Analyzing The Effect of Hurricane Irma on Birth Outcomes in Florida

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Abstract:

This paper investigates the impact of Hurricane Irma on birth outcomes including low birth weight and preterm birth. In addition to psychological stress, Hurricane Irma may have affected the birth outcome through some other pathways including hurricane Irma-led evacuation of 7 million residents of Florida, knocking out power to 6.7 million utility customers, and damage in residential buildings. Following Currie and Rossin-Slater (2013), we examine whether stress induced by Hurricane Irma is the only casual role of birth outcome, or other aforementioned channels have also contributed to the outcome. We use cross-sectional birth records provided by the Florida Department of Health over the period 2016-2018 to explore the effect of hurricane Irma on birth outcomes through stress, and other related causal mechanisms mentioned earlier. To build the main model, the pregnant women stratified into treatment and control groups. Treatment group includes pregnant women living in the path of the hurricane and control group consists of those living away from the hurricane path. Using difference-in-difference model, we capture the effect of hurricane exposure on the treated group before and after the hurricane. Also, geospatial information of Hurricane Irma such as the hurricane track and the wind speed were obtained from the Florida Division of Emergency Management and FEMA’s HAZUS program. The results suggest that infants born in the path of Hurricane Irma were 6 grams lighter on average compared to infants born outside the hurricane path. The impact of the hurricane is larger in magnitude if pregnant women were exposed to the hurricane in their third trimester. Also, we found no impact of the hurricane exposure on the pregnant women’s behaviors. We report some robustness checks and examine possible causal mechanisms that could contribute to the outcome.

Keywords: Hurricane Irma, Adverse birth outcome, causal mechanisms, difference-in-difference models

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Introduction

During the last few decades, climate change has increased the frequency and intensity of extreme weather events, such as hurricanes (Karl et al., 2008; Mousavi et al., 2011; Duan et al., 2018), affecting death, disease, and/or psychosocial stress among the residents in the U.S. coastal regions (NOAA, 2020; Grabich et al., 2016; Bourque et al., 2006; Doocy et al., 2013; Shultz et al., 2005). Hurricanes mostly affect the Atlantic and Gulf Coast regions, containing the largest centers of the U.S. population. In the coming years, hurricanes will likely affect even more people considering the steady increase in the number of people living in U.S. coastal regions. In fact, according to the 2016 U.S. Census Report, the coastline county population has expanded to 59.6 million in 2016 from 51.9 million in 2000 (Cohen, 2018).

Hurricanes have the potential to cause stress in pregnant women, potentially leading to adverse pregnancy and birth outcomes, including spontaneous abortions, preterm births (defined as birth before 37 weeks of gestation), or low birthweight deliveries (defined as birth weight lower than 2500g). Pregnant women undergoing pregnancy-induced hormonal changes are especially vulnerable to psychological or physical stress (Currie & Rossin-Slater, 2013; Douros et al., 2017). Psychological stress is caused by the fear of the hurricane. Physical stress is generated by injury experiences (Currie and Rossin-Slater, 2013). Further, women may also experience other negative conditions, including limited access to drinkable water, limited access to nutrition, exposure to toxic contaminants, and lack of access to medical care services (Currie and Rossin-Slater, 2013; Cordero, 1993).

Maternal stress has been a cause of concern among practitioners and academicians alike. This is because stress during pregnancy has been linked to a score of adverse pregnancy and childbirth outcomes. The intervention mechanism includes release of stress hormones negatively affecting the fetus through changes in the neuroendocrine and immune system and through changes in maternal behaviors (Dunkel-Schetter, 2011; Currie & Rossin-Slater, 2013). Preterm birth and low birth weight have been systematically linked to developmental delays and mental and behavioral disorders (Zijlmans et al., 2015; Currie & Rossin-Slater, 2013; Kim et al., 2017). However, isolating the hurricane-induced psychological stress from other stressors is not easy. The existing literature on the impact of catastrophic events on birth outcome applies either contextual information or causal mechanisms to conclude that the birth outcome results are more likely derived by psychological stress rather than other related pathways (Kim et al., 2017).

At least 200,000 pregnant women affected by Hurricane Irma may have experienced physical and psychological stress. There are a few studies that examine the impact of Hurricane Irma and Maria on maternal and child health in Puerto Rico (Welton et al., 2020; Rosario et al., 2019). However, to our knowledge, no studies have focused on the impact of Hurricane Irma on prenatal and parental health outcomes. Hence, it is vital to investigate the possible effect of Hurricane Irma as a source of stress on pregnancy outcomes. The current study investigates the impact of Hurricane Irma-induced stress on birth outcomes in Florida. As for sources of stress, we will consider several potential sources, including psychological stress, evacuation, and property damage (Issa et al., 2018; FEMA, 2018). We use cross-sectional birth records (at the longitude and latitude levels) provided by the Florida Department of Health, Bureau of Vital Statistics, over the period of 2016-2018. The birth records include information on birth weight, gestation, abnormal condition of newborn baby, complications in delivery, pregnant women's residential locations, and parents' sociodemographic information. Additionally, we apply FEMA damage assessment data and evacuation order data provided by the Florida Division of Emergency Management (FDEM) to investigate the effect of evacuation order and damage in residential buildings on pregnancy outcomes. The geospatial information of Hurricane Irma, such as the hurricane track and maximum wind speed, was obtained from the FDEM and FEMA's HAZUS program.

Using a difference-in-difference strategy, we stratify pregnant women into two groups: the treatment and control groups. The treatment group includes pregnant women living in the hurricane path (29-mile band around the hurricane path, which represents the diameter of the eye of Hurricane Irma (Pasch, 2017), and the control group consists of pregnant women not living in the hurricane path. Using pregnant women's residential locations and ArcGIS technology, we calculated the distance of their residential locations to the hurricane path. Also, we employ multiple fixed effects such as county, month, and year fixed effects to isolate the impact of the hurricane-induced stress on birth outcomes. Both binary and continuous measures of birth weight and gestation are examined, and the impact of the hurricane by trimester of exposure is investigated as well.

Our study makes several contributions: First, this is the first study that examines the impact of one of the strongest hurricanes in the Atlantic basin and the first of a major hurricane in Florida since October 2005 (when Hurricane Wilma made landfall on Florida) on pregnancy outcomes. Second, while the majority of existing medical and economic literature examines the impact of hurricanes on the birth outcome using birth records at county levels (Zahran et al., 2013; Grabich et al., 2016, 2017), our study uses the confidential birth records containing latitude and longitude of mothers' residential locations, which helps us to calculate the accurate distance of pregnant women to hurricane path, and enables us to easily control for geo-special indicators such as maximum wind speed derived from ArcGIS technology. Third, we examine the impact of the potential channels such as changes in mothers' maternal behaviors on birth outcomes; control for indicators such as hurricane-induced evacuation and residential building damages at the census tract level; and include several fixed effects such as county, birth month, and birth year fixed effects in our estimation.

Background

Hurricane Irma

On September 10, 2017, Hurricane Irma made landfall at Cudjoe Key, Florida, as a category 4 hurricane with 130 mph winds. Later, it weakened while moving northward and made its second landfall at Marco Island in Collier County, Florida, as a category 3 hurricane with 115 mph winds. Irma continued moving north, northwestward through Florida state, losing its intensity but continued to induce high wind, heavy rainfall, and storm surge inundation (Benfield, 2018) (see Figure 1). Hurricane Irma was the first main hurricane that struck Florida since Hurricane Wilma in 2005 and was one of the Atlantic basin's strongest and costliest hurricanes in U.S. history, which caused catastrophic damages in Florida. NOAA National Centers for Environmental Information (NCEI) approximates that damages caused by hurricane Irma-induced wind, storm surge, and flooding caused almost $50 billion (Cangialosi et al., 2018). The cost estimates were based on the physical damages to residential, governmental, and commercial buildings, interruption in businesses, and the damage to public infrastructures such as roads, bridges, and power utilities (FEMA, 2018).

Estimates from Pacific Disaster Center (PDC) and FEMA's HAZUS program (2017) indicated that two medical facilities in the Florida Keys were shut down for 1-12 days; more than 350,000 residential buildings were damaged in Florida: 2,200 buildings were destroyed; 3,800 buildings were severely damaged; 58,000 buildings were moderately damaged; 290,000 buildings sustained minor damages. As a result, almost 12,000 households were displaced, and 2,900 had to take short-term shelter. Furthermore, almost 7 million residents who were living mainly in Florida coastal areas had to evacuate, where besides zone A as a mandatory evacuation order, the evacuation zone was expanded to evacuation zone B as well (See Figure 2 and Figure 3).

In terms of disruption in power, more than 6.7 million customers in the state experienced power outage during and after Hurricane Irma, which denotes almost two-thirds of all customers in Florida. Based on FDEM (2017), in some areas, the customers did not have electricity for more than a week (Chakalian et al., 2018). Power outages endangered the health and safety of millions of residents in Florida, particularly vulnerable groups such as elderly people and pregnant women due to dehydration, exhaustion, and carbon monoxide poisoning. Also, Irma caused the discharge of 28 million gallons of untreated water into the surrounding areas (Smith et al., 2018).

It has been reported that there were hundreds of injuries, seven direct and eighty indirect deaths caused by Hurricane Irma in Florida (Cangialosi et al., 2018). The conditions of deaths associated with Hurricane Irma have been classified into direct hurricane-related conditions (such as drowning from flooding; and electrocution from lightning), and indirect hurricane-related conditions (such as disruption of access to medical and mental health services; disruption of electricity required for medical treatment such as dialysis; disruption of cooling systems; carbon monoxide poisoning caused by using generators) (Issa et al., 2018).

Literature Review

Different mechanisms linking prenatal stress and adverse birth outcomes

Adverse birth outcomes are oftentimes recognized by low birth weight and preterm birth. Low birth weight (which is defined as birth weight less than 5.5 pounds (2500 grams) irrespective of gestational length) can be caused by intrauterine growth restrictions (IUGR) (which is defined as birth weight/birth length below the 10th percentile for gestational length) and preterm birth (which is defined as birth before 37 completed weeks of gestation). Low birth weight and preterm birth can lead to child growth impairment and increase the chances of getting diseases such as hypertension, and cardiovascular, and renal disease later in life (Zohdi et al., 2012).

A large body of epidemiological research and a growing body of economic research has consistently found that maternal stress during pregnancy is a risk factor for the adverse birth outcomes (Hobel et al., 2008; Beijers et al., 2014; Zijlmans et al., 2015; Justus et al., 2004). There are several possible mechanisms by which maternal stress affects birth outcomes.

Hormonal: prenatal stress triggers a rise in the release of glucocorticoids, the key driver of the endocrine response to stress (Whirledge & Cidlowski, 2010). Glucocorticoids are produced by Hypothalamic Pituitary Adrenal (HPA) axis and the placenta (Zijlmans et al., 2015). Although essential for fetal growth, glucocorticoids released excessively can potentially harm the fetus. When the brain perceives an event as a severe stressor, the corticotrophin releasing hormone (CRH), which is the primary molecular regulator of HPA, induces releases of adrenocorticotropin hormone (ACTH) through the pituitary gland (Hobel et al., 2008). The ACTH then stimulates the adrenal gland to release cortisol (which is a glucocorticoid that functions as a major stress hormone) in the body. The cortisol blocks the stress response by inhibiting the release of ACTH and the release of CRH (Gunnar & Quevedo, 2007; Hobel et al., 2008). However, under severe stressful events, the concentration of cortisol will rise in blood leading early parturition and affecting fetal growth (Hobel et al., 2008).

Further, some argue that the timing of maternal exposure to cortisol may modify the extent to which maternal stress is adversarial to birth outcomes. This is because as fetus brain development occurs at different stages, different birth outcomes will be achieved by exposing to stress in different gestational periods (Zijlmans et al., 2015). Davis and Sandman (2010) show that maternal exposure to high levels of cortisol in early pregnancy is associated with slower infant growth. Similarly, Glynn et al. (2001) show that the exposure to stress in early pregnancy is more visible than in later months of pregnancy. In another study, Class et al. (2011) show that exposure to the stress in Months 5 and 6 are more likely to lead to adverse pregnancy outcomes.

Behavioral: Stress-induced maternal behaviors, such as smoking, drinking alcohol, not attending prenatal visits, can also affect adverse birth outcomes (Littleton et al., 2007). Smoking during pregnancy may mediate the association between prenatal stress and birth weight by increasing the levels of catecholamines, CRH, ACTH, and cortisol (Justus et al., 2004). Smoking can affect fetal growth by increasing the level of catecholamines in the body, thus boosting metabolism while suppressing appetite at the same time (Hobel et al., 2008). There is abundant evidence that alcohol consumption could have a potential negative effect on birth weight and preterm birth (Parazzini et al., 2003; Cook & Randal, 1998; Pereira et al., 2019). The alcohol consumption may induce preterm birth by increasing the level of prostaglandins (which play important regulatory roles in different aspects of pregnancy such as fetal growth and development) (Cook & Randal 1998).

Physiological: Extreme drops in barometric pressure can also affect birth outcomes through premature fetal membrane rupture, which induces preterm birth (Akutagawa et al., 2007; Mackenzie et al., 2020, Noller et al., 1996; King et al., 1997). Mackenzie et al. (2020) used a model to examine the strength of the fetal membrane against the stress caused by a drop of barometric pressure during strong hurricanes. Their model showed that the impact of stress on the fetal membrane depends on the barometric pressure and the length of gestation. The author argued that the increased stress induced by a hurricane with low barometric pressure can cause preterm birth through increasing the strength of fetal membrane prior to the full-term gestation. The strength of fetal membrane starts decreasing after week 30 of pregnancy, but the stress caused by the lower barometric pressure can rupture the fetal membrane through increasing the strength of it, which induces preterm birth. However, some other related studies found no relationship between atmospheric pressure and birth outcomes (Trap et al., 1989; Polansky et al., 1985; Marks et al., 1983), leaving open the question about the association between barometric pressure and birth outcomes.

There is a considerable body of research that addresses the effect on birth outcomes of catastrophic events (both manmade and natural disasters) such as earthquakes (Kim et al., 2017; Tan et al., 2009; Torche, 2011), armed conflict (Mansour & Rees, 2012; Maric et al., 2010); terrorist attacks (Engel et al., 2005; Brown, 2013); heat waves (Cil & Cameron, 2017; Wolf & Armstrong, 2012; Strand et al., 2012); and dust storms (Adhvaryu et al., 2019; Currie and Schwandt, 2016; Jones, 2020).

There is a considerable body of epidemiological literature (Harville et al., 2015; Xiong et al., 2008; Hamilton et al., 2009; Grabich et al., 2016, 2017; Christopher et al., 2019) investigating the empirical association between hurricanes and birth outcome. The majority of these studies include few if any control variables, making their causality claims rarely justified (Currie and Rossin-Slater, 2013). However, in the economic literature, the impact of hurricanes and other natural disasters such as earthquake and dust storms on birth outcome were examined using various control variables, difference-in-difference techniques, and instrumental variables to control the omitted variables bias due to other variables that are correlated with stress and birth outcome (Currie and Rossin-Slater, 2013; Zahran et al., 2010, 2013, 2014; Jones, 2020; Kim et al., 2017).

In the context of the impact of an earthquake on birth outcomes, Kim et al. (2017) examined the impact of Northridge earthquake on birth outcomes, including low birth weight and preterm birth. Using a difference-in-difference approach, they found that pregnant women who were exposed to the earthquake were 0.2 percentage point more likely to have infants with low birth weight. Also, the impact was larger when the exposure to the earthquake was in the first and third trimester of pregnancy. However, the impact of earthquake-induced stress was stronger with single and first-time mothers, where the probability of having an infant with low birth weight increased by 0.5 percentage point. The authors concluded that the endogenous migration and disruption of healthcare services did not have a major impact on birth outcomes. Instead, they concluded that maternal psychological stress led to low birth weight.

Another related study is conducted by Jones (2020), which examined the impact of dust storms on U.S. birth outcomes over the period 2010-2017. Using the difference-in-difference approach, several fixed effects, and control variables, the effect of dust storms on birth outcomes was plausibly isolated. The findings showed that the dust storm exposure during pregnancy led to an increase in the probability of low birth weight and preterm birth by 1.4 and 1.8 percentage points, respectively, and the effect is larger when the dust storm exposure happens during the third trimester of pregnancy. Also, he found that mothers who experienced the dust storm for the first time were 0.9 and 1.1 percentage points more likely to have infants with low birth weight and preterm birth, respectively. However, the probability of low birth weight and preterm birth increase by 5.7 and 8.7 percentage points, respectively, when pregnant women experienced six or more dust storms.

The most closely relevant study to our work is Currie and Rossin-Slater (2013), where the effect of multiple hurricanes on birth outcomes was investigated. Currie and Rossin-Slater (2013) used vital statistics records of 485,111 births of pregnant women exposed to several major hurricanes in Texas over the period 1996-2008. They compared the pregnant women who were living in the path of hurricanes to those living farther away from the path (Currie and Rossin-Slater, 2013). They added new indicators of infant health, including abnormal conditions of the infants, and complications of labor aside from birth weight and gestation outcomes to the existing literature (Currie and Rossin-Slater, 2013). They also examined the effect of possible channels, including changes to migration, parental behavior, and interruption of medical care induced by hurricanes on the birth outcome (Currie and Rossin-Slater, 2013). Methodologically, they applied mother fixed effects and instrumental variables estimations to control for time invariant factors that are likely associated with pregnant women's residential location and pregnancy outcomes (Currie and Rossin-Slater, 2013). They showed that the impact of hurricanes on birth weight and gestation is sensitive to measurements and econometric design, but they found more precise estimates of the impact of hurricane exposure on infant health. Accordingly, the findings indicate that the pregnant women who were exposed to hurricanes were more likely to experience complications during labor and delivery and were more likely to have an infant with abnormal conditions (such as meconium aspiration syndrome) (Currie and Rossin-Slater, 2013). Also, using the placebo test, the exposure to hurricanes six months after childbirth was investigated, but no placebo effects were found. However, they ruled out potential channels, including hurricane-induced migration, disruption of medical care services, and maternal behaviors and thus, concluded that stress might be the only factor to explain the birth outcome results (Currie and Rossin-Slater, 2013).

The current study adds to the existing literature on hurricanes and birth outcomes. We tried to examine the possible effects of hurricane-induced physical mechanisms, including hurricane-induced mandatory migration and residential building damage to isolate the effect of psychological stress caused by hurricane exposure on birth outcomes.

Data

We obtained data from two sources. First, we obtained confidential birth data over the period 2016-2018 from the Florida Department of Health, Bureau of Vital Statistics.[4] The birth records include information about birth weight, length of gestation, abnormal condition of newborn baby, infant's sex, complications of labor/delivery, methods of delivery, prenatal care visits, number of previous live births, infant's birth order, multiple births resulted from the current pregnancy, parents' sociodemographic information, whether mother smoked during pregnancy, and the longitude/latitude coordinates of pregnant women's residential locations. Second, we obtained data on Hurricane Irma's path, maximum wind speed (at the longitude and latitude levels), Irma-induced evacuation orders (at the census tract level), and rate of damage in residential buildings (at census tract level) from the Florida Division of Emergency Management and FEMA's HAZUS center.[5][6] Using longitude/latitude coordinates of pregnant women's residential locations,

[4] http://www.floridahealth.gov/statistics-and-data/data-and-statistics/index.html

[5] https://www.floridadisaster.org/

[6] https://msc.fema.gov/portal/resources/hazus

we estimate the distance to the nearest point on the hurricane path applying Arc GIS technology. We formed a 30-mile band around the hurricane path, which represents the diameter of the eye of Hurricane Irma, where the devastating damages and impact were experienced. The eye of a strong hurricane is usually 19-40 miles in diameter, where the strongest wind occurs (Pasch, 2017).

The main analysis sample consists of 640,649 live births. Our outcomes of interest include continuous and binary measures of birth weight and gestation length. The continuous indicators include birth weight in grams and gestational length in weeks. The binary indicators include preterm birth (which is equal to one if an infant was born before 37 weeks of gestation, and zero otherwise) and low birth weight (which is equal to one if an infant was born weighing less than 2500g, and zero otherwise).

Methodology

We aim to investigate the causal effect of Hurricane Irma on birth outcomes, including preterm birth, low birth weight, abnormal conditions of newborns, and complication of labor/delivery.[7] Using the difference-in-difference (DID) approach, we examine the causal effect of the treatment by comparing the outcome between the control and treatment groups before and after the treatment. In our study, the treatment is the exposure to Hurricane Irma.

Our DID analyses consider two alternative approaches to measuring the treatment. First, we define the hurricane exposure based on the distance to the eye of the hurricane (in

[7] Based on Florida Vital Statistics Code Manual for Birth the abnormal conditions include: "anemia, birth injury, fetal alcohol, syndrome, hyaline membrane disease, meconium, aspiration syndrome, assisted ventilation <30 min, assisted ventilation >30 min, seizures". For more information, see: http://www.floridahealth.gov/statistics-and-data/data-and statistics/_documents/BirthCodeBookOctober2012.pdf

miles). Second, we define hurricane exposure based on the peak wind speed (miles per hour). However, we report the results from the first approach; we report the results from the second by way of robustness check.

Using the first approach, we stratified pregnant women into two groups: the treatment and control groups. Based on the first approach, the treatment group consists of the pregnant women living within 30-mile radius of Hurricane Irma, and the control group consists of the pregnant women living outside the hurricane path. According to the second approach, the treatment group consists of the women who were exposed to Irma's maximum wind speed of 74 mph (category 1 hurricane) or more during pregnancy, and control group consists of mothers who were exposed to less than 74 mph maximum wind speed (we will look at this measurement closely in the robustness check section).

We examine the following hypotheses for the first and second approaches (where first approach to measuring Hurricane Irma exposure is defined as living within 30-mile radius of Hurricane Irma during pregnancy; and the second approach to measuring Hurricane Irma exposure is defined as being exposed to Irma's maximum wind speed of 74 mph or more during pregnancy):

Hypothesis 1: H_0: Exposure of pregnant women to Hurricane Irma has no significant impact on preterm birth and low birth weight.

Hypothesis 2: H_0: Exposure of pregnant women to Hurricane Irma has no significant impact on abnormal conditions of newborns, and complication of labor/delivery.

First approach

We examine the causal impact of Hurricane Irma on birth outcomes by applying the following DID model (Kim et al., 2017):

$$Birthoutcome_{icdmt} = \beta_0 + \beta_1 BornPost2017_{icdmt} + \beta_2 HIPath_{icdmt} + \beta_3(BornPost2017_{icdmt} * HIPath_{icdmt}) + \beta_4 X_{icdmt} + M_m + Y_t + \theta_j + \varepsilon_{icdmt} \quad (1)$$

Where i is a newborn, c is the county of the mother' residence, d, m, and t are the day, month, and the year that newborn i is born; $Birthoutcome_{icdmt}$ represents birth outcomes including birth weight (both continuous and binary measures), gestation (both continuous and binary measures), and abnormal condition of newborn baby, complications in delivery/labor; $BornPost2017_{icdmt}$ is an indicator equal to 1 if the birth occurred between Sep 10 2017 and July 15 2018, and 0 otherwise; $HIPath_{icdmt}$ is an indicator equal to 1 if the mother lived in the path of Hurricane Irma, and 0 otherwise; X_{icdmt} include infant i's mother's sociodemographic characteristics such as mother's age, education, and marital status. The interaction term $BornPost2017_{icdmt} * HIPath_{icdmt}$ captures the causal impact of Hurricane Irma on birth outcome; M_m, Y_t, and θ_j are fixed effects for birth month, birth year, and county, respectively; and ε_{icdmt} is an error term.

To investigate the hurricane exposure by the trimester of pregnancy, we estimate the following model:

$$Birthoutcome_{icdmt} = \beta_0 + \beta_1 first_{icdmt} + \beta_2 second_{icdmt} + \beta_3 third_{icdmt} + \beta_4 HIPath_{icdmt} + \beta_5(HIPath_{icdmt} * first_{icdmt}) + \beta_6 (HIPath_{icdmt} * second_{icdmt}) + \beta_7(HIPath_{icdmt} * third_{icdmt}) + \beta_8 X_{icdmt} + M_m + Y_t + \theta_j + \varepsilon_{icdmt} \quad (2)$$

Where $first_{ijdmt}$, $second_{ijdmt}$, and $third_{ijdmt}$ represent the mother's exposure to Hurricane Irma when they were in their $first_{ijdmt}$ (infants were conceived between Jun 11, 2017 and Sep 10, 2017), $second_{ijdmt}$ (infants were conceived between March 12, 2017 and June 10, 2017), and $third_{ijdmt}$ trimester (infants were conceived between Dec 16, 2016 and March 11, 2017) of their pregnancy.

Second approach

Using the second approach, our DID analysis is specified according to the cutoff for category 1 hurricane (with winds range from 74 to 95 mph). Using data on Hurricane Irma's maximum wind speed (miles per hour) at longitude and latitude levels, mothers were stratified into two groups. Mothers living in the area impacted by the wind speed of more than 74 mph were considered as a treatment group, and those affected by wind speed less than 74 mph are considered as a control group.

To analyze the hurricane exposure based on maximum wind speed (mph), the following equation (which is the modified form of Eq. 1) is applied.

$$Birthoutcome_{icdmt} = \beta_0 + \beta_1\, BornPost2017_{icdmt} + \beta_2 WindSp74mph_{icdmt} + \beta_5(BornPost2017_{icdmt} * WindSp74mph_{\,icdmt}) + \beta_8 X_{icdmt} + M_m + Y_t + \theta_j + \varepsilon_{icdmt} \quad (3)$$

Moreover, to estimate Hurricane Irma's induced maximum wind speed exposure on birth outcomes by trimester of pregnancy, we defined the following DID model (which is the modified form of Eq. 2).

$$Birthoutcome_{icdmt} = \beta_0 + \beta_1 first_{icdmt} + \beta_2 second_{icdmt} + \beta_3 third_{icdmt} + \beta_4 HIPath_{icdmt} + \beta_5(WindSp74mph_{icdmt} * first_{\,icdmt}) + \beta_6\,(WindSp74mph_{icdmt} * second_{icdmt}) + \beta_7(WindSp74mph_{icdmt} * third_{icdmt}) + \beta_8 X_{icdmt} + M_m + Y_t + \theta_j + \varepsilon_{icdmt} \quad (4)$$

Maternal characteristics and exposure to Hurricane Irma

Following Currie and Rossin-Slater (2013), to investigate whether the birth month, birth year, and county fixed effects are sufficient to control for selection within areas that more likely to be affected by hurricanes, we estimate the following model:

$$X_{icdmt} = \beta_0 + \beta_1 BornPost2017_{icdmt} + \beta_2 HIPath_{icdmt} + \beta_5 (BornPost2017_{icdmt} * HIPath_{icdmt}) + +M_m + Y_t + \theta_j + \varepsilon_{icdmt} \quad (5)$$

Based on Eq. 5, we evaluate whether there is a relationship between hurricane exposure (living within 30 miles of the hurricane path) and maternal characteristics. The variables are defined as Eq. 1 and Eq. 2. If the aforementioned fixed effects included in Eq. 5 can control for selection, then the interaction coefficient would not be statistically significant. However, the statistically significant interaction coefficient suggests that the fixed effects, including county fixed effect, are not able to control for selection (Currie and Rossin-Slater, 2013). As Table 1 depicts, panel (A) estimated Eq. 5 without county fixed effect, whereas panel (B) estimated Eq. 5 with county fixed effect. Panel (A) shows that mothers exposed to hurricanes were 0.43 percentage points more likely to be African American. As panel (B) shows, by including the county fixed effects, this difference was captured effectively (Currie and Rossin-Slater, 2013). Thus, we conclude that including county fixed effect were effective to control for selection.

Results

Summary statistics

Table 2 reports summary statistics. On average, 12.5% of infants were born prematurely, and 8.17% were born with low birth weight. The mean birth weight is 3251.37 grams, and the mean gestation length is 38.53 weeks. Almost 13% of infants have abnormal conditions, and 4.1% of births have complications during labor/delivery. Also, 71%, 23%, and 34% of mothers are White, Black, and Hispanic, respectively. Figure 4 shows mothers' residential locations (at the longitude and latitude levels) over the period 2016-2018, respectively.

Regression results

Table 3 reports the estimated effects of Hurricane Irma exposure (living within 30 miles of the hurricane path) on birthweight (Column 1); gestational age at birth (Column 2); low birthweight (Column 3); premature birth (Column 4) using Eq. 1. We included birth year, birth month, and mother's county fixed effects and clustered the error term at the mother's county level.

Table 3, Column (1) shows the results of continuous measure of birth weight outcome. The estimate of the coefficient interaction term $BornPost2017_{icdmt} * HIPath_{icdmt}$ is -6.8919 and statistically significant, suggesting that hurricane exposure (living within 30 miles of the hurricane path) decreased birth weight by about 7 grams. Column (2) reports the results of continuous measure of gestation length outcome. The coefficient on the interaction term is -0.0130. However, this coefficient is not statistically significant, indicating that there is no significant gestation length (continuous measure) outcome difference between treatment (mothers living within the hurricane path) and control group (mothers living outside the hurricane path). Moreover, Column (3) and Column (4) show the results for low birth wight and preterm birth outcomes (using a linear probability model). As the results of Column (2), the results for the coefficients on interaction term reported in Column 2 and Column 3 are not statistically significant. It indicates that there is no significant difference between treatment and control groups in terms of preterm birth and a low birthweight outcome.

Table 3 also reports coefficients on mother and infant characteristics. The signs and magnitude of the coefficient estimates are in line with our expectations. For instance, married and educated mothers experienced an improvement in the birth outcomes. In contrast, teen mothers (mothers under the age of 19) are more likely to have low birth weight and premature infants. Similarly, African American, Hispanic mothers, and mothers who were smoking during pregnancy experienced higher adverse birth outcomes. In terms of infant characteristics, the estimated coefficients on infant's gender are negative and statistically significant, indicating that female infants are more likely to be born with low birth weight.

Using Eq. 2, we estimate the impact of Hurricane Irma on birth outcomes by trimester. Table 4 reports the results of the impact of the hurricane exposure on continuous and binary measures of birth weight and gestational length. The results indicate that there is a higher negative impact on birth outcomes when mothers exposed to the hurricane in their first and third trimester of pregnancy. In Table 4, Column (1), and Column (2) show that exposure to the hurricane (coefficients on the interaction term) in the third trimester of pregnancy decreased birth weight, and gestation length by about 12 grams, and 0.07 week, respectively. Moreover, findings in Table 4 Column (3) depicts that the exposure to the hurricane during the first and the third trimesters of pregnancy increased the likelihood of low birth weight by 0.52 and 0.46 percentage point, respectively. Our results are in line with the previous studies suggesting that the exposure to natural disasters in the first and third trimesters of pregnancy are linked with a higher risk of low birth weight and preterm birth (Torche, 2011; Currie & Rossin-Slater, 2013; Kim et al., 2017; Jones, 2020). It is worth highlighting that fetal growth can be adversely impacted when the hurricane exposure (as a stressor) occurs in the first and third trimester of pregnancy. It is evident that in the first trimester, the infant's most critical development occurs. Also, the fetal gains the most weight during the third trimester of pregnancy. Thus, any stressor that restricts the first trimester and third trimester growth can increase the likelihood of low birth weight and preterm birth (Smith, 2004).

Besides investigating the effect of hurricane exposure on birth weight and gestation length, we also look at the impact of Hurricane Irma on abnormal conditions of the infants and complications of labor and/or delivery. The results in Table 5 reports that hurricane exposure (living within 30 miles of the hurricane path) is estimated to increase the risk of an abnormal condition in the infants, and complications of labor and delivery by 2.4 and 0.66 percentage points, respectively.

Robustness check

Hurricane exposure based on the cutoff of Hurricane Irma's maximum wind speed (second approach)

Besides our main model, which analyzes the hurricane exposure based on the 30 miles symmetrical distance buffer around the hurricane path, we are interested in investigating the hurricane exposure based on the hurricane's maximum wind speed (miles per hour) (see Figure 5).

Table 6 reports various estimates of the impact of Hurricane Irma exposure on the birth outcome using Eq. 3. Table 6, Panel (A), Column (1) and Column (2) report the results of the continuous measure of birth weight, and gestation length outcomes. In Column (1), the estimate of the coefficient on the interaction term $\text{BornPost2017}_{icdmt} * \text{WindSp74mph}_{icdmt}$ is -5.0562, but it is not statistically significant. Column (2) reports the results of continuous variable of gestation length. The coefficient estimate on the interaction term is -0.0687 and statistically significant, suggesting that the exposure to the maximum wind speed has decreased the gestation length by 0.0873 weeks. The results for low birth weight, and preterm birth outcomes reported in Column (3) and Column (4); however, the results for the coefficients on the interaction terms are not statistically significant.

Panel (B) of Table 6 shows various estimates of the impact of maximum wind speed exposure (induced by Hurricane Irma) on birth outcomes by trimester using Eq. 4. The results in Panel (B), Column (1), indicates that exposure to the maximum wind speed in the third trimester of pregnancy decreased birth weight by about 15 grams. However, the estimated impact of wind exposure on birth weight in the first and the second trimester of pregnancy are not statistically significant. The results in Panel (B), Column (2), reports the impact of the wind speed exposure on the gestation length by trimester. The coefficients on the interaction terms are negative and statistically significant, suggesting that the exposure to the maximum wind speed in the first, second, and third trimester of pregnancy decreased gestation length by 0.0873, 0.0517, and 0.0502 weeks, respectively. However, the impact of exposure on gestation is not very strong (lowered gestation length by less than a day). Furthermore, Panel (B) Column (3) and Column (4) show the results for low birth weight, and preterm birth outcomes (using a linear probability model). However, the estimated coefficients in both models are statistically insignificant. In summary, the estimated impact of wind exposure induced by Hurricane Irma on gestation length is more robust to estimation methods. Moreover, both results in Table 6 and the results of our main model (reported in Table 3 and 4) suggest that exposure in the third trimester has a stronger negative impact on birth weight, which varies from -11 to -15 grams.

Estimating the main model using different radii

We estimate the impact of different distance buffers on birth outcomes to investigate how varying distance buffers could affect our main results. We have defined two radii (including 50 miles and 60 miles) around the main distance buffer (30 miles). Panel (B) and Panel (C) of Table 7 present the estimated effect of Hurricane Irma on birth outcomes (both binary and continuous measures of birth weight and gestation) based on the 50 miles, and 60 miles symmetrical distance buffer around the hurricane path, respectively. The results show that none of the estimated coefficients on the interaction terms are statistically significant. It may suggest that although the 30 miles distance buffer is an arbitrary measure around the hurricane path, using different radii do not have a significant impact on our main result (presented in Table 3).

Causal mechanisms

We also investigated possible causal mechanism which could stress pregnant women. Following Currie and Rossin-Slater (2013), we look at the behavioral mechanisms that could contribute to the results. Moreover, we analyze the impact of other stressors such as hurricane-led evacuation, and economic loss, which have not been investigated in the previous studies.

The impact of Hurricane Irma on maternal behavior

The hurricane exposure (by living in the path of the hurricane, by the maximum wind speed) can stress pregnant women and consequently could impact the birth outcome. However, it is possible that stress could change maternal behaviors. For instance, stress induced by the hurricane may cause mothers to engage in risky behaviors such as smoking more cigarettes, drinking alcohol, gaining or losing noticeable weight through changing their diet, and negative change in their prenatal care. Table 8 presents the analysis of the behavioral mechanisms that could contribute to our results. We investigated whether stress could cause mothers to smoke in the first, second, and third trimester of the pregnancy, gain more than 60 pounds, have inadequate prenatal care. However, all the estimates in Table 8 are statistically insignificant, indicating that there is no impact of hurricane exposure on maternal behavior. Thus, we suggest that our findings are due to stress, not because of changes in maternal behavior.

Including the residential buildings damage rate and evacuation order as additional controls

We analyze the impact of physical stressors (evacuation order and rate of damage in mother's residential buildings (see Figure 2 and 3)) induced by Hurricane Irma on birth outcome. To bound the impact of the stress on birth outcome more precisely, we estimate the Eq. 1 by adding the following control variables: $Build_{icdmt}$ is an indicator for the level of damage in mother's residential building; $Evacuationorder_{icdmt}$ is an indicator equal to one if a mother receives mandatory evacuation, and zero otherwise. Table 9 reports the estimated coefficients of the impact of hurricane exposure on birth outcomes using Eq. 1 and including the aforementioned control variables. Each column of Table 9 presents the coefficient estimates of a specific birth outcome regression. We included birth year, birth month, and mother's county fixed effects and clustered the error term at the mother's county level. Table 9, Column (1) reports the results of birth weight outcome (continuous measure). The estimate of the coefficient interaction term $BornPost2017_{icdmt} * HIPath_{icdmt}$ is -6.8860 and statistically significant, indicating that hurricane exposure (living within 30 miles of the hurricane path) decreased birth weight by about 7 grams (which is almost the same as the result obtained from Eq. 1 presented in Table 3 Column (1)). Comparing the results in Table 9 with the main results (presented in Table 3 Column (1)), we can suggest that including the aforementioned control variables in the main model had small impact on the birth weight outcome. It indicates that stressors like damage in residential buildings and receiving evacuation orders had small impact on birth outcomes. Thus, it may suggest that our findings are due to stress, not because of other stressors explained above.

Conclusion

This paper analyzes the causal impact of Hurricane Irma exposure on birth outcomes, including birth weight, gestation, abnormal condition of newborn baby, complications in labor and delivery. We combined Florida confidential birth data (obtained from Florida Department of Health, Bureau of Vital Statistics) over the period 2016-2018 with data on FEMA damage assessment, evacuation order, and maximum wind speed (provided by FDEM). We controlled for indicators such as the rate of damage in residential buildings and evacuation order caused by Hurricane Irma at the census tract level for the first time to bound the impact of stress (living within Hurricane Irma's path) on birth outcomes more tightly. Moreover, we investigated the impact of maximum wind speed as the second approach on birth outcome.

The findings show that hurricane exposure (living in the path of Hurricane Irma) decreased birth weight by about 7 grams. We also show that exposure to the hurricane in the third trimester of pregnancy causes a 0.46 percentage point increase in the likelihood of low birth weight, and the exposure in the third trimester of pregnancy has the highest negative impact on birth outcomes. In terms of other birth outcomes (complication of labor/delivery and abnormal condition of newborn) the hurricane exposure (living within 30 miles of the hurricane path) is estimated to increase the risk of abnormal condition in the infant, and complications of labor and delivery by 2.4 and 0.66 percentage point, respectively.

The estimated impact of hurricane Irma on birth weight and gestation length (the continuous measure) are robust to estimation methods. It is worth highlighting that the magnitude of the impact of hurricane exposure in our study are smaller than the effects found in the Currie and Rossin-Slater (2013) (1.5, 4.0, and 2.6 percentage point increase in likelihood of low birth weight, abnormal condition of newborn, and complication of labor/delivery, respectively), where they have used several estimation methods (such as OLS with county fixed effects and IV with mother fixed effects).

We investigated the impact of changes in maternal behavior, which could contribute to the results. However, we found no evidence that could account for these impacts. We also assessed the impact of other indicators such as evacuation order, residential building damage rate to isolate the impact of stress on birth outcomes. Comparing the results presented in Table 9 (where the aforementioned indicators controlled for) with the main results (shown in Table 3), we suggest that including the control variable mentioned above had small impact on the main results (presented in Table 3).

This work offers a contribution to the literature on climate change and health economics, by supporting the idea of the association between hurricanes and birth outcomes, where to our knowledge, no studies have tested the impact of a strong hurricane like Hurricane Irma on birth outcome. The findings can inform the public health sectors regarding the possible impact of hurricanes, especially in the State of Florida (where is the most hurricane-prone state in the country), on public health, especially pregnant women's health. This information can be used by the health organizations to aid pregnant women to reduce their stress through preparation for hurricanes, including creating a secure place for pregnant women who seek shelter during the pregnancy, informing mothers regarding the possible risks after the hurricane, and facilitating access to their essential needs such as water, and foods.

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TABLES

Table 1: Maternal characteristics and exposure to Hurricane Irma in Florida

Panel A: NO county fixed effects	**Mother's age: <20**	**Mother's age: 45+**	**Married mother**	**Mother's ed: <HS**	**Mother's ed: HS degree**	**Mother's ed: some college**	**Mother's ed: college+**	**Black mother**	**Hispanic mother**
BornPost2017* HIPath	0.0007 (0.0018)	0.0002 (0.0003)	0.0011 (0.0035)	-0.0029 (0.0038)	-0.0047 (0.0053)	0.0024 (0.0031)	-0.0041 (0.0034)	0.0043** (0.0021)	0.0066 (0.0058)
N	591058	591058	591058	591058	591058	591058	591058	591058	591058
R^2	0.0008	0.0001	0.0007	0.0015	0.0032	0.0003	0.0045	0.0054	0.0021

Panel B: County fixed effects	**Mother's age <20**	**Mother's age 45+**	**Married mother**	**Mother's ed: <HS**	**Mother's ed: HS degree**	**Mother's ed: some college**	**Mother's ed: college+**	**Black mother**	**Hispanic mother**
BornPost2017* HIPath	0.0007 (0.0018)	0.0001 (0.0003)	0.0015 (0.0036)	-0.0028 (0.0038)	-0.0050 (0.0052)	0.0028 (0.0031)	-0.0041 (0.0035)	0.0036 (0.0022)	0.0069 (0.0049)
N	591058	591058	591058	591058	591058	591058	591058	591058	591058
R^2	0.0052	0.0004	0.0113	0.0147	0.0168	0.0087	0.0278	0.0505	0.1700

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. Low birth weight refers to newborn under 2500 gram. Prematurity" refers to gestation age under 37 weeks. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Table 2: Summary statistics of Florida births, 2016–2018

Variable	Mean	Std. Dev.	N
birth weight (g)	3251.367	570.908	640,649
Low birth weight (<2500 g)	0.082	0.274	640,649
gestation (weeks)	38.532	2.346	640,649
premature (<37 weeks)	0.125	0.331	640,649
Mother's age <20	0.047	0.212	640,649
Mother's age 20-24	0.195	0.396	640,649
Mother's age 25-34	0.577	0.494	640,649
Mother's age 35-44	0.178	0.383	640,649
Mother's age 45>	0.002	0.049	640,649
Mother smoked prior pregnancy	0.051	0.219	640,649
Mother smoked in the 1st trimester	0.039	0.194	632,417
Mother smoked in the 2nd trimester	0.036	0.187	633,515
Mother smoked in the 3rd trimester	0.035	0.184	634,522
Mother used alcohol during pregnancy	0.005	0.068	636,382
C-section delivery	0.372	0.483	640,407
Mother white	0.712	0.453	640,649
Mother black	0.230	0.421	640,649
Mother Hispanic	0.341	0.474	640,649
Mother's education: <HS degree	0.116	0.320	640,649
Mother's education: graduated HS	0.307	0.461	640,649
Mother's education: some college	0.289	0.453	640,649
Mother's education: college+	0.277	0.448	640,649
Multiple birth	0.031	0.173	640,591
Female infant	0.489	0.500	640,649
Mother married	0.537	0.499	640,649
Number of prenatal visits	10.822	3.924	603,328
Birth order	1.511	0.515	19,891
Mother gained <16 (lbs.)	0.156	0.363	640,649
Mother gained >60 (lbs.)	0.093	0.291	640,649
Any abnormal condition of newborn	0.126	0.332	640,649
Any complication labor/delivery	0.041	0.199	640,649

Table 3: The effect of Hurricane Irma exposure (living within 30 miles of the hurricane path) on birth outcomes

	Birthweight (gram)	**Gestation (week)**	**Low birth weight (<2500 gram)**	**prematurity (<37 weeks)**
BornPost2017* HIPath	-6.8919* (3.9522)	-0.0130 (0.0157)	0.0003 (0.0013)	0.0008 (0.0022)
Mother age	-2.3089*** (0.3293)	-0.0309*** (0.0007)	0.0019*** (0.0001)	0.0028*** (0.0001)
Teen mother	-45.1641*** (5.3495)	-0.2643*** (0.0177)	0.0171*** (0.0017)	0.0291*** (0.0024)
Mother's ed: <HS	-28.9719* (15.8924)	-0.0316 (0.0362)	0.0046 (0.0056)	0.0136*** (0.0051)
Mother's ed: HS degree	-18.7537 (15.3482)	-0.0775** (0.0351)	-0.0015 (0.0040)	0.0117** (0.0050)
Mother's ed: some college	4.3830 (16.7745)	-0.0250 (0.0350)	-0.0109** (0.0041)	0.0002 (0.0049)
Mother's ed: college+	26.8950 (18.9913)	0.0756** (0.0350)	-0.0236*** (0.0043)	-0.0144*** (0.0049)
Mother Hispanic	-16.0488*** (5.5128)	-0.0627*** (0.0073)	-0.0030** (0.0013)	0.0037*** (0.0010)
Mother African American	-68.8117*** (11.6924)	-0.3232*** (0.0141)	0.0364*** (0.0033)	0.0380*** (0.0020)
Mother smoked in the 1st trimester	-49.6525*** (13.5217)	-0.0047 (0.0517)	0.0141** (0.0055)	0.0003 (0.0072)
Mother smoked in the 2nd trimester	-80.3426*** (17.6963)	-0.0938 (0.0768)	0.0184** (0.0076)	0.0198* (0.0105)
Mother smoked in the third trimester	-82.8049*** (20.2248)	-0.0900 (0.0692)	0.0397*** (0.0070)	0.0049 (0.0098)
Female infant	-121.5958*** (1.1348)	0.0798*** (0.0060)	0.0167*** (0.0006)	-0.0072*** (0.0008)
Mother Married	42.0681*** (4.6660)	0.0992*** (0.0071)	-0.0152*** (0.0011)	-0.0136*** (0.0010)
Birth month fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1496	0.0908	0.1259	0.0779
Number of observations	549,244	549,244	549,244	549,244

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. Low birth weight refers to newborn under 2500 gram. Prematurity" refers to gestation age under 37 weeks. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Table 4: The effect of Hurricane Irma exposure (living within 30 miles of the hurricane path) on birth outcomes by trimester

	Birthweight (gram)	**Gestation (week)**	**Low birth weight (<2500 gram)**	**prematurity (<37 weeks)**
1st trimester*HIPath	-8.7823 (6.1658)	-0.0322 (0.0499)	0.0052* (0.0026)	0.0046 (0.0058)
2nd trimester*HIPath	-7.5561 (6.0257)	0.0148 (0.0638)	-0.0014 (0.0026)	-0.0006 (0.0078)
3rd trimester**HIPath	-11.6522** (4.7231)	-0.0681*** (0.0237)	0.0046** (0.0022)	0.0060 (0.0042)
Mother age	-2.3080*** (0.3291)	-0.0309*** (0.0017)	0.0021*** (0.0001)	0.0028*** (0.0002)
Teen mother	-45.1387*** (5.3509)	-0.2642*** (0.0208)	0.0155*** (0.0020)	0.0291*** (0.0033)
Mother's ed: <HS	-28.9279* (15.8791)	-0.0314 (0.0497)	-0.0017 (0.0041)	0.0137*** (0.0045)
Mother's ed: HS degree	-18.7071 (15.3429)	-0.0772 (0.0493)	-0.0001 (0.0045)	0.0117** (0.0048)
Mother's ed: some college	4.4328 (16.7604)	-0.0247 (0.0560)	-0.0068 (0.0042)	0.0002 (0.0052)
Mother's ed: college+	26.9406 (18.9790)	0.0760 (0.0560)	-0.0184*** (0.0041)	-0.0144*** (0.0053)
Mother Hispanic	-16.0474*** (5.5117)	-0.0626*** (0.0163)	-0.0049** (0.0019)	0.0037* (0.0021)
Mother African American	-68.7979*** (11.6862)	-0.3231*** (0.0241)	0.0344*** (0.0030)	0.0379*** (0.0033)
Mother smoked in the 1st trimester	-49.6606*** (13.5243)	-0.0048 (0.0554)	0.0056 (0.0054)	0.0003 (0.0064)
Mother smoked in the 2nd trimester	-80.3667*** (17.7119)	-0.0930 (0.0789)	0.0144 (0.0098)	0.0198** (0.0087)
Mother smoked in the third trimester	-82.7683*** (20.2234)	-0.0905 (0.0793)	0.0387*** (0.0107)	0.0049 (0.0095)
Female infant	-121.5879*** (1.1335)	0.0799*** (0.0064)	0.0171*** (0.0008)	-0.0072*** (0.0009)
Mother Married	42.0753*** (4.6606)	0.0993*** (0.0116)	-0.0110*** (0.0012)	-0.0136*** (0.0019)
Month of the year fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1496	0.0908	0.1259	0.0779
Number of observations	549,244	549,244	549,244	549,244

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. Low birth weight refers to newborn under 2500 gram. Prematurity" refers to gestation age under 37 weeks. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 5: The effect of Hurricane Irma exposure (living within 30 miles of the hurricane path) on abnormal condition of newborn and complication in labor/delivery

	Any abnormal condition of newborn	**Any complication of labor/delivery**
BornPost2017* HIPath	0.0246***	0.0066***
	(0.0023)	(0.0013)
Month of the year fixed effect	Yes	Yes
Birth year fixed effect	Yes	Yes
County fixed effect	Yes	Yes
R-squared	0.0559	0.0491
Number of observations	589070	589070

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. *p < 0.1, **p < 0.05, ***p < 0.01.

Table 6: The effect of Hurricane Irma on birth outcomes based on maximum wind speed

Panel A:

The effect of Hurricane Irma on birth outcomes: The main model (Based on maximum wind speed (mph))

	Birthweight (gram)	**Gestation (week)**	**Low birth weight (<2500)**	**prematurity (<37 weeks)**
BornPost2017*WindSp74mph	-5.0562 (3.6335)	-0.0687** (0.0290)	0.0025 (0.0016)	0.0023 (0.0035)
Month of the year fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1339	0.0718	0.1145	0.0673
Number of observations	581495	581495	581495	581495

Panel B:

The effect of the Hurricane Irma on birth outcomes: By trimester (Based on maximum wind speed (mph))

	Birthweight (gram)	**Gestation (week)**	**Low birth weight (<2500 gram)**	**prematurity (<37 weeks)**
1st trimester*WindSp74mph	-8.5376 (6.3051)	-0.0873*** (0.0264)	0.0038 0.0030	0.0066 0.0057
2nd trimester*WindSp74mph	6.5986 (5.3406)	-0.0517** (0.0261)	-0.0007 0.0030	0.0011 0.0071
3rd trimester*WindSp74mph	-15.1139*** (5.2160)	-0.0502** (0.0244)	0.0047 0.0029	0.0022 0.0030
Month of the year fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1339	0.0718	0.1145	0.0673
Number of observations	581495	581495	581495	581495

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. Low birth weight refers to newborn under 2500 gram. Prematurity" refers to gestation age under 37 weeks. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Table 7: The effect of Hurricane Irma exposure on birth outcomes: Different distance cutoffs

Panel A: Distance buffer =30 mile (Main result)

	Birthweight (gram)	**Gestation (week)**	**Low birth weight (<2500 gram)**	**prematurity (<37 weeks)**
BornPost2017* HIPath	-6.8919*	-0.0130	0.0003	0.0008
	(3.9522)	(0.0157)	(0.0013)	(0.0022)
Month of the year fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1496	0.0908	0.1259	0.0779
Number of observations	549244	549244	549244	549244

Panel B: Distance buffer =50 mile

	Birthweight (gram)	**Gestation (week)**	**Low birth weight (<2500 gram)**	**prematurity (<37 weeks)**
BornPost2017* HIPath	-4.6705	0.0080	0.0007	-0.0022
	(3.6304)	(0.0407)	(0.0021)	(0.0046)
Month of the year fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1496	0.0908	0.1259	0.0779
Number of observations	549244	549244	549244	549244

Panel C: Distance buffer = 60 mile

	Birthweight (gram)	**Gestation (week)**	**Low birth weight (<2500 gram)**	**prematurity (<37 weeks)**
BornPost2017* HIPath	-3.0682	0.0286	0.0003	-0.0041
	(3.5877)	(0.0422)	(0.0019)	(0.0047)
Month of the year fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1496	0.0908	0.1259	0.0779
Number of observations	549244	549244	549244	549244

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. Low birth weight refers to newborn under 2500 gram. Prematurity" refers to gestation age under 37 weeks. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Table 8: Other possible mechanism for the impact of Hurricane Irma

	Mother smoked in the first trimester	Mother smoked in the second trimester	Mother smoked in the third trimester	Number of cigarettes smoked	Weight gain>60 pounds	Number of prenatal visits	Adequate prenatal care (Kessner Index)
BornPost2017*HIPath	0.0033 (0.0025)	0.0010 (0.0019)	0.0004 (0.0018)	0.0217 (0.7050)	-0.0092 (0.0064)	0.0391 (0.0922)	0.0264 (0.0459)
Month of the year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.0731	0.0713	0.0706	0.0582	0.0244	0.0871	0.0752
Number of observations	549644	550559	551445	549101	589070	555865	588674

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 9: Main results with additional controls including evacuation order and structural damage rates

	Birthweight (gram)	Gestation (week)	Low birth weight (<2500 g)	prematurity (<37 weeks)
BornPost2017* HIPath	-6.8860* (3.9531)	-0.0127 (0.0371)	0.0015 (0.0021)	0.0008 (0.0022)
Month of the year fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
County fixed effect	Yes	Yes	Yes	Yes
R-squared	0.1496	0.0908	0.1259	0.0779
Number of obs	549244	549,244	549244	549244

Note: Standard errors in parentheses. Standard errors are clustered by mother's current county of residence. Low birth weight refers to newborn under 2500 gram. Prematurity" refers to gestation age under 37 weeks. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Figure 1: Hurricane Irma's Path

Figure 2: Evacuation orders caused by Hurricane Irma, Florida

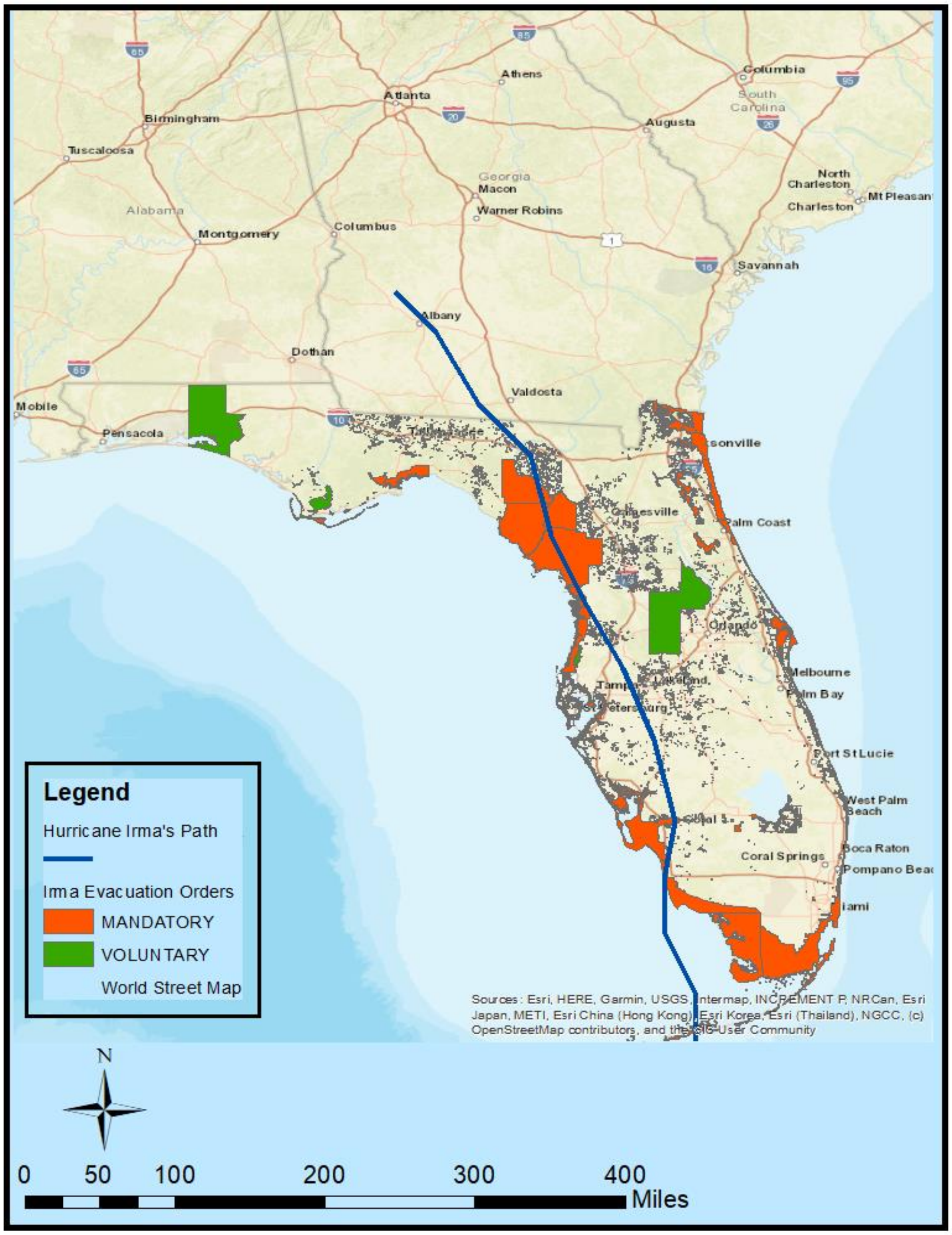

Figure 3: Economic losses for buildings by census tract

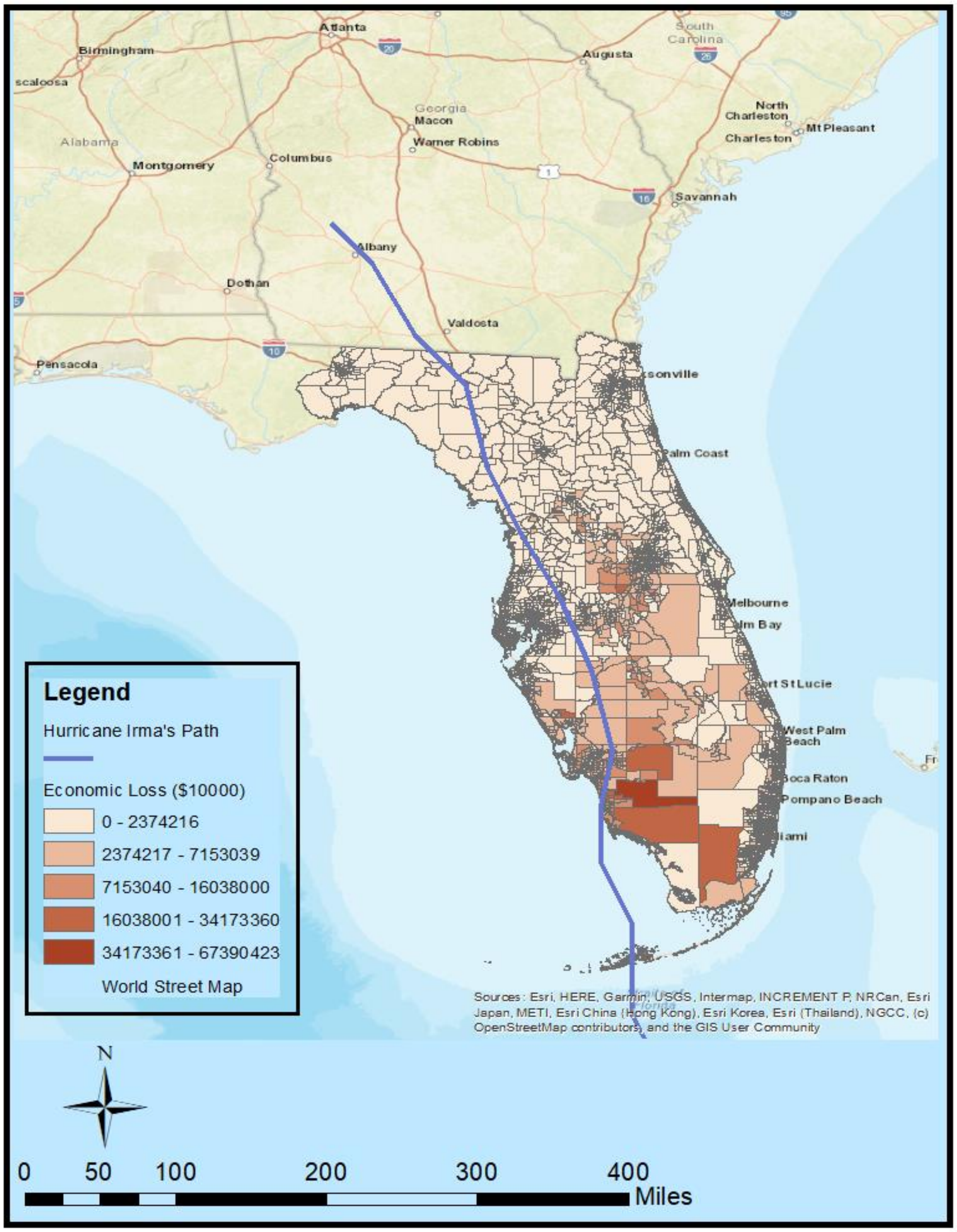

Figure 4: Live births over the period of 2016-2018, Florida

Figure 5: Hurricane Irma – peak wind gusts (mph) by census tract, Florida