The Effect of Prenatal Natural Disaster Exposure on School Outcomes

Sarah Crittenden Fuller

March 25, 2012

Abstract

This study uses regression analysis to look at the impact of exposure to natural disasters during pregnancy on the educational outcomes of North Carolina children at third grade. A broad literature relates negative birth outcomes to poor educational performance. However, very few studies are able to make use of an exogenous source of variation in prenatal development. Combining North Carolina administrative data on births and school performance with disaster declarations from the Federal Emergency Management Agency (FEMA) allows identification of children who were exposed to disasters in each trimester of prenatal development. Using a fixed effect strategy, these children are compared to other children born in the same county who were not exposed to disasters while in utero. Results suggest that children exposed to hurricanes, flooding or tornadoes prenatally have lower scores on third grade standardized tests in math and reading and a higher probability of being identified as special education. Additionally, results suggest that these negative effects are more concentrated among children in disadvantaged subgroups, especially children born to Black mothers. However, there is no evidence that these effects are mediated by common measures of birth outcomes, including birth weight and gestational age.

Introduction

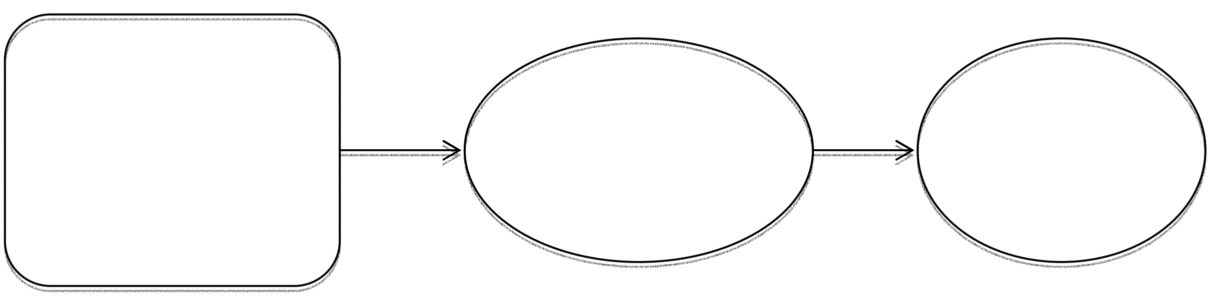
In 2010, the Federal Emergency Management Agency (FEMA) reported 81 major disasters across the United States. The immediate costs of natural disasters both for individuals and communities are substantial. FEMA distributed an average of $3.3 billion in Public Assistance Grants annually from 1999 to 2010 (FEMA, 2010). The costs borne by individuals, families, and insurance companies were likely even higher. The short term effects of these disasters, including injuries, evacuations, prolonged power outages, damage to buildings, and lost days of school and work, are well documented. However, much less is known about the long term costs of disasters in terms of their effects on families and children.

Very few studies look at the impact of natural disasters on prenatal development. Among the studies that do, they find mostly negative effects on birth outcomes (Torche, forthcoming; Glynn et al., 2001). However, because they are limited in focus to a single disaster, they are not able to distinguish effects of the disaster from cohort effects. They are also not able to differentiate differences in the effects of multiple types of disasters. Studies that consider longer run outcomes for children prenatally exposed to disasters are even rarer (Laplante et al., 2004) and have many of the same weaknesses.

The current study is able to look at the effects of 15 different disasters on a large sample of children born in North Carolina over a period of 13 years. Three different categories of disasters are represented in this study, which allows for some exploration of the differences in effects by disaster type. Additionally, the large sample size allows for consideration of differences in effects by demographic subgroups. The focus on educational outcomes at third grade in this study also gives a longer run perspective on the effects of prenatal shocks caused by disasters.

Background

The conceptual framework for this study assumes that natural disasters are unpredictable exogenous shocks which have effects on the prenatal development of babies who are in utero at the time of the disaster. Through the effect on prenatal development, the natural disasters may have long term effects on the educational outcomes of children exposed prenatally.



Natural Disasters and Prenatal Development

Two studies on natural disasters and the effect on newborn health have found negative impacts on birth outcomes among women exposed to disasters (Torche, forthcoming; Glynn et al., 2001). However, these studies each focused on a single earthquake and one of the studies (Glynn et al., 2001) had a small sample size. Further, these studies attributed the effects of natural disasters on birth outcomes to maternal stress. While stress is undoubtedly an important factor and other studies of stressful shocks have also found negative impacts on birth weights and gestational ages (Catalano & Hartig, 2001; Eskenazi et al., 2007; Engel et al., 2005; Berkowitz et al., 2003), natural disasters may affect other health mechanisms as well. Power disruptions and relocation due to evacuations or damage to housing may result in poorer nutrition among pregnant women experiencing a disaster. Travel difficulties or relocation may result in missed prenatal care appointments, lowering the overall amount of prenatal care received by women affected by a disaster. The disruption may also cause changes in established health related habits, such as drinking alcohol and smoking.

Studies looking at changes in maternal nutrition induced by famines or fasting have found large effects on birth weight (Roseboom et al., 2001; Almond & Mazumder, 2010; Antonov, 1957), and a study looking at the effect of a bus strike on prenatal care showed decreases in birth weight and gestational age (Evans & Lien, 2005). To the extent that natural disasters also affect these behaviors, they are important to consider as mechanisms influencing prenatal development.

Prenatal Development and Educational Outcomes

The relationship between poor health at birth and negative educational outcomes is well documented. Low birth weight and preterm birth are associated with a higher risk of significant physical and mental impairments (Saigal, Szatmarl, Rosenbaum, Campbell & King, 1991; Reichman, 2005; Goosby & Cheadle, 2006; Goosby & Cheadle, 2009) which translates into higher levels of special education placements once students reach school age. Even for children who do not suffer from serious impairments, newborn health has been used to predict cognitive skills and achievement test scores (Hack et al., 2002; Reichman, 2005; Black, Devereux, & Salvanes, 2007; Goosby & Cheadle, 2009; Andreias et al., 2010; Aarnoudse-Moens et al., 2009; Boardman et al., 2002). Other school related outcomes may also be affected by health at birth, including retention, behavior, attention, and executive function (Aarnoudse-Moens et al., 2009; Temple, Reynolds, & Artega, 2010; Conley, Strully, & Bennett, 2003; Saigal et al., 1999). Ultimately, early health may influence important life outcomes, including educational attainment and labor market success (Black et al., 2007; Conley et al., 2003; Hack et al., 2002). This literature suggests that health at birth, or health capital (Currie, 2009), may be an important factor to consider for improving educational performance.

However, there is also a strong association between birth outcomes and disadvantage, so some researchers have questioned whether the relationship between newborn health and educational outcomes is causal or if poor health at birth is simply a marker for other types of disadvantage that are difficult to measure (Almond & Currie, 2010; Almond, Chay & Lee, 2005; Currie, 2009; Conley, Strully & Bennett, 2003). While it is possible to control for some measures of disadvantage, there is still a concern that low birth weight students are more disadvantaged on average than students who appear otherwise similar (Saigal et al.,1991; Goosby & Cheadle, 2006; Goosby & Cheadle, 2009).

Yet, there are theoretical reasons to believe that health at birth may have a causal impact on educational outcomes. The Fetal Origins hypothesis asserts that poor health at birth may actually be a sign of negative developmental adaptations that have significant consequences for later life (Godfrey &

Barker, 2001; Barker et al., 1993; Barker, 1995; Shonkoff et al., 2009; Rasmussen, 2001). According to this hypothesis, negative impacts that occur during critical periods of fetal development cause the fetus to adapt by making permanent changes that may ensure immediate survival at the expense of long term welfare (Godfrey & Barker, 2001; Currie, 2009; Shonkoff et al., 2009; Ellis et al., 2011). Other researchers have suggested that early stress may lead to adaptations that make the individual more susceptible to environmental influences, good or bad (Pluess & Belsky, 2011; Elllis et al., 2011). The exogenous nature of the shocks caused by natural disasters provides an opportunity to examine support for a causal explanation.

Other studies of shocks that influence birth outcomes, including famines (Antonov, 1957; Roseboom et al., 2001; Doblhammer, 2004), natural disasters (Torche, forthcoming; Glynn et al., 2001), and national tragedies (Catalano & Hartig, 2001; Eskenazi et al., 2007; Engel, Berkowitz, Wolff & Yehuda, 2005; Lederman et al., 2004; Berkowitz et al., 2003), have typically not linked the effects to educational outcomes. One study of women exposed to an ice storm found that their children had lower levels of intellectual ability and language skill at age two and that these effects were not explained by birth weight (Laplante et al., 2004). However, the sample size was small and there were no measures of performance in school. A few other studies have looked at other types of prenatal shocks in relation to educational and labor market outcomes. These studies have used the birth dates and locations of adults to determine whether they would have been exposed to disruptions such as disease (Almond, 2006), famine (Neugebauer et al., 1999) and fasting (Almond & Mazumder, 2005) in utero and then demonstrated that exposed individuals had worse outcomes than the unexposed. These studies did not, however, include actual data on the health of the individuals at birth and cannot distinguish the effect of the prenatal shocks from other cohort effects.

Previous studies have suggested that the effects of prenatal shocks may not be universal. Research indicates that an infant's health may be more negatively impacted by a shock during earlier pregnancy or later pregnancy (Roseboom et al., 2001; Catalano & Hartig, 2001; Hedegaard et al., 1996; Glynn et al., 2001; Lederman et al., 2004; Torche, forthcoming; Almond & Mazumder, 2010) rather than having a uniform effect across all trimesters. Other studies in the literature have found that families of higher socioeconomic status (SES) can compensate for poor birth outcomes (Almond & Currie, 2010; Goosby & Cheadle, 2006; Conley, Strully, & Bennett, 2003) while other studies have found no difference by SES (Saigal, Szatmaril, Rosenbaum, Campbell & King, 1999; Goosby & Cheadle, 2009; Andreias et al., 2010).

This study will extend this literature by explicitly linking individual prenatal natural disaster exposure to educational outcomes across a number of different disasters. In doing so, this study will avoid the potential problems of cohort effects and provide evidence of longer term effects accruing from prenatal exposure beyond health effects measurable at birth. The study will also allow for a more nuanced look at how effects vary by disaster type and subgroup and the role played by birth weight and gestational age in mediating these effects.

Methods

Data

This study combines three data sets to create a longitudinal data set containing individual prenatal disaster exposure, birth characteristics, and school outcomes. The sample includes all singleton births from 1988 to 2000 in North Carolina that can be matched to their third grade test score records in North Carolina public schools from 1997 to 2010. While the sample initially included all children born alive in North Carolina during the time period, some individuals were dropped from the sample because they could not be matched to their public school records. Some of the missing school records are a result of children who left the state or did not attend public schools. Moreover, some who did attend public schools may not be matched due to errors or discrepancies in the data recording. The full data set includes 879,303 children for whom third grade test data was available out of a total of 1,323,489 births in North Carolina between 1988 and 2000.

School outcome variables came from administrative records for all school districts in North Carolina, provided by the North Carolina Education Research Data Center. The outcome variables are scores on the third grade End of Grade reading and math tests and identification as special education or gifted at third grade. The school data also provided information on student ethnicity and identification for specific programs such as the federal school lunch program and English Language Learners.

Information on birth date and county of residence at birth came from detailed birth certificate information, obtained from the North Carolina Department of Vital Statistics. These records include all children born in North Carolina. The birth records also served as a source of demographic information about the parents, including the mother's age, ethnicity and education, the marital status of the mother, and information on the father if any was available.

A matching procedure was performed using student names and birth dates to link each individual student's school records to their birth record for the sample of students for whom both records are available. Across all years, an average of 66% of all individuals born in the state from 1988 to 2000 were matched with 3rd grade school records. The match rate for births in each year was at least 64%. See Table 1 for year-by-year match rates.

Table 1. Match Rate between Birth Data and School Data, Birth Years 1988 to 2000

Year of Birth	Total Births	Number Matched	Percent Matched
1988	93,509	60,439	64.6%
1989	97,996	63,982	65.3%
1990	100,359	66,182	65.9%
1991	98,126	65,826	67.1%
1992	99,820	65,700	65.8%
1993	97,384	65,312	67.1%
1994	97,656	65,992	67.5%
1995	98,003	66,120	67.5%

Year of Birth	Total Births	Number Matched	Percent Matched
1996	101,068	67,309	66.6%
1997	103,534	68,547	66.2%
1998	108,319	72,291	66.7%
1999	110,564	74,104	67.0%
2000	117,151	77,569	66.2%
Total	**1,323,489**	**879,303**	**66.4%**

Table 2 compares the demographics of the birth records that were matched to those that could not be matched. The matched sample had mothers that were somewhat less educated, less likely to be married and less likely to be immigrants than the unmatched sample. These differences are probably accounted for by general trends in those more likely to move out of state or attend private school. However, the differences in disaster exposure were quite small.

Table 2. Comparison of Births that were and were not Matched to School Data

Variable	Matched	Unmatched	Difference
Female	49.5%	47.4%	2.1%
Mother's Age	25.9	26.3	-0.5
Mother Married	66.8%	74.6%	-7.8%
No Father on Birth Certificate	14.2%	12.1%	2.1%
White Mother	63.9%	66.9%	-3%
Black Mother	29.6%	23.0%	6.6%
Native American Mother	1.6%	1.1%	0.5%
Asian Mother	1.2%	2.3%	-1.1%
Hispanic Mother	3.6%	6.5%	-2.9%
Other Race Mother	0.1%	0.1%	-0.1%
Immigrant Mother	6.0%	10.6%	-4.6%
Mother Less than High School	22.9%	19.1%	3.8%
Mother High School	38.2%	32.6%	5.6%
Mother Some College	21.3%	22.1%	-0.8%
Mother College Graduate	17.7%	26.2%	-8.5%
First Birth	35.1%	32.9%	2.2%
Disaster Exposure	21.2%	21.1%	0.1%
Hurricane Exposure	10.7%	11.4%	-0.7%
Winter Storm Exposure	7.1%	8.0%	-0.9%
Severe Storm Exposure	2.6%	2.5%	0.1%

The source of data on natural disasters for the study was FEMA records of major disaster declarations. Presidential disaster declarations are made at the request of the governor of the state receiving the declaration. In order to be eligible for federal disaster assistance, the needs for recovery must exceed the combined resources of the state and local governments (FEMA website, 2011). Declarations designate eligibility for federal assistance at the county level.

Using the date of birth and county of residence at birth for each child in the data set, a determination was made as to whether or not the child was exposed to a disaster declaration during the prenatal period. For the purposes of determining disaster exposure, gestation is assumed to have begun 40 weeks before birth for all children. The child is considered to be exposed to the disaster if the date of the initial disaster declaration fell between the beginning of gestation and the birth date. Reported gestational age was not used to avoid the bias created by the fact that children who were born early simply had fewer weeks of possible exposure. The data includes the type of disaster and trimester of the exposure.

Between 1988 and 2000, North Carolina experienced 15 major disaster declarations. All 100 counties in North Carolina experienced at least one disaster declaration with individual counties experiencing between 1 and 7 disasters over the 13 year time period. The types of disasters included hurricanes, winter storms, and severe storms associated with flooding and tornadoes. Table 3 shows details on the number of counties and the fraction of births affected by each disaster type.

Table 3. Descriptive Data on Natural Disasters and Prenatal Natural Disaster Exposure, 1988 to 2000

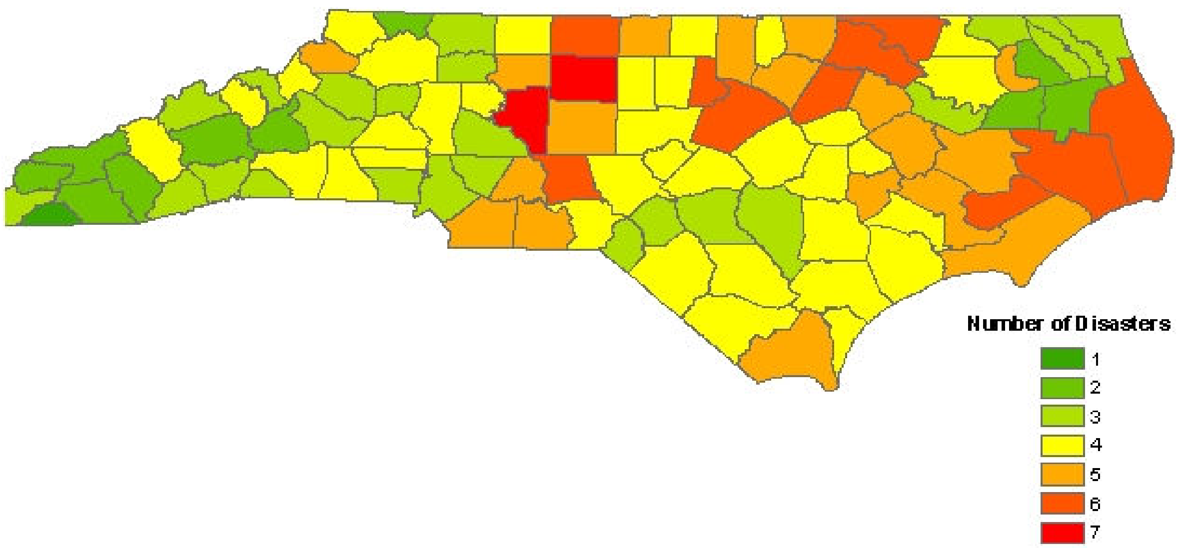
	All Disasters	Hurricanes	Winter Storms	Other Disasters
Events	15	7	3	5
Counties	100	88	74	42
Number of Births	~179,000	~92,000	~63,000	~23,000
Percent of Births	21%	11%	7%	3%

Empirical Analysis

This study uses regression analysis with county fixed effects to look at the relationship between prenatal disaster exposure and educational outcomes. Test score outcomes are examined using linear regressions and for special education and gifted placement are examined using logistic regressions. The assumption underlying the strategy is that given residence in a particular county the exposure to natural disasters in a particular year is random and difficult to predict in advance.

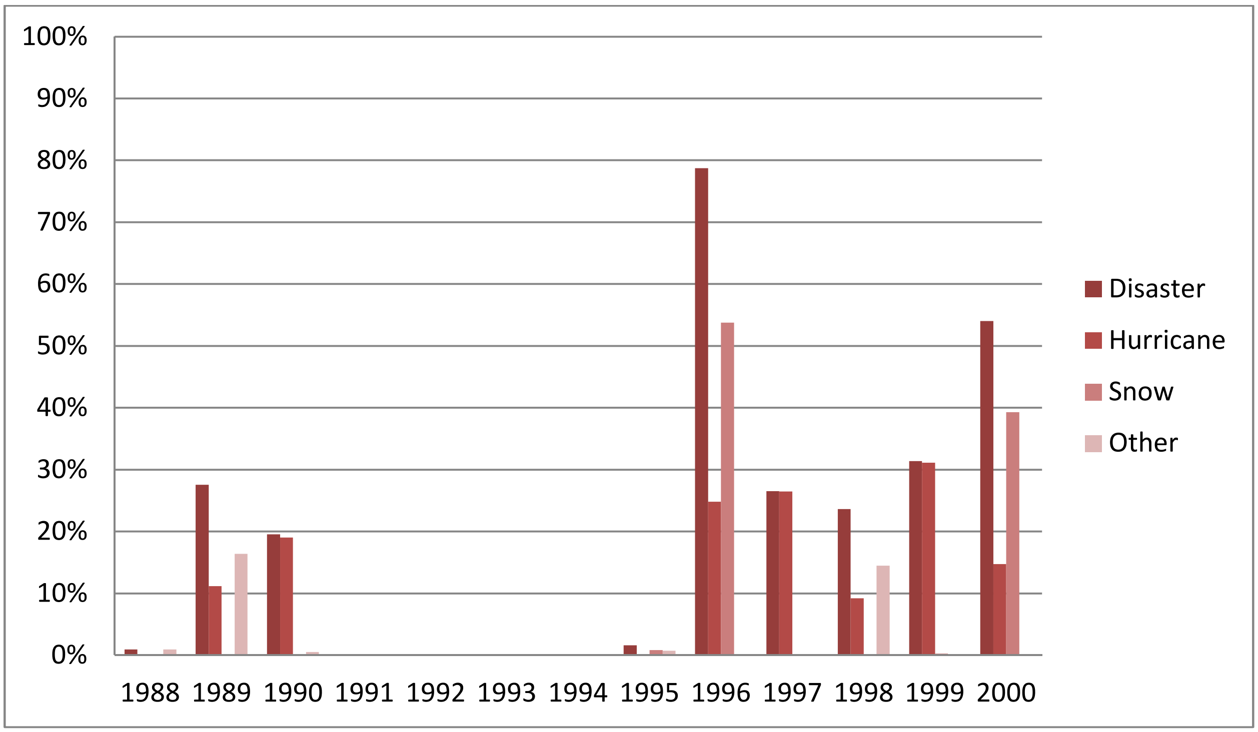
As shown in Figure 1, there is considerable geographic variation in disaster exposure, and disasters are not concentrated in any one part of the state.

Figure 1. Natural Disaster Exposure by County, 1988 to 2000



As Figure 2 illustrates, there is also considerable variation across years in the percent of births affected by disasters of various types. The total percent of births affected range from 0% in years that did not have any disasters to 78% of births in 1996 when 4 disasters occurred.

Figure 2. Percent of Births Affected by Disaster Type and Year



Since individuals are unlikely to be able to anticipate the occurrence of a natural disaster, their reproductive decisions are unlikely to be influenced by disasters. Therefore, families with a pregnancy at the time of the disaster should be similar to other families with children of similar ages. Any other long term effects of disasters on families should not vary between families who had children born just before and families with a pregnancy during the disaster. The regression analyses should, therefore, provide unbiased estimates of the effects of prenatal natural disaster exposure on educational outcomes.

The independent variables in the analysis are disaster declarations in each trimester of pregnancy. Exposure is divided by trimester to allow for differences in the consequences of exposure by the period of development during which it occurs. In some specifications, all disasters are treated as identical, and in some specifications, disasters are divided according to type: hurricanes, winter storms, and severe storms with tornadoes or flooding. The individual and community effects of different disasters may be different and may, therefore, result in different influences on school outcomes.

The dependent variables in these analyses are third grade reading and math scores and identification as special education or gifted. The test scores are standardized to have a statewide mean of zero and standard deviation of one for each year of the test. Special education and gifted status are indicator variables for whether the child was identified as special education or gifted in third grade testing data.

As control variables, the regressions include demographic information, including an indicator for first birth to mother, maternal age, maternal education, maternal race, maternal immigrant status, maternal marital status, presence of a father on the birth certificate, and English Language Learner status. County of birth, week of birth, and year of birth fixed effects are also included in this analysis. Week of birth fixed effects control for systematic differences in outcomes by season of birth that have been documented in previous literature (Doblhammer, 2004). Year fixed effects control for changes due to changes in technology, economic conditions, or other factors. County fixed effects account for differences in counties that experience more or less frequent natural disasters by comparing across individuals born at different times in the same county. Standard errors in all regressions are clustered at the county year level to acknowledge that treatment status is assigned based on county of residence at a particular time rather than individual exposure.

The initial analyses include all individuals with matched records. The analysis is then extended to consider differences in the effects for different subgroups. Analyses are rerun for children born to White mothers or Black mothers, as well as children born to mothers with no education beyond high school or mothers with at least some college. A mediation analysis is the conducted to determine the role played by common measures of health at birth in mediating the effects on educational outcomes. Finally, sensitivity test are performed to eliminate the possibility of confounding influences.

Results

Table 3 displays descriptive statistics for all independent, dependent, and control variables used in the regressions.

Table 3. Descriptive Statistics

Variable	Mean	Std. Dev.
Gender of Child	0.50	
Mother's Age	25.89	5.88
First Birth to Mother	0.35	
Marital Status of Mother	0.67	
No Information on Father	0.14	
White Mother	0.64	
Black Mother	0.30	
Native American Mother	0.02	
Asian Mother	0.01	
Hispanic Mother	0.04	
Other Race Mother	0.00	
Mother Less than High School	0.23	
Mother High School Grad	0.38	
Mother Some College	0.21	
Mother College Grad	0.18	
Immigrant Mother	0.06	
Limited English Proficiency	0.03	
Birth Weight (lbs.)	7.30	1.32
Gestational Age (weeks)	38.93	2.20
Low Birth Weight (<5.5lbs.)	0.07	
Preterm (<37 weeks)	0.09	
Small for Gestational Age (lowest 10%)	0.10	
N=879303		

Table 4 displays the basic results for the influence of disaster exposure in each trimester on test scores in math and reading and special education and gifted placement. In this specification, all types of disasters are treated as equivalent. The results show significant reductions in math test scores of about 1.5% of a standard deviation associated with being exposed to a natural disaster during any trimester and reduction in reading scores of about 1% of a standard deviation for trimesters 1 and 3. Exposure during trimester 3 is also associated with a 15% greater chance of being identified as special education and an 8% reduced chance of being identified as gifted. These effects are quite small. For example, the reduction in math scores is approximately one fifth the size of the effect of having a married mother and the increase in special education placement is twice as large as the effect of having a married mother.

Table 4. Regressions of Math and Reading Scores, Special Education Placement, and Gifted Placement on Disaster Exposure

	(1)	(2)	(3)	(4)
VARIABLES	**Math (OLS)**	**Reading (OLS)**	**Special Education (Logit)**	**Gifted (Logit)**
Trimester 1 Disaster	-0.016**	-0.011**	1.017	0.951
	(0.006)	(0.004)	(0.045)	(0.045)
Trimester 2 Disaster	-0.016**	-0.008	1.082	1.000
	(0.005)	(0.005)	(0.047)	(0.042)
Trimester 3 Disaster	-0.015**	-0.009*	1.154*	0.922*
	(0.006)	(0.005)	(0.076)	(0.037)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	846,679	842,960	848,296	848,296
R-squared	0.252	0.240		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year. Results for special education and gifted status are reported as odds ratios with standard errors referring to original coefficients.

In Table 5, similar regressions are performed with indicator variables for the three different types of disasters across the trimesters of pregnancy. The negative effects of disasters seen in the previous analysis are mostly concentrated among those exposed to hurricanes. Hurricane exposure in any trimester is associated with reduced math and reading scores and exposure during the third trimester increases identification for special education. Being exposed to flooding or tornadoes in the first trimester also reduces math scores. Winter storms, however, show no significant effect. These differences by disaster type may indicate important differences in influences on health mechanisms that may warrant further exploration.

Table 5. Regressions of Math and Reading Scores, Special Education Placement, and Gifted Placement by Disaster Type

	(1)	(2)	(3)	(4)
VARIABLES	**Math (OLS)**	**Reading (OLS)**	**Special Education (Logit)**	**Gifted (Logit)**
Trimester 1 Hurricane	-0.026**	-0.019**	1.129	0.976
	(0.008)	(0.006)	(0.083)	(0.064)
Trimester 2 Hurricane	-0.025***	-0.014*	1.128	1.022
	(0.007)	(0.006)	(0.075)	(0.055)
Trimester 3 Hurricane	-0.027***	-0.024***	1.180*	0.931
	(0.007)	(0.006)	(0.097)	(0.056)
Trimester 1 Winter Storm	0.011	0.007	0.886	0.896
	(0.010)	(0.009)	(0.063)	(0.062)
Trimester 2 Winter Storm	0.008	0.004	0.860	0.943
	(0.009)	(0.008)	(0.073)	(0.075)
Trimester 3 Winter Storm	0.008	0.012	0.816	0.884
	(0.010)	(0.008)	(0.090)	(0.072)
Trimester 1 Flooding/Tornado	-0.032*	-0.012	0.936	0.987
	(0.015)	(0.009)	(0.111)	(0.121)
Trimester 2 Flooding/Tornado	-0.020	-0.003	1.408	1.012
	(0.016)	(0.010)	(0.305)	(0.110)
Trimester 3 Flooding/Tornado	0.001	0.008	1.619	0.915
	(0.015)	(0.009)	(0.445)	(0.116)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	846,679	842,960	848,296	848,296
R-squared	0.253	0.240		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year. Results for special education and gifted status are reported as odds ratios with standard errors referring to original coefficients.

Subgroup Analysis

Rather than being distributed evenly across all groups, effects of prenatal disaster exposure are likely to be concentrated among disadvantaged groups which are less able to buffer themselves from negative consequences. This section tests this theory by conducting regressions separately for children white mothers, black mothers, mothers with a high school degree or less, and mothers with at least some college. Table 6 shows the subgroup results for math scores. The largest effect sizes, ranging from 4-5.5% of a standard deviation decrease, are for children of Black mothers who were exposed to hurricanes. There are also significant effects associated with hurricane exposure for mothers with a high school degree or less and white mothers across all trimesters, but the effect sizes are smaller. For children of highly educated mothers, hurricane exposure is significantly negative only in the third trimester, although the point estimates are negative in the other trimesters. Children of white mothers also show significant negative effects of flooding or tornado exposure in trimester 1. However, all four groups have similar point estimates for this type of exposure, so the lack of statistical significance may simply reflect the smaller group of kids exposed to these types of disasters.

Table 6. OLS Regressions of Math Scores by Disaster Type and Maternal Subgroup

	(1)	(2)	(3)	(4)
VARIABLES	**White**	**Black**	**High School or Less**	**More Than High**
Trimester 1 Hurricane	-0.021**	-0.043**	-0.026**	-0.020
	(0.008)	(0.015)	(0.009)	(0.011)
Trimester 2 Hurricane	-0.018*	-0.046***	-0.029***	-0.014
	(0.008)	(0.011)	(0.008)	(0.009)
Trimester 3 Hurricane	-0.019*	-0.055***	-0.024**	-0.030**
	(0.009)	(0.011)	(0.008)	(0.009)
Trimester 1 Winter Storm	0.011	0.005	0.011	0.011
	(0.010)	(0.018)	(0.012)	(0.010)
Trimester 2 Winter Storm	0.012	-0.006	0.007	0.010
	(0.009)	(0.016)	(0.011)	(0.010)
Trimester 3 Winter Storm	0.007	0.010	0.002	0.017
	(0.011)	(0.017)	(0.012)	(0.011)
Trimester 1 Flooding/Tornado	-0.033*	-0.032	-0.030	-0.034
	(0.016)	(0.021)	(0.017)	(0.018)
Trimester 2 Flooding/Tornado	-0.032	-0.002	-0.016	-0.022
	(0.018)	(0.021)	(0.014)	(0.028)
Trimester 3 Flooding/Tornado	-0.005	0.005	-0.007	0.013
	(0.018)	(0.024)	(0.018)	(0.018)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	542,310	250,976	518,161	328,518
R-squared	0.168	0.083	0.142	0.203

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year.

Table 7 shows similar results for reading scores. Again, children of Black mothers exposed to hurricanes have the largest effect sizes, ranging from 2.5 to 5% of a standard deviation. The effect sizes for hurricanes are smaller for the other three groups and only significant in some trimesters for white and highly educated mothers. The other two disaster types are only significant for highly educated mothers exposed to winter storms in the third trimester, who show a 2% of a standard deviation increase in reading scores. The subgroup results for test scores in both subjects are consistent with disadvantaged groups suffering the most from disaster exposure.

Table 7. OLS Regressions of Reading Scores by Disaster Type and Maternal Subgroup

	(1)	(2)	(3)	(4)
VARIABLES	**White**	**Black**	**High School or Less**	**More Than High**
Trimester 1 Hurricane	-0.015*	-0.029*	-0.020*	-0.016
	(0.007)	(0.013)	(0.008)	(0.008)
Trimester 2 Hurricane	-0.008	-0.025*	-0.020**	-0.002
	(0.007)	(0.011)	(0.008)	(0.008)
Trimester 3 Hurricane	-0.015	-0.050***	-0.019*	-0.031***
	(0.008)	(0.012)	(0.008)	(0.009)
Trimester 1 Winter Storm	0.010	-0.002	0.010	0.005
	(0.010)	(0.018)	(0.011)	(0.010)
Trimester 2 Winter Storm	0.015	-0.020	0.001	0.011
	(0.010)	(0.013)	(0.010)	(0.011)
Trimester 3 Winter Storm	0.010	0.015	0.008	0.020*
	(0.010)	(0.015)	(0.010)	(0.010)
Trimester 1 Flooding/Tornado	-0.008	-0.017	-0.018	-0.004
	(0.012)	(0.015)	(0.013)	(0.015)
Trimester 2 Flooding/Tornado	-0.006	-0.006	0.006	-0.013
	(0.013)	(0.019)	(0.011)	(0.017)
Trimester 3 Flooding/Tornado	0.005	0.007	0.006	0.009
	(0.011)	(0.017)	(0.014)	(0.012)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	540,307	249,637	515,172	327,788
R-squared	0.164	0.102	0.137	0.183

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year.

The subgroup results for special education placement, shown in table 8, suggest increases in identification associated with hurricane exposure during the third trimester for all groups except children of White mothers. Children of Black mothers and highly educated mothers also show significant effects for hurricanes in other trimesters. Among children of highly educated mothers, those exposed to winter storms have a significantly lower chance of being identified as special education, and those exposed to tornadoes or flooding a significantly high chance. This pattern is not consistent with disadvantaged groups experiencing the worst effects. However, it may suggest that highly educated parents are more likely to react to small changes in cognitive ability by getting children evaluated for special education.

Table 8. Logistic Regressions of Special Education Placement by Disaster Type and Maternal Subgroup

	(1)	(2)	(3)	(4)
VARIABLES	**White**	**Black**	**High School or Less**	**More Than High**
Trimester 1 Hurricane	1.161	1.076	1.053	1.250*
	(0.096)	(0.073)	(0.051)	(0.126)
Trimester 2 Hurricane	1.096	1.195**	1.075	1.208
	(0.082)	(0.071)	(0.049)	(0.126)
Trimester 3 Hurricane	1.192	1.173*	1.119*	1.312*
	(0.114)	(0.079)	(0.057)	(0.171)
Trimester 1 Winter Storm	0.864	0.967	0.952	0.778*
	(0.071)	(0.063)	(0.041)	(0.092)
Trimester 2 Winter Storm	0.843	0.908	0.956	0.710*
	(0.084)	(0.056)	(0.045)	(0.104)
Trimester 3 Winter Storm	0.800	0.867	0.927	0.656*
	(0.100)	(0.072)	(0.055)	(0.124)
Trimester 1 Flooding/Tornado	0.896	0.995	1.000	0.852
	(0.118)	(0.095)	(0.070)	(0.180)
Trimester 2 Flooding/Tornado	1.417	1.345	1.131	1.846*
	(0.313)	(0.286)	(0.139)	(0.440)
Trimester 3 Flooding/Tornado	1.674	1.477	1.196	2.359**
	(0.502)	(0.334)	(0.170)	(0.732)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	543,046	251,668	519,538	328,758

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year. Results for special education status are reported as odds ratios with standard errors referring to original coefficients.

Table 9 displays subgroup results for gifted placement. The only significant result for gifted placement is an increase for children of black mothers exposed to hurricanes in the first trimester. However, given the lack of other evidence to support this pattern, the result may be spurious.

Table 9. Logistic Regressions of Gifted Placement by Disaster Type and Maternal Subgroup

	(1)	(2)	(3)	(4)

VARIABLES	White	Black	High School or Less	More Than High
Trimester 1 Hurricane	0.938	1.195*	1.000	0.963
	(0.065)	(0.096)	(0.068)	(0.071)
Trimester 2 Hurricane	0.976	1.135	1.099	0.980
	(0.056)	(0.094)	(0.060)	(0.065)
Trimester 3 Hurricane	0.917	0.874	0.985	0.906
	(0.057)	(0.092)	(0.064)	(0.058)
Trimester 1 Winter Storm	0.890	0.954	0.868	0.913
	(0.065)	(0.096)	(0.071)	(0.063)
Trimester 2 Winter Storm	0.915	1.063	0.935	0.958
	(0.078)	(0.095)	(0.089)	(0.078)
Trimester 3 Winter Storm	0.864	1.083	0.876	0.906
	(0.076)	(0.090)	(0.073)	(0.080)
Trimester 1 Flooding/Tornado	1.039	0.881	1.019	0.972
	(0.132)	(0.128)	(0.111)	(0.135)
Trimester 2 Flooding/Tornado	1.038	1.003	1.146	0.955
	(0.120)	(0.152)	(0.131)	(0.116)
Trimester 3 Flooding/Tornado	0.933	0.814	0.911	0.906
	(0.122)	(0.136)	(0.111)	(0.132)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	543,046	251,256	519,538	328,758

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year.
Results for gifted status are reported as odds ratios with standard errors referring to original coefficients.

The subgroup results generally indicate that disadvantaged groups are more negatively affected by prenatal disaster exposure. However, all groups experience some negative effects.

Mediation Analysis

The next section of the analysis considers the role played by common measures of health at birth. As a first step, table 10 displays the results of regressions of birth outcomes on indicators of disaster exposure. The outcomes in these regressions are birth weight, gestational age, low birth weight (less than 5.5 lbs.), preterm birth (earlier than 37 weeks), and small for gestational age (below the 10^{th} percentile). There is little evidence that disaster exposure affects birth outcomes. The only significant effects are 5% increases in the probability of low birth weight and small for gestational age from exposure to a hurricane in the second trimester.

Table 10. Regressions of Birth Outcomes by Disaster Type

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**Birth Weight (OLS)**	**Gestational Age (OLS)**	**Low Birth Weight (Logit)**	**Preterm Birth (Logit)**	**Small for Gestational Age (Logit)**
Trimester 1 Hurricane	-0.008	-0.006	1.018	1.010	1.000
	(0.009)	(0.016)	(0.024)	(0.025)	(0.021)
Trimester 2 Hurricane	0.002	0.031	1.050*	0.959	1.051*
	(0.008)	(0.018)	(0.025)	(0.022)	(0.025)
Trimester 3 Hurricane	0.004	0.018	1.011	0.977	1.021
	(0.008)	(0.015)	(0.025)	(0.021)	(0.023)
Trimester 1 Winter Storm	-0.002	-0.022	1.035	1.020	1.004
	(0.012)	(0.018)	(0.029)	(0.028)	(0.030)
Trimester 2 Winter Storm	0.017	0.019	0.971	0.980	0.988
	(0.009)	(0.018)	(0.028)	(0.024)	(0.026)
Trimester 3 Winter Storm	0.011	0.036	0.954	0.955	1.024
	(0.011)	(0.019)	(0.027)	(0.027)	(0.031)
Trimester 1 Flooding/Tornado	-0.021	-0.011	1.039	1.062	1.041
	(0.018)	(0.030)	(0.049)	(0.040)	(0.035)
Trimester 2 Flooding/Tornado	0.008	-0.003	0.999	0.998	0.984
	(0.009)	(0.022)	(0.035)	(0.025)	(0.033)
Trimester 3 Flooding/Tornado	-0.006	-0.039	1.030	1.043	0.984
	(0.012)	(0.034)	(0.049)	(0.046)	(0.041)
Controls	Yes	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	855,040	853,045	855,212	855,212	852,886
R-squared	0.071	0.021			

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year. Results for low birth weight, preterm birth, and small for gestational age are reported as odds ratios with standard errors referring to original coefficients.

Given the limited evidence that disaster exposure affects birth outcomes, it is not surprising that inclusion of birth outcomes as controls in the basic model does not change the effect of disasters on school outcomes, shown in table 11.

Table 11. Regressions of Educational Outcomes by Disaster Type with Birth Outcomes as Controls

	(1)	(2)	(3)	(4)
VARIABLES	**Math (OLS)**	**Reading (OLS)**	**Special Education (Logit)**	**Gifted (Logit)**
Trimester 1 Hurricane	-0.025**	-0.019**	1.130	0.978
	(0.008)	(0.006)	(0.083)	(0.064)

Trimester 2 Hurricane	-0.024***	-0.014*	1.127	1.022
	(0.007)	(0.006)	(0.076)	(0.055)
Trimester 3 Hurricane	-0.027***	-0.025***	1.181*	0.929
	(0.007)	(0.006)	(0.097)	(0.055)
Trimester 1 Winter Storm	0.012	0.008	0.884	0.897
	(0.010)	(0.009)	(0.063)	(0.063)
Trimester 2 Winter Storm	0.007	0.004	0.861	0.944
	(0.009)	(0.008)	(0.073)	(0.076)
Trimester 3 Winter Storm	0.008	0.012	0.817	0.883
	(0.010)	(0.008)	(0.090)	(0.072)
Trimester 1 Flooding/Tornado	-0.032*	-0.011	0.934	0.987
	(0.015)	(0.009)	(0.110)	(0.122)
Trimester 2 Flooding/Tornado	-0.020	-0.003	1.409	1.013
	(0.016)	(0.010)	(0.307)	(0.110)
Trimester 3 Flooding/Tornado	0.001	0.007	1.618	0.917
	(0.015)	(0.009)	(0.449)	(0.118)
Birth Weight	0.033***	0.024***	0.969***	1.066***
	(0.001)	(0.001)	(0.004)	(0.005)
Gestational Age in Weeks	0.002**	-0.001	0.980***	1.003
	(0.001)	(0.001)	(0.003)	(0.004)
Low Birth Weight	-0.039***	-0.015**	1.126***	0.972
	(0.006)	(0.006)	(0.020)	(0.032)
Preterm	0.012*	0.007	1.016	1.001
	(0.005)	(0.005)	(0.018)	(0.030)
Small for Gestational Age	-0.066***	-0.054***	1.126***	0.856***
	(0.004)	(0.004)	(0.016)	(0.020)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	844,359	840,659	845,975	845,975
R-squared	0.256	0.241		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year. Results for special education and gifted placement are reported as odds ratios with standard errors referring to original coefficients.

The fact that common measures of birth outcomes do not mediate the relationship between disaster exposure and school outcomes suggests that more subtle influences on cognitive development may not be captured by these blunt measures. More complex measures of health at birth may be needed to capture these types of effects.

Robustness Checks

The next section addresses some potential concerns about the primary estimation strategy used in this study and attempts to assess to what extent those concerns may bias the results in the previous sections.

One of the most serious concerns is in regards to whether the effects of disasters demonstrated in the previous results are solely a result of impacts on prenatal development or may also partially be composed of other effects of disasters on families with young children, such as income effects. I take several approaches to dealing with this concern.

The first approach is simply to look at graphs of average educational outcomes of children who were exposed to the disaster prenatally and those born near the same time that were not exposed prenatally. Graphs 3 through 6 show the weekly average residuals of educational outcomes based on week of birth relative to the most recent hurricane once the effects of county, week and year of birth as well as individual covariates are removed. These graphs focus on hurricanes since the effects of hurricanes were the largest and most consistent. If the effects observed in earlier analyses were primarily due to income effects or some other type of effect that impacted families with young children more generally, one would expect to see a general reduction in outcomes that is not concentrated among those exposed prenatally. However, if the effects are primarily caused by influences on prenatal development, one would expect a sharp divergence from the general trend among those exposed prenatally.

Figures 3 and 4 show that the average weekly test scores in reading and math generally appear to be lower among those who were exposed to a hurricane prenatally than among those born in the six months before and after. The drop in test scores is relatively small compared to the overall variation in test scores, but appears to fit well with the 1.5-2.5% of a standard deviation decreases indicated by the regression analyses in previous sections.

Figure 3. Average Weekly Math Score Residuals by Week of Birth Relative to Most Recent Hurricane

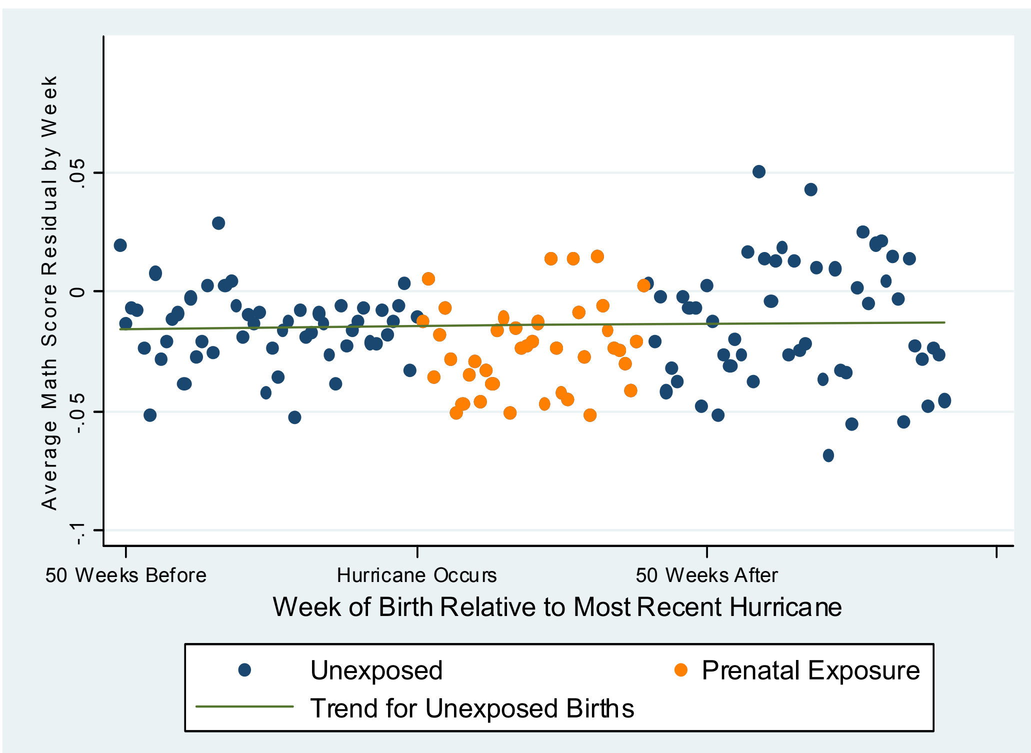
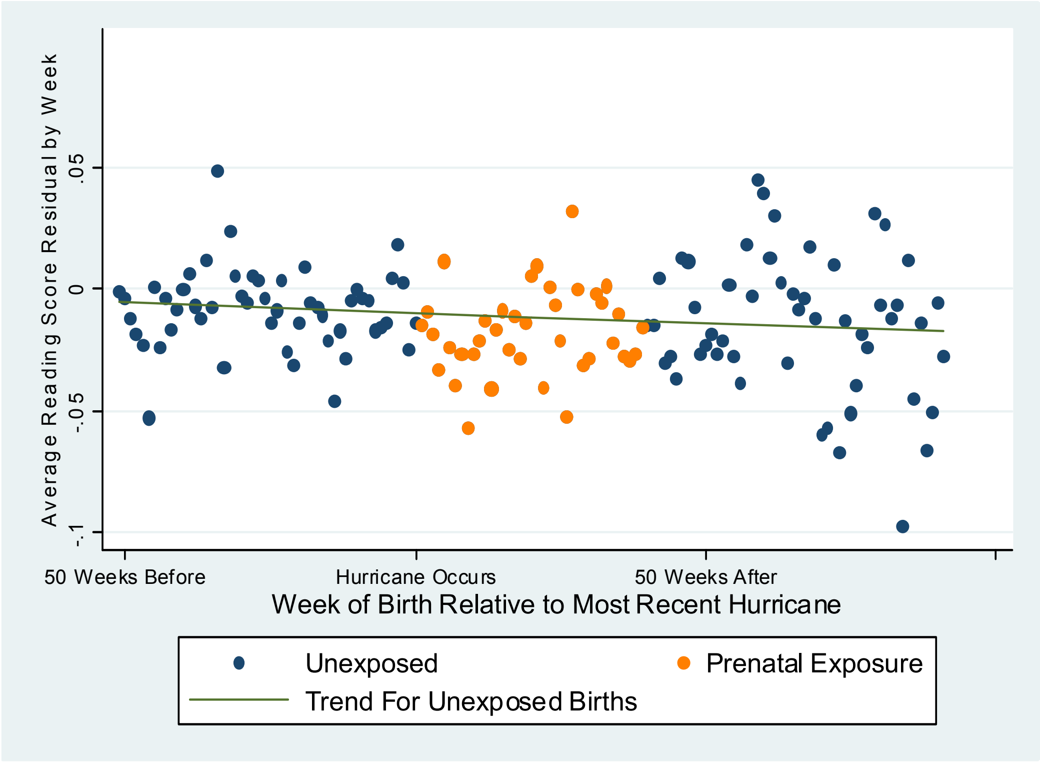


Figure 4. Average Weekly Reading Score Residuals by Week of Birth Relative to Most Recent Hurricane



Graph 5 is more difficult to interpret given that there is more general variation over time in special education placement. However, special education placement does appear to be somewhat higher among those exposed to a hurricane prenatally. Graph 6 seems to indicate that gifted placement does not respond to prenatal hurricane exposure or may show a small positive response. Again, these patterns seem to math what was found in the regression analyses.

Figure 4. Average Special Education Placement Residuals by Week of Birth Relative to Most Recent Hurricane

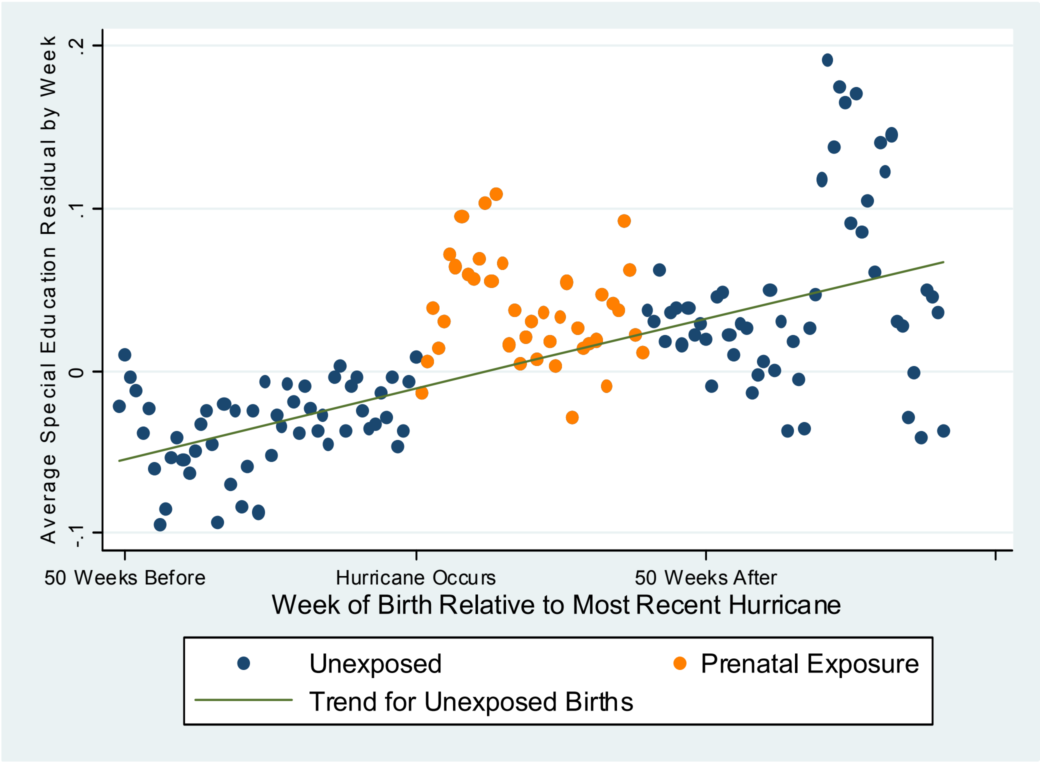
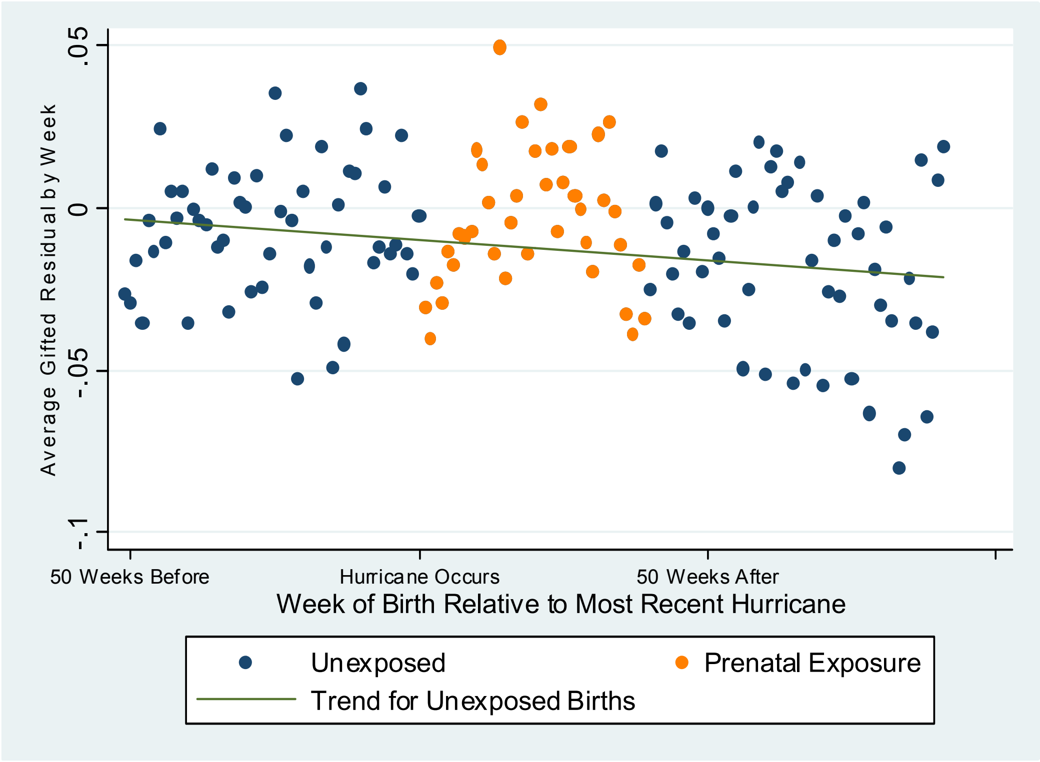


Figure 5. Average Gifted Placement Residuals by Week of Birth Relative to Most Recent Hurricane



The second approach to determining if there are any more general responses to disaster exposure that may be confounded with effects on prenatal development is to consider the effects on children born just before the disaster occurred. To do this, a synthetic "fourth trimester" is included in the basic regression equations. This trimester is equal in length to the other three trimesters and includes all kids born in the approximately three months before a disaster in the counties where the disaster occurs. Since any effects of disaster exposure on children who were born before the disaster could not operate through prenatal development, any significant effects for trimester 4 would indicate other confounding effects of disaster exposure.

The results of this analysis are shown in table 12. In general, there do not appear to be significant effects of disaster exposure in "trimester 4." There are two exceptions, however. There is a significant decrease in math scores of 1.7% of a standard deviation for children exposed to a hurricane "trimester 4". This suggests that some of the effects of hurricane exposure on math test scores may be operating through a mechanism other than prenatal development. However, the size of the decrease in math test scores is much smaller in "trimester 4" than in the other trimesters. The other effect observed in trimester 4 is a decrease in special education and gifted placement associated with winter storms. It is difficult to interpret this finding given that there is no significant effect of winter storms in the three trimesters of prenatal development.

One important consideration when using "trimester 4" as a falsification test in this study is that many of the students born just before a disaster will attend school with students who were exposed prenatally, so they may also be experiencing spillover effects if they are as a result sharing a classroom with students with weaker cognitive skills. The general conclusion from this test would suggest that while the effects of hurricanes on reading scores and special education are robust, caution should be used in interpreting the size of the effects on math scores.

Table 12. Regressions of Educational Outcomes with Synthetic Fourth Trimester

	(1)	(2)	(3)	(4)
VARIABLES	**Math (OLS)**	**Reading (OLS)**	**Special Education (Logit)**	**Gifted (Logit)**
Trimester 1 Hurricane	-0.026**	-0.020**	1.135	0.978
	(0.008)	(0.006)	(0.085)	(0.064)
Trimester 2 Hurricane	-0.025***	-0.014*	1.145*	1.028
	(0.007)	(0.006)	(0.077)	(0.055)
Trimester 3 Hurricane	-0.030***	-0.026***	1.178*	0.934
	(0.008)	(0.007)	(0.098)	(0.059)
"Trimester 4" Hurricane	-0.017*	-0.010	0.905	1.005
	(0.008)	(0.007)	(0.048)	(0.054)
Trimester 1 Winter Storm	0.011	0.008	0.882	0.889
	(0.010)	(0.009)	(0.063)	(0.063)
Trimester 2 Winter Storm	0.008	0.005	0.856	0.938
	(0.009)	(0.008)	(0.073)	(0.076)

Trimester 3 Winter Storm	0.006	0.011	0.818	0.888
	(0.010)	(0.008)	(0.089)	(0.073)
"Trimester 4" Winter Storm	-0.002	0.001	0.892*	0.894*
	(0.008)	(0.008)	(0.047)	(0.044)
Trimester 1 Flooding/Tornado	-0.034*	-0.013	0.960	0.979
	(0.015)	(0.009)	(0.104)	(0.124)
Trimester 2 Flooding/Tornado	-0.019	-0.002	1.482	1.011
	(0.016)	(0.010)	(0.372)	(0.118)
Trimester 3 Flooding/Tornado	0.002	0.009	1.718	0.919
	(0.015)	(0.010)	(0.541)	(0.126)
"Trimester 4" Flooding/Tornado	-0.019	-0.006	1.606	0.974
	(0.014)	(0.010)	(0.522)	(0.144)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	846,679	842,960	848,296	848,296
R-squared	0.253	0.240		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year. Results for special education and gifted placement are reported as odds ratios with standard errors referring to original coefficients.

In a third test for more general effects of natural disasters, the group of children in the analysis is limited to those born in a two year window immediately around the occurrence of a disaster in their county of birth. This two year window includes those born in the year just before the disaster and those born in the year following the disaster. Table 13 shows the results of this analysis. The effect sizes for math and reading scores among those exposed to hurricanes and tornadoes or flooding are quite a bit smaller and some coefficients are no longer significant. However, the effects of hurricane exposure in the third trimester on math and reading scores are still significant although somewhat reduced in size. The effects of hurricane exposure in trimesters 2 and 3 for hurricanes and tornadoes or flooding on special education placement are actually quite a bit larger. Additionally, with this more limited sample, winter storms seem to be associated with large decreases in special education placement and large increases in gifted placement.

Again, students included in this more limited control group are more likely than other students to experience spillover effects from attending school with children affected by disaster prenatally. Additionally, county, week and month of birth fixed effects are likely to be less accurately estimated on this reduced sample.

Table 13. Regressions of Educational Outcomes with Control Group of Children Born in 2 Years Surrounding the Disaster

	(1)	(2)	(3)	(4)
VARIABLES	**Math (OLS)**	**Reading (OLS)**	**Special Education**	**Gifted (Logit)**

			(Logit)	
Trimester 1 Hurricane	0.001	-0.009	1.051	0.997
	(0.007)	(0.007)	(0.042)	(0.058)
Trimester 2 Hurricane	-0.002	-0.005	1.152*	1.061
	(0.007)	(0.007)	(0.078)	(0.048)
Trimester 3 Hurricane	-0.016*	-0.018**	1.293**	0.936
	(0.007)	(0.007)	(0.108)	(0.075)
Trimester 1 Winter Storm	0.005	0.006	0.817*	1.159**
	(0.009)	(0.008)	(0.076)	(0.058)
Trimester 2 Winter Storm	0.003	0.003	0.797*	1.168**
	(0.009)	(0.008)	(0.082)	(0.061)
Trimester 3 Winter Storm	0.006	0.010	0.790	1.090
	(0.010)	(0.008)	(0.101)	(0.067)
Trimester 1 Flooding/Tornado	-0.019	-0.001	0.843	1.079
	(0.015)	(0.010)	(0.175)	(0.083)
Trimester 2 Flooding/Tornado	-0.008	0.007	1.249	1.049
	(0.017)	(0.011)	(0.162)	(0.088)
Trimester 3 Flooding/Tornado	0.017	0.018	1.486*	0.938
	(0.016)	(0.010)	(0.235)	(0.084)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	372,241	370,844	373,355	373,177
R-squared	0.260	0.251		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year. Results for special education and gifted placement are reported as odds ratios with standard errors referring to original coefficients.

In summary, the preceding evidence seems to suggest that effects not operating through prenatal development may account from some of the effect of natural disasters on children exposed prenatally. However, there is still reason to believe that natural disasters, especially hurricanes, have a negative impact on prenatal development leading to decreases in school outcomes. Exact effect sizes, particularly those for math scores, should be interpreted with caution.

A second concern for this study is the possibility that disaster occurrences alter the composition of births in counties exposed to the disaster. Disasters may affect the composition of births in a county in three ways. First, pregnant women exposed to the disaster may make the decision to move out of the county before the birth of their child. These women may be more likely to be more advantaged women with more resources which would lead to the appearance of worse birth outcomes in the county. Since county of residence is determined at the time of the birth, there is no way to observe whether pregnant women are leaving the county as a result of the disaster.

Second, women exposed to a disaster may be more likely to have a miscarriage than other women resulting in fewer births. If this is occurring, it is likely to be occurring among pregnancies that were at the highest risk and would bias the results towards the appearance of better birth outcomes. Since many miscarriages occur before women even know that they are pregnant, it is impossible to test for this directly. Third, women who experience significant disruption to their lives due to a disaster may be more likely to decide to terminate a pregnancy. Since this is more likely to occur among disadvantaged mothers, this would bias the results towards better birth outcomes.

It is not possible to test directly for any of the three mechanisms that would lead to a change in the composition of births. However, it is possible to test for changes in the total number of births per month in counties exposed to a disaster. An increase in miscarriages would be most likely lead to fewer births among those exposed to disasters during the first trimester, while an increase in abortions would most likely lead to fewer births among those exposed during the first and second trimester. Finally, an increase in movement out of the county would likely lead to fewer births across all three trimesters.

Table 14 shows regressions of the total number of births per month in each county of the percent of births in the month exposed to a disaster in each trimester. The regressions include county, month and year fixed effects and have R^2>.97. The second column also includes county time trends since some counties may have more or less births over time simply due to changing populations. The third column limits the observations to the two years immediately surrounding a disaster as used in table 13.

The results in table 14 suggest that there may be small decreases in the number of births that are exposed to a disaster during trimester 1 or 2. However, the second column indicates that this may be at least partially accounted for by county time trends. Given the timing of these decreases any “missing births” are probably the result of miscarriages or terminations and would likely bias the results towards positive outcomes. The results also suggest an increase in the number of births following exposure to a winter storm in trimester 1. However, this result may simply reflect some measurement error regarding the timing of the beginning to trimester 1 and incorporate some births that were in fact conceived after the snow storm.

Table 14. Regressions of Total Number of Births in Each County in Each Month on Prenatal Disaster Exposure

	(1)	(2)	(3)
VARIABLES	**Basic**	**County Trends**	**2 Year Control**
Trimester 1 Hurricane	-3.613*	-1.125	-4.598***
	(1.491)	(0.673)	(1.384)
Trimester 2 Hurricane	-1.753	-0.336	-3.373**
	(1.146)	(0.631)	(1.282)
Trimester 3 Hurricane	-0.322	0.746	-0.419
	(1.334)	(0.678)	(1.346)
Trimester 1 Winter Storm	8.942*	3.532***	2.131
	(3.738)	(0.877)	(1.666)
Trimester 2 Winter Storm	5.541	0.854	1.074
	(3.034)	(0.833)	(1.532)

Trimester 3 Winter Storm	6.944*	1.054	2.330
	(3.075)	(0.878)	(1.620)
Trimester 1 Flooding/Tornado	-2.212	0.816	-0.749
	(2.826)	(1.171)	(2.091)
Trimester 2 Flooding/Tornado	1.895	5.001***	3.780
	(3.143)	(1.138)	(2.017)
Trimester 3 Flooding/Tornado	-0.937	1.856	1.101
	(2.683)	(1.166)	(2.060)
County Fixed Effects	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes
Month of Birth Fixed Effects	Yes	Yes	Yes
County Time Trends	No	Yes	No
Limited Control Group	No	No	Yes
Observations	15,578	15,578	5,764
R-squared	0.978	0.989	0.976

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year.

Finally, there is a potential concern regarding the designation of disaster exposure to a particular trimester of pregnancy. The primary method used in this study is to assign the trimester of exposure based on the date of birth and a normal length of gestation of 40 weeks. This method is common in the literature, but does lead to some measurement error given that not all children are born at exactly 40 weeks of gestation. It is possible to assign disaster exposure based on reported gestational age and birthdate. However, this is not desirable for 2 reasons. First, gestational age is often an unreliable measure and may be systematically biased if disaster exposure leads to changes in healthcare usage. Second, using reported gestational age results in children with longer gestation having more opportunity to be exposed to a disaster and, therefore, induces a mechanical correlation between gestational age and disaster exposure.

To assess how much of an impact the method of designating trimester of exposure has on the results, this study takes two alternate approaches. First, the original analyses (reported in table 4) are repeated with the sample restricted to children with a reported gestational age of 37 to 42 weeks. With this limited range of gestational age, the original method of designating trimester of exposure will have minimal measurement error. The results of this analysis (available upon request) are nearly identical to the initial estimates.

The second approach is based on an approach used by Currie and Rossin (2011) to look at prenatal hurricane exposure in Texas. In this strategy, actual birth date and gestational age are used to calculate the beginning of gestation and actual exposure during each trimester. The date of the beginning of gestation is also used to calculate the expected exposure during each trimester if the pregnancy had lasted a normal 40 weeks. Expected exposure is then used to instrument for actual exposure using an instrumental variable regression. The results of this analysis are displayed in table 15. In general, the effects are quite similar or somewhat larger than those seen in the basic analysis. However, the results of hurricane exposure in trimester 3 are somewhat smaller than those seen in the basic analysis.

Overall, this analysis suggests that measurement error in the assignment of exposure to particular trimesters may be biasing the basic results somewhat downward.

Table 15. IV Regressions of Educational Outcomes on Instrumented Disaster Exposure

	(1)	(2)	(3)	(4)
VARIABLES	**Math (2SLS)**	**Reading (2SLS)**	**Special Education (2SLS)**	**Gifted (2SLS)**
Trimester 1 Hurricane	-0.028***	-0.020***	0.014***	-0.002
	(0.005)	(0.006)	(0.002)	(0.001)
Trimester 2 Hurricane	-0.024***	-0.015**	0.012***	0.002
	(0.005)	(0.005)	(0.002)	(0.001)
Trimester 3 Hurricane	-0.017*	-0.014	0.018***	-0.005**
	(0.007)	(0.007)	(0.003)	(0.002)
Trimester 1 Winter Storm	0.003	-0.003	-0.015***	-0.009***
	(0.007)	(0.007)	(0.003)	(0.002)
Trimester 2 Winter Storm	0.014*	0.006	-0.014***	-0.004*
	(0.007)	(0.007)	(0.003)	(0.002)
Trimester 3 Winter Storm	0.007	0.014	-0.026***	-0.010***
	(0.010)	(0.010)	(0.004)	(0.003)
Trimester 1 Flooding/Tornado	-0.036***	-0.019*	-0.003	-0.002
	(0.009)	(0.009)	(0.004)	(0.003)
Trimester 2 Flooding/Tornado	-0.016	0.002	0.046***	-0.002
	(0.009)	(0.009)	(0.004)	(0.002)
Trimester 3 Flooding/Tornado	-0.000	0.015	0.064***	-0.010**
	(0.015)	(0.015)	(0.006)	(0.004)
Controls	Yes	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes
Week of Birth Fixed Effects	Yes	Yes	Yes	Yes
Observations	846,679	842,960	848,296	848,296
R-squared	0.251	0.239	0.037	0.090

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are clustered by county year.

In sum, the tests performed in this section indicate that while some caution should be exercised in interpreting exact effect sizes, the overall results, that prenatal exposure to natural disasters, especially hurricanes, has a negative effect on school outcomes is relatively robust. In particular, the effect of hurricanes on special education placement persists in all specifications.

The first set of robustness checks indicates that some of the effects of hurricanes may not be operating through prenatal exposure and that the initial results may represent an upper bound. However, the analysis of missing births suggests that a reduction in births due to miscarriages or terminations may result in a population of births that are relatively more advantaged and therefore bias the initial results downward. Additionally, the analysis of the measurement error surrounding placement into particular trimester indicates that this measurement error may be biasing initial estimates downward. Altogether, there is reason to believe that the initial estimates presented in this paper represent moderate estimates of the impact of prenatal exposure to natural disasters across the whole population of births exposed. The effects on individual births, of course, probably vary a great deal and are probably concentrated among certain individuals.

Discussion

Natural disaster exposure is fairly common throughout the United States. In North Carolina from 1988 to 2000, more than 20% of children were exposed to at least once disaster during their mother's pregnancy. This study provides evidence that shocks to prenatal development caused by exposure to natural disasters can have impacts on educational performance in elementary school. Test scores in math and reading decrease between 1 and 5% of a standard deviation, and the probability of special education placement increases between 10 and 20%. The effects are relatively small and effect sizes should be interpreted with some caution, but they are of a magnitude that is comparable to other factors policymakers worry about, such as being low birth weight. So, while these are not large effects, they are substantial enough to warrant policy concern. This is especially true if we consider that the average effects probably include many children who experienced only minimal adverse outcomes related to their disaster exposure as well as some children who experienced substantial impacts. Additionally, these outcomes are measured at a quite distant point in time, approximately 9 years after exposure. Effects may have been larger in early grades and may have influenced student trajectories in school through mechanisms such as track placement and grade retention. The relatively larger size of the effects on special education placement may reflect more significant differences at a younger grade.

The size of the effects varies across disaster type, trimester of exposure, and subgroup. Of disaster types, hurricanes show consistent negative effects. Severe storms associated with tornadoes and flooding also show signs of negative effects on test scores, but winter storms, if anything, may have some small positive effects. These differences illustrate the importance of understanding the mechanisms by which natural disasters influence prenatal development. Winter storms may have far less devastating effects in terms of housing displacement, property damage, and overall stress.

As hypothesized, disadvantaged subgroups seem to show larger negative effects from disaster exposure. In particular, children born to Black mothers experienced negative effects from hurricane exposure that were twice as large as the average effects experienced by all children in the sample. Children whose mothers had no more than a high school education also appeared to experience somewhat larger effects. On the other hand, children of White mothers and mothers with at least some college appeared to experience smaller than average effects. This supports the hypothesis that more advantaged groups are less vulnerable to shocks such as those created by natural disasters. This invulnerability may be related to greater resources which can be directed to replace or repair resources damaged in the disaster or may simply reflect that better health overall cushions the effects of shocks. The results also suggest the importance of targeting additional resources to assist those most at risk in the wake of natural disasters.

The effects of prenatal exposure to disasters on educational outcomes in this study also provide evidence for the theory that early development can have long lasting impacts. Studies in the medical literature have suggested this type of relationship between fetal development and later life outcomes (Godfrey & Barker, 2001; Barker et al., 1993; Barker, 1995; Shonkoff et al., 2009; Rasmussen, 2001), and many studies have established associations between birth outcomes and educational performance (Hack et al., 2002; Reichman, 2005; Black, Devereux, & Salvanes, 2007; Goosby & Cheadle, 2009; Andreias et al., 2010; Aarnoudse-Moens et al., 2009; Boardman et al., 2002). However, the close relationship between health at birth and family socioeconomic status has made it difficult to make causal connections between early development and school outcomes. The random and unpredictable nature of the shocks caused by natural disasters in this study provides strong support for the causal role of prenatal health impacts on school performance.

The lack of significant effects on birth outcomes and the failure of these variables to mediate the effects on educational outcomes is important to note. Birth weight and gestational age are commonly used as overall summary measures of health at birth, yet other studies have also documented effects that seem to bypass measures of health at birth and yet affect later outcomes (Almond et al., 2009; Aizer, Stroud, & Buka, 2009). The findings in this study indicate the importance of considering other measures of neonatal health.

Policy Implications

Millions of dollars and decades of effort have been invested in attempting to improve the educational outcomes of American school children. However, this study suggests that influences on outcomes may begin much earlier and far outside the classroom. No one doubts that natural disasters are costly, but this study suggests that the costs may be much larger and longer term than typically assumed. Policymakers may wish to respond to these additional costs. The costs to pregnant women and their children in terms of decreased educational performance should be included in cost-benefit analyses when deciding how much to invest in efforts to mitigate the impact of disasters. The long term nature of these costs also suggests potential benefits that could be derived by investing resources to reduce the negative impact of disasters on pregnant women when they do occur, and especially the benefit of targeting disadvantaged groups that may be at the highest risk.

Future Directions

Future work on this topic should focus on understanding the mechanisms that mediate the effects of natural disasters on prenatal development. The short term consequences of natural disasters are many and varied, and understanding which mechanisms are most important for long term outcomes may facilitate better responses to disaster occurrences. It would also be useful to extend this research to consider other long term consequences from disaster exposure including long term health and economic outcomes that may be influenced by disaster exposure either prenatally or at other vulnerable periods of life.

References

Aarnoudse-Moens, C. S. H., Weisglas-Kuperus, N., van Goudoever, J. B., & Oosterlaan, J. (2009). Meta-Analysis of Neurobehavioral Outcomes in Very Preterm and/or Very Low Birth Weight Children. Pediatrics, 124(2), 717-728.

Aizer, A., Stroud, L., & Buka, S. (2009). Maternal Stress and Child Well-Being: Evidence from Siblings. Unpublished.

Almond, D., Chay, K. Y., & Lee, D. S. (2005). The costs of low birth weight. Quarterly Journal of Economics, 120(3), 1031-1083.

Almond, D., Currie, J., & National Bureau of Economic Research. Human Capital Development before Age Five. NBER Working Paper No. 15827 (Reports - Evaluative No. ED508916): National Bureau of Economic Research. 1050 Massachusetts Avenue, Cambridge, MA.

Almond, D., Edlund, L., & Palme, M. (2009). Chernobyl's Subclinical Legacy: Prenatal Exposure to Radioactive Fallout and School Outcomes in Sweden. The Quarterly Journal of Economics. 1729-1772.

Almond, D., & Mazumder, B. (2005). The 1918 influenza pandemic and subsequent health outcomes: An analysis of SIPP data. American Economic Review, 95(2), 258-262.

Almond, D., Mazumder, B., & Federal Reserve Bank of Chicago. Research Dept. (2007). Prenatal nutrition and adult outcomes the effect of maternal fasting during Ramadan, Working paper series WP-2007-22 Available from http://www.chicagofed.org/economic_research_and_data/wp_abstract.cfm?pubsID=26935

Andreias, L., Borawski, E., Schluchter, M., Taylor, G., Klein, N., & Hack, M. (2010). Neighborhood Influences on the Academic Achievement of Extremely Low Birth Weight Children. Journal of Pediatric Psychology, 35(3), 275-283.

Antonov, A. N. (1947). Children Born during the Siege of Leningrad in 1942. Journal of Pediatrics, 30(3), 250-259.

Barker, D. J. P. Fetal origins of coronary heart disease. BMJ: British Medical Journal, 311(6998), 4p.

Berkowitz, et al., (2003). The World Trade Center Disaster and Intrauterine Growth Restriction. Journal of the American Medical Association, 290(5) 595-96.

Black, S. E., Devereux, P. J., & Salvanes, K. G. (2007). From the cradle to the labor market? The effect of birth weight on adult outcomes. Quarterly Journal of Economics, 122(1), 409-439.

Catalano, R., & Hartig, T. (2001). Communal bereavement and the incidence of very low birth weight in Sweden. J Health Soc Behav, 42(4), 333-341.

Conley, D., Strully, K.W., & Bennett, N.G. (2003). *The Starting Gate.* University of California Press: Berkley, CA.

Currie, J. (2009). Healthy, Wealthy, and Wise: Socioeconomic Status, Poor Health in Childhood, and Human Capital Development. Journal of Economic Literature, 47(1), 87-122.

Currie, J. & Rossin, M. (2011). Weathering the Storm: Hurricanes and Birth Outcomes. Unpublished.

Doblhammer, G. (2004). The Late Life Legacy of Very Early Life. New York: Springer.

Ellis, B. J., Boyce, W. T., Belsky, J., Bakermans-Kranenburg, M. J., & van Ijzendoorn, M. H. (2011). Differential susceptibility to the environment: an evolutionary--neurodevelopmental theory. Dev Psychopathol, 23(1), 7-28.

Engel, S. M., Berkowitz, G. S., Wolff, M. S., & Yehuda, R. (2005). Psychological trauma associated with the World Trade Center attacks and its effect on pregnancy outcome. Paediatric and Perinatal Epidemiology, 19(5), 334-341.

Eskenazi, B., Marks, A. R., Catalano, R., Bruckner, T., & Toniolo, P. G. (2007). Low birth weight in New York City and upstate New York following the events of September 11th. Hum Reprod, 22(11), 3013-3020.

Evans, W. & Lien, D. (2005). The benefits of prenatal care: evidence from the PAT bus strike. Journal of Econometrics. 125, 207-239.

Glynn, L. M., Wadhwa, P. D., Dunkel-Schetter, C., Chicz-DeMet, A., & Sandman, C. A. (2001). When stress happens matters: Effects of earthquake timing on stress responsivity in pregnancy. American Journal of Obstetrics and Gynecology, 184(4), 637-642.

Godfrey, K. M., & Barker, D. J. (2001). Fetal programming and adult health. Public Health Nutr, 4(2B), 611-624.

Goosby, B. and Cheadle, J. E. , (2006)"Low Birth Weight and Children's Cognitive Development and Behavior: Evidence from the ECLS-K" Paper presented at the annual meeting of the American Sociological Association, Montreal Convention Center, Montreal, Quebec, Canada

Goosby, B. J. & Cheadle, J. E. (2009). “Birth Weight, Math and Reading Achievement Growth: A Multilevel Between-Sibling, Between-Families Approach.” Social Forces, 87(3) 1291-1320.

Hack, M., Flannery, D. J., Schluchter, M., Cartar, L., Borawski, E., & Klein, N. (2002). Outcomes in young adulthood for very-low-birth-weight infants. New England Journal of Medicine, 346(3), 149-157.

Hedegaard, M., Henriksen, T. B., Secher, N. J., Hatch, M. C., & Sabroe, S. (1996). Do stressful life events affect duration of gestation and risk of preterm delivery? Epidemiology, 7(4), 339-345.

Kar, N., & Bastia, B. K. (2006). Post-traumatic stress disorder, depression and generalised anxiety disorder in adolescents after a natural disaster: a study of comorbidity. Clin Pract Epidemiol Ment Health, 2, 17.

La Greca, A. & Silverman, W. (2009). Treatment and Prevention of Posttraumatic Stress Reactions in Children and Adolescents Exposed to Disasters and Terrorism: What is the Evidence? Child Development Perspectives, 3(1), 4-10.

Laplante, D. P., Barr, R. G., Brunet, A., Galbaud du Fort, G., Meaney, M. L., Saucier, J. F., et al. (2004). Stress during pregnancy affects general intellectual and language functioning in human toddlers. Pediatr Res, 56(3), 400-410.

Lederman, S. A., Rauh, V., Weiss, L., Stein, J. L., Hoepner, L. A., Becker, M. & Perera, F. P. (2004). The Effects of the World Trade Center Event on Birth Outcomes Among Term Deliveries at Three Lower Manhattan Hospitals. Environmental Health Perspectives, 112(17) 1772-778.

Neria, Y., Nandi, A., & Galea, S. (2008). Post-traumatic stress disorder following disasters: a systematic review. Psychol Med, 38(4), 467-480.

Neugebauer, R., Hoek, H., & Susser, E. (1999). Prenatal Exposure to Wartime Famine and Development of Antisocial Personality Disorder in Early Adulthood. Journal of American Medical Association, 281(5), 455-462.

Osofsky, H. J., Osofsky, J. D., Kronenberg, M., Brennan, A., & Hansel, T. C. (2009). Posttraumatic stress symptoms in children after Hurricane Katrina: predicting the need for mental health services. Am J Orthopsychiatry, 79(2), 212-220.

Pluess, M., & Belsky, J. (2011). Prenatal programming of postnatal plasticity? Dev Psychopathol, 23(1), 29-38.

Rasmussen, K. M. (2001). The "fetal origins" hypothesis: challenges and opportunities for maternal and child nutrition. Annu Rev Nutr, 21, 73-95.

Reichman, Nancy E. 2005. “Low birth weight and school readiness.” Future of Children. Vol. 15, No. 1. (Spring). 91-116.

Roseboom, T. J., van der Meulen, J. H., Ravelli, A. C., Osmond, C., Barker, D. J., & Bleker, O. P. (2001). Effects of prenatal exposure to the Dutch famine on adult disease in later life: an overview. Mol Cell Endocrinol, 185(1-2), 93-98.

Saigal, S., Szatmarl, P., Rosenbaum, P. Campbell, D., & King, S. (1991). “Cognitive Abilities and School Performance of Extremely Low Birth Weight Children and Matched Term Control Children at Age 8 Years: A Regional Study.” The Journal of Pediatrics, 751-760.

Shonkoff, J. P., Boyce, W. T., & McEwen, B. S. (2009). Neuroscience, molecular biology, and the childhood roots of health disparities: building a new framework for health promotion and disease prevention. JAMA, 301(21), 2252-2259.

Smilde-van den Doel, D. A., Smit, C., & Wolleswinkel-van den Bosch, J. H. (2006). School performance and social-emotional behavior of primary school children before and after a disaster. Pediatrics, 118(5), e1311-1320.

Temple, J. A., Reynolds, A. J., & Arteaga, I. (2010). Low Birth Weight, Preschool Education, and School Remediation. [Reports - Research]. Education and Urban Society, 42(6), 705-729.

Torche, F. (2011). The Effect of Maternal Stress on Birth Outcomes: Exploiting a Natural Experiment. Demography.

Appendix A.

Natural Disasters in North Carolina 1988 to 2000

- December 2, 1988 storms & tornadoes
- May 17, 1989 tornadoes
- September 24, 1989 Hurricane Hugo
- September 10, 1993 Hurricane Emily
- October 23, 1995 storms & flooding
- January 13, 1996 blizzard
- February 23, 1996 winter storm
- July 18, 1996 Hurricane Bertha
- September 6, 1996 Hurricane Fran
- January15, 1998 storms & flooding
- March 22, 1998 storms & tornadoes
- August 27, 1998 Hurricane Bonnie
- September 9, 1999 Hurricane Dennis
- September 16, 1999 Hurricanes Floyd & Irene
- January 31, 2000 ice storm