The Effects of Natural Disasters on Birth and School Outcomes

of Children in North Carolina

by

Sarah Crittenden Fuller

Public Policy Studies
Duke University

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Approved:

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Helen F. Ladd, Supervisor

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Kenneth A. Dodge

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Christina M. Gibson-Davis

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Seth G. Sanders

Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor
of Philosophy in
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ABSTRACT

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Abstract

This dissertation consists of three studies exploring the effects of natural disasters in North Carolina on the longer term outcomes of children. The first study looks at the effect of prenatal natural disaster exposure on maternal health behaviors and birth outcomes for twenty cohorts of children born in North Carolina. Combining North Carolina administrative and survey data on births with disaster declarations from the Federal Emergency Management Agency (FEMA) allows me to identify children who were exposed to disasters in each trimester of prenatal development. Using a county fixed effect strategy, I compare these children to other children born in the same county who were not exposed to disasters while in utero. Results indicate that prenatal natural disaster exposure, especially exposure to hurricanes, has a significant effect on some maternal health behaviors, but this study provides only limited support for the theory that natural disaster exposure negatively affects birth outcomes, as measured by birth weight and gestational age.

The second study looks 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, and a number of recent studies examine the effect of prenatal exposure to natural disasters on birth outcomes. This study takes the next step by considering how prenatal exposure

affects later outcomes. The children identified in the first study as exposed to disasters prenatally 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 prenatally have lower scores on third grade standardized tests in math and reading. Those exposed to flooding or tornadoes also have somewhat lower math scores. Additionally, results suggest that these negative effects are more concentrated among children in disadvantaged subgroups, especially children born to Black mothers.

The third study addresses the question of whether the disruption caused by a natural disaster has an impact on student academic outcomes in the school year during which the natural disaster occurs. The effects of disasters on school performance are important because natural disasters often constitute a major community disruption with widespread impacts on the lives of children. The educational data in this study comes from administrative records for all school districts in North Carolina. Results suggest that hurricanes have a negative overall impact on reading test scores, with the effect concentrated among middle schools. However, winter storms have a positive effect on both math and reading scores in middle school. This difference in effect and additional analysis of mechanisms suggests that mobility is more important than missed days of schools in mediating negative effects of hurricanes on school performance.

Dedication

For Andy who was with me through it all.

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Introduction

Natural disasters are significant events that lead to substantial disruption in the communities that they affect. For example, when Hurricane Irene struck the Outer Banks of North Carolina in August 2011, 38 counties required federal assistance. In the affected counties, more than 10,000 people were displaced from their homes into shelters and more than 600,000 homes were without power. After the storm, more than 270 roads were closed due to flooding or debris and more than 27,000 homes were damaged. The Federal Emergency Management Agency (FEMA) provided temporary housing for more than 400 families and unemployment insurance to 800 workers. Altogether, more than 200 million dollars of aid was distributed to deal with immediate needs following the hurricane (NCEMD 2012).

Hurricane Irene is not unique, many natural disasters occur each year with different levels of accompanying destruction. Yet, relatively little research has explored the longer term effects of natural disasters on the children who experience them. This dissertation begins to fill that gap by looking at the effects of natural disasters on children who were born or went to school in North Carolina from 1988 to 2011.

During the time period from 1988 to 2011, the state of North Carolina experienced 26 natural disasters, which comes to an average of just over one disaster a year. Every county in the state experienced at least one disaster, and some experienced as many as ten disasters. These disasters were divided among three general types:

hurricanes, winter storms, and severe storms associated with flooding or tornadoes. Figure 1 shows the counties affected by the 14 hurricanes that occurred over the 24 year time period.

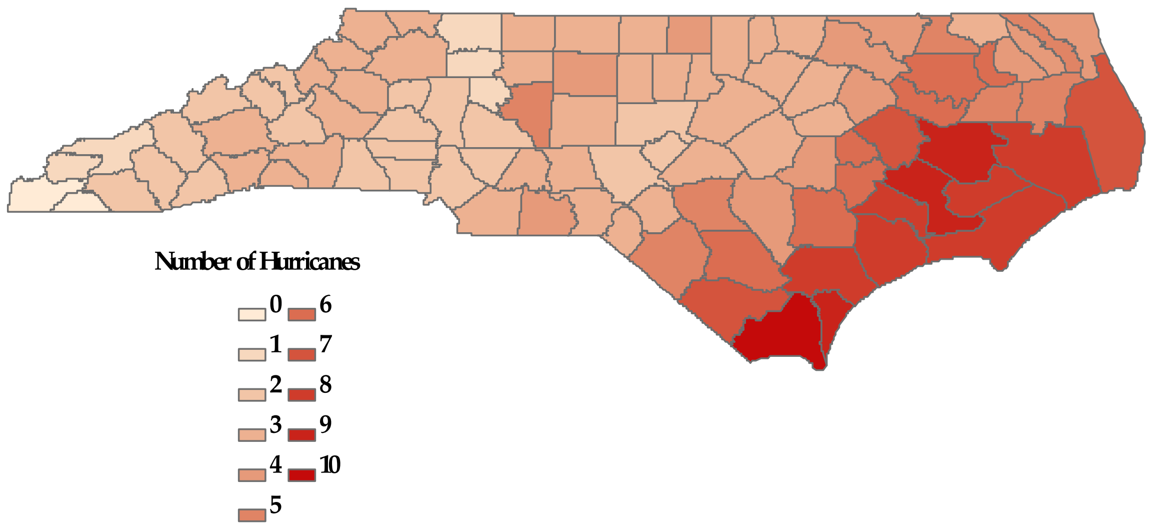

Figure 1. Hurricanes in North Carolina, 1988 to 2011

Similarly, Figure 2 shows the counties affected by the six winter storms.

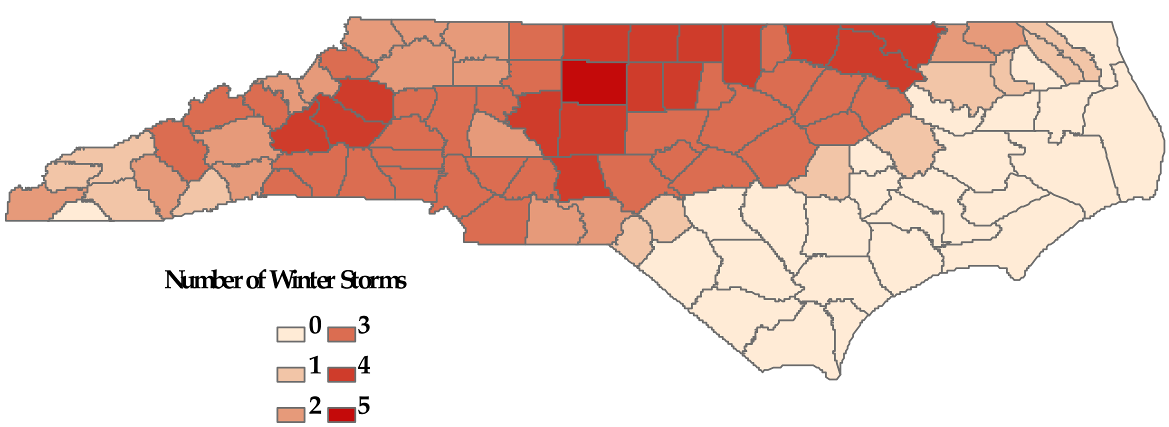

Figure 2. Winter Storms in North Carolina, 1988 to 2011

Figure 3 shows the counties affected by the six severe storms that resulted in flooding or tornadoes.

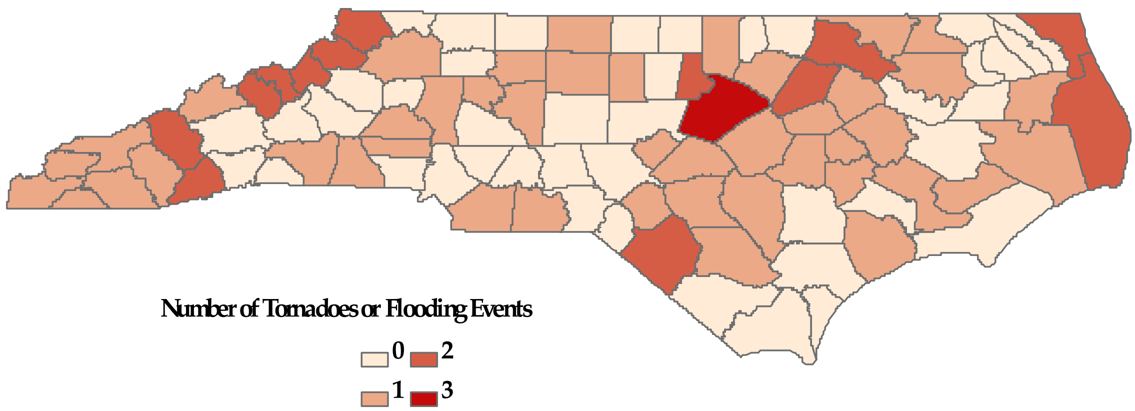

Figure 3. Tornadoes or Flooding Events in North Carolina, 1988 to 2011

The first of the three studies that make up this dissertation explores the question of how exposure to natural disasters during the prenatal period affects the health behaviors of pregnant mothers and, ultimately, the birth outcomes of their children. The second study builds upon the first and answers the question of whether the effects of being exposed to a disaster during the prenatal period affect academic achievement outcomes once the children reach third grade. Finally, the third chapter looks at the effects of natural disasters on the academic achievement of children in third through eighth grade at the time of the disaster.

The Effect of Natural Disaster Exposure on Prenatal Health and Birth Outcomes

Introduction

Many people are accustomed to thinking of major natural disasters, such as Hurricane Katrina, the 2011 earthquake and tsunami in Japan, or Hurricane Sandy, as extremely rare, perhaps once in a lifetime events, but serious natural disasters occur with some regularity in many areas in the United States and internationally. In 2011, the Federal Emergency Management Agency (FEMA) made 99 major disaster declarations affecting 43 states, the District of Columbia, and Puerto Rico. The short term effects of these disasters for individuals include injuries, evacuations, prolonged power outages, damage to buildings, and lost days of school and work. Many individuals may also experience long term effects on their health and well-being, and these effects are likely to be most substantial for vulnerable populations, including pregnant women and their developing children.

Several recent studies have looked at the impact of natural disasters on prenatal development. Most of these studies find negative impacts of disasters on birth outcomes, as measured by birth weight and gestational age (Glynn, Wadhwa et al. 2001; Xiong, Harville et al. 2008; Simeonova 2009; Tan, Li et al. 2009; Auger, Kuehne et al. 2011; Dancause, Laplante et al. 2011; Torche 2011; Oyarzo, Bertoglia et al. 2012). In contrast, a recent high quality study of hurricanes in Texas found no effects on birth weight or gestational age (Currie and Rossin-Slater 2012). In addition to this discrepancy, these studies have not provided answers regarding potential mechanisms by which disasters influence prenatal development. Finally, these previous studies do not look at potential differences across population subgroups. The current study will add to the literature by looking at effects across multiple disasters, exploring subgroup effects and considering the role of maternal health behaviors and conditions.

This study uses 20 years of data on North Carolina births and disaster exposure at the county level. The primary data set includes all births in the state over two decades and covers 21 different disasters, including hurricanes, winter storms, tornadoes, and flooding. Additionally, detailed birth records provide information on several important behavioral mechanisms that may influence prenatal development. Finally, a second survey-based data set allows for the exploration of potential mechanisms not typically found in administrative data sets.

As shown in Figure 4, the conceptual model underlying this study suggests that disasters have direct effects on maternal health behaviors and conditions, which in turn influence health at birth. In keeping with this model, this study begins by examining the effect of prenatal disaster exposure on maternal health behaviors and conditions, including prenatal care usage, maternal substance use, maternal weight gain, and the wantedness of the pregnancy. In addition, this study looks at the ultimate effects of disaster exposure on birth outcomes as measured by birth weight and gestational age. I hypothesize that prenatal disaster exposure will have a negative effect on both maternal health behaviors and birth outcomes.

The next section reviews the previous literature on natural disasters, health behaviors, and birth outcomes. The paper then continues with a description of the analysis, results, and a discussion of the findings.

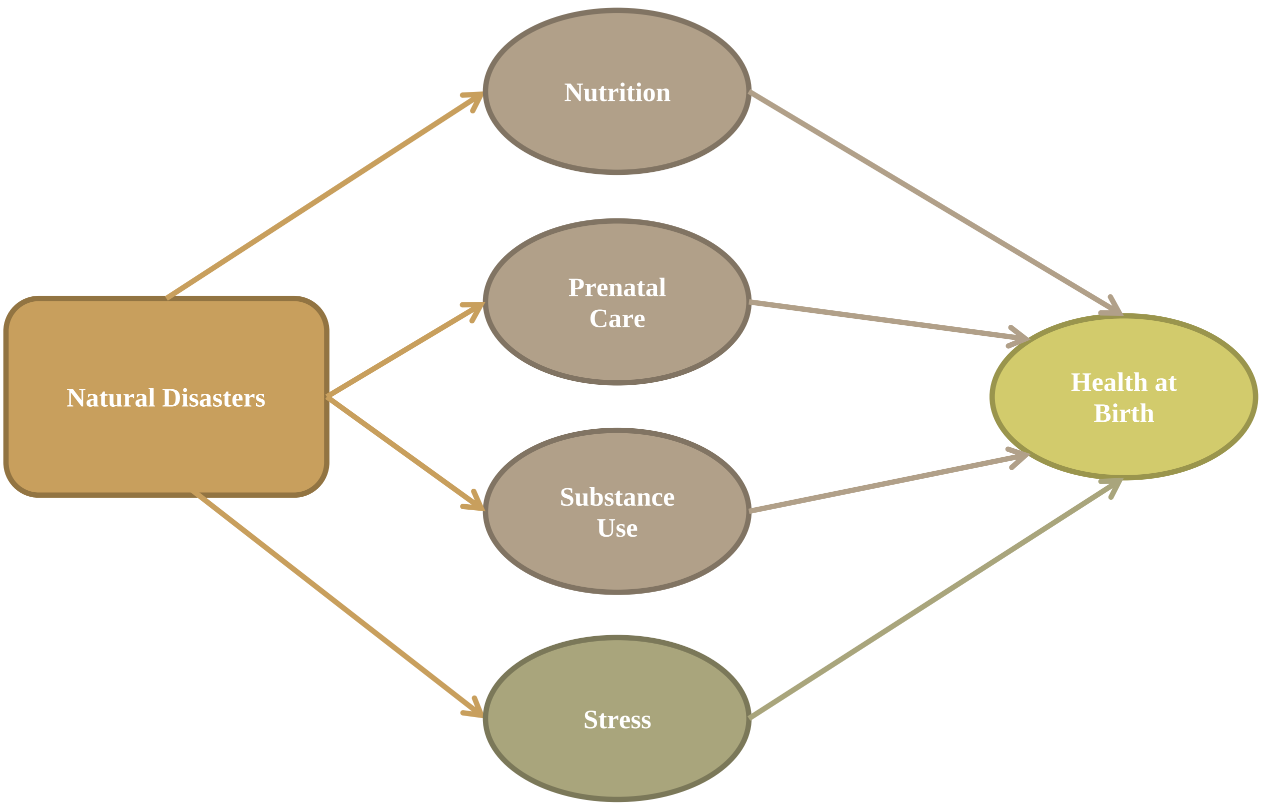

Figure 4. Conceptual Model

Background

Personal injuries from natural disasters in the United States are quite rare relative to the total number of people exposed. Exposure to a disaster during pregnancy may influence prenatal development in more subtle ways. Power disruptions, travel difficulties, evacuations and relocations may translate into poorer nutrition, missed prenatal care, or changes in health related habits, such as smoking or drinking alcohol. Additionally, all forms of disruption create stress, which may directly influence health at birth. These influences on health at birth are critical because they may have lifelong effects on children.

The Long Run Impact of Health at Birth

Health at birth, often measured using birth weight or gestational age, is associated with a variety of later life outcomes, including cognitive skills, achievement test scores, educational attainment and labor market success (Boardman, Powers et al. 2002; Hack, Flannery et al. 2002; Conley, Strully et al. 2003; Reichman 2005; Black, Devereux et al. 2007; Aarnoudse-Moens, Weisglas-Kuperus et al. 2009; Goosby and Cheadle 2009; Andreias, Borawski et al. 2010).

The Fetal Origins hypothesis asserts that poor health at birth may be a sign of negative developmental adaptations that have significant consequences for later health (Barker, Osmond et al. 1993; Barker 1995; Godfrey and Barker 2001; Rasmussen 2001; Shonkoff, Boyce et al. 2009). 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 and Barker 2001; Currie 2009; Shonkoff, Boyce et al. 2009; Ellis and

Boyce 2011). Therefore, prenatal shocks have the potential to affect long term outcomes through health at birth.

A few studies indicate that prenatal exposure to natural disasters specifically may have longer term impacts on cognitive development and school performance (Laplante, Barr et al. 2004; Laplante, Brunet et al. 2008). Studies of other prenatal shocks also find long run effects on educational and economic outcomes (Almond 2005; Almond, Edlund et al. 2009; Almond and Currie 2011). The potential lifelong consequences of health at birth make it critical to understand how events like natural disasters impact these birth outcomes.

Effects of Natural Disasters on Health at Birth

Research on natural disasters and the effect on newborn health has generally found negative impacts on birth outcomes among women exposed to the disasters. The earliest of these studies looked at birth outcomes among a small group of mothers who reported stress following an earthquake in California (Glynn, Wadhwa et al. 2001). Maternal stress related to the earthquake was associated with lower gestational ages (Glynn, Wadhwa et al. 2001). A subsequent study of an earthquake in Chile also found lower gestational ages in areas most affected by the earthquake (Torche 2011). The same study found lower birth weights among babies whose mothers experienced the earthquake (Torche 2011) as did a study of an earthquake in China (Tan, Li et al. 2009). The study of the Chinese earthquake also observed higher rates of birth defects (Tan, Li et al. 2009) and, along with a study of a second earthquake in Chile, found increases in preterm births (Tan, Li et al. 2009; Oyarzo, Bertoglia et al. 2012).

A study of Hurricane Katrina found an increase in preterm births among mothers who reported more stressful hurricane related experience (Xiong, Harville et al. 2008). Similarly, babies whose mothers were exposed to a severe ice storm in Canada were more likely to be born preterm (Auger, Kuehne et al. 2011). A second study of the same ice storm found shorter gestation lengths and lower birth weights among mothers who reported greater stress (Dancause, Laplante et al. 2011).

The aforementioned studies all focus on single events that were notable for their severity. However, many more pregnant mothers are exposed to natural disasters of moderate size. Two studies have looked at average effects on birth outcomes across a broader range of disasters. The first study (Simeonova 2009) looked at the effect of all weather related disasters in the United States on the population of births from 1968 to 1988. With data collapsed at the county-month-year level, Simeonova found small average effects on preterm birth and gestational age. There were no average effects on birth weight, but more severe events and those of longer duration led to lower birth weights (Simeonova 2009). The second study (Currie and Rossin-Slater 2012) used sibling fixed effects to examine average effects across several hurricanes in Texas. This study found no significant effects on gestational age or birth weight but a significant increase in birth complications (Currie and Rossin-Slater 2012).

Overall, these studies suggest that natural disasters have negative effects on health at birth but leave open questions about whether these effects are limited to particularly severe disasters or certain disaster types. They also do not address whether the effects apply equally to all mothers or are limited to particularly vulnerable groups. The literature on social vulnerability finds that social groups with limited access to information, resources, and political representation experience disproportionately large effects from disasters (Cutter, Boruff et al. 2003; Zahran, Brody et al. 2008). Among the more vulnerable groups are racial and ethnic minorities, the less educated, and those with lower socioeconomic status (Cutter, Mitchell et al. 2000; Cutter, Boruff et al. 2003; Fothergill and Peek 2004; Zahran, Brody et al. 2008).

Additionally, previous studies of natural disasters tend to attribute the negative effects of disasters to maternal stress but do not directly measure other prenatal health mechanisms. Studies of other events with similarly stressful effects on expectant mothers have also found negative impacts on birth weights and gestational ages (Catalano and Hartig 2001; Berkowitz, Wolff et al. 2003; Engel, Berkowitz et al. 2005; Eskenazi, Marks et al. 2007). However, natural disasters may also affect other health mechanisms which may play a role in mediating the effect on birth outcomes. Studies looking at changes in maternal nutrition induced by famines or fasting have found large effects on birth weight (Roseboom, van der Meulen et al. 2001; Almond and Mazumder 2011), and a study looking at the effect of a bus strike on prenatal care showed decreases in birth weight and gestational age (Evans and Lien 2005). To the extent that natural disasters also affect maternal health behaviors, it is necessary to consider them as mechanisms mediating any effects on birth outcomes.

Maternal Health Behaviors and Conditions

Maternal health is an important determinant of the health of a child at birth (Rosenzweig and Wolpin 1991; Almond, Chay et al. 2005; Reichman 2005). Many components of the mother's health at the time of the pregnancy are fixed. For example, parents who themselves were low birth weight are more likely to have low birth weight children (Reichman 2005). However, there are also a number of important health factors that are not fixed and healthy pregnancy behaviors that can improve the health outcomes of the newborn.

Prenatal Care

Prenatal care is widely believed to influence the health of newborns, and many studies find that prenatal care reduces the chance of being born preterm or with low birth weight (Rosenzweig and Wolpin 1991; Conley, Strully et al. 2003; Rous, Jewell et al. 2004). However, there are also studies that find that the amount of prenatal care has no effect on birth weight and gestational age (Fiscella 1995; Lu, Tache et al. 2003). Estimating the effect of prenatal care has been difficult because utilizing care is closely related to other maternal factors such as income and education, and because the quantity of care is more easily measured than the quality. Additionally, women with previous health problems or experiencing a difficult pregnancy are more likely to seek prenatal care than other women (Guillory, Samuels et al. 2003; Rous, Jewell et al. 2004). One study that used a bus strike as a source of variation in prenatal care, found that those who received less prenatal care had babies with lower birth weights and gestational ages (Evans and Lien 2005). This study was possible because barriers to transportation are an important determiner of prenatal care among poor women (Evans and Lien 2005). A similar effect may occur when travel is disrupted by a natural disaster.

Nutrition

Maternal nutrition is also an important factor in fetal development, and according to the fetal origins hypothesis, nutritional shocks are important in driving fetal adaptations that may have negative long term consequences (Godfrey and Barker 2001). Among women in developed countries, nutritional factors such as protein consumption (Moore, Davies et al. 2004) and frequency of eating (Siega-Riz, Herrmann et al. 2001) can have important consequences for birth outcomes. Studies looking at maternal nutritional assistance during pregnancy have found that programs, such as the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), improve birth outcomes (Figlio, Hamersma et al. 2009; Almond and Currie 2010) suggesting that effecting improvements in maternal nutrition can improve health at birth. Additionally, disruptions to maternal nutrition caused by famine or fasting can have negative impacts on birth weight and gestational age (Roseboom, van der Meulen et al. 2001; Doblhammer 2004; Almond and Mazumder 2011). A disruption in the supply of nutritious food resulting from travel limitations and power disruptions following a disaster could have negative health consequences for the fetus.

Substance Use

Maternal use of substances, such as alcohol and tobacco, during pregnancy is a significant influence on the birth outcomes of the child (Rosenzweig and Wolpin 1991; Almond, Chay et al. 2005; Reichman 2005). Reducing rates of smoking may be an important function of prenatal care (Evans and Lien 2005). Stress from exposure to a disaster may increase rates of substance use, but alternatively, travel limitations may disrupt supply and aid attempts to quit.

Stress

Stress, while not strictly a health behavior, is also mutable during the course of pregnancy and may play a particularly significant role in the relationship between natural disasters and birth outcomes. General maternal stress levels have been associated with negative birth outcomes (Hedegaard, Henriksen et al. 1996; Lobel, DeVincent et al. 2000; Dole, Savitz et al. 2003; Kinsella and Monk 2009) and longer term physical and mental health of the child (Beydoun and Saftlas 2008). In particular, the release of cortisol related to maternal stress may contribute to preterm delivery (Wadhwa, Culhane et al. 2001). A number of studies have shown that disaster exposure significantly increased rates of Post-Traumatic Stress (PTS) (Neria, Nandi et al. 2008; La Greca and Silverman 2009; Osofsky, Osofsky et al. 2009).

Measures of wantedness, whether the pregnancy was intended or unintended, are also associated with lower birth weights and an increased chance of preterm birth (Shah, Balkhair et al. 2011). The effects of wantedness may operate through increased stress as well as changes in risky behaviors and prenatal care usage(Shah, Balkhair et al. 2011). Although most previous studies have considered wantedness to be a fixed characteristic determined at the beginning of the pregnancy, there is some evidence that wantedness can change during the course of the pregnancy (Williams, Piccinino et al. 2001; Miller and Jones 2009). It is not clear how a change in wantedness affects outcomes associated with overall wantedness, but an increased tendency for mothers to report that a pregnancy is unwanted following a disaster probably indicates a negative change in the family circumstances or the mother's state of mind.

Beyond the question of birth outcomes, exposure to the stress hormone cortisol in utero has been associated with permanent changes in hypothalamo-pituitary-adrenal function and levels of cortisol in the child (Kapoor, Dunn et al. 2006). Maternal stress is considered an important factor in some theories of early life adaptations (Shonkoff, Boyce et al. 2009; Belsky, Steinberg et al. 2010; Ellis and Boyce 2011; Pluess and Belsky 2011). Studies of exogenous shocks from national tragedies during pregnancy have demonstrated that maternal stress related to these shocks can affect the health of the developing fetus (Catalano and Hartig 2001; Engel, Berkowitz et al. 2005; Eskenazi, Marks et al. 2007). However, developmental changes in utero may not always be associated with easily measurable changes in birth weight and gestational age (Laplante, Barr et al. 2004).

This study provides evidence of the impact of moderate natural disasters across a large group of children born in North Carolina over 20 years. Additionally, data on maternal health behaviors and conditions are used to consider possible mechanisms other than stress linking disaster exposure to birth outcomes. Finally, the large size of the sample is leveraged to explore differences in effects by population subgroup.

Methods

Data

The primary source of information on birth outcomes in this study comes from detailed birth certificate information, obtained from the North Carolina Department of Vital Statistics. These records include all children born in North Carolina from 1988 to 2007. They provide information on birth weight and gestational age, the primary birth outcomes in the study. The birth records provide information on health behaviors during pregnancy, including prenatal care, maternal weight gain, and maternal smoking and drinking. The birth records also serve 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 is available. The records also include the county of residence of the mother at the time of birth. The total birth certificate sample for the study is all 2,161,389 births that occurred from 1988 to 2007 across all counties in North Carolina. The health behaviors looked at using this data are whether the mother received any prenatal care, whether care began in the first trimester, the month prenatal care began, whether the mother received at least the 13 recommended prenatal care visits, the number of prenatal care visits, tobacco use, number of cigarettes smoked, alcohol use, number of alcoholic drinks, and maternal weight gain. The birth outcomes in the birth certificate data are birth weight in pounds, gestational age in weeks, low birth weight, preterm birth, and small for gestational age.

The North Carolina Pregnancy Risk Assessment Monitoring System (PRAMS) serves as a secondary source of data on birth outcomes and maternal health behaviors. PRAMS is an initiative of the Center for Disease Control and Prevention to survey women who have recently given birth about the time before, during and just after their pregnancy. The PRAMS data includes information on birth weight, gestational age, and maternal demographics. The PRAMS data also includes valuable information not available in the birth certificate records on the wantedness of the pregnancy, barriers to prenatal care, and maternal weight status before pregnancy. However, the number of births and the timespan included in PRAMS is much smaller with a total sample size of 16,606 births from 1997 to 2007. The maternal health behaviors explored using the PRAMS data are whether prenatal care began later than the mother wanted, whether there was a barrier to prenatal care, whether the reason for later care was the lack of an appointment, whether the reason for later care was too many other things going on, maternal weight gain, whether the mother gained no weight, whether weight gain was lower than recommended, whether the gain was higher than recommended, whether the pregnancy was unintended, mistimed, or unwanted, and whether the pregnancy was unwanted by the mother's partner. The birth outcomes are birth weight in grams, gestational age in days, low birth weight, preterm birth, and small for gestational age.

The source of data on natural disasters is the Federal Emergency Management Agency's (FEMA) records of major disaster declarations. Disaster Declarations are presidential declarations 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.

I used the date of birth and county of residence at birth for each child in the data sets to determine if the child was exposed to a disaster declaration in his county during the nine months before his birth. The data includes information on the type of disaster and trimester of the exposure. For the purposes of determining disaster exposure, all pregnancies are assumed to have started 40 weeks before birth. This assumption regarding the length of pregnancy avoids two problems. First, gestational age is difficult to measure accurately, and if disaster exposure affects prenatal care use, it may also affect the accuracy of reported gestational age. Second, additional weeks of gestation present additional opportunities for a pregnant mother to be exposed to a disaster, and, therefore, those babies with higher gestational ages are more likely to be exposed if true gestational age is used.

Between 1988 and 2007, North Carolina experienced 21 Major Disaster Declarations. All 100 counties in North Carolina experienced at least one disaster declaration during the 20 year time period. The types of disasters included hurricanes, winter storms, and severe storms associated with flooding or tornadoes. Overall, about 20% of births were affected by at least one disaster exposure. Table 1 shows details on the numbers of counties and births affected by each disaster type.

Table 1. Descriptive Data on Natural Disasters and Prenatal Natural Disaster Exposure, 1988 to 2007

	All Disasters	Hurricanes	Winter Storms	Other Disasters
Events	21	11	5	5
Counties	100	98	75	42
Number of Births	~443,000	~243,000	~165,000	~34,000
Percent of Births	20.5%	11.3%	7.7%	1.6%

Empirical Model

This study uses regression analysis with county fixed effects to look at the relationship between prenatal disaster exposure and maternal health behaviors and birth outcomes. Given residence in a particular county, families are not likely to be able to predict exposure to natural disasters in a particular year. Considerable variation exists across years in the number of births affected by disasters of various types, ranging from 0 to 78% of all births in the state in a given year.

The difficulty of predicting the occurrence of a natural disaster suggests that individual 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 close in age. Regression analysis with county fixed effects should, therefore, provide unbiased estimates of the effects of prenatal natural disaster exposure on birth outcomes by comparing across children born in the same county. Compared to identification strategies used in most other studies of the effects of natural disasters on birth outcomes, the county fixed effect method ensures more similar comparison groups. The model for the primary analysis in this study is:

(1) $$M_i = \beta_1 H_{i1-3} + \beta_2 S_{i1-3} + \beta_3 F_t + \beta_4 X_i + \kappa_c + \omega_w + \gamma_y + \varepsilon_i$$

where the variables are defined as:

M_i is an outcome variable, either a health behavior or a birth outcomes, for newborn *i*.

H_{i1-3} is an indicator for whether newborn *i* was exposed to a hurricane in trimesters 1-3.

S_{i1-3} is an indicator for whether newborn *i* was exposed to a winter storm in trimesters 1-3.

$F_{i1\text{-}3}$ is an indicator for whether newborn *i* was exposed to flooding or a tornado in trimesters 1-3.

X_i is a vector of demographic variables related to newborn *i.*

κ_c is a fixed effect for county of birth c.

ω_w is a fixed effect for week of birth w.

γ_y is a fixed effect for year of birth y.

ε_i is the error term for newborn i.

The outcome variables M_i fall into two categories. The first category is health behaviors and conditions, including prenatal care, smoking, drinking alcohol, maternal weight gain, and wantedness. The second category of outcomes is birth outcomes, measured using birth weight and gestational age. Some of the outcome variables are continuous and are, therefore, calculated using linear ordinary least squares (OLS) models. Other outcome variables are indictor variables and will be analyzed using a logistic models with the same covariates listed in equation one.

The independent variables of interest in the model are the indicators $H_{1\text{-}3i}$, $S_{1\text{-}3i}$, and $F_{1\text{-}3i}$ which are equal to one if a disaster declaration making the individual's county of residence eligible for federal assistance occurred in the individual's county of birth during the relevant trimester. The disasters are divided according to type, hurricanes, winter storms, and severe storms with tornadoes or flooding, in order to allow the effects to differ across disaster types. The coefficients β_1- β_3 are each a vector of coefficients for each trimester of possible disaster exposure. I will only present results for hurricanes and winter storms using the PRAMS data because the number of individuals exposed to other disaster types was quite small (fewer than 300).

The model also includes an array of individual covariates X_i. These contols include birth order, maternal age, education, race, immigrant status and marital status. The controls are the same for the birth certificate data and the PRAMS data, save for mother's immigrant status, which does not appear in the PRAMS data. Week of birth fixed effects fixed effects ω_w are included in the model to absorb systematic differences in outcomes by week of birth, as documented in previous literature (Doblhammer 2004). Year of birth fixed effects γ_y similarly absorb variance across years due to changes in technology, economic conditions, or other factors. County fixed effects κ_c account for any differences in counties that may be correlated with disaster exposure because of geographic and demographic differences across the state. In effect, the county fixed effects create a comparison across individuals born at different times in the same county.

Standard errors in all regressions are based on individuals clustered within county-years to acknowledge that disaster exposure is assigned based on county of residence at a particular time rather than individual exposure. For regressions using PRAMS data, sampling weights are used to make the data representative of all births in the state.

I also look at heterogeneous impacts of natural disasters across subgroups. The literature on disaster vulnerability suggests that some groups may be more susceptible to damage (Shah, Balkhair et al. 2011), and the literature on health at birth suggests that mothers with higher socioeconomic status may be better able to buffer their children from the effects of shocks (Conley, Strully et al. 2003). I run the model in equation 1 separately 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. I use a post-estimation test to determine whether the coefficients on the disaster exposure variables are equal across racial and educational subgroups.

Results

Table 2 displays basic demographic variables in both the birth certificate data and the PRAMS data. Overall, the two samples appear to be quite similar. Mothers in the PRAMS sample are slightly less likely to be married, more likely to be Hispanic, and more likely to be college educated. These differences are probably due to the difference in the time period covered by the two datasets. If the birth certificate data is restricted to the years covered by the PRAMS data, most of the differences disappear.

Table 2. Descriptive Statistics

	Birth Certificate 1988-2007		Prams 1997-2007	
	Percent/ Mean	Std. Dev	Percent/ Mean	Std. Dev.
Female	48.8%		48.6%	
Mother's Age	26.4	6.0	26.8	6.1
First Birth to Mother	41.8%		42.7%	
Mother Married	66.9%		64.0%	
No Father on Birth Certificate	12.5%		15.6%	
Maternal Race				
White	62.1%		60.4%	
Asian	2.0%		2.5%	
Black	25.8%		23.2%	
Hispanic	8.6%		12.4%	
Native American	1.4%		1.4%	
Other	0.1%		0.1%	
Maternal Education				
Less than High School	22.1%		22.9%	
High School Grad	33.5%		29.8%	
Some College	21.7%		21.6%	
College Grad	22.7%		25.8%	
Immigrant Mother	12.0%			
Birth Weight (lbs.)	7.3	1.4	7.3	1.4
Gestational Age (weeks)	38.7	2.5	38.6	2.3
N	**2,161,389**		**16,606**	

Note: Observations in PRAMS data are weighted to be representative of all births in the state.

Maternal Health Behaviors

The first set of results in this study looks at the effect of natural disasters on maternal health behaviors. Table 3 and Table 4 show selected results from of regressions of measures of prenatal care on disaster exposure in the birth certificate and PRAMS data respectively. All models also include the full set of control variables. The measures of prenatal care usage in Table 3 are whether the mother received any prenatal care, whether she started care in the first trimester, the month she started prenatal care, whether she received at least 13 visits (the number recommended for the mean gestation of 39 weeks), and the total number of prenatal care visits. Results for whether the mother received any prenatal care, whether she started care in the first trimester, and whether she received at least 13 visits are calculated using logistic models. Results for logistic models are reported as odds ratios with standard errors referring to the original coefficients.

The results show negative effects of exposure on prenatal care usage only among those exposed to hurricanes. Hurricane exposure across all three trimesters decreases the number of total prenatal care visits by 0.14 to 0.17 visits, which is roughly one in seven women missing a prenatal care visit due to exposure to hurricane. Exposure during the first two trimesters also decreases the likelihood that mothers receive care in the first trimester and increases the likelihood that mothers receive no care at all. Converting the odds ratios for these outcomes to relative risk, shows that the likelihood of receiving care in the first trimester is decreased by about 1% and the likelihood of not receiving care at all increased by about 10%. These are small effects in terms of the total number of births but may be important because they reduce the likelihood that serious conditions are detected early in pregnancy. The unexpected relationship between exposure in the second trimester and the probability of beginning prenatal care in the first trimester is probably due to some degree of measurement error in determining in which trimester a child was exposed.

Table 3. The Effect of Natural Disaster Exposure on Prenatal Care Usage by Disaster Type, Birth Certificate Data

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**No Prenatal Care (Logit)**	**Began in First Trimester (Logit)**	**Month Care Began (OLS)**	**At Least 13 Visits (Logit)**	**Number of Visits (OLS)**
Trimester 1 Hurricane	1.105*	0.935**	0.028*	0.924*	-0.168***
	(0.053)	(0.021)	(0.012)	(0.031)	(0.043)
Trimester 2 Hurricane	1.103*	0.963*	0.001	0.946	-0.143***
	(0.052)	(0.018)	(0.010)	(0.031)	(0.040)
Trimester 3 Hurricane	1.066	0.964	0.012	0.949	-0.137**
	(0.050)	(0.022)	(0.012)	(0.031)	(0.043)
Trimester 1 Winter Storm	1.015	0.985	0.018	0.976	-0.021
	(0.084)	(0.026)	(0.016)	(0.032)	(0.053)
Trimester 2 Winter Storm	1.068	0.981	0.010	0.951	-0.074
	(0.058)	(0.033)	(0.015)	(0.033)	(0.053)
Trimester 3 Winter Storm	0.979	1.025	0.004	0.981	-0.024
	(0.062)	(0.028)	(0.015)	(0.032)	(0.053)
Trimester 1 Flooding/Tornado	0.978	0.971	0.010	1.061	0.011
	(0.094)	(0.036)	(0.019)	(0.076)	(0.102)
Trimester 2 Flooding/Tornado	0.970	1.033	-0.008	1.044	0.031
	(0.083)	(0.063)	(0.031)	(0.099)	(0.127)
Trimester 3 Flooding/Tornado	1.100	1.008	-0.022	1.131	0.071
	(0.098)	(0.046)	(0.024)	(0.079)	(0.083)

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

Exposure to a hurricane in the first trimester also causes mothers to start care an average of about a day later. First trimester hurricane exposure also decreases the likelihood that mothers receive the recommended 13 visits. Converting the odds ratio to a relative risk shows that this effect represents about a 4% decrease in receiving the recommended number of visits, which is equal to about 2% of exposed mothers not completing all their visits as a result of the hurricane.

The results in Table 3 show a clear pattern of decreased prenatal care use for mothers exposed to hurricanes but reveal nothing about the causes of these changes in care. Table 4 uses survey data from PRAMS to give a more detailed picture of how disaster exposure impacts prenatal care use. All of the models in this table use logistic regressions, and the results are reported as odds ratios with standard errors referring to the original coefficients. Exposure to a hurricane during the first or second trimester causes an increase of approximately 33 to 38% in the number of women who begin prenatal care later than they wanted. This result may be due to the fact that women with these exposures are also found to be 25 to 33% more likely to face at least one barrier to starting prenatal care. In particular, women are 41 and 63% more likely to report beginning care later because “they could not get an earlier appointment” due to exposure to a hurricane in the first or second trimester respectively. Women are also 82% more likely to report that they did not receive care as early as they wanted because “they had too many other things going on”. These findings suggest that the reductions in prenatal care related to hurricane exposure are related to more difficulty acquiring such care rather than a reduced desire to receive care. It also suggests that many women who ultimately received adequate care as measured by the outcomes in Table 3 may have still experience stress related to the difficulty in finding care after a hurricane.

Table 4. The Effect of Natural Disaster Exposure on Prenatal Care Usage by Disaster Type, PRAMS Data

	(1)	(2)	(3)	(4)
VARIABLES	**Prenatal Care Later than Wanted (Logit)**	**Barrier to Beginning Prenatal Care (Logit)**	**Couldn't Get Earlier Appointment (Logit)**	**Too Many Other Things Going On (Logit)**
Trimester 1 Hurricane	1.517**	1.419*	1.697**	1.851*
	(0.233)	(0.210)	(0.336)	(0.543)
Trimester 2 Hurricane	1.444*	1.308*	1.449*	0.994
	(0.217)	(0.174)	(0.256)	(0.272)
Trimester 3 Hurricane	0.906	0.848	1.066	0.706
	(0.134)	(0.119)	(0.232)	(0.305)
Trimester 1 Winter Storm	1.286	1.303	1.377	0.183+
	(0.253)	(0.252)	(0.370)	(0.162)
Trimester 2 Winter Storm	0.863	0.893	0.605	0.471
	(0.146)	(0.149)	(0.201)	(0.283)
Trimester 3 Winter Storm	0.727	0.735	0.290**	0.399+
	(0.142)	(0.145)	(0.121)	(0.214)

Note: *** $p<0.001$, ** $p<0.01$, * $p<0.05$, + $p<0.1$; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

Table 5 uses birth certificate data to look at the effect of disaster exposure on maternal tobacco use, the number of cigarettes smoked per week, maternal alcohol use, the number of alcoholic drinks per week, and maternal weight gain. Tobacco use and alcohol use were modeled using logistic equations and are reported as odds ratios. The number of cigarettes and alcoholic drinks per week are analyzed using OLS but only for mothers who reported smoking tobacco or drinking alcohol during their pregnancy. Two important caveats are important to keep in mind when assessing the results of these analyses. Maternal alcohol use during pregnancy is often severely under reported, so the results here probably underestimate the true amount of alcohol use. Additionally, there is no simple formula for determining the ideal amount of weight gain during pregnancy, since recommendations vary by starting weight of the mother and have varied over time. Therefore, without pre-pregnancy weight status, it is not entirely clear whether more or less weight gain is good or bad.

The results suggest that both hurricanes and winter storms reduce the likelihood that mothers smoked tobacco during their pregnancy by 3 to 4%. Given that both of these types of disasters are likely to be associated with widespread travel difficulties, the decreases in smoking may be associated with an inability to buy new cigarettes. Exposure to a tornado or flood in the first trimester of pregnancy may increase the likelihood that a mother drinks alcohol during pregnancy by as much as 18%. Since very few mothers ever report drinking alcohol during pregnancy, this increase only results in 1.4% of mothers reporting drinking as compared to 1.2% when no disaster occurred. Winter storms are also associated with an increase in maternal weight gain of 0.22 pounds from exposure in the first trimester. This is a small increase given that the average weight gain during pregnancy was 30 pounds.

Table 5. The Effect of Natural Disaster Exposure on Tobacco and Alcohol Usage and Maternal Weight Gain by Disaster Type, Birth Certificate Data

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**Tobacco Use (Logit)**	**Cigarettes Per Week (OLS)**	**Alcohol Use (Logit)**	**Drinks Per Week (OLS)**	**Weight Gain in Lbs. (OLS)**
Trimester 1 Hurricane	0.964*	-0.017	1.048	-0.262	-0.087
	(0.015)	(0.085)	(0.056)	(0.158)	(0.081)
Trimester 2 Hurricane	0.964*	-0.120	0.971	0.207	-0.130
	(0.016)	(0.078)	(0.046)	(0.167)	(0.074)
Trimester 3 Hurricane	0.973	0.113	0.933	-0.190	-0.088
	(0.016)	(0.081)	(0.047)	(0.156)	(0.076)
Trimester 1 Winter Storm	0.985	-0.013	1.019	-0.117	0.223**
	(0.019)	(0.105)	(0.091)	(0.304)	(0.084)
Trimester 2 Winter Storm	0.960*	-0.173	0.995	0.239	0.097
	(0.018)	(0.111)	(0.077)	(0.358)	(0.084)
Trimester 3 Winter Storm	0.938**	-0.143	0.923	-0.171	0.123
	(0.019)	(0.106)	(0.068)	(0.315)	(0.081)
Trimester 1 Flooding/Tornado	1.060	0.136	1.184*	-0.324	-0.010
	(0.044)	(0.171)	(0.084)	(0.185)	(0.207)
Trimester 2 Flooding/Tornado	1.072	0.101	1.084	-0.246	0.214
	(0.045)	(0.210)	(0.104)	(0.169)	(0.218)
Trimester 3 Flooding/Tornado	1.019	-0.074	0.973	-0.076	0.006
	(0.046)	(0.155)	(0.105)	(0.249)	(0.302)

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

Unlike the birth certificate data, the PRAMS data contains information on pre-pregnancy Body Mass Index (BMI) which allows for a more detailed look at maternal weight gain. Table 6 displays regressions of measures of maternal weight gain in the PRAMS data on indicators of disaster exposure. The first column of Table 6 includes all mothers; all other columns are restricted to mothers whose BMI was normal or underweight. Exposure to a hurricane during the second trimester reduced weight gain by about 1.2 pounds among all mothers and 2.1 pounds among those with normal weights or below normal weight.

Table 6. The Effect of Natural Disaster Exposure on Maternal Weight Gain by Disaster Type, PRAMS Data

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**Weight Gained – All Mothers (OLS)**	**Weight Gained – Normal Weight (OLS)**	**No Weight Gained – Normal Weight (Logit)**	**Higher than Recommended Gain – Normal Weight (Logit)**	**Lower than Recommended Gain – Normal Weight (Logit)**
Trimester 1 Hurricane	-1.045	-0.649	1.838	0.858	1.198
	(0.691)	(0.827)	(0.918)	(0.133)	(0.203)
Trimester 2 Hurricane	-1.210+	-2.066*	2.671**	0.731*	1.433*
	(0.632)	(0.870)	(0.853)	(0.102)	(0.233)
Trimester 3 Hurricane	-0.422	-0.469	1.445	0.879	1.099
	(0.797)	(0.951)	(0.508)	(0.146)	(0.191)
Trimester 1 Winter Storm	-0.633	-1.567	1.707	0.883	1.300
	(0.816)	(1.420)	(0.838)	(0.239)	(0.207)
Trimester 2 Winter Storm	-0.919	-0.525	2.303	1.087	1.013
	(0.884)	(1.003)	(1.171)	(0.220)	(0.197)
Trimester 3 Winter Storm	-0.559	1.563+	0.622	1.257	0.606*
	(0.731)	(0.853)	(0.344)	(0.215)	(0.126)

Note: *** p<0.001, ** p<0.01, * p<0.05, + p<0.1; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

Logistic regressions on indicators for gaining no weight, gaining a higher than recommended amount of weight and gaining a lower than recommended amount show that normal weigh mothers exposed to a hurricane during the second trimester are more than twice as likely to gain no weight, 24% more likely to gain less than the current recommendation, and 23% less likely to gain more than the current recommendation. Normal weight mothers exposed to a winter storm in the third trimester gained 1.5 pounds more weight than unexposed mothers and were less likely to gain below the recommended amount of weight. Because recommendations have changed over time, I still cannot draw firm conclusions about the implications of these changes in weight gain, but the reductions in weight gain among normal weight mothers exposed to a hurricane could signal difficulty getting proper nutrition in the wake of the disaster.

Table 7 uses the PRAMS data to look at the wantedness of pregnancy, which is whether the mother reports after the birth that the pregnancy was intended or unintended. For natural disasters to affect wantedness, parents would have to change their opinions about whether they wanted the pregnancy during the course of pregnancy. This type of change could reflect stress or other negative family impacts that made pregnancy less desirable.

Table 7 shows the influence of disaster exposure on the overall likelihood that the mother reports that the pregnancy was unintended and the likelihood that the mother reports that the pregnancy was mistimed (wanted later) or unwanted altogether as well as whether the mother reports that her partner did not want the pregnancy. The results show that mothers exposed to a hurricane in the first trimester are more likely to report that their pregnancy was unintended or unwanted by their partner. There is not a statistically significant effect on mistimed or unwanted pregnancies, but the point estimates suggest increases in both contribute to the increase in unintended pregnancies. The size of the effects works out to about 6% of pregnancies that would otherwise have been reported as wanted by both the mother and her partner.

Table 7. The Effect of Natural Disaster Exposure on Wantedness by Disaster Type, PRAMS Data

	(1)	(2)	(3)	(4)
VARIABLES	Unintended Pregnancy (Logit)	Mistimed Pregnancy (Logit)	Unwanted Pregnancy (Logit)	Unwanted by Partner (Logit)
Trimester 1 Hurricane	1.286*	1.169	1.311	1.663*
	(0.151)	(0.153)	(0.280)	(0.330)
Trimester 2 Hurricane	1.223	1.135	1.237	0.899
	(0.155)	(0.145)	(0.235)	(0.166)
Trimester 3 Hurricane	1.018	1.051	0.957	0.937
	(0.126)	(0.139)	(0.214)	(0.192)
Trimester 1 Winter Storm	0.816	0.880	0.697	1.378
	(0.134)	(0.131)	(0.195)	(0.289)
Trimester 2 Winter Storm	1.047	1.006	1.008	1.130
	(0.145)	(0.130)	(0.231)	(0.274)
Trimester 3 Winter Storm	1.020	1.028	0.958	0.995
	(0.148)	(0.146)	(0.226)	(0.202)

Note: *** p<0.001, ** p<0.01, * p<0.05, + p<0.1; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

The effect on wantedness as well as the effects on prenatal care, substance use, and maternal weight gain could have long term consequences for developing children. The precise size of the long term effects is difficult to predict given that the relationship between these health behaviors and outcomes is not a simple one. However, the impact is likely to be increased because many pregnancies are likely to be affected by effects on more than one health behavior. The next section looks at whether these or other effects of disaster exposure translate into impacts on birth weight and gestational age.

Birth Outcomes

Birth weight and gestational age are commonly used as measures of overall infant health. Table 8 displays regressions of birth weight, gestational age, low birth weight, preterm birth, and small for gestational age on disaster exposure by trimester and disaster type for the birth certificate data. A birth is considered low birth weight if the child weighs less than 5.5lbs; it is considered a preterm birth if the child was born before 37 weeks of gestation. A child is labeled small for gestational age if they are below the 10^{th} percentile in weight for children born at a particular gestational age. Low birth weight, preterm birth, and small for gestational age are modeled using logistic equations and are reported as odds ratios with standard errors referring to the original coefficients.

These analyses suggest that there may be a small increase in birth weight and reduced likelihood of being born small for gestational age associated with exposure to winter storms in early trimesters. Winter storms may also slightly decrease the likelihood of preterm birth. The effects are quite small. The reduction in birth weight comes to less than seven grams, and the reductions in preterm birth and small for gestational age would affect less than 0.3% of births exposed to winter storms in the later trimesters.

Table 8. The Effect of Natural Disaster Exposure on Birth Outcomes by Disaster Type, Birth Certificate Data

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**Birth Weight in Pounds (OLS)**	**Gestational Age in Weeks (OLS)**	**Low Birth Weight (Logit)**	**Preterm Birth (Logit)**	**Small for Gestational Age (Logit)**
Trimester 1 Hurricane	-0.009	-0.020	1.027	1.020	0.996
	(0.006)	(0.012)	(0.018)	(0.015)	(0.014)
Trimester 2 Hurricane	0.005	0.022	1.004	0.980	1.030
	(0.006)	(0.012)	(0.016)	(0.015)	(0.016)
Trimester 3 Hurricane	0.002	0.013	1.014	0.980	1.004
	(0.005)	(0.012)	(0.017)	(0.015)	(0.015)
Trimester 1 Winter Storm	0.014*	0.009	0.983	0.979	0.969
	(0.006)	(0.012)	(0.019)	(0.018)	(0.019)
Trimester 2 Winter Storm	0.015*	0.015	0.974	0.979	0.961*
	(0.006)	(0.012)	(0.018)	(0.016)	(0.017)
Trimester 3 Winter Storm	0.008	0.023	0.974	0.968*	1.011
	(0.007)	(0.012)	(0.018)	(0.015)	(0.018)
Trimester 1 Flooding/Tornado	-0.019	-0.023	1.047	1.068	1.040
	(0.016)	(0.027)	(0.043)	(0.042)	(0.027)
Trimester 2 Flooding/Tornado	-0.004	-0.027	1.025	1.020	0.971
	(0.011)	(0.029)	(0.033)	(0.032)	(0.025)
Trimester 3 Flooding/Tornado	0.001	-0.024	1.024	1.049	0.986
	(0.013)	(0.037)	(0.043)	(0.049)	(0.042)

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

The previous regressions looking at the effects of winter storms on maternal health behaviors suggested that exposure to these disasters may cause decreases in the rates of smoking during pregnancy and may slightly increase maternal weight gain.

These changes in behavior may account for the small improvements in birth outcomes among children exposed to winter storms. However, there is no indication that hurricanes or tornadoes or flooding have any effect on birth weight or gestational age. This is an interesting finding given the significant effects found for maternal health behaviors.

Table 9 shows regressions of the same birth outcomes in the PRAMS data. The results are similar in showing little evidence of significant effects. Exposure to a winter storm in the third trimester is associated with a decrease in the likelihood of being small for gestational age. In this case, however, exposure to a hurricane in the third trimester is associated with an increase in the likelihood of being low birth weight. However, given the number of regressions in this study, a single result outside of a clear pattern should probably be considered a statistical artifact.

The limited effect of disasters on birth outcomes, in spite of more substantial effects on health behaviors, suggests two possibilities. The first possibility is that changes in maternal health behaviors do not translate into changes in health at birth. This finding would be surprising given that the literature on these health behaviors suggests that they have important effects on birth outcomes. The other possibility is that birth weight and gestational age do not fully capture the types of effects on prenatal development caused by natural disasters. This second possibility is particularly important because it would imply that birth weight and gestational age, although commonly used, are not sufficient to measure important impacts on prenatal development.

Table 9. The Effect of Natural Disaster Exposure on Birth Outcomes by Disaster Type, PRAMS Data

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**Birth Weight in Grams (OLS)**	**Gestational Age in Days (OLS)**	**Low Birth Weight (Logit)**	**Preterm Birth (Logit)**	**Small for Gestational Age (Logit)**
Trimester 1 Hurricane	-0.017	2.142	0.904	0.980	1.153
	(26.235)	(1.569)	(0.093)	(0.163)	(0.214)
Trimester 2 Hurricane	-22.770	2.362	0.879	0.962	1.156
	(21.965)	(2.084)	(0.078)	(0.124)	(0.213)
Trimester 3 Hurricane	-23.542	0.652	1.201+	1.070	1.174
	(27.750)	(1.629)	(0.128)	(0.172)	(0.211)
Trimester 1 Winter Storm	20.112	1.352	0.970	0.752	1.148
	(33.455)	(2.792)	(0.122)	(0.142)	(0.300)
Trimester 2 Winter Storm	34.794	-1.159	0.923	0.805	0.704
	(26.429)	(1.912)	(0.121)	(0.151)	(0.159)
Trimester 3 Winter Storm	8.482	-1.418	1.031	0.837	0.589*
	(26.333)	(1.815)	(0.119)	(0.124)	(0.143)

Note: *** p<0.001, ** p<0.01, * p<0.05, + p<0.1; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

Subgroup Analysis

This section looks at how the impacts of natural disaster exposure on maternal health behaviors and birth outcomes vary across different subgroups. Since advantaged groups may be able to utilize their resources to buffer themselves from the effects of disasters, disadvantaged groups may experience more negative effects (Cutter, Mitchell et al. 2000; Cutter, Boruff et al. 2003; Fothergill and Peek 2004; Zahran, Brody et al. 2008).

To examine this possibility, the regressions from the previous sections were rerun separately for children of White mothers, Black mothers, mothers with a high school degree or less and mothers with at least some college. Although I ran subgroup regressions for all of the health behaviors and birth outcomes in the previous section, I only report those that showed significant subgroup differences in post-estimation tests.

Table 10 shows the results for the prenatal care usage by subgroup. The results in Table 10 show that Black mothers and mothers with lower education are more likely than White mothers and mothers with higher education levels to start prenatal care later as a result of hurricane exposure in the third trimester. Black mothers are also less likely than White mothers to receive the recommended 13 prenatal care visits after a hurricane during their third trimester. Mothers with lower education are also more likely than those with higher education to fail to get prenatal care as early as they wanted after a hurricane. In contrast, mothers with higher education are more likely to report that not being able to get an appointment was a barrier to prenatal care. In general, these finding supports the theory that some mothers are more able than others to buffer themselves and their children from negative outcomes. There were no significant subgroup differences in the other maternal health behaviors.

Table 10. The Effect of Hurricane Exposure on Prenatal Care Usage by Maternal Subgroup

	(1)	(2)	(3)	(4)
VARIABLES	**White**	**Black**	**High School or Less**	**More Than High**
Began Care in First Trimester (Logit) – Birth Certificate Data				
Trimester 3 Hurricane	0.993	0.925**	0.951*	1.016
	(0.023)	(0.023)	(0.023)	(0.031)
Month Care Began (OLS)				
Trimester 3 Hurricane	0.002	0.047**	0.030*	-0.009
	(0.011)	(0.017)	(0.015)	(0.011)
At Least 13 Visits (Logit) –Birth Certificate Data				
Trimester 3 Hurricane	0.960	0.897**		
	-0.031	-0.037		
Prenatal Care Later than Wanted (Logit) –PRAMS Data				
Trimester 2 Hurricane			1.750**	1.096
			(0.317)	(0.252)
Couldn't Get Earlier Appointment (Logit) – PRAMS Data				
Trimester 1 Hurricane			1.153	2.813***
			(0.316)	(0.726)

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results are reported as odds ratios with standard errors referring to original coefficients.

Table 11 displays regressions of birth outcomes on disaster exposure for the subgroups of children born to White mothers, Black mothers, mothers with a high school degree or less and mothers with at least some college in both data sets. In the PRAMS data, hurricane exposure in second trimesters has a negative effect on birth weight among children born to black mothers. The effects are quite small, between 2.5 and 3 ounces, but they do indicate that these hurricanes may have similar effects to previous studies but of smaller magnitude. In the birth certificate data, children born to black mothers who were exposed to hurricanes in the third trimester have lower birth weights than children born to White mothers, but the coefficient is not statistically different from zero. There is also a positive effect of winter storm exposure on birth weight but only among mothers with higher education.

Table 11. The Effect of Natural Disaster Exposure on Birth Outcomes by Maternal Subgroup

	(1)	(2)	(3)	(4)
VARIABLES	**White**	**Black**	**High School or Less**	**More Than High**
Birth Weight (OLS) – Birth Certificate Data				
Trimester 3 Hurricane	0.012	-0.019		
	(0.006)	(0.011)		
Birth Weight (OLS) – PRAMS Data				
Trimester 2 Hurricane	6.606	-92.426^{+}		
	(29.445)	(50.070)		
Trimester 1 Winter Storm			-38.619	77.175^{+}
			(40.846)	(43.950)
Low Birth Weight (Logit) – PRAMS Data				
Trimester 3 Hurricane	1.077	1.581*	1.451**	0.874
	(0.148)	(0.300)	(0.208)	(0.138)
Small for Gestational Age (Logit) – Birth Certificate Data				
Trimester 2 Hurricane	1.001	1.067**		
	(0.021)	(0.023)		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results are reported as odds ratios with standard errors referring to original coefficients.

In the PRAMS data, third trimester hurricane exposure may lead to increases in low birth weight among children born to Black mothers and mothers with lower education. The PRAMS data also shows an increase in the probability of being small for gestational age associated with hurricanes for children born to Black mothers. In keeping with the effects on maternal health behaviors, the negative effects here are found for the disadvantaged subgroups and the positive effects for the advantaged groups.

Overall, the subgroup analyses suggest that there are small negative effects of hurricanes, concentrated among disadvantaged groups, and small positive effects of winter storms, concentrated among advantaged groups. These results suggest that the effects of a shock, like a natural disaster, on health behaviors do not necessarily fully translate into measureable birth outcomes. However, in all cases, disadvantaged groups suffered more.

Sensitivity Test for Selection Bias

One possible threat to the identification strategy used in this paper is selection out of counties exposed to a disaster. Exposure to a disaster could make a woman more likely to miscarry or chose to have an abortion. There are no reliable records of the total number of abortions and miscarriages, and in many cases a woman may miscarry before she even knows she is pregnant. Therefore, it is not possible to directly measure whether natural disasters affect the prevalence of miscarriages and abortions. A mother may also choose to move out of a county between the occurrence of a disasters and the birth of her baby, and cause the birth not to be recorded in the birth data for the county. Again we cannot directly measure whether pregnant mothers move out of a county following a disaster. However, we can measure whether there is an effect on the total number of births in the county, which can be used to approximate the combined effect of natural disaster exposure on miscarriages, abortions, and mobility. Table 12 shows the effect of disaster exposure by trimester and disaster type on the log of the number of births per month in a county for each disaster set. The regressions also include county, year and month fixed effects.

Table 12. The Effect of Natural Disaster Exposure on the Log of the Number of Births in a County in a Month

	(1)	(2)
VARIABLES	**Log(Births) Birth Certificate (Logit)**	**Log(Births) PRAMS (Logit)**
Trimester 1 Hurricane	-0.013	0.005
	(0.009)	(0.017)
Trimester 2 Hurricane	-0.015	0.004
	(0.008)	(0.018)
Trimester 3 Hurricane	0.005	-0.030
	(0.009)	(0.018)
Trimester 1 Winter Storm	0.013	0.009
	(0.011)	(0.023)
Trimester 2 Winter Storm	0.010	-0.033
	(0.010)	(0.022)
Trimester 3 Winter Storm	0.017	-0.012
	(0.011)	(0.025)
Trimester 1 Flooding/Tornado	-0.007	-0.024
	(0.019)	(0.065)
Trimester 2 Flooding/Tornado	0.008	0.004
	(0.021)	(0.037)
Trimester 3 Flooding/Tornado	-0.012	-0.019
	(0.020)	(0.039)

Note: *** p<0.001, ** p<0.01, * p<0.05, + p<0.1; standard errors are calculated based on observations clustered within the county-year. All regressions also include control variables and county, week, and year of birth fixed effects. Results of logit regressions are reported as odds ratios with standard errors referring to original coefficients.

The results indicate no significant effect of disaster exposure on the total number of births per month. This suggests that selection into the sample is not a serious concern for this study.

Discussion

Natural disasters occur quite frequently in the United States and affect a large number of families. Between 1988 and 2007, the state of North Carolina experienced 21 disasters severe enough to result in a major disaster declaration from FEMA. While few of the disasters resulted in large numbers of deaths or injuries, they did lead to often serious community disruptions. These types of disruptions have the potential to lead to long lasting effects in the lives of children who are in the vulnerable period of prenatal development.

This study finds significant effects of natural disaster exposure on prenatal care usage, cigarette smoking, maternal weight gain, and wantedness, which are important health factors related to prenatal development. Most notably, hurricane exposure seems to have clear negative effects on prenatal care usage. These results may suggest that community disruptions caused by hurricanes reduce the ability of pregnant women to access medical care. The reduction in cigarette smoking following exposure to hurricanes and winter storms could indicate that a temporary reduction in access to cigarettes or a break in routine may assist the efforts of pregnant mothers to quit smoking. The changes in maternal weight gain are more difficult to interpret, but the reductions associated with hurricanes may indicate that the same disruption in access that are positive for smoking is negative for nutrition.

The effect of hurricane exposure on whether the mother and her partner want the pregnancy may be both a reflection and a cause of stress. Wantedness may also be an important influence on other health behaviors, such as prenatal care use. Overall, this study indicates that hurricanes influence maternal health in ways that have the potential to negatively affect prenatal development.

On the other hand, the results of this study show much smaller effects of natural disaster exposure on birth weight and gestational age than previous studies. Hurricanes may have small negative impacts for some subgroups, but if anything, winter storms have a small positive impact. The positive effect of winter storms compared to the negative effect of hurricanes indicates the importance of distinguishing between disaster types when looking at prenatal exposures. Winter storms may be far less disruptive for individuals and families than hurricanes. Indeed, most federal assistance for winter storms was in the form of public assistance which helps local communities with emergency work in areas like debris removal, road and bridge work, and utilities. For hurricanes, much of the aid is available as assistance to individuals. These differences in individual level impacts reflect the importance of the type of impact in determining the effect of a prenatal disaster exposure. This study represents a first step towards understanding that distinction.

There are two ways to interpret the disparity between the significant effects on maternal health behaviors and the relatively small effects on birth outcomes. The first is that effects on maternal health behaviors of the magnitude observed in this study are not important in terms of birth outcomes. The second is that birth weight and gestational age, which are broad summary measures, may not capture more subtle effects, such as the influence of maternal cortisol levels on neural development. A study of children exposed to radiation from the Chernobyl accident prenatally showed effects at school age that were not observable at birth (Almond, Edlund et al. 2009). My own study of educational outcomes in this same population also shows negative impacts on school performance. This discrepancy between outcomes measured in the short term and the long term suggests the need for a more complex understanding of how prenatal shocks affect development and better ways of measuring these effects.

This study also makes the first attempt to look at how the effects of disaster vary between population subgroups. In keeping with the vulnerability literature, which suggests that disadvantaged groups experience more adverse impacts (Cutter, Mitchell et al. 2000; Cutter, Boruff et al. 2003; Fothergill and Peek 2004; Zahran, Brody et al. 2008), I generally find larger negative effects and smaller positive effects for children born to Black mothers and mothers with lower levels of education. However, this is just a first step. A great deal of work remains to understand how individual and community disadvantage moderate the effects of disasters on prenatal development.

Policy Implications

The effect of natural disasters on maternal health behaviors is important because it may reflect the need for a particular targeting of resources following a disaster to include a focus on pregnant women. In particular, the negative impact of hurricanes on prenatal care usage suggests a need for additional health care resources in the immediate aftermath of a major hurricane. The potential long term nature of the effects on prenatal development suggests potential benefits could be derived by investing resources to reduce the negative impact of disasters on pregnant women and especially the benefit of targeting disadvantaged groups that may be at the highest risk.

Future Directions

More research is needed in the area of the long term effects of disasters on children. Future work should look at the link between the effect of disasters on maternal health behaviors and later outcomes. In addition, researchers should strive for a more complex understanding of the biological mechanisms, such as maternal cortisol, that mediate the effect of disaster exposure on prenatal development. There is also more research to be done in exploring how disasters affect different subgroups. Finally, researchers should seek data on individual disaster experiences to better understand how disasters affect pregnant women and how those effects might be reduced.

The Effect of Prenatal Natural Disaster Exposure on School Outcomes

Introduction

In 2011, the Federal Emergency Management Agency (FEMA) reported 99 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. The costs borne by individuals, families, and insurance companies were even higher. The short term effects of 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.

Natural disasters may be particularly damaging to vulnerable populations, such as developing fetuses. A number of recent studies have found negative impacts of prenatal exposure to natural disasters on birth outcomes and complications (Glynn, Wadhwa et al. 2001; Xiong, Harville et al. 2008; Simeonova 2009; Tan, Li et al. 2009; Auger, Kuehne et al. 2011; Dancause, Laplante et al. 2011; Torche 2011; Currie and Rossin-Slater 2012; Oyarzo, Bertoglia et al. 2012). A natural addition to this literature is to consider how effects of prenatal exposures on birth outcomes translate into later life outcomes. Researchers, in a study called "Project Ice Storm", looking at a severe ice storm that occurred in Canada in 1998 have done just that by looking at the effect of prenatal exposure on cognitive development at ages two and five (Laplante, Barr et al. 2004; Laplante, Brunet et al. 2008). These researchers find negative effects on cognitive development. However, the generalizability of their results is limited by small sample sizes and the focus on a single disaster at a single point in time.

The current study adds to the literature in several ways. This study looks at the effects of 15 different disasters on the third grade educational outcomes of a large sample of children born in North Carolina over a period of 13 years. Three different categories of disasters are represented, which allows for some exploration of the differences in effects by disaster type. Additionally, the large sample size allows for the consideration of differences in effects across demographic subgroups, especially disadvantaged groups. The focus on educational outcomes at third grade also gives a longer run perspective on the effects of prenatal shocks caused by disasters. This longer run perspective provides a better estimate of the enduring impact of prenatal exposure to disasters and its cost to society.

Background

The conceptual framework for this study assumes that natural disasters are unpredictable exogenous shocks which may affect the prenatal development of babies who are in utero at the time of the disaster. Through their effects on prenatal development, the natural disasters may have long term effects on the educational outcomes of children exposed prenatally. However, these effects may be modified by the type and timing of the disaster as well as family characteristics.

Natural Disasters and Prenatal Development

Recent interest in the effects of prenatal shocks on birth outcomes has led to a number of studies looking at natural disasters. Most of these studies examine pregnant women exposed to a particular disaster and compare their birth outcomes to other women who were not exposed due to geography or timing. The earliest of these studies (Glynn, Wadhwa et al. 2001) found that maternal stress resulting from an earthquake in California was associated with lower gestational ages. Later studies of earthquakes in other countries confirmed the findings of reduced gestational ages (Torche 2011) as well as finding higher rates of preterm births (Tan, Li et al. 2009; Oyarzo, Bertoglia et al. 2012), higher rates birth defects (Tan, Li et al. 2009), and lower birth weights (Tan, Li et al. 2009; Torche 2011). Similar studies of a severe ice storm in Canada and Hurricane Katrina also found reductions in birth weight and increases in preterm births (Xiong, Harville et al. 2008; Auger, Kuehne et al. 2011; Dancause, Laplante et al. 2011).

In addition to these studies of single events, there have been two studies that have looked at average effects across a broader group of disasters. The first (Simeonova 2009) pools the effects of all weather-related disasters in the United States from 1968 to 1988 and finds small negative effects on preterm birth and gestational age. The second (Currie and Rossin-Slater 2012) uses sibling fixed effects to examine the effects of several hurricanes in Texas and finds an increase in birth complications. These studies in combination with the studies of single disasters provide reason to be concerned about the impact of prenatal exposure to natural disasters on longer term outcomes including education.

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, Szatmari et al. 1991; Reichman 2005; Goosby and Cheadle 2006; Goosby and Cheadle 2009), which translates into higher levels of special education placements once students reach school age. For children who do not suffer from serious impairments, newborn health has been used to predict cognitive skills and achievement test scores (Boardman, Powers et al. 2002; Hack, Flannery et al. 2002; Reichman 2005; Black, Devereux et al. 2007; Aarnoudse-Moens, Weisglas-Kuperus et al. 2009; Andreias, Borawski et al. 2010). Other school-related outcomes are also associated with health at birth, including retention, behavior, attention, and executive function (Saigal, Szatmari et al. 1991; Conley, Strully et al. 2003; Aarnoudse-Moens, Weisglas-Kuperus et al. 2009; Temple, Reynolds et al. 2010). Ultimately, early health may influence important life outcomes, including educational attainment and labor market success (Hack, Flannery et al. 2002; Conley, Strully et al. 2003; Black, Devereux et al. 2007). This literature suggests that health at birth, or health capital (Currie 2009), may be an important factor to consider in attempts to improve 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 (Conley, Strully et al. 2003; Almond, Chay et al. 2005; Currie 2009; Almond and Currie 2011). 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 (Barker, Osmond et al. 1993; Barker 1999; Godfrey and Barker 2001; Rasmussen 2001; Shonkoff, Boyce et al. 2009). 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 and Barker 2001; Currie 2009; Shonkoff, Boyce et al. 2009; Ellis and Boyce 2011). The exogenous nature of shocks, like those caused by natural disasters, provides an opportunity to examine support for the Fetal Origins Hypothesis.

The stress hormone cortisol, in particular, has been cited as a possible mechanism connecting prenatal shocks, birth outcomes, and later life outcomes. The release of cortisol resulting from maternal stress may be a contributing factor in preterm delivery (Wadhwa, Culhane et al. 2001). Exposure to cortisol in utero has also been associated with lasting changes in hypothalamo-pituitary-adrenal function and later levels of cortisol in the child (Kapoor, Dunn et al. 2006). Maternal prenatal stress levels, in general, have been associated with negative birth outcomes (Hedegaard, Henriksen et al. 1996; Lobel, DeVincent et al. 2000; Dole 2003; Kinsella and Monk 2009) and longer term physical and mental health (Beydoun and Saftlas 2008).

Several studies in the economics literature have used various types of stressful disruption to provide support for the Fetal Origins Hypothesis in reference to educational and economic outcomes (Almond and Currie 2011). These studies have shown that prenatal exposure to the 1918 flu epidemic (Almond and Mazumder 2005), 2005) and the Chernobyl disaster (Almond, Edlund et al. 2009), for example, have negatively affected educational or economic performance later in life. It is reasonable to hypothesize that prenatal exposures to natural disasters might result in similar long run effects. Indeed, the researchers in "Project Ice Storm" studying women exposed to the 1998 ice storm in Canada found that their children had lower levels of intellectual ability and language skill at age two and five (Laplante, Barr et al. 2004; Laplante, Brunet et al. 2008). However, the sample sizes were quite small, 58 and 89 respectively, and did not look at actual school performance outcomes.

This study will extend the literature by linking individual prenatal natural disaster exposure to educational outcomes across a large group of children and a number of different disasters. In doing so, this study will provide evidence of longer term effects accruing from prenatal exposure, beyond health effects measured at birth.

The size of the study will allow for a nuanced look at how effects vary by disaster type, subgroup, and trimester. The literature on social vulnerability has found that some population subgroups are more likely to experience large negative effects from natural disasters (Cutter, Boruff et al. 2003; Zahran, Brody et al. 2008). Among the most vulnerable groups are racial and ethnic minorities, the less educated, and those with lower socioeconomic status (Cutter, Mitchell et al. 2000; Cutter, Boruff et al. 2003; Fothergill and Peek 2004; Zahran, Brody et al. 2008). This increased vulnerability is due to limited access to information, resources, and political representation (Cutter, Boruff et al. 2003; Zahran, Brody et al. 2008). In addition, some studies of prenatal health effects have found that families of higher socioeconomic status (SES) can compensate for poor birth outcomes (Conley, Strully et al. 2003; Goosby and Cheadle 2006; Almond and Currie 2010; Almond and Currie 2011).

Research also indicates that an infant's health may be more negatively impacted by a shock during early pregnancy or late pregnancy (Hedegaard, Henriksen et al. 1996; Catalano and Hartig 2001; Glynn, Wadhwa et al. 2001; Roseboom, van der Meulen et al. 2001; Lederman, Rauh et al. 2004; Almond and Mazumder 2011; Torche 2011) rather than having a uniform effect across all trimesters. Potential differences in outcomes of these different exposures are critical for understanding mechanisms as well as possibilities for intervention.

Methods

Data

This study combined three administrative data sets to create a longitudinal data set containing individual prenatal disaster exposure, birth characteristics, and school outcomes. The sample included all singleton births from 1988 to 2000 in North Carolina that could be matched to third grade test score records in North Carolina public schools from 1997 to 2011. 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 were a result of children who left the state or did not attend public schools. However, some who did attend public schools may not have been matched due to errors or discrepancies in the data recording. The full data set included 880,967 children for whom third grade education data was available, out of a total of 1,323,489 births in North Carolina between 1988 and 2000.

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 included all children born in the state of North Carolina. 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.

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 were scores on the third grade End of Grade reading and math tests and identification as special education and gifted measured at third grade. School data also provided information on student ethnicity and identification for specific programs such as the federal school lunch program and English Language Learners.

A matching procedure was performed using student names and birth dates to link each individual student's school records to the corresponding birth record for the sample of students for whom both records are available. Across all years, an average of 67% of all individuals born in the state from 1988 to 2000 were matched with third grade school records. The match rate for births in each year was at least 64%. Most of the unmatched records probably consist of children who moved out of the state before reaching third grade or who were enrolled in private school. Indeed, among eight to ten year olds in the American Community Survey Public Use Microdata Sample (ACS PUMS) from the years 2000 to 2011 who were born in the state of North Carolina, 22% had moved to other states and an additional nine percent were enrolled in private school. This leaves just 69% of the ACS PUMS children who were born in North Carolina enrolled in public school in the state at the age that most children attend third grade. These results compare favorably with the match rates for children in this study.

Table 13 provides descriptive statistics and 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 were statistically significant but are probably accounted for by general trends in those more likely to move out of state or attend private school.

Table 13. Comparison of Births and were and were not Matched to School Data

Variable	Matched		Unmatched	
	Mean	Std. Dev.	Mean	Std. Dev
Female	49.5%		47.4%	
Mother's Age	25.9	5.88	26.3	5.85
Mother Married	66.8%		74.7%	
No Father on Birth Certificate	14.2%		12.0%	
White Mother	63.9%		67.0%	
Black Mother	29.7%		23.0%	
Native American Mother	1.6%		1.1%	
Asian Mother	1.2%		2.3%	
Hispanic Mother	3.6%		6.5%	
Other Race Mother	0.1%		0.1%	
Immigrant Mother	6.0%		10.6%	
Mother Less than High School	22.9%		19.0%	
Mother High School	38.2%		32.6%	
Mother Some College	21.3%		22.1%	
Mother College Graduate	17.6%		26.3%	
First Birth	44.1%		44.9%	
Limited English Proficiency	2.5%			
Disaster Exposure	21.2%		21.1%	
Hurricane Exposure	12.0%		12.7%	
Winter Storm Exposure	7.6%		8.5%	
Severe Storm Exposure	2.6%		2.5%	
Birth Weight (lbs.)	7.3	1.32	7.3	1.54
Gestational Age (weeks)	38.9	2.20	38.7	3.03
Low Birth Weight (<5.5 lbs.)	7.4%		8.8%	
Preterm (<37 weeks)	9.5%		11.0%	
Small for Gestational Age (lowest 10%)	9.8%		9.1%	
Math Score	0.0	0.99		
Reading Score	0.0	0.99		
Special Education	13.3%			
Gifted	6.7%			
N	**880,967**		**442,522**	

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. Since the degree of damage caused by a particular disaster is idiosyncratic to the specifics of the disaster and the landscape of the area, disaster declarations may more accurately reflect exposure to a disaster than weather-based measurements.

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 was assumed to have begun 40 weeks before birth for all children. The child was 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 an artificial correlation created by the fact that children who were born early are less likely to be exposed during gestation because there are fewer weeks of gestation during which a disaster could occur. In addition, gestational age is difficult to measure accurately and may even be less accurate following a disaster if prenatal care usage was affected. All analyses were also conducted using an alternate measure of disaster exposure calculated by counting forward 40 weeks from the presumed date of conception based on birthdate and gestational age. The results were very similar.

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 one and seven disasters over the 13 year time period. The types of disasters included hurricanes, winter storms, and severe storms associated with flooding and tornadoes. Table 14 provides details on the number of counties and the fraction of births affected by each disaster type.

Table 14. Descriptive Data on Natural Disasters and Prenatal Natural Disaster Exposure, 1988 to 2000

	All Disasters	Hurricanes	Winter Storms	Flooding/ Tornado
Events	15	7	3	5
Counties	100	88	74	42
Number of Births	~187,000	~94,000	~75,000	~31,000
Percent of Births	21%	11%	9%	3%

Empirical Analysis

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

For the time period in question, there was considerable geographic variation in the frequency of disaster exposure, but disasters were not concentrated in any one part of the state. There was also considerable variation across years in the percent of births affected by disasters of various types. The total percent of affected births ranged from 0% in several years that did not have any disasters to 80% of births in 1996 when four separate disasters occurred.

Since individuals were unlikely to be able to anticipate the occurrence of a natural disaster, their reproductive decisions were unlikely to be influenced by disasters. Therefore, families with a pregnancy at the time of the disaster should have been similar to other families with children of similar ages. Any other long term effects of disasters on families should not have varied between families who had children born just before the disaster 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 main analysis were disaster declarations in each trimester of pregnancy. Exposure was divided by trimester to allow for differences in the consequences of exposure by the period of development during which it occurred. Disasters were also 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 prenatal development and school outcomes. Aid provided by FEMA for winter storms tends to be solely Public Assistance aid for use by local and state governments for purposes like debris removal and repair of roads, bridges and utilities. This is in contrast to hurricanes and severe storms where a significant percent of the federal aid consists of individual assistance grants for families. This difference suggests that hurricanes and severe storms are associated with significantly more individual property damage. The per capital aid funding for hurricanes in the sample is also much higher than for the other types of storms, suggesting that hurricanes may be more severe for a larger number of people.

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

As control variables, the regressions included 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 were also included in this analysis. Week of birth fixed effects controlled for systematic differences in outcomes by season of birth that have been documented in previous literature (Doblhammer 2004). Year fixed effects controlled for changes over time due to changes in technology, economic conditions, or other factors. County fixed effects allowed for comparisons across children who were born in the same county at different times. The county fixed effects were important because they accounted for any unmeasured differences in county populations that are correlated with the frequency of disaster exposure. Standard errors in all regressions were calculated based on individuals clustered within county-year of birth to acknowledge that treatment status is assigned based on county of residence at a particular time rather than individual exposure.

The initial analyses included all individuals with matched records. The analysis was then extended to consider differences in the effects for different subgroups. Analyses were 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 was then conducted to determine the role played by common measures of health at birth in mediating the effects on educational outcomes. Finally, sensitivity tests were performed to eliminate the possibility of confounding influences.

Selection Bias

One serious concern for this study was the possibility that disaster occurrences altered the composition of births in counties exposed to the disaster. Disasters may have affected the composition of births in a county in three ways. First, pregnant women exposed to the disaster may have made the decision to move out of the county before the birth of their child. These women may have been 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 was determined at the time of the birth, there was no way to observe whether pregnant women were leaving the county as a result of the disaster.

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

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

Table 15 shows regressions of the number of births per month in each county on the percent of births in the month exposed to a disaster during each trimester. The first column shows the effect of disaster exposure on the total number of births. This column suggests that there may be some decrease in the number of births associated with early trimester exposure to a hurricane, and an increase in the number of births associated with exposure to a winter storm. The second column uses the natural log of total births as the outcomes measure. This is probably the better outcome measure given that the significance of an increase on decrease of a certain number of births depends on the overall birth rate. This column indicates no statistically significant effect of winter storm or hurricane or flood exposure on the total number of births. However, hurricane exposure in the first two trimesters appears to reduce the number of births between 2.6 and 3.6%. Given that this decrease in births occurs in the early trimesters, it probably signals an increase in miscarriages and abortions which are likely to bias the results towards an improvement in scores. However, I will discuss the implications of the selection in more detail in the results section.

Table 15. Regressions of Total Number of Births and Natural Log of the Number of Births in Each County in Each Month on Prenatal Disaster Exposure

	(1)	**(2)**
VARIABLES	**Births**	**Log(Births)**
Trimester 1 Hurricane	-3.598*	-0.036**
	(1.500)	(0.012)
Trimester 2 Hurricane	-1.727	-0.026*
	(1.143)	(0.011)
Trimester 3 Hurricane	-0.342	-0.013
	(1.337)	(0.012)
Trimester 1 Winter Storm	8.935*	0.014
	(3.766)	(0.016)
Trimester 2 Winter Storm	5.515	0.008
	(3.041)	(0.014)
Trimester 3 Winter Storm	6.940*	0.023
	(3.108)	(0.015)
Trimester 1 Flooding/Tornado	-2.213	0.003
	(2.735)	(0.021)
Trimester 2 Flooding/Tornado	1.922	0.029
	(3.031)	(0.021)
Trimester 3 Flooding/Tornado	-0.981	-0.000
	(2.574)	(0.026)
County Fixed Effects	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes
Month of Birth Fixed Effects	Yes	Yes
Observations	15,600	15,600
R-squared	0.978	0.963

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are calculated based on observations clustered within county.

A second serious concern for this study is the possibility that exposure to a disaster affects the likelihood that a child born in the state appears in the sample of students matched to their school records. If children move out of the state or attend private school at higher or lower rates following a disaster, it could affect the composition of children included in the matched sample. Table 16 shows the results of logistic regressions of an indicator for being in the matched sample on disaster exposure variables for children of all mothers and children born to mothers in different demographic subgroups. The results indicate the hurricanes and winter storms have no effect on matching. However, flooding and tornadoes may increase the match rates, particularly among disadvantaged groups. For this reason, all results for flooding and tornadoes will be interpreted with caution.

Table 16. Matching of Birth Records to School Records as a Function of Prenatal Disaster Exposure for Subgroups of Mothers (Logit)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**All Mothers**	**White Mothers**	**Black Mothers**	**Mothers w/ High School or Less**	**Mothers w/ Some College**
Trimester 1 Hurricane	1.004	0.981	1.012	1.018	0.986
	(0.013)	(0.028)	(0.015)	(0.022)	(0.018)
Trimester 2 Hurricane	1.011	0.990	1.019	1.022	0.997
	(0.013)	(0.026)	(0.016)	(0.023)	(0.020)
Trimester 3 Hurricane	0.996	0.969	1.002	0.998	0.994
	(0.013)	(0.028)	(0.018)	(0.024)	(0.016)
Trimester 1 Winter Storm	1.017	0.995	1.012	1.024	1.005
	(0.017)	(0.040)	(0.016)	(0.030)	(0.017)
Trimester 2 Winter Storm	1.026	0.989	1.026	1.023	1.025
	(0.018)	(0.049)	(0.019)	(0.027)	(0.023)
Trimester 3 Winter Storm	1.014	0.954	1.026	1.008	1.022
	(0.018)	(0.028)	(0.024)	(0.023)	(0.035)
Trimester 1 Flooding/Tornado	1.006	0.985	1.013	0.968	1.042*
	(0.018)	(0.041)	(0.019)	(0.025)	(0.019)
Trimester 2 Flooding/Tornado	1.080***	1.047	1.087***	1.055	1.090***
	(0.021)	(0.039)	(0.023)	(0.039)	(0.026)
Trimester 3 Flooding/Tornado	1.044*	1.024	1.061***	1.025	1.057**
	(0.019)	(0.045)	(0.019)	(0.029)	(0.019)
County Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year of Birth Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month of Birth Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	1,285,574	351,863	834,996	747,299	538,275

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

Results

Table 17 displays the basic results for the influence of prenatal disaster exposure on test scores and special education and gifted placement by disaster type and trimester of exposure. The negative effects of disasters are mostly concentrated among those exposed to hurricanes. Hurricane exposure in any trimester is associated with reduced math scores of about 2.3% of a standard deviation and reduced reading scores ranging from 1.6% to 2.2% of a standard deviation. Being exposed to flooding or tornadoes in the first trimester reduces math scores by 3.2% of a standard deviation. Winter storms in the later trimesters reduce the relative odds of placement into special education. None of the disaster types show significant effects on gifted placement. Overall, the effects on test scores are quite small but not trivial. The effects are similar in size to the effects of having a teacher with National Board Certification (Clotfelter, Ladd et al. 2007), a qualification for which the state of North Carolina pays $3,000 extra in salary per year. For the "missing births" shown in Table 15 to have effects of this size, it would be necessary for the "missing" children to have had average scores of three quarters to a whole standard deviation larger than the average. This seems quite unlikely, so it is unlikely that selection is the primary driver of the effect.

Table 17. 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	-0.023**	-0.016*	1.112	0.980
	(0.008)	(0.006)	(0.083)	(0.064)
Trimester 2 Hurricane	-0.021**	-0.010	1.105	1.028
	(0.007)	(0.006)	(0.075)	(0.055)
Trimester 3 Hurricane	-0.025***	-0.022***	1.167	0.934
	(0.007)	(0.006)	(0.096)	(0.056)
Trimester 1 Winter Storm	0.012	0.008	0.881	0.897
	(0.010)	(0.009)	(0.063)	(0.063)
Trimester 2 Winter Storm	0.012	0.008	0.837*	0.945
	(0.009)	(0.008)	(0.071)	(0.076)
Trimester 3 Winter Storm	0.011	0.014	0.799*	0.885
	(0.010)	(0.008)	(0.088)	(0.072)
Trimester 1 Flooding/Tornado	-0.032*	-0.014	0.938	0.991
	(0.015)	(0.009)	(0.111)	(0.121)
Trimester 2 Flooding/Tornado	-0.020	-0.002	1.407	1.011
	(0.016)	(0.010)	(0.305)	(0.109)
Trimester 3 Flooding/Tornado	0.000	0.007	1.613	0.919
	(0.015)	(0.010)	(0.445)	(0.117)
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	848,002	844,252	849,873	849,873
R-squared	0.254	0.247		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are calculated based on individuals clustered within 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 more vulnerable to negative consequences of disaster exposure. This section tests this theory by conducting regressions separately for children of white mothers, black mothers, mothers with a high school degree or less, and mothers with at least some college. A post estimation test then compares the size of the coefficients on disaster exposures for the two racial groups and the two education levels.

Table 18 shows the subgroup results for math, reading, and special education. Each pair of subgroup columns is followed by a column that indicates the statistical significance of the difference in coefficient size. As shown in the first two columns, children born to black mothers suffer significantly greater negative effects on math test scores from exposure to hurricanes in the second or third trimester compared to children of white mothers. Children of black mothers also suffer greater negative effects on reading test scores from third trimester exposure to hurricanes, as shown in the two middle columns of Table 18. The size of the test score effects for children of black mothers is quite a bit larger than the average effects across all children, ranging from 2.6 to 5.4% of a standard deviation. There were no significant differences in test scores between children of mothers with different education levels.

Table 18. Subgroup Differences in Effects on Math, Reading and Special Education

	Math (OLS)			Reading (OLS)			Special Education (Logit)		
VARIABLES	**White**	**Black**	**Sig.**	**White**	**Black**	**Sig.**	**High School or Less**	**More Than High**	**Sig.**
Trimester 1 Hurricane	-0.019*	-0.040**		-0.012	-0.026*		1.034	1.239*	*
	(0.008)	(0.015)		(0.007)	(0.013)		(0.051)	(0.127)	
Trimester 2 Hurricane	-0.015	-0.041***	*	-0.004	-0.021		1.049	1.193	
	(0.008)	(0.011)		(0.007)	(0.011)		(0.049)	(0.126)	
Trimester 3 Hurricane	-0.017	-0.052***	**	-0.013	-0.047***	*	1.104	1.302*	
	(0.009)	(0.011)		(0.008)	(0.011)		(0.056)	(0.170)	
Trimester 1 Winter Storm	0.011	0.006		0.010	-0.002		0.947	0.775*	*
	(0.010)	(0.018)		(0.010)	(0.018)		(0.040)	(0.091)	
Trimester 2 Winter Storm	0.015	0.001		0.017	-0.014	*	0.926	0.700*	*
	(0.009)	(0.016)		(0.010)	(0.013)		(0.043)	(0.102)	
Trimester 3 Winter Storm	0.009	0.015		0.011	0.018		0.906	0.649*	*
	(0.011)	(0.017)		(0.010)	(0.015)		(0.054)	(0.122)	
Trimester 1 Flooding/ Tornado	-0.033*	-0.033		-0.010	-0.019		1.003	0.854	
	(0.016)	(0.022)		(0.012)	(0.016)		(0.070)	(0.179)	
Trimester 2 Flooding/ Tornado	-0.031	-0.004		-0.004	-0.008		1.127	1.851**	***
	(0.018)	(0.021)		(0.012)	(0.019)		(0.138)	(0.441)	
Trimester 3 Flooding/ Tornado	-0.005	0.005		0.004	0.007		1.189	2.356**	***
	(0.018)	(0.024)		(0.011)	(0.017)		(0.169)	(0.736)	
Controls	Yes	Yes		Yes	Yes		Yes	Yes	
County Fixed Effects	Yes	Yes		Yes	Yes		Yes	Yes	
Year of Birth Fixed Effects	Yes	Yes		Yes	Yes		Yes	Yes	
Week of Birth Fixed Effects	Yes	Yes		Yes	Yes		Yes	Yes	

Note: *** p<0.001, ** p<0.01, * p<0.05; columns labeled `sig.' indicates whether the pair of coefficients to the left are significantly different from each other; standard errors displayed in parenthesis are calculated based on individuals clustered within county-year.

The last two columns of Table 18 show significant differences in the effects of disaster exposures on the probability of special education placement for children born to mothers with higher or lower education. The differences between these two groups are statistically significant for at least one trimester for all disaster types. However, children of highly educated mothers are more likely to be placed in special education if they were exposed to a hurricane, tornado or flooding but less likely to be placed in special education if they were exposed to a winter storm. This pattern of results suggests that highly educated mothers are more likely to respond to small changes in their child's cognitive abilities by seeking special education placement. It also raises the possibility that certain types of disaster exposure may be good rather than bad for educational outcomes. There was no difference in effects of exposure on special education placement between mothers of different races.

Mediation Analysis

The next section of the analysis considers the role played by common measures of health at birth. As a first step, Table 19 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 a 4.6% increase in the relative odds of low birth weight and a 4.7% increase in the relative odds of being small for gestational age related to exposure to a hurricane in the second trimester.

Given the limited evidence that disaster exposure affects birth outcomes, one would not expect these variables to mediate the effect on school outcomes. Indeed, regressions including birth outcomes as controls in the basic model do not show any changes in the effect of disasters on school outcomes.

This study's finding of no impact of disaster exposure on common measures of birth outcomes is at odds with much of the literature. However, a recent study of the effects of hurricane exposure similarly found no effects on birth weight and gestational age, but did find effects on birth complications (Currie and Rossin-Slater 2012). Additionally, a study using sibling fixed effects to examine the influence of prenatal cortisol exposure on educational outcomes found negative effects of cortisol exposure on adult educational attainment as well as IQ at age seven but no effects on birth outcomes (Aizer, Stroud et al. 2009). These types of findings, in addition to my own, suggest a need to understand the more subtle influences on prenatal cognitive development that may not be captured in broad summary measures such as birth weight.

Table 19. 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	-0.009	-0.005	1.020	1.011	1.001
	(0.009)	(0.016)	(0.024)	(0.025)	(0.021)
Trimester 2 Hurricane	0.001	0.031	1.050*	0.958	1.052*
	(0.008)	(0.018)	(0.025)	(0.022)	(0.024)
Trimester 3 Hurricane	0.004	0.019	1.011	0.977	1.022
	(0.008)	(0.015)	(0.025)	(0.021)	(0.023)
Trimester 1 Winter Storm	-0.002	-0.022	1.033	1.019	1.002
	(0.012)	(0.018)	(0.029)	(0.028)	(0.030)
Trimester 2 Winter Storm	0.017	0.019	0.971	0.979	0.989
	(0.009)	(0.018)	(0.028)	(0.024)	(0.026)
Trimester 3 Winter Storm	0.013	0.036	0.952	0.954	1.022
	(0.011)	(0.019)	(0.027)	(0.027)	(0.031)
Trimester 1 Flooding/Tornado	-0.020	-0.013	1.044	1.065	1.039
	(0.018)	(0.030)	(0.049)	(0.040)	(0.035)
Trimester 2 Flooding/Tornado	0.007	-0.004	1.000	0.995	0.979
	(0.009)	(0.022)	(0.035)	(0.025)	(0.032)
Trimester 3 Flooding/Tornado	-0.007	-0.036	1.037	1.041	0.987
	(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	0.075	0.021			

Note: *** $p<0.001$, ** $p<0.01$, * $p<0.05$; standard errors displayed in parenthesis are calculated based on individuals clustered within 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.

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 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 to consider the effects on children born just before the disaster occurred. To do this, a synthetic "zero trimester" and a synthetic "fourth trimester" is included in the basic regression equations. These trimesters are equal in length to the three real trimesters and include all children born in the three months before a disaster or conceived in the three months after in the counties where the disaster occurred. 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 four" would indicate other confounding effects of disaster exposure. "Trimester zero" may capture confounding effects as well but is also very likely to be affected by selection into having a baby immediately following a disaster.

The results of this analysis are shown in Table 20. Hurricane exposure in "trimester zero" is associated with significant changes in test scores and special education placement that suggest that there is quite a bit of selection into having a baby following a hurricane. There is also a significant decrease in math scores of 1.7% of a standard deviation for children exposed to a hurricane in “trimester four”. 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 smaller in “trimester four” than in the other trimesters, so some of the effect may indeed operate through prenatal development. “Trimester four” also shows 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. Math and reading test scores both seem to show a negative effect of “trimester four” tornado or flooding exposure but there are also other reasons to believe caution is necessary in interpreting these results.

One important consideration when using “trimester four” 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. As a general conclusion, the results from this test 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 20. Regressions of Educational Outcomes with Synthetic "Trimester 0" and "Trimester 4"

	(1)	(2)	(3)	(4)
VARIABLES	Math (OLS)	Reading (OLS)	Special Ed. (Logit)	Gifted (Logit)
"Trimester 0" Hurricane	-0.037***	-0.028***	1.152*	0.968
	(0.008)	(0.007)	(0.080)	(0.065)
Trimester 1 Hurricane	-0.027**	-0.020**	1.158	0.966
	(0.008)	(0.007)	(0.105)	(0.070)
Trimester 2 Hurricane	-0.025***	-0.013*	1.154	1.040
	(0.007)	(0.006)	(0.089)	(0.061)
Trimester 3 Hurricane	-0.029***	-0.024***	1.158	0.946
	(0.008)	(0.007)	(0.093)	(0.057)
"Trimester 4" Hurricane	-0.020**	-0.012	0.910	0.994
	(0.008)	(0.006)	(0.050)	(0.053)
"Trimester 0" Winter Storm	-0.007	-0.008	0.996	0.762***
	(0.009)	(0.008)	(0.140)	(0.059)
Trimester 1 Winter Storm	0.014	0.010	0.870	0.843*
	(0.010)	(0.009)	(0.067)	(0.065)
Trimester 2 Winter Storm	0.014	0.009	0.821*	0.879
	(0.010)	(0.008)	(0.072)	(0.078)
Trimester 3 Winter Storm	0.007	0.011	0.795*	0.827*
	(0.011)	(0.008)	(0.085)	(0.079)
"Trimester 4" Winter Storm	0.001	0.003	0.867**	0.863**
	(0.008)	(0.008)	(0.043)	(0.046)
"Trimester 0" Flooding/Tornado	-0.025	-0.016	0.794	1.176
	(0.014)	(0.011)	(0.101)	(0.203)
Trimester 1 Flooding/Tornado	-0.037***	-0.028***	1.152*	0.968
	(0.008)	(0.007)	(0.080)	(0.065)
Trimester 2 Flooding/Tornado	-0.027**	-0.020**	1.158	0.966
	(0.008)	(0.007)	(0.105)	(0.070)
Trimester 3 Flooding/Tornado	-0.025***	-0.013*	1.154	1.040
	(0.007)	(0.006)	(0.089)	(0.061)
"Trimester 4" Flooding/Tornado	-0.029***	-0.024***	1.158	0.946
	(0.008)	(0.007)	(0.093)	(0.057)

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

In a second test for more generalized effects of natural disasters on families with small children, 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, so that all families would have had a very young child during or soon after the disaster. Table 21 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. In this test, hurricane or tornado or flooding exposure in the third trimester are also associated with increased odds of being placed in special education. 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 21. 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 (Logit)**	**Gifted (Logit)**
Trimester 1 Hurricane	-0.001	-0.014	1.062	1.014
	(0.009)	(0.008)	(0.072)	(0.077)
Trimester 2 Hurricane	-0.002	-0.007	1.146	1.076
	(0.007)	(0.007)	(0.090)	(0.063)
Trimester 3 Hurricane	-0.014*	-0.017*	1.256**	0.951
	(0.007)	(0.007)	(0.106)	(0.070)
Trimester 1 Winter Storm	0.002	0.002	0.811*	1.166*
	(0.010)	(0.008)	(0.086)	(0.072)
Trimester 2 Winter Storm	0.004	0.003	0.769*	1.182**
	(0.010)	(0.008)	(0.081)	(0.064)
Trimester 3 Winter Storm	0.006	0.009	0.751*	1.116
	(0.011)	(0.009)	(0.095)	(0.070)
Trimester 1 Flooding/Tornado	-0.021	-0.005	0.814	1.134
	(0.016)	(0.010)	(0.180)	(0.100)
Trimester 2 Flooding/Tornado	-0.010	0.006	1.230	1.073
	(0.017)	(0.011)	(0.176)	(0.088)
Trimester 3 Flooding/Tornado	0.015	0.016	1.447*	0.967
	(0.017)	(0.010)	(0.237)	(0.087)
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	372,891	371,479	374,132	373,954
R-squared	0.262	0.257		

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are calculated based on individuals clustered within 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 mechanisms other than prenatal development may account for some of the effects 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.

There is also 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 two 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 weeks in which to be exposed to a disaster and, therefore, results in an artificial 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 17) 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 are nearly identical to the initial estimates.

The second approach is based on an approach used by Currie and Rossin-Slater (2012) 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 22. 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 three are somewhat smaller than those seen in the basic analysis. In addition, the effect of hurricane exposure on special education is significant in all trimesters. Overall, this analysis suggests that measurement error in the assignment of exposure to particular trimesters may be biasing the basic results somewhat downward. However, this method is vulnerable to bias if exposure to disasters affects the accuracy of measure gestational age.

Table 22. 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	-0.025***	-0.017**	0.012***	-0.001
	(0.005)	(0.006)	(0.002)	(0.001)
Trimester 2 Hurricane	-0.021***	-0.012*	0.010***	0.002
	(0.005)	(0.005)	(0.002)	(0.001)
Trimester 3 Hurricane	-0.017*	-0.016*	0.017***	-0.005**
	(0.007)	(0.007)	(0.003)	(0.002)
Trimester 1 Winter Storm	0.004	-0.002	-0.015***	-0.009***
	(0.007)	(0.007)	(0.003)	(0.002)
Trimester 2 Winter Storm	0.017**	0.008	-0.017***	-0.004*
	(0.007)	(0.007)	(0.003)	(0.002)
Trimester 3 Winter Storm	0.007	0.010	-0.027***	-0.011***
	(0.010)	(0.010)	(0.004)	(0.003)
Trimester 1 Flooding/Tornado	-0.036***	-0.021*	-0.003	-0.002
	(0.009)	(0.009)	(0.004)	(0.003)
Trimester 2 Flooding/Tornado	-0.016	0.002	0.045***	-0.002
	(0.009)	(0.009)	(0.004)	(0.002)
Trimester 3 Flooding/Tornado	-0.007	0.004	0.065***	-0.011**
	(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	848,002	844,252	849,873	849,873
R-squared	0.253	0.245	0.038	0.090

Note: *** p<0.001, ** p<0.01, * p<0.05; standard errors displayed in parenthesis are calculated based on individuals clustered within 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 result that prenatal exposure to some natural disasters, especially hurricanes, has a negative effect on school outcomes is relatively robust. 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 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 probably vary a great deal.

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 one 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 test score 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. As mentioned earlier, the increase in test scores associated with a teacher being National Board Certified is similar to the size of effect associated with hurricane exposure. Controlling for other factors, the effect of an additional pound of birth weight on test scores is 3 to 3.5% of a standard deviation, again a similar effect size to the effect of hurricane exposure. Finally, the largest effect sizes, those for hurricane exposure among children born to black mothers are as large as 5% of the total test score gap between Black and White students.

These effects warrant policy concern. This is especially true if we consider that the average effects across entire exposed counties 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 nine 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 lack of significant effects on birth outcomes and the failure of these variables to mediate the effects on educational outcomes are important to note. An important potential mechanism that may relate prenatal disaster exposure to educational outcomes is cortisol exposure related to prenatal maternal stress. Housing damage, power failures, and evacuations may also play an important role in the effect of prenatal natural disaster exposure, but the biological mechanisms mediating the effect of these disruptions of prenatal development is likely to be maternal stress as well.

Previous studies have found effects of increased maternal cortisol on both birth outcomes and educational outcomes (Beydoun and Saftlas 2008). However, the literature does not suggest that birth weight or gestational age *mediate* the effects of maternal cortisol on educational outcomes. Rather, birth weight and gestational age simply serve as signals of potentially negative developmental changes that may also have other effects. In this study, maternal stress and resulting cortisol exposure are likely an important mechanism affect cognitive development, but due to timing, intensity or other biological factors, cortisol exposure in this study does not affect birth outcomes. Other studies have also documented effects of stressors that seem to bypass measures of health at birth and yet affect later outcomes (Aizer, Stroud et al. 2009; Almond, Edlund et al. 2009).

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 similar relationships between fetal development and later life outcomes (Barker, Osmond et al. 1993; Barker 1999; Godfrey and Barker 2001; Rasmussen 2001; Shonkoff, Boyce et al. 2009), and many studies have established associations between birth outcomes and educational performance (Boardman, Powers et al. 2002; Hack, Flannery et al. 2002; Reichman 2005; Black, Devereux et al. 2007; Aarnoudse-Moens, Weisglas-Kuperus et al. 2009; Goosby and Cheadle 2009; Andreias, Borawski et al. 2010). 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 variation in size of effects across disaster type, trimester of exposure, and subgroup, provide some insight. Of disaster types, hurricanes show the most 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 discussed earlier, federal aid figures indicate that hurricanes are associated with more overall damage and more individual property damage than winter storms. This difference hints that family disruptions and stress associated with housing loss and displacement may be more important than short term damage to roads and utilities in influencing longer term educational outcomes of prenatal exposure.

As hypothesized, disadvantaged subgroups seem to show larger negative effects on test scores 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. On the other hand, children of White mothers 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 relative invulnerability may be related to greater resources which can be directed to replace or repair resources damaged in the disaster or a higher likelihood of avoiding damage in the first place (Cutter, Boruff et al. 2003; Zahran, Brody et al. 2008). The vulnerability of children born to Black mothers in this study may be particularly great because many suffer a double disadvantage with 67% of Black mothers being low education compared to just 47% of White mothers. Subgroup results suggest the importance of targeting additional resources to assist those most at risk in the wake of natural disasters. Future studies should work to better understand the mechanisms that mediate the effect of disasters on prenatal development.

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, particularly targeting disadvantaged groups that may be at the highest risk.

Future Directions

Future work on this topic should focus on discerning and 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.

The Effect of Natural Disasters on Children in School

Introduction

Natural disasters are relatively frequent events in the United States and throughout the world. Between 1995 and 2012, the Federal Emergency Management Agency (FEMA) made an average of 58 major disaster declarations annually (F.E.M.A. 2013). The International Disaster Database reports 260 disasters affecting over 100 million people in 2012 alone (EM-DAT 2013). Many children along with their families are affected by natural disasters, yet relatively little is known about the effects of such disasters on the success of children in school.

The effect of disasters on school performance is important because natural disasters often constitute a major community disruption with a number of impacts on the lives of children. To the extent that natural disasters negatively influence the ability of students to perform well in school, governments may want to address resources to mitigate these problems. For example, policy makers may want to reconsider policies for school closings and making up missed days of school, and they may want to put in place supports to help children experiencing stress or a disruption in their home life following a natural disaster. The presence of high stakes testing and accountability make it particularly important to understand the effect of disasters on test scores. Even a short run negative effect on test scores could have long run effects if it causes students to fail to be promoted to the next grade, teachers to be labeled ineffective, or schools to miss their accountability targets.

Research on the effects of disasters on children shows significant effects on stress symptoms (Vogel and Vernberg 1993; La Greca, Silverman et al. 1998; Ceyhan and Ceyhan 2007; Neria, Nandi et al. 2008; Osofsky, Osofsky et al. 2009; Dogan-Ates 2010). In some cases, these symptoms can lead to post-traumatic stress disorder (PTSD) (Shannon, Lonigan et al. 1994; Russoniello, Skalko et al. 2002; Galea, Nandi et al. 2005; Goenjian, Walling et al. 2005) or depression (Goenjian, Walling et al. 2005; Kar and Bastia 2006). The rates of PTSD in children may be quite high, perhaps higher than their parents (Vogel and Vernberg 1993; Neria, Nandi et al. 2008; Osofsky, Osofsky et al. 2009). These stress responses in children may directly affect their cognitive abilities or may lead to behavioral problems (Smilde-van den Doel, Smit et al. 2006; Swenson, Saylor et al. 2010) which could indirectly affect academic performance.

Disasters could also influence school success through lost days of school due to school closures or increased absences for individual students resulting in less time for learning. The destruction in housing that often follows a disaster could cause students to move to different schools, which could have negative impacts on educational performance (Pane, McCaffrey et al. 2008). Community disruptions could also lead to fewer resources for schools which could reduce student performance.

A few studies have attempted to address the question of whether natural disasters affected the academic performance of children exposed to the disaster. However, these studies have found contradictory results. Two studies have found negative effects related to an earthquake and a hurricane, especially among children with high levels of post-traumatic stress symptoms (Shannon, Lonigan et al. 1994; Ceyhan and Ceyhan 2007). Other studies of a different hurricane, a series of earthquakes, a tornado, and a super-cyclone found no average effect on academic achievement, in spite of significant stress symptoms (Martin and Little 1986; La Greca, Silverman et al. 1998; Kar and Bastia 2006; Kemp, Helton et al. 2012). Studies of the effects of man-made disasters on student achievement have shown similar contradictory results (Saigh, Mroueh et al. 1997; Smilde-van den Doel, Smit et al. 2006). Moreover, many of these studies also confront challenges with small sample sizes or a lack of pre-disaster measurement that may explain some of the inconsistent findings across studies.

This study uses a longitudinal administrative data set from the state of North Carolina to examine the question of whether natural disasters have an impact on student academic outcomes. The size and longitudinal nature of the data set allows for both pre- and post-disaster measures for more than 1.5 million students exposed to 22 different disasters across 17 years. This study calculates the effect of natural disaster exposure on math and reading scores in the year of the storm and in the years that follow. Compared to previous studies this study is able to produce a better causal estimate of the impact of natural disasters on school performance. In addition, the large sample size allows for an examination of differences in the effects across different student subgroups.

Background

Disasters and Educational Outcomes

Disasters can substantially disrupt the daily life of children in school and, therefore, have clear potential to have a negative effect on the school performance of children who experience a disaster. The unexpected nature of disasters makes them difficult to study because researchers rarely have the opportunity to establish measures of student school performance before the disaster. In addition, the intense disruption after the disaster often makes it difficult to field a study in the immediate aftermath.

Nevertheless, a number of researchers have taken on the challenge of exploring the effects of different types of disasters on student achievement. The primary types of natural disasters that have been studied are earthquakes, hurricanes, and tornadoes. A study of college students in Turkey who were exposed to a pair of earthquakes that occurred six years prior found significant negative effects on academic achievement (Ceyhan and Ceyhan 2007). In contrast, a study of college students exposed to a series of earthquakes in New Zealand in early 2011 found no significant change in overall student performance compared to performance in the previous year (Kemp, Helton et al. 2012).

Studies of hurricanes show similarly inconclusive results. A study of students exposed to Hurricane Hugo in South Carolina showed a decline in performance at least among a subset of the students who showed post-traumatic stress symptoms (Shannon, Lonigan et al. 1994). However, fourth through sixth graders exposed to Hurricane Andrew in Florida showed no change in school performance in spite of stress symptoms (La Greca, Silverman et al. 1998). Adolescents exposed to a cyclone in India also showed no change in student performance (Kar and Bastia 2006). A study of fourth and fifth graders exposed to a tornado in Texas also found no effect on school performance in the year of the storm, but there was some evidence of negative effects a year later (Martin and Little 1986).

Studies of the effect of man-made disasters on student performance are equally inconclusive. A study of Lebanese youth exposed to significant war related trauma showed negative effects on school performance among students with stress-related symptoms (Saigh, Mroueh et al. 1997). In contrast, school children exposed to an explosion of a firework storage facility in the Netherlands did not have lower academic performance compared to children who were not exposed (Smilde-van den Doel, Smit et al. 2006).

The lack of consistent findings among these studies maybe due to the extreme diversity in the methods, study populations, and timing of the studies. There were significant differences in the measures of academic performance used, including grades, test scores and self-reported academic performance. Additionally, only four studies have pretest measures (Martin and Little 1986; La Greca, Silverman et al. 1998; Smilde-van den Doel, Smit et al. 2006; Kemp, Helton et al. 2012). In addition, in many of the studies, the comparison group consists of children who were exposed to the disasters but suffered less severe consequences.

The population being studied also varies considerably between studies. Ages under study range from elementary school to college, and the studies range across four continents. The time that had passed since the disaster also ranged from less than a month to more than six years. Finally, many of the studies suffered from small sample sizes. Four studies had fewer than 120 participants (Martin and Little 1986; Saigh, Mroueh et al. 1997; La Greca, Silverman et al. 1998; Kar and Bastia 2006), and only one study had more than 1000 participants (Shannon, Lonigan et al. 1994). These large differences in study types, disaster types, and findings make it hard to draw definite conclusions about the effect of disasters on the school performance of exposed children.

The Effect of Disasters on Children's Stress Responses

The lack of conclusive evidence regarding the effect of disasters on the academic achievement of children is particularly surprising in light of very clear evidence regarding the effect of disasters on a number of stress-related symptoms. Reviews of the literature find that a large number of studies across many different contexts all show increases in post-traumatic stress symptoms among children exposed to disasters and related traumas (Vogel and Vernberg 1993; La Greca, Silverman et al. 2002; Galea, Nandi et al. 2005; La Greca and Silverman 2009; Dogan-Ates 2010).

Focusing specifically on natural disasters, a number of studies of earthquakes and hurricanes find a variety of stress symptoms among children of various ages. Two studies of the effects of earthquakes on college students found an increase in sleep disruptions, anxiety and depression (Kemp, Helton et al. 2012) and a decrease in quality of life (Ceyhan and Ceyhan 2007). Among adolescents, earthquake exposure was associated with PTSD and depressive symptoms (Goenjian, Walling et al. 2005).

Preschoolers exposed to Hurricane Hugo were more likely to develop significant behavior problems (Swenson, Saylor et al. 2010), and older children exposed to Hugo had increased rates of PTSD (Lonigan, Shannon et al. 1994; Shannon, Lonigan et al. 1994). Children exposed to Hurricanes Andrew, Floyd and Katrina also show significant increases in post-traumatic stress symptoms (La Greca, Silverman et al. 1998; Russoniello, Skalko et al. 2002; Osofsky, Osofsky et al. 2009). These children may even develop more severe stress reactions than their parents (Vogel and Vernberg 1993; Osofsky, Osofsky et al. 2009).

Several studies have connected more severe stress symptoms with declines in academic performance. Lebanese youth who developed PTSD following exposure to war trauma had decreased academic performance while similarly exposed students without PTSD showed no declines in performance (Saigh, Mroueh et al. 1997). The same pattern holds true for children who develop PTSD after exposure to Hurricane Hugo compared to their peers who didn't develop PTSD (Shannon, Lonigan et al. 1994). After a series of earthquakes in New Zealand, only college students who showed increased sleep disruption, anxiety and depression had decreased academic performance (Kemp, Helton et al. 2012). These findings suggest that stress reactions could play an important role in mediating any effect of natural disasters on academic achievement.

Differential Effects

Responses to disasters are not uniform across all groups of students. Many studies, particularly of hurricanes, suggest that girls have more significant stress responses than boys (Vogel and Vernberg 1993; Lonigan, Shannon et al. 1994; Shannon, Lonigan et al. 1994; La Greca, Silverman et al. 1998; Russoniello, Skalko et al. 2002). Likewise, several studies find larger stress effects for minority students (Shannon, Lonigan et al. 1994; La Greca, Silverman et al. 1998; Galea, Nandi et al. 2005).

Differences in stress responses by age are more complicated. All age groups seem to show some post-traumatic stress reactions, but the types of symptoms vary by age (Vogel and Vernberg 1993; La Greca and Silverman 2009; Dogan-Ates 2010). Younger children are more likely to have specific fears and separation anxiety (Vogel and Vernberg 1993) while older children and adolescents are more likely to develop anxiety, depression and PTSD (Shannon, Lonigan et al. 1994; Deering 2007; Dogan-Ates 2010). Adolescents may also be more likely to respond to stress from a disaster by acting out (Deering 2007). These differences in stress response by age may result in different academic effects from disaster exposure in different grades.

In addition to the differential susceptibility to stress responses, some groups may simply be more vulnerable to damage from the disaster. Racial and ethnic minorities, families with lower levels of educated, and families of lower socioeconomic status are more vulnerable to negative effects from disasters (Cutter, Mitchell et al. 2000; Cutter, Boruff et al. 2003; Fothergill and Peek 2004; Zahran, Brody et al. 2008). The social vulnerability literature suggests that this increased vulnerability in certain social groups is due to limited access to information, resources, and political representation (Cutter, Boruff et al. 2003; Zahran, Brody et al. 2008). Higher levels of vulnerability to damage may compound already more severe stress responses.

Mobility and Missed Schooling

Stress responses are not the only mechanisms that could result in a reduction in academic achievement in the aftermath of a disaster. Disasters also have the potential to increase mobility of students between schools as a result of families being displaced from their homes. This increase in mobility may be connected with decreased school performance (Vogel and Vernberg 1993). A study of Louisiana school children following Hurricanes Katrina and Rita found that those that were displaced from their schools for the rest of the school year had lower performance than those who were never displaced or were temporarily displaced and then returned (Pane, McCaffrey et al. 2008).

Students may also miss days of instruction either because schools are closed or because they are unable to get to school. In addition, students may respond to stress from the disaster by increases in truancy or school refusal (Dogan-Ates 2010). Children who missed more days of school following Hurricanes Katrina and Rita had lower test scores (Pane, McCaffrey et al. 2008). In addition, there may be a connection between mobility and missed days because students who are displaced from their schools may be more likely to have an unusual number of absences (Pane, McCaffrey et al. 2008). The extent to which school mobility and missed days mediate the effect of disaster exposure on academic achievement is unclear.

Contributions of the Current Study

This study uses a large administrative data set to avoid the problems with small sample sizes and lack of pre-disaster measures that plagued many previous studies. In addition, the long time frame allows the study to consider general effects across many disasters rather than focusing on a single event. The large sample size also makes subgroup analysis possible, in order to determine how academic achievement effects vary between different groups. Finally, this study can examine the possible mechanisms of between school mobility and missed days of school. Altogether, the analyses performed in this study create a clearer picture of the how the effects of natural disasters operate to influence children's school achievement.

Method

Data

The educational data in this study comes from administrative records for all school districts in North Carolina from 1996 to 2011. Educational data was provided by the North Carolina Education Research Data Center. The data includes over 10 million individual test records for over 2.9 million unique students in grades three through eight. The data set contains test score records for each student in each year that they were tested in North Carolina. Records for each student can be linked across different grades allowing for comparisons of individual students' scores before and after a disaster occurs. The main academic achievement variables in this study are scores on End of Grade reading and math tests in third through eighth grades.

The source of data on natural disasters is the Federal Emergency Management Agency's (FEMA) records of major disaster declarations. A major disaster declaration designates specific counties as eligible for federal aid through FEMA's Public Assistance and Individual Assistance grant programs. Between 1996 and 2011, North Carolina experienced 22 Major Disaster Declarations. Of these disasters, 12 were hurricanes, six were winter storms, and four were severe storms associated with flooding or tornadoes.

Each type of disaster is considered separately in this paper to account for the potential difference in impacts for different types of disasters.

Table 23 shows the percent of counties and students in the data that were affected by each disaster type.

Table 23. Major Disaster Declarations in North Carolina 1995 to 2011

	All Disasters	Hurricanes	Winter Storms	Tornadoes/ Flooding
Events	22	12	6	4
Counties Affected	100%	95%	75%	38%
Students Affected	54%	40%	23%	10%

Analysis

The outcome variables in the main analysis are math and reading test scores standardized to have a mean of zero and a standard deviation of one for each grade, year, and subject. The independent variables in the analysis are two indicator variables, one indicating a disaster in the current year and the other indicating a disaster in the previous year. The model for the main analysis is:

(2) $$Y_{itc} = \beta_1 D_{tc} + B_2 D_{t-1c} + \Gamma_i + \kappa_t + \varepsilon_{it}$$

Where the variables are as follows:

Y_{it} is an outcome variable for student *i* in year *t* in county *c.*

D_t is an indicator for a disaster in county *c* in year *t*.

D_{t-1c} is an indicator for a disaster in county *c* in year *t*-1.

Γ_i is an individual student fixed effect.

K_t is a year fixed effect.

ε_{it} is the error term for each student in each year.

Student fixed effects are included in the model in order to compare a students' score after the disaster to their own scores in other years. No other student level covariates are included in the models because student fixed effects absorb all time invariant student traits. However, year fixed effects are included to control for potential difference in the overall test performance in the year of a given disaster.

A potential source of bias for this analysis is the possibility that students move to a different county between the disaster itself and the test at the end of the school year. To deal with the problem posed by selective mobility out of counties experiencing a disaster, each student's disaster exposure is based on the county that where they first appeared in the educational data. In addition, students who are retained in grade are excluded from the analysis because they are more likely to be exposed to a disaster in a given grade simply because there is more opportunity for exposure. Standard errors are calculated based on students clustered within counties.

Following this basic analysis, I ran the model in equation two separately for elementary school students (grades three through five) and middle school students (grades six through eight). The literature indicates that natural disasters have different psychological effects for children of different ages, so one might expect differences in the effects of disasters on children in different grades. Specifically, older students may be more prone to PTSD or depression after a disaster, so middle schoolers may experience larger effects.

The next step of the analysis is to consider the effects of disasters separately for different population subgroups. The model in equation two was rerun with the subsamples of White students, Black students, students receiving free or reduced price lunch and students not receiving free or reduced price lunch. The analyses of subgroups defined by free or reduced price lunch receipt only include the school years 1999 to 2011 because individual level free lunch data is not available before 1999.

The final section of the analysis looks at two possible mechanisms mediating the effect of natural disasters on student achievement. The first possible mechanism is between school mobility. In this analysis, the outcome variable is an indicator for whether the student appeared in a different school from the school where they were tested in the previous year. In the case of school mobility, it does not make sense to use a student as their own point of comparison because a move one year does not necessarily indicate that a student is more likely to move in another year. Therefore, for the mobility analysis, student fixed effects are replaced with county fixed effects and student covariates for student race, gender and grade level are included in the model. The model for mobility is shown in equation three:

(3) $$Y_{itc} = \beta_1 D_{tcg} + \beta_2 X_i + \Gamma_c + \kappa_t + \varepsilon_{it}$$

Where the variables are as follows:

Y_{it} is an outcome variable for student *i* in year *t* in county *c.*

D_{tcg} is a vector of indicators for a disaster in county *c* in year *t* in grade *g*.

X_i is a vector of student level controls for student *i.*

Γ_c is a county fixed effect.

K_t is a year fixed effect.

ε_{it} is the error term for each student in each year.

A second possible mechanism is missed days of school. The total number of days missed by a given student was calculated based on the gap between the number of days that the student attended and the total number of school days in the state. The outcome variable was then analyzed using a the model in equation two.

Results

Table 24 shows the results of the main analysis for the effect of hurricane exposure on math and reading test scores. Hurricane exposure appears to have a negative effect on reading test scores, especially in middle school grades. The size of the effect is quite small, a bit more than 1% of a standard deviation. The point estimates are negative for the effect on math scores as well, but the effects are not statistically significant. By the school year after the hurricane, the effect sizes have reduced toward zero and all are insignificant.

Table 24. Effect of Hurricanes on Math and Reading Test Scores

	Math			Reading		
	All Grades	**Elementary Grades**	**Middle Grades**	**All Grades**	**Elementary Grades**	**Middle Grades**
Hurricane Exposure	-0.007	-0.003	-0.005	-0.013***	-0.006	-0.012**
	(0.007)	(0.007)	(0.005)	(0.004)	(0.004)	(0.004)
Year Post Hurricane	-0.001	-0.002	-0.001	-0.008	-0.006	-0.003
	(0.012)	(0.009)	(0.011)	(0.010)	(0.007)	(0.010)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Student Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,988,890	4,594,130	4,394,760	8,959,930	4,575,397	4,384,533

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties.

Table 25 shows the results of the same models for exposure to winter storms. In the case of winter storms, there appear to be positive effects on math and reading achievement for middle schoolers. The size of the effects is similar to the size of the effect from hurricanes or a bit larger. In addition, the effect on middle school math scores does not appear to fade in the subsequent school year. Compared to hurricanes, winter storms are associated with far less housing damage and disruption. However, both likely caused missed days of school. The difference in effects between hurricanes and winter storms, therefore, suggests that missed days of school may not be the primary mechanism mediating disasters' influence on test scores.

Table 25. Effect of Winter Storms on Math and Reading Test Scores

	Math			Reading		
	All Grades	**Elementary Grades**	**Middle Grades**	**All Grades**	**Elementary Grades**	**Middle Grades**
Winter Storm Exposure	0.016	-0.005	0.018*	0.016**	0.005	0.018*
	(0.008)	(0.007)	(0.008)	(0.005)	(0.005)	(0.007)
Year Post Winter Storm	0.016	-0.004	0.015*	0.006	0.001	0.001
	(0.010)	(0.006)	(0.006)	(0.007)	(0.005)	(0.005)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Student Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,988,856	4,594,113	4,394,743	8,959,892	4,575,381	4,384,511

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties.

Table 26 displays the main analysis for severe storms accompanied by tornadoes or flooding. These results are all statistically insignificant. The finding of no result for these storms is not surprising because, while often severe, the damage is likely to be limited to a small portion of the population in the affected counties.

Table 26. Effect of Severe Storms with Tornadoes or Flooding on Math and Reading Test Scores

	Math			Reading		
	All Grades	Elementary Grades	Middle Grades	All Grades	Elementary Grades	Middle Grades
Tornado/Flooding Exposure	-0.012	0.001	0.009	-0.007	0.012	0.007
	(0.023)	(0.033)	(0.023)	(0.021)	(0.032)	(0.025)
Year Post Tornado/ Flooding	-0.005	0.012	0.018	-0.005	0.017	0.019
	(0.013)	(0.012)	(0.011)	(0.006)	(0.015)	(0.018)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Student Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,988,967	4,594,201	4,394,766	8,960,005	4,575,467	4,384,538

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties.

Subgroups

To better understand how disasters affect different groups of students, this section shows the analyses separately for White students, Black students, students receiving free or reduced price lunch and students not receiving subsidized lunch.

Table 27 displays subgroup results for hurricane exposure. The negative effects on middle school reading observed in the main analysis appear to be concentrated among Black students and students receiving subsidized lunch. The size of effects is similar to the main analysis. In addition, there is evidence of a negative effect on elementary reading scores among students receiving free or reduced price lunch, and this effect may persist over time.

Table 27. Effect of Hurricanes on Math and Reading Test Scores by Subgroup

	Math				Reading			
	White Students	Black Students	Paid Lunch Students	Free/ Reduced Lunch Students	White Students	Black Students	Paid Lunch Students	Free/ Reduced Lunch Students
	All Grades				All Grades			
Hurricane Exposure	0.005	0.002	0.006	-0.012	-0.002	-0.010**	-0.004	-0.017***
	(0.005)	(0.008)	(0.006)	(0.008)	(0.004)	(0.003)	(0.004)	(0.004)
Year Post Hurricane	0.016	0.008	0.014	-0.014	0.007	-0.002	0.003	-0.018*
	(0.014)	(0.007)	(0.014)	(0.010)	(0.011)	(0.006)	(0.011)	(0.008)
	Elementary Grades				**Elementary Grades**			
Hurricane Exposure	0.004	0.005	0.006	-0.005	0.000	0.000	0.002	-0.009*
	(0.006)	(0.009)	(0.006)	(0.007)	(0.004)	(0.006)	(0.004)	(0.004)
Year Post Hurricane	0.012	0.001	0.012	-0.010	0.005	-0.002	0.004	-0.014*
	(0.010)	(0.007)	(0.010)	(0.009)	(0.007)	(0.005)	(0.007)	(0.006)
	Middle School Grades				**Middle School Grades**			
Hurricane Exposure	0.005	0.001	0.003	-0.008	-0.002	-0.013**	-0.007	-0.013**
	(0.004)	(0.005)	(0.006)	(0.006)	(0.003)	(0.004)	(0.005)	(0.005)
Year Post Hurricane	0.015	0.010	0.008	-0.011	0.010	0.002	0.004	-0.008
	(0.013)	(0.006)	(0.013)	(0.009)	(0.010)	(0.005)	(0.010)	(0.007)

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties; all regressions include student and year fixed effects.

Subgroup effects for winter storms, displayed in Table 28, suggest positive effects on reading scores, but no clear pattern of subgroup differences.

Table 28. Effect of Winter Storms on Math and Reading Test Scores by Subgroup

	Math				Reading			
	White Students	Black Students	Paid Lunch Students	Free/ Reduced Lunch Students	White Students	Black Students	Paid Lunch Students	Free/ Reduced Lunch Students
	All Grades				All Grades			
Winter Storm Exposure	0.004	0.001	0.010	0.016	0.005	0.012*	0.011**	0.012
	(0.007)	(0.006)	(0.008)	(0.013)	(0.005)	(0.006)	(0.004)	(0.007)
Year Post Winter Storm	0.010	-0.000	0.018*	0.004	0.001	-0.005	0.002	-0.005
	(0.009)	(0.006)	(0.009)	(0.012)	(0.005)	(0.006)	(0.006)	(0.009)
	Elementary Grades				Elementary Grades			
Winter Storm Exposure	-0.018*	-0.016	-0.005	0.013	-0.004	-0.001	0.002	0.011
	(0.007)	(0.009)	(0.008)	(0.011)	(0.006)	(0.007)	(0.005)	(0.007)
Year Post Winter Storm	-0.009	-0.012*	0.001	-0.004	-0.006	-0.002	-0.004	0.002
	(0.006)	(0.006)	(0.008)	(0.009)	(0.005)	(0.006)	(0.005)	(0.006)
	Middle School Grades				Middle School Grades			
Winter Storm Exposure	0.004	0.007	0.007	0.022*	0.003	0.019	0.014	0.031***
	(0.008)	(0.007)	(0.009)	(0.010)	(0.006)	(0.010)	(0.008)	(0.009)
Year Post Winter Storm	0.008	0.007	0.008	0.006	-0.002	-0.010	0.000	-0.002
	(0.006)	(0.006)	(0.006)	(0.008)	(0.004)	(0.006)	(0.005)	(0.009)

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties; all regressions include student and year fixed effects.

Table 29 shows subgroup results for tornadoes and flooding. In general, the lack of results matches the main analysis. There is, however, some evidence that these storms have a negative effect on students receiving free or reduced price lunch. These effects are about 4 to 5% of a standard deviation and are larger than the effects associated with hurricanes or winter storms.

Table 29. Effect of Tornadoes or Flooding on Math and Reading Test Scores by Subgroup

	Math				**Reading**			
	White Students	Black Students	Paid Lunch Students	Free/ Reduced Lunch Students	White Students	Black Students	Paid Lunch Students	Free/ Reduced Lunch Students
	All Grades				**All Grades**			
Tornado/ Flooding	0.001	-0.002	-0.003	-0.049*	0.008	0.004	0.005	-0.041*
	(0.026)	(0.014)	(0.052)	(0.019)	(0.019)	(0.011)	(0.034)	(0.020)
Year Post Tornado/ Flooding	-0.011	0.017	-0.029	0.003	-0.004	0.006	-0.008	0.012
	(0.009)	(0.022)	(0.024)	(0.022)	(0.005)	(0.012)	(0.012)	(0.017)
	Elementary Grades				**Elementary Grades**			
Tornado/ Flooding	-0.002	-0.007	0.006	-0.024	0.006	-0.001	0.025	-0.015
	(0.018)	(0.012)	(0.038)	(0.023)	(0.014)	(0.012)	(0.031)	(0.022)
Year Post Tornado/ Flooding	-0.013	0.011	-0.055	0.025	-0.002	-0.001	-0.035	0.009
	(0.010)	(0.017)	(0.031)	(0.037)	(0.006)	(0.010)	(0.020)	(0.029)
	Middle School Grades				**Middle School Grades**			
Tornado/ Flooding	0.002	0.004	-0.004	-0.030	0.004	0.004	-0.000	-0.021
	(0.012)	(0.016)	(0.026)	(0.017)	(0.009)	(0.007)	(0.016)	(0.012)
Year Post Tornado/ Flooding	-0.010	0.009	-0.020	-0.005	0.001	0.014	0.006	0.017
	(0.007)	(0.017)	(0.018)	(0.014)	(0.005)	(0.014)	(0.013)	(0.021)

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties; all regressions include student and year fixed effects.

The results in this section suggest that the negative effects of hurricanes, and perhaps tornadoes and flooding, are concentrated among disadvantaged groups. There is no pattern for the positive effects of winter storms.

Mechanisms

This section shows the results of analyses looking at potential mechanisms mediating the effects of hurricanes and winter storms on reading and math test scores. Tornadoes and flooding are not included in this section because of the overall lack of effects on test scores.

Table 30 shows the effects of disaster exposure in each grade on the probability that a student has changed schools since the previous year. Each grade of exposure is considered separately because the probability of changing schools varies significantly between grades. Third grade is omitted because there is no data on the schools where students were enrolled the previous year. Sixth grade is omitted because the vast majority of North Carolina students change schools in sixth grade as part of a move to middle school.

Table 30. The Effect of Disaster Exposure on School Mobility

	Hurricane	Winter Storm
Exposure in 4th Grade	0.030**	-0.005
	(0.011)	(0.013)
Exposure in 5th Grade	0.033**	-0.019
	(0.011)	(0.013)
Exposure in 7th Grade	0.007	-0.001
	(0.011)	(0.011)
Exposure in 8th Grade	0.025**	-0.009
	(0.009)	(0.017)
Observations	6,919,720	6,919,720

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties; all regressions include county and year fixed effects.

The results for hurricane exposure suggest that hurricanes increase the probability of school mobility in fourth, fifth and eighth grade. There does not appear to be a significant effect on mobility in seventh grade. In the second column of Table 30, which shows effects from winter storm exposure, there are no statistically significant effects on mobility. This difference in the effects on mobility across disaster types paired with the opposite direction effects on test scores suggest that mobility may be an important mediator of the negative effect of hurricanes.

Table 31 shows the effects of hurricanes and winter storms on the total number of days missed by affected students. There is a significant increase in days missed related to exposure to a winter storm but no significant change in days missed associated with hurricane exposure. On the surface, this result is surprising because, anecdotally, schools are often closed for a period of time following a hurricane. There is, however, an important difference in timing between hurricanes and winter storms. Hurricanes typically occur between August and October, near the beginning of the school year. Winter storms more often occur in January and February. This difference in timing may mean that schools have more time to make up missed days due to hurricanes than missed days due to winter storms. Even for winter storms the average student misses less than one day as a result of the storm. The difference in effects on missed days suggests that missed days are not an important mechanism underlying the negative effect of hurricanes on test scores.

Table 31. The Effects of Hurricane and Winter Storm Exposure on Missed Days of School

	Hurricanes			**Winter Storms**		
	All Grades	**Elementary Grades**	**Middle Grades**	**All Grades**	**Elementary Grades**	**Middle Grades**
Disaster Exposure	-0.211	-0.195	-0.215	0.758*	0.739**	0.836*
	(0.164)	(0.161)	(0.178)	(0.327)	(0.274)	(0.326)
Year Post Disaster	-0.538	-0.398	-0.557	-0.036	0.230	0.129
	(0.298)	(0.292)	(0.322)	(0.292)	(0.255)	(0.284)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Student Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

Note: *p<.05; **p<.01; ***p<.001; standard errors displayed in parenthesis are calculated based on observations clustered within counties.

Discussion

Overall, the results of this study suggest that natural disasters have small but significant impacts on the performance of students in school. Hurricanes have negative effects on student test score performance, especially for middle school reading test scores. The size of these effects is quite small, but these are average effects across all students in counties that were exposed to a hurricane. Much larger effects may exist for students and counties that experienced particularly severe disaster related experiences. Also, negative effects are concentrated among disadvantaged students who can least afford to fall behind.

In contrast, winter storms appear to have a positive influence on student test score performance in the same grades. This positive effect is surprising, and this study does not provide a clear explanation for the mechanisms by which winter storms improve student performance. However, a couple of possibilities are worth exploring in future studies. First, days of school missed for school are likely to be made up at a later point in the semester which may result in more days of school closer to the testing date. Second, parents are likely to remain home with their children during snow days which may offer an opportunity for parental enrichment activities. Additionally, far from having a negative psychological effect, snow days may be viewed by children as a positive event. Finally, the influx of disaster assistance could create jobs and improve the economic conditions in the community.

The difference in effects between hurricanes and winter storms does offer a window into a few potential mechanisms that may mediate the effects. Since winter storms are more likely to result in missed days, but hurricanes have a negative effect on test scores, it suggests that missed days of school are not an important influence on academic performance in the wake of these disasters. School mobility, which is increased by hurricanes but not by winter storms, may be a more negative influence. This study cannot directly assess the influence of stress effects on student performance, but psychological impacts may be another important influence in the case of hurricanes. Middle school students may be more likely to experience PTSD and depression, which may explain the differential impacts in these grades.

Policy Implications

The negative effect of hurricanes on tests scores appear to fade out over time, making the long term implications of the negative effects for academic performance uncertain. However, even short term changes in academic achievement can have serious consequences for students, teachers and schools that face rewards or sanctions from test based accountability systems in the wake of a hurricane. In addition, effects on early test scores may result in effects on other school factors that have long term consequences, such as grade retention and course tracking. Policymakers could benefit from being aware of the effect of natural disasters on the performance of children when designing policies to apply to schools in areas that frequently experience such disasters.

In addition, policymakers could intervene to reduce the negative impact of disasters on children's psychological wellbeing. Research suggests that school-based interventions can improve the mental health of children impacted by a disaster and even lead to improvements in their school performance (Goenjian, Walling et al. 2005; Weems, Taylor et al. 2009). These types of interventions may be an important tool for policymakers that wish to maintain high test scores in areas affected by frequent hurricanes.

Conclusion

The three studies that make up this dissertation explore three aspects of the effects of natural disaster exposure on children. The first study looks at the influence of exposure during the prenatal period on maternal health behaviors and birth outcomes. The second study takes a longer view and explores the impact of prenatal exposure to a natural disaster on academic achievement in the third grade. Finally, the third study considers the impact of exposure to a natural disaster on the academic achievement of children who are in school at the time of the disaster.

Across all three studies I find that exposure to hurricanes has a negative impact on the outcomes of children. Prenatal exposure to hurricanes decreases prenatal care use and increases the probability that mothers report that their pregnancy was unwanted. In the longer term, children exposed to hurricanes prenatally are less likely to perform well in math and reading once they reach third grade. Finally, children in middle school at the time of a hurricane have lower reading test scores.

Winter storms, on the other hand, appear to be largely positive in their effects on children. Exposure to winter storms reduces maternal smoking during pregnancy and may also lead to small improvements in birth outcomes. In addition, children exposed to winter storms prenatally or while they are in school may have better math and reading test scores. Across both types of disasters, children from more disadvantaged families appeared to suffer more negative consequences and enjoy fewer benefits.

These findings lead to some general conclusions about the longer term effects of natural disasters for children. First, not all disasters are equal. Different types of disasters have distinct effects on the children who experience them. Second, children do experience long term negative effects from hurricanes. Policymakers and communities should pay attention to these potential long term costs as they prepare for and respond to natural disasters. Lastly, the greatest assistance is likely to be needed by disadvantaged families, who are the most vulnerable to natural disasters.

References

Aarnoudse-Moens, C. S., N. Weisglas-Kuperus, et al. (2009). "Meta-analysis of neurobehavioral outcomes in very preterm and/or very low birth weight children." Pediatrics 124(2): 717-728.

Aizer, A., L. Stroud, et al. (2009). "Maternal stress and child well-being: Evidence from siblings." Unpublished manuscript, Brown University, Providence, RI.

Almond and J. Currie (2010). "Human Capital Development Before Age Five." National Bureau of Economic Research Working Paper Series No. 15827.

Almond and J. Currie (2011). "Killing Me Softly: The Fetal Origins Hypothesis." The Journal of Economic Perspectives 25(3): 153-172.

Almond, L. Edlund, et al. (2009). "Chernobyl's subclinical legacy: prenatal exposure to radioactive fallout and school outcomes in Sweden." The Quarterly Journal of Economics 124(4): 1729-1772.

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

Almond, D. (2005). Is the 1918 Influenza Pandemic over?

Almond, D., K. Y. Chay, et al. (2005). "The costs of low birth weight." Quarterly Journal of Economics 120(3): 1031-1083.

Almond, D. and B. Mazumder (2011). "Health Capital and the Prenatal Environment: The Effect of Ramadan Observance During Pregnancy." American Economic Journal-Applied Economics 3(4): 56-85.

Andreias, L., E. Borawski, et al. (2010). "Neighborhood Influences on the Academic Achievement of Extremely Low Birth Weight Children." Journal of Pediatric Psychology 35(3): 275-283.

Andreias, L., E. Borawski, et al. (2010). "Neighborhood influences on the academic achievement of extremely low birth weight children." Journal of Pediatric Psychology 35(3): 275-283.

Auger, N., E. Kuehne, et al. (2011). "Preterm Birth During an Extreme Weather Event in Qu,bec, Canada: A "Natural Experiment"." Maternal and Child Health Journal 15(7): 1088-1096.

Barker, D. J. (1995). "Fetal origins of coronary heart disease." BMJ 311(6998): 171-174.

Barker, D. J. P. (1999). "The fetal origins of coronary heart disease and stroke: Evolutionary implications." Evolution in Health and Disease: 246-250.

Barker, D. J. P., C. Osmond, et al. (1993). "The Relation of Small Head Circumference and Thinness at Birth to Death from Cardiovascular-Disease in Adult Life." British Medical Journal 306(6875): 422-426.

Belsky, J., L. Steinberg, et al. (2010). "The development of reproductive strategy in females: early maternal harshness --> earlier menarche --> increased sexual risk taking." Dev Psychol 46(1): 120-128.

Berkowitz, G. S., M. S. Wolff, et al. (2003). "The World Trade Center disaster and intrauterine growth restriction." Jama-Journal of the American Medical Association 290(5): 595-596.

Beydoun, H. and A. F. Saftlas (2008). "Physical and mental health outcomes of prenatal maternal stress in human and animal studies: a review of recent evidence." Paediatric and Perinatal Epidemiology 22(5): 438-466.

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

Boardman, J. D., D. A. Powers, et al. (2002). "Low birth weight, social factors, and developmental outcomes among children in the United States." Demography 39(2): 353-368.

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

Ceyhan, E. and A. A. Ceyhan (2007). "Earthquake survivors' quality of life and academic achievement six years after the earthquakes in Marmara, Turkey." Disasters 31(4): 516-529.

Clotfelter, C. T., H. F. Ladd, et al. (2007). "Teacher credentials and student achievement: Longitudinal analysis with student fixed effects." Economics of Education Review 26(6): 673-682.

Conley, D., K. W. Strully, et al. (2003). The starting gate: birth weight and life chances, University of California Press.

Currie and M. Rossin-Slater (2012). "Weathering the Storm: Hurricanes and Birth Outcomes." National Bureau of Economic Research Working Paper Series No. 18070.

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.

Cutter, S. L., B. J. Boruff, et al. (2003). "Social vulnerability to environmental hazards*." Social Science Quarterly 84(2): 242-261.

Cutter, S. L., J. T. Mitchell, et al. (2000). "Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina." Annals of the Association of American Geographers 90(4): 713-737.

Dancause, K. N., D. P. Laplante, et al. (2011). "Disaster-related prenatal maternal stress influences birth outcomes: Project Ice Storm." Early Human Development 87(12): 813-820.

Deering, C. G. (2007). "A cognitive developmental approach to understanding how children cope with disasters." Journal of Child and Adolescent Psychiatric Nursing 13(1): 7-16.

Doblhammer, G. (2004). The late life legacy of very early life, Springer.

Dogan-Ates, A. (2010). "Developmental differences in children's and adolescents' post-disaster reactions." Issues in Mental Health Nursing 31(7): 470-476.

Dole, N. (2003). "Maternal Stress and Preterm Birth." American Journal of Epidemiology 157(1): 14-24.

Dole, N., D. A. Savitz, et al. (2003). "Maternal stress and preterm birth." American Journal of Epidemiology 157(1): 14-24.

Ellis, B. J. and W. T. Boyce (2011). "Differential susceptibility to the environment: toward an understanding of sensitivity to developmental experiences and context." Dev Psychopathol 23(1): 1-5.

EM-DAT (2013). The OFDA/CRED International Disaster Database U. C. d. Louvain. Brussels (Belgium).

Engel, S. M., G. S. Berkowitz, et al. (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., A. R. Marks, et al. (2007). "Low birthweight in New York City and upstate New York following the events of September 11th." Hum Reprod 22(11): 3013-3020.

Evans, W. N. and D. S. Lien (2005). "The benefits of prenatal care: evidence from the PAT bus strike." Journal of Econometrics 125(1-2): 207-239.

F.E.M.A. (2013). "Disaster Declarations by Year." Retrieved February 25, 2013, from http://www.fema.gov/disasters/grid/year.

Figlio, D., S. Hamersma, et al. (2009). "Does prenatal WIC participation improve birth outcomes? New evidence from Florida." Journal of Public Economics 93(1-2): 235-245.

Fiscella, K. (1995). "Does Prenatal-Care Improve Birth Outcomes - a Critical-Review." Obstetrics and Gynecology 85(3): 468-479.

Fothergill, A. and L. A. Peek (2004). "Poverty and disasters in the United States: A review of recent sociological findings." Natural Hazards 32(1): 89-110.

Galea, S., A. Nandi, et al. (2005). "The epidemiology of post-traumatic stress disorder after disasters." Epidemiologic Reviews 27(1): 78-91.

Glynn, L. M., P. D. Wadhwa, et al. (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. and D. J. Barker (2001). "Fetal programming and adult health." Public Health Nutr 4(2B): 611-624.

Goenjian, A. K., D. Walling, et al. (2005). "A prospective study of posttraumatic stress and depressive reactions among treated and untreated adolescents 5 years after a catastrophic disaster." American Journal of Psychiatry 162(12): 2302-2308.

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

Goosby, B. J. and J. E. Cheadle (2009). "Birth weight, math and reading achievement growth: a multilevel between-sibling, between-families approach." Social Forces 87(3): 1291-1320.

Guillory, V. J., M. E. Samuels, et al. (2003). "Prenatal care and infant birth outcomes among Medicaid recipients." J Health Care Poor Underserved 14(2): 272-289.

Hack, M., D. J. Flannery, et al. (2002). "Outcomes in young adulthood for very-low-birth-weight infants." New England Journal of Medicine 346(3): 149-157.

Hedegaard, M., T. B. Henriksen, et al. (1996). "Do stressful life events affect duration of gestation and risk of preterm delivery?" Epidemiology 7(4): 339-345.

Kapoor, A., E. Dunn, et al. (2006). "Fetal programming of hypothalamo-pituitary-adrenal function: prenatal stress and glucocorticoids." J Physiol 572(Pt 1): 31-44.

Kar, N. and B. K. Bastia (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.

Kemp, S., W. S. Helton, et al. (2012). How Does a Series of Earthquakes Affect Academic Performance? Forces of Nature and Cultural Responses, Springer: 51-67.

Kinsella, M. T. and C. Monk (2009). "Impact of Maternal Stress, Depression and Anxiety on Fetal Neurobehavioral Development." Clinical Obstetrics and Gynecology 52(3): 425-440.

La Greca, A. M. and W. K. Silverman (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.

La Greca, A. M., W. K. Silverman, et al. (2002). Helping children cope with disasters and terrorism, American Psychological Association.

La Greca, A. M., W. K. Silverman, et al. (1998). "Children's predisaster functioning as a predictor of posttraumatic stress following Hurricane Andrew." Journal of Consulting and Clinical Psychology; Journal of Consulting and Clinical Psychology 66(6): 883.

Laplante, D. P., R. G. Barr, et al. (2004). "Stress during pregnancy affects general intellectual and language functioning in human toddlers." Pediatr Res 56(3): 400-410.

Laplante, D. P., A. Brunet, et al. (2008). "Project ice storm: Prenatal maternal stress affects cognitive and linguistic functioning in 51/2-year-old children." Journal of the American Academy of Child and Adolescent Psychiatry 47(9): 1063-1072.

Lederman, S. A., V. Rauh, et al. (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): 1772-1778.

Lobel, M., C. J. DeVincent, et al. (2000). "The impact of prenatal maternal stress and optimistic disposition on birth outcomes in medically high-risk women." Health Psychology 19(6): 544-553.

Lonigan, C. J., M. P. Shannon, et al. (1994). "Children exposed to disaster: II. Risk factors for the development of post-traumatic symptomatology." Journal of the American Academy of Child & Adolescent Psychiatry 33(1): 94-105.

Lu, M. C., V. Tache, et al. (2003). "Preventing low birth weight: is prenatal care the answer?" J Matern Fetal Neonatal Med 13(6): 362-380.

Martin, S. and B. Little (1986). "The Effects of a Natural Disaster on Academic Abilities and Social Behavior of School Children." BC Journal of Special Education 10(2): 167-182.

Miller, W. B. and J. Jones (2009). "The effects of preconception desires and intentions on pregnancy wantedness." Journal of Population Research 26(4): 327-357.

Moore, V. M., M. J. Davies, et al. (2004). "Dietary composition of pregnant women is related to size of the baby at birth." J Nutr 134(7): 1820-1826.

NCEMD. (2012). "Hurricane Irene by the Numbers." NC Emergency Management Division NC Department of Public Safety 2013, from https://www.ncdps.gov/Index2.cfm?a=000003,000010,002050,002063.

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

Osofsky, H. J., J. D. Osofsky, et al. (2009). "Posttraumatic stress symptoms in children after Hurricane Katrina: predicting the need for mental health services." Am J Orthopsychiatry 79(2): 212-220.

Oyarzo, C., P. Bertoglia, et al. (2012). "Adverse perinatal outcomes after the February 27th 2010 Chilean earthquake." J Matern Fetal Neonatal Med.

Pane, J. F., D. F. McCaffrey, et al. (2008). "Effects of student displacement in Louisiana during the first academic year after the hurricanes of 2005." Journal of Education for Students Placed at Risk 13(2-3): 168-211.

Pluess, M. and J. Belsky (2011). "Prenatal programming of postnatal plasticity?" Development and Psychopathology 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, N. E. (2005). "Low birth weight and school readiness." Future of Children 15(1): 91-116.

Roseboom, T. J., J. H. van der Meulen, et al. (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.

Rosenzweig, M. R. and K. I. Wolpin (1991). "Inequality at Birth - the Scope for Policy Intervention." Journal of Econometrics 50(1-2): 205-228.

Rous, J. J., R. T. Jewell, et al. (2004). "The effect of prenatal care on birthweight: a full-information maximum likelihood approach." Health Econ 13(3): 251-264.

Russoniello, C. V., T. K. Skalko, et al. (2002). "Childhood posttraumatic stress disorder and efforts to cope after Hurricane Floyd." Behavioral Medicine 28(2): 61-71.

Saigal, S., P. Szatmari, et al. (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 118(5): 751-760.

Saigh, P. A., M. Mroueh, et al. (1997). "Scholastic impairments among traumatized adolescents." Behaviour research and therapy 35(5): 429-436.

Shah, P. S., T. Balkhair, et al. (2011). "Intention to become pregnant and low birth weight and preterm birth: A systematic review." Maternal and Child Health Journal 15(2): 205-216.

Shannon, M. P., C. J. Lonigan, et al. (1994). "Children exposed to disaster: I. Epidemiology of post-traumatic symptoms and symptom profiles." Journal of the American Academy of Child & Adolescent Psychiatry 33(1): 80-93.

Shonkoff, J. P., W. T. Boyce, et al. (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.

Siega-Riz, A. M., T. S. Herrmann, et al. (2001). "Frequency of eating during pregnancy and its effect on preterm delivery." American Journal of Epidemiology 153(7): 647-652.

Simeonova, E. (2009). Out of sight, out of mind?: the impact of natural disasters on pregnancy outcomes, CESifo, Center for Economic Studies & Ifo Institute for economic research.

Smilde-van den Doel, D. A., C. Smit, et al. (2006). "School performance and social-emotional behavior of primary school children before and after a disaster." Pediatrics 118(5): e1311-1320.

Swenson, C. C., C. F. Saylor, et al. (2010). "Impact of a natural disaster on preschool children: Adjustment 14 months after a hurricane." American Journal of Orthopsychiatry 66(1): 122-130.

Tan, C. E., H. J. Li, et al. (2009). "The Impact of the Wenchuan Earthquake on Birth Outcomes." PLoS One 4(12).

Temple, J. A., A. J. Reynolds, et al. (2010). "Low Birth Weight, Preschool Education, and School Remediation." Education and Urban Society 42(6): 705-729.

Torche, F. (2011). "The Effect of Maternal Stress on Birth Outcomes: Exploiting a Natural Experiment." Demography 48(4): 1473-1491.

Vogel, J. M. and E. M. Vernberg (1993). "Part 1: Children's psychological responses to disasters." Journal of Clinical Child Psychology 22(4): 464-484.

Wadhwa, P. D., J. F. Culhane, et al. (2001). "Stress and preterm birth: neuroendocrine, immune/inflammatory, and vascular mechanisms." Matern Child Health J 5(2): 119-125.

Weems, C. F., L. K. Taylor, et al. (2009). "Effect of a school-based test anxiety intervention in ethnic minority youth exposed to Hurricane Katrina." Journal of Applied Developmental Psychology 30(3): 218-226.

Williams, L., L. Piccinino, et al. (2001). "Pregnancy wantedness: Attitude stability over time*." Biodemography and Social Biology 48(3-4): 212-233.

Xiong, X., E. W. Harville, et al. (2008). "Exposure to Hurricane Katrina, post-traumatic stress disorder and birth outcomes." American Journal of the Medical Sciences 336(2): 111-115.

Zahran, S., S. D. Brody, et al. (2008). "Social vulnerability and the natural and built environment: a model of flood casualties in Texas." Disasters 32(4): 537-560.

Biography

Sarah Elizabeth Crittenden Fuller was born on September 3, 1984 in Raleigh, North Carolina to David and Susan Crittenden. She spent her childhood in Cary, North Carolina. In 1996, she encountered Hurricane Fran, and the idea for this study was born. She attended the University of North Carolina at Chapel Hill. In 2006, Sarah received in B.A. in Psychology and Sociology with highest honors and distinction. During college, she was also inducted into Phi Beta Kappa.

On entering Duke, Sarah received a James B. Duke Fellowship. She also received support from the Sulzberger Family/Dan Levitan Social Policy Graduate Research Fellowship and the Stuart Irwin Harris Fellowship. Her research has focused on early childhood development and educational performance. While in graduate school, she published an article titled "School Based Accountability and the Distribution of Teacher Quality across Grades in Elementary Schools" in *Education Finance and Policy.*