the full sample that includes students who attended schools that did not close due to Hurricane Florence. All specifications include covariates as described in Table 2, Column (2). Column (6) includes quintile-specific, linear prior test score controls. Standard errors are clustered by $t-1$ school.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.