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Abstract

We study the impacts of in utero exposure to Hurricane Catarina of March 2004, the first hurricane to hit Brazil. Catarina was unexpected and is representative of other recent hurricanes in the Americas in terms of wind speed, direct economic costs, and population affected. We use a triple differences strategy (close vs. far municipality, 2004 vs. 2003, after March vs. before) to highlight the importance of accounting for flexible season of birth effects compared to a standard differences-in-differences strategy. Using administrative data, we find that average birth weight declined and post-neonatal mortality increased among babies exposed to the hurricane in utero. The adverse effects are driven by babies of younger mothers. Our documented impacts are not explained by reductions in employment or healthcare use. Maternal stress seems to be a plausible mechanism if younger women are more financially vulnerable to negative shocks, consistent with recent work highlighting the relationship between socioeconomic status, stress, and birth outcomes. Our findings are robust to various checks, including testing for pre-trends in infant health outcomes.

Keywords: in utero shocks, infant health, birth weight, fetal mortality, infant mortality, healthcare use

JEL Codes: I1, I12, J13, Q54

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1 Introduction

Millions of individuals are exposed to severe natural disasters every year. Due to climate change, the frequency and severity of such disasters are increasing (Kim, 2016; Ornes, 2018). Between 2010 and 2019, 119 disasters in the United States met or exceeded $1 billion in damages and costs each (Smith, 2020). Pregnant women and their newborns may be particularly vulnerable to natural disasters for several reasons. Disasters may cut off access to medical care, including pre-natal care. Pregnant women may suffer from malnutrition caused by disruptions to food supply or contaminated water, especially in developing countries. The existing literature points to a relationship between stress and adverse birth outcomes such as pre-term births and low birth weight (Brown et al., 2011; Coussons-Read, 2013). Furthermore, multiple studies illustrate the importance of in utero shocks and health at birth for longer-term socioeconomic outcomes including educational attainment and adult earnings (e.g. Almond and Currie, 2011; Black et al., 2007; Figlio et al., 2014; Karbownik and Wray, 2019). Given the increasing frequency and severity of natural disasters, the vulnerability of pregnant women and newborns to such events, and the long-lasting nature of these effects, understanding how natural disasters impact infant health is important.

While several studies have investigated the impact of natural disasters on infant health, evidence remain mixed or inconsistent (Jeffers and Glass, 2020). In this paper, we study the impacts of Hurricane Catarina on birth outcomes (including birth weight, gestational length, and Apgar score), birth rates, as well as fetal and infant mortality. Catarina hit the Southern Coast of Brazil on March 28 2004 with a wind speed of roughly 160 km per hour. There are several features of Catarina that make it an interesting case to investigate. First, there is consensus among meteorological researchers that Catarina was an unexpected event. This means that populations living close to where the hurricane hit were unlikely to have anticipated it and reacted to it by moving residential areas. Second, in terms of its destructive power (measured in damages) and wind speed, Catarina is similar to the "median" hurricane in the Americas over the period 1991–2019 (EM-DAT).[1] This suggests that studying the effects of Catarina may be informative for other contexts too. These two features respectively support the internal and external validity of our study.

We use a difference-in-difference-in-differences (DDD) strategy that exploits variation in newborns' year of birth (2004 vs. 2003), season of birth (after March vs. before), and geographical proximity to the hurricane (close vs. far municipality) as defined by the mother's residential municipality at the time of birth. This DDD strategy makes clear and transparent the importance of controlling for season of birth effects, year-specific season of birth effects, as well as region-specific season of birth effects. Accounting for year-specific season of birth effects and region-specific season of birth effects seems important in light of previous studies showing that season of birth is likely to be endogenously determined by parents (Buckles and Hungerman, 2013; Clarke et al., 2019).

Our results suggest that exposure to Catarina in utero had adverse effects on birth outcomes and that such effects are concentrated among young mothers (i.e., 15 –24 years old, approximately 50% of our sample). Among babies born to young mothers, birth weight decreased by 83 g (-2.6% relative to the pre-hurricane mean) while the probability of being low birth weight increased by 3.4 pp, equivalent to 50% of the pre-hurricane low birth weight prevalence. The hurricane also decreased the likelihood of babies being born with high birth weight by 3.1 pp. Among babies born to older mothers (i.e., 25–49 years old), the estimated effect on birth weight is -4 g [95% CI: -57, 48], while the estimated effects on the probability of being born low birth weight and high birth weight are -1.1 pp [95% CI: -3.3, 1.2] and -0.3 pp [95% CI: -3.5, 2.9], respectively. For both young and older mothers, we do not detect statistically significant effects of Catarina on gestational length or Apgar score within the first 5 minutes of birth.

[1] The Emergency Disasters Database (EM-DAT) is maintained by the Centre for Research on the Epidemiology of Disasters (CRED; http://www.emdat.be). CRED divides disasters according to the following types: climatological, hydrological, meteorological, and geophysical. For a disaster to be included in the database, at least one of the following criteria must be fulfilled: 10 or more people are reported killed; 100 or more people are reported affected; declaration of a state of emergency; or call for international assistance.

We also find that being exposed to the hurricane led to a statistically significant increase in fetal deaths among babies born to young mothers. The fetal death rate increased by 16.7 per 1000 live births and fetal deaths, over five times the pre-hurricane mean of 3 deaths per 1000 live births and fetal deaths. After accounting for this culling effect among babies born to young mothers, we find that our estimates of the effect of the hurricane on birth weight are attenuated by 8–15%. Furthermore, we find that the post-neonatal death rate (deaths occurring 28 and 364 days of birth, per 1000 live births) increased by 4.2 as a result of the hurricane regardless of the mother's age. We do not find evidence that the hurricane had an impact on the live birth rate for either young or older mothers, reducing concerns of selective fertility.

Related literature and contribution. A large number of recent studies suggest that experiencing negative events during pregnancy leads to worse birth outcomes of the offspring. Table 1 provides a summary of recent studies and compares them to our estimates of the impact of Catarina on birth outcomes.[2] A variety of studies have focused on the effect of natural disasters (panel A) such as earthquakes (Kim et al., 2017; Liu et al., 2015; Menclova and Stillman, 2020; Torche, 2011) and hurricanes (Currie and Rossin-Slater, 2013; Simeonova, 2011). Another set of studies (panel B) look at the impact of exposure to conflict or violence while pregnant. Quintana-Domeque and Ródenas-Serrano (2017) study the effects of ETA terrorism on birth outcomes in Spain, including the Hipercor Bombing of 1987 in Barcelona; Brown et al. (2014) examine the effect of exposure to the 9/11 terror attacks; Camacho (2008) investigates the impact of landmine exposures in Colombia.[3] A third set of studies (panel C) examine the effects of exposure to other negative shocks. Black et al. (2016) and Persson and Rossin-Slater (2018) look at the impact of a death in the family. Carlson (2015) looks at the impact of receiving bad economic news such as an impending

[2] Results are presented for the full sample of mothers.

[3] Other studies that contribute to the literature on the effect of exposure to conflict on birth outcomes include: Mansour and Rees (2012) and Lee (2014).

job lost while in utero.[4] Bozzoli and Quintana-Domeque (2014) investigate how exposure to economic fluctuations affects birth weight in Argentina between 2000 to 2005.[5]

Overall, these studies suggest that exposure to these negative events in utero leads to worse birth outcomes by decreasing birth weight by as much as 50 g in Torche (2011), increasing the probability of being born low birth weight (by up to 1.7 pp), and by increasing the incidence of pre-term births (by up to 2.6 pp). Given that health at birth is a crucial component of human capital development (Almond et al., 2005; Clarke et al., 2017; Currie and Almond, 2011; Rosales-Rueda, 2018), affecting educational attainment and later earnings (Black et al., 2007), the findings of these studies entail that exposure to negative shocks in utero can affect one's life trajectory and contribute to the intergenerational transmission of inequality.

The first contribution of our paper is to document the effects of an unexpected hurricane, the first hurricane to hit Brazil, which is close to the "median" hurricane in the Americas over 1991-2019 (EM-DAT). This is important for both internal and external validity concerns. In a recent review of pregnancy and birth outcomes after exposure to a hurricane, Jeffers and Glass (2020) write that "hurricane exposure was frequently associated with pregnancy complications, preterm birth, low birth weight, caesarean birth, and abnormal newborn conditions. However, these associations were not always consistent." This study aims to add to the literature that investigates the effects of natural disasters. As noted by Angrist and Pischke (2010) and quoted by Rohrer (2018), "In the empirical universe, evidence accumulates across settings and study designs, ultimately producing some kind of consensus".

[4]Furthermore, Carlson (2018) finds that mean gestational age fell by 1.5 days as a result of announcements that projected a 20% drop in employment.

[5]Other research has investigated the impact of rainfall fluctuations during the gestational period on health at birth in the Brazilian semiarid (Rocha and Soares, 2015) and the impact of in utero exposure to temperature shocks on birth outcomes in rural Colombia (Andalón et al., 2016). More recently, a few studies have investigated the impact of environmental pollution on infant health in Puerto Rico (Bobonis et al., 2020) and Brazil (Carrillo et al., 2020).

Table 1: Comparison of results

Study	**Event**	**Location**	**Results**		
			Birthweight	**P(Low BW)**	**P(Preterm)**
A. Natural disasters					
This paper	Hurricane	Brazil	↓ 44.4g	↑ 1.7pp	No effect
Torche (2011)	Earthquake	Chile	↓ 50.84g	↑ 1.7pp	↑ 2.6pp
Currie and Rossin-Slater (2013)	Hurricane/tropical storm	US	—	↑ 1.55pp	—
Kim et al. (2017)	Earthquake	US	↓ 9-11g	↑ 0.2-0.5pp	No effect
Menclova and Stillman (2020)	Earthquake	New Zealand	↓ 10g	No effect	No effect
B. Conflict/Violence					
Quintana-Domeque and Ródenas-Serrano (2017)	Hipercor Bombing	Barcelona	↓ 11.5g	↑ 1.2 pp	↑ 0.8 pp
Mansour and Rees (2012)	Fatalities from al-Aqsa Intifada	West Bank	↓ 2.2g	↑ 0.10-0.27pp	—
Camacho (2008)	Landmine explosions	Columbia	↓ 8-12g	—	—
Brown et al. (2014)	9/11 (outside NY/DC)	US	↓ 5-15g	↑ 0.02–0.03 pp	↑ 0.04–0.11 pp
C. Other shocks					
Bozzoli and Quintana-Domeque (2014)	Macroeconomic crisis	Argentina	↓ 34-35g	↑ 0.007 pp	—
Carlson (2015)	News of a future layoff	US	↓ 15-20g	↑ 0.68-0.92 pp	↑ 1.04-1.30 pp
Black et al. (2016)	Loss of grandparent	US	↓ 15-20g	No effect	—
Persson and Rossin-Slater (2018)	Family death	Sweden	↓ 11g	↑0.39pp	↑0.62pp

Notes: This table summarizes results in the existing literature. This paper: results are presented for the full sample (young and old mothers) using the baseline specification. Torche (2011): results presented here capture the effects of first-trimester exposure. Currie and Rossin-Slater (2013): results presented here capture effects of third-trimester exposure using their OLS with county fixed-effects specification, counting backwards from birth date. Kim et al. (2017): the range of results presented here represents heterogeneity across all mothers and single/first time mothers. Menclova and Stillman (2020): results presented here capture effect of third-trimester exposure using their mother's fixed effects with IV for location specification. Quintana-Domeque and Ródenas-Serrano (2017): results presented here capture effect of being exposed in the first-trimester. Brown et al. (2014): results presented here are translated into percentage points based on % effects provided in paper. Bozzoli and Quintana-Domeque (2014): results presented here capture the effect of a 11% decrease in the long term trend in economic activity. Black et al. (2016): results presented here capture estimates from various specifications used. See footnote 19 in Black et al. (2016) for a discussion on LBW. "–" indicates that results are not reported in the paper.

Many existing studies discussed above attribute the negative effects to the stress induced by such events. Aizer et al. (2016) examines the impact of general stress and mental health problems. Menclova and Stillman (2020) highlight that younger women might have a harder time dealing with stress while being pregnant and thus be more vulnerable to adverse shocks. More broadly, studies that explore the heterogeneity of such shocks have emphasized the importance of other factors such as credit constraints and nutritional deprivation. Bozzoli and Quintana-Domeque (2014) find that the birth weights of Argentinian children born to low-educated mothers are sensitive to macroeconomic fluctuations whereas children born to high-educated mothers are not, consistent with low-educated women facing credit constraints and consequential nutritional deprivation. Rosales-Rueda (2018) finds that households affected by El Niño floods in Ecuador suffered a decline in income, total consumption, and food consumption in the aftermath of the shock, while Henry et al. (2020) find that, in the context of Jamaica, tropical storms significantly reduce household consumption and that such reductions are concentrated among households with low savings and remittances.

Most studies focus on the effect of negative shocks on birth outcomes. Only a handful of studies also look at the impacts on fetal and infant mortality. As acknowledged by Christopher (2017), there are especially few studies examining the causal effect of hurricanes (Kanter, 2010; Zahran et al., 2014, 2013) on fetal and infant deaths. Mendez-Figueroa et al. (2019) shows that children exposed in utero to Hurricane Harvey were 1.03-1.94 times more likely to experience neonatal morbidity, but state that their study "is not able to draw any conclusions on causality". The impact of in utero exposure to a hurricane on fetal deaths is currently ambiguous. Grabich et al. (2017) find no association between hurricane exposure and fetal deaths after Hurricane Catarina. However, Zahran et al. (2014) report that fetal deaths increased in areas of Louisiana where the housing stock was severely affected.[6]

The second contribution of our paper is that, in addition to birth outcomes, we also

[6]Liu et al. (2015) also study the effect on fetal mortality, focusing on the effects of the 1999 Taiwan earthquake. They find that a negative shock during the first trimester increases fetal losses by 4.4% and that such losses are concentrated among male fetuses.

examine the effects of the hurricane on live births, fetal deaths, as well as neonatal and post-neonatal mortality rates. These outcomes are not only of interest in their own right, but assessing how they are affected also allows us to adjust for survivor bias and selective fertility. Hence, we provide a more holistic analysis of the impact of natural disasters, focusing on both birth and mortality outcomes.

The majority of studies discussed above use a difference-in-difference strategy to estimate the effect of exposure to negative shocks. The first source of variation is geographical proximity to the shock while the second source is the timing of the birth relative to the negative shock. Studies with access to mother identifiers are also able to use a mothers fixed effects strategy to eliminate additional sources of unobserved outcomes (e.g. Camacho, 2008; Currie and Rossin-Slater, 2013; Menclova and Stillman, 2020).

The third contribution of our paper is that we use a DDD strategy instead of the more commonly-used DD strategy. A DDD makes clear and transparent the importance of controlling for season of birth, which previous studies have found to be not only a variable correlated with parental characteristics (Buckles and Hungerman, 2013) but one which is valued by parents (Clarke et al., 2019). The identification of the impact of in utero exposure on infant health by means of a standard DD may be compromised by year-specific or region-specific season of birth effects which are directly accounted for by a DDD design.

The rest of this paper is structured as follows. Section 2 provides information about Catarina, data sources and damages. Section 3 describes the characteristics of babies, mothers and municipalities before the hurricane. Section 4 outlines our main empirical strategy and identification assumptions. Section 5 presents our main results. Section 6 discusses potential mechanisms that explain the main effects. Lastly, section 7 concludes.

2 Hurricane Catarina, Data and Damages

2.1 Hurricane Catarina

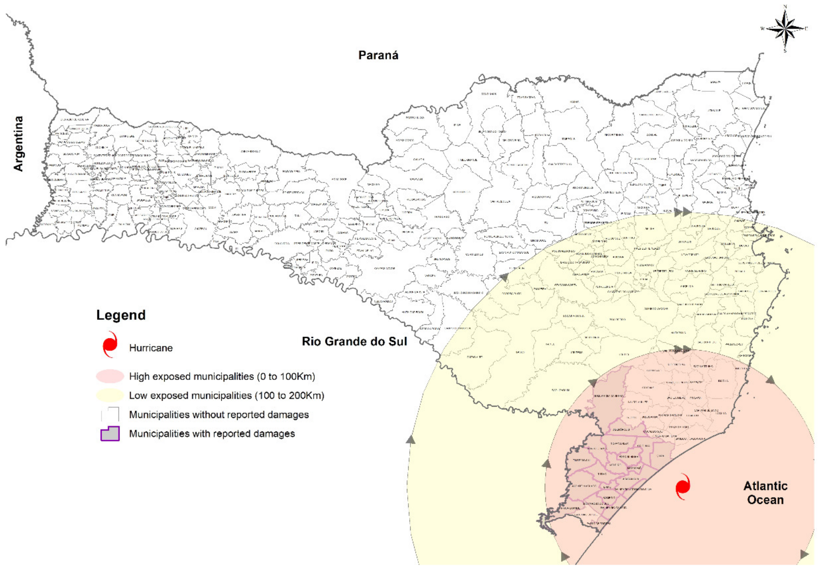
This study focuses on the effect of the first-ever reported hurricane to hit Brazil (Hurricane Catarina) on infant health. On March 28 2004, Hurricane Catarina hit Santa Catarina in Southern Brazil, a state neighboured by Rio Grande do Sul in the South and Paraná in the North (see Figure 1). Catarina began as an extra-tropical storm on March 19 2004, became a hybrid system[7] on March 24, and morphed into a Category I hurricane with a wind speed of 148.2 km/h on March 26. On March 28 at 6.00 am, the hurricane reached category II with a wind speed of about 157.4 km/h, 28.2 km away from Balneário Arroio Silva, the nearest municipality to the hurricane. After reaching category II, the diameter of the cloud shield reached 400 km (200 km radius), which is small by the standards of North Atlantic hurricanes. Six hours later at 12.00 pm, the hurricane lost its intensity, becoming a tropical storm and moving 138 km inland where the wind speed decreased from 111 to 83 km/h (McTaggart-Cowan et al., 2006).

Many meteorological forecasters and researchers have commented on the unexpected nature of Catarina. Pezza et al. (2009) suggest that because Catarina started as an extra-tropical cyclone, a common occurrence during any season, Catarina did not draw much attention from forecasters when it first formed. Until the occurrence of Catarina, it has been generally accepted that hurricanes could not form over the South Atlantic because of the relatively high environmental vertical wind shear (i.e., velocity and direction) and low sea surface temperatures, but Catarina made the community rethink this interpretation (Pezza and Simmonds, 2005).[8] McTaggart-Cowan et al. (2006) confirm that there have been no

[7] A hybrid systems can occur under two situations. The first is when an initial extra-tropical cyclone changes into a tropical cyclone, as was the case of Catarina. The second is when the reverse happens: a tropical cyclone changes into an extra-tropical cyclone. Such transitions imply sudden changes in the sea surface temperatures and in the environmental vertical wind shear (Pezza and Simmonds, 2005).

[8] To form, hurricanes need a long track over a warmer ocean, small wind speed in the upper levels promoting a small vertical wind variation (small shear), and an unstable environment prone to cyclone wave development (Pezza and Simmonds, 2008).

Figure 1: Map of Brazilian municipalities and hurricane position



tropical storms of hurricane strength that occurred in the South Atlantic in the satellite era up to that date. Overall, meteorological evidence suggests that the hurricane could not have been anticipated by those residing in or near Santa Catarina, preventing any residential sorting in anticipation of the hurricane.

2.2 Data Sources

Damages. To document the damages of Catarina we use data from the Damage Assessment Reports (Formulário de Avaliação de Danos - AVADAN) that municipal governments must send to the State Civil Defence Agency in order to declare an emergency situation or public calamity. The reports must be filed by qualified professionals within 120 hours of the disaster. We also use GDP data from the Brazilian Institute of Geography and Statistics.[9]

Infant health. To investigate the impact of hurricane Catarina on birth outcomes, we use birth outcomes data for 2001–2005 from the Information System on Live Births (Sistema

[9]Data on GDP at municipality level can be accessed at `https://www.ibge.gov.br/estatisticas/downloads-estatisticas.html`.

de Informações sobre Nascidos Vivos – SINASC) provided by the Ministry of Health.[10] These data provide information on birth outcomes (birth weight, intervals of gestational age, and Apgar score), as well as the socio-demographic characteristics of the child (gender and race/color) and the mother (age, educational attainment, marital status, and parity). To study the impact of Catarina on fetal, neonatal, and post-neonatal deaths, we use the Information System on Deaths (Sistema de Informações sobre Mortalidade – SIM) which is also provided by the Ministry of Health.

Health care services and employment. We analyze the effect of the hurricane on the provision of public health services using information on hospital admissions due to infections and due to complications during pregnancy from the Hospital Information System (Sistema de Informações Hospitalares - SIH). We also use data from the Outpatient Information System (Sistema de Informações Ambulatoriais – SIA), which provides information on prenatal appointments and obstetric ultrasound scan appointments. Finally, to assess whether employment was affected by Catarina, we use data on formal employment at the municipality level between 2002 and 2005 from the Ministry of Economy.[11]

Appendix A contains the links to all data sources used in this paper.

2.3 Evidence on Damages

Table B.1 in Appendix B provides a summary of the damages to municipalities in Santa Catarina due to the hurricane. It should be noted that the figures in these reports may be subject to measurement error for various reasons, including the fact that municipal governments only have a short period of time after the disaster to estimate damage costs and that municipal governments may have incentives to overestimate costs since federal transfer funds depend on claimed costs.

[10] Information on live birth records and deaths can be accessed at `http://www2.datasus.gov.br/DATASUS/index.php?area=0901`.

[11] Data on formal employment at municipality level can be found at `http://bi.mte.gov.br/bgcaged/login.php`.

Panel A shows that 21 out of 293 municipalities in Santa Catarina reported being directly affected by the hurricane. Among these municipalities, the average distance from the center of the hurricane is 56 km, with a range of 28.2 to 88.8 km. Panel B shows how the residents of these municipalities were affected. Overall, 6.4% of the population (27,025 people) were affected. Of those affected, 94% had to temporarily leave their homes, about 4.9% had to be moved to a shelter, 1.6% were injured or sick, and 0.01% were missing or dead. Panel C depicts how the infrastructure in these municipalities was affected by the hurricane. 71,646 were dwellings damaged by the hurricane (11% of the total dwellings in affected municipalities). This represents 88% of the total number of buildings damaged. Most dwellings that were affected by the hurricane experienced partial damage to its structure (e.g. damage to the roof, windows, door), while 1% of the affected dwellings collapsed.

Panel D shows that damages resulting from the hurricane amount to 5.8% of the GDP of affected municipalities.[12] However, our back-of-the-envelope calculation of the cost of Catarina is much smaller when we use official GDP statistics.[13] Comparing the log GDP in 2004 with that of 2003 between municipalities with a damage report and municipalities without a damage report, we estimate a reduction of the GDP of 3.8%.

Figure 2 illustrates the relationship between the cost due to damages and the distance from the hurricane, with the size of the circles representing the population of the municipality.[14] All four figures reveal that among municipalities with a damage report, the closer the municipality is to the hurricane, the larger is the reported damage in terms of direct economic cost (panel A), size of the affected population (panel B), dwellings (panel C) and health services (panel D).[15] Of course, a negative relationship between distance and reported

[12] 45% of this reduction in GDP due to the damaged crops, 40% due to building/infrastructure damages and the remaining 15% is due to damages to essential services (transportation, communication, water supply, electricity supply, sewage, and garbage), environment or natural resources (water, soil, flora and fauna), livestock and others.

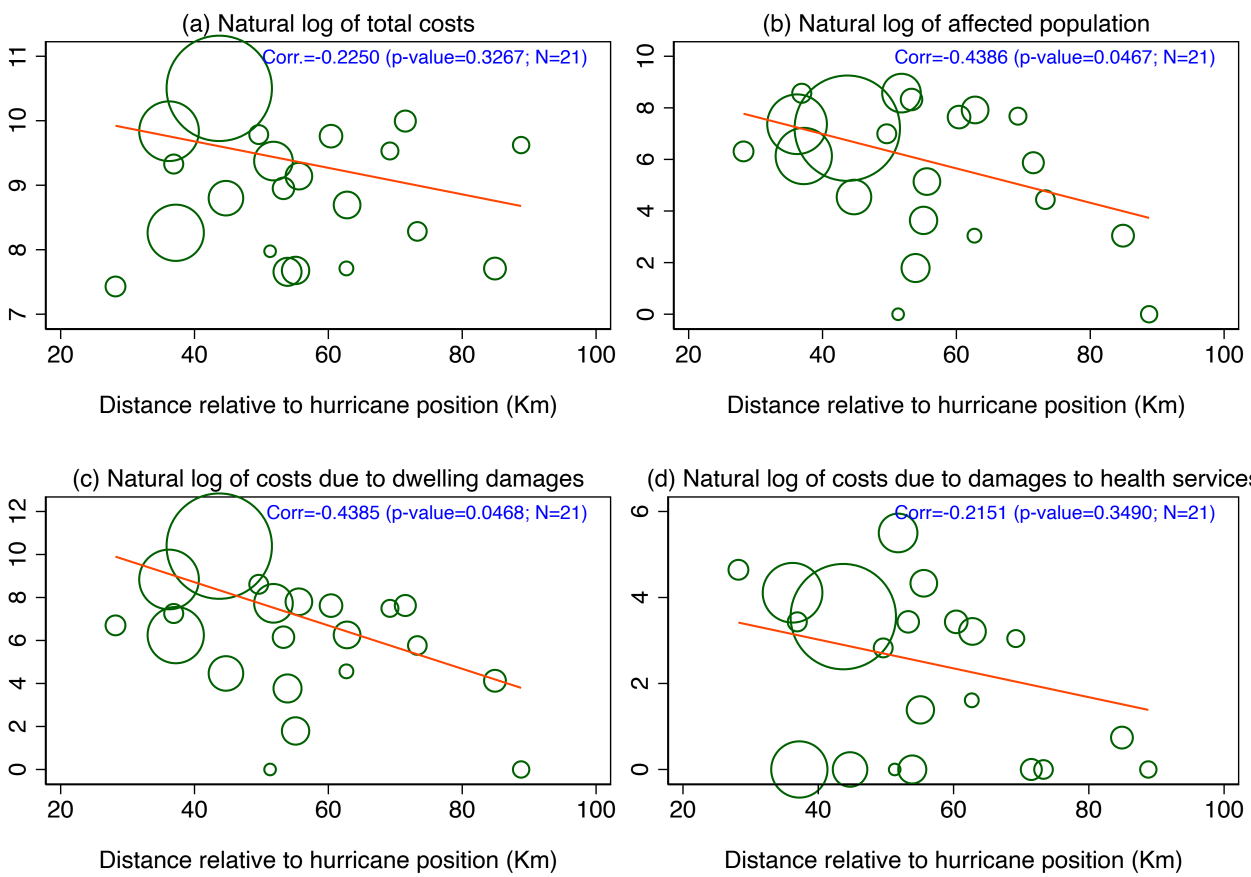
[13] GDP data come from the Brazilian Institute of Geography and Statistics. Data on GDP at municipality level can be accessed at `https://www.ibge.gov.br/estatisticas/downloads-estatisticas.html`.

[14] The scatter plots are weighted by the population size of municipalities from the 2000 Demographic Census.

[15] Damages to health services in the AVADAN refers to healthcare assistance and prevention.

damages could be driven by collider bias (if filing a report depends on both distance to the hurricane and damage) or by municipalities closer to Catarina inflating reported costs more than those further away from Catarina.[16]

Figure 2: Relationship between damages and distance to hurricane



How does Catarina compare to other hurricanes? Figure C.1 in Appendix C uses data on recent hurricanes in the Americas from 1991 to 2019 (EM-DAT) and depicts the relationship between wind speed and direct economic cost (panel A), deaths (panel B) and affected population (panel C). Two patterns are noticeable. First, the stronger the wind speed, the higher the destructive power of the hurricane along all the three measures. Second, in terms of its destructive power and wind speed, hurricane Catarina is similar to the median. This suggests that studying the effects of Catarina may be informative for other contexts too.

[16]In Section 6, we find little evidence that access to healthcare services among pregnant women is affected by Catarina. This suggests that the figures in the damage reports should be interpreted with caution.

3 Babies, mothers and municipalities

3.1 Samples

For our baseline analysis, we restrict our sample to *babies* born between January 1 2003 and December 31 2004. For our extended analysis, we include babies born in 2001, 2002, and 2005 as well. To be included in the main sample, newborns must have the following characteristics: (a) they are singletons, (b) their mother's age is between 15 and 49 years at the time of birth, (c) their birth weight is at least 500 grams but less than 6,000 grams, (d) their Apgar score is between 0 and 10, and (e) their gestational length is at least 28 weeks (Currie and Rossin-Slater, 2013). Condition (e) means that we include pre-term babies from 7 months onwards. Additional checks show that our results are robust to dropping pre-term babies. This gives us 53,006 births for the baseline sample (2003–2004) and 133,513 for the extended sample (2001–2005).[17]

We restrict our main sample to *municipalities* within 200 km of the hurricane location (rather than using all municipalities in Santa Catarina) because meteorological data show that the hurricane radius is 200 km from the vortex (McTaggart-Cowan et al., 2006). We define municipalities within 100 km of the hurricane center as being "close" to Catarina and municipalities within 100–200 km of the hurricane center as being "far" from Catarina. There are two reasons for this definition of geographical proximity. First, among municipalities that reported damages from the hurricane (21 out of the 293 municipalities in Santa Catarina), all of them are within 90 km of the hurricane position (see Table B.1). Second, this distance cutoff is consistent with the empirical design used in previous studies, enhancing the comparability of magnitudes across studies. For example, Currie and Rossin-Slater (2013) define geographically exposed mothers to be those "who ever lived within 100 km of any point along a storm path". We later demonstrate that our results are robust to alternative

[17]The original sample size is 144,518 live births. Applying sample selection criteria (a) to (e) reduces the sample size to 138,398. Because some variables (e.g. marital status, education, and parity) have missing observations, the final sample size is 133,513 live births for the extended sample.

ways of defining geographical proximity. Overall, this gives us a sample of 87 municipalities (out of 293) in Santa Catarina. Of these 87 municipalities, 43 are close to Cataroma (<100 km away) and 44 are far from Catarina (100-200 km away).

3.2 Descriptive statistics in the year 2000

In Table 2, we present characteristics of municipalities within Santa Catarina that are close to and far from the hurricane location (columns 1-3). We also present statistics for Santa Catarina and the rest of Brazil (columns 4-6). We use data from 2000, four years prior the hurricane, to construct these statistics in order to check whether there are pre-existing differences across municipalities.

Panel A of Table 2 presents information on municipality-level characteristics. Columns (1) to (3) show that municipalities closer to the hurricane are better off socioeconomically than municipalities further away from the hurricane. For example, there are statistically significant and quantitatively relevant differences in the illiteracy rate (8% vs. 9.8%, p-value<0.001) and extreme poverty rate (3.6% vs. 5.6%, p-value<0.01).[18] Columns (4) to (6) illustrate that Santa Catarina is a richer region than the rest of Brazil. The average household income per capita is $185 (PPP) higher and the extreme poverty ratio is 14.02 pp lower. Health outcomes also appear to be better in Santa Catarina than the rest of Brazil. There are sizeable and statistically significant differences in the infant mortality rate (22.53 vs 33.24 per 1000 live births) and life expectancy (72.52 vs. 68.18).

Panel B examines newborn characteristics in these municipalities. Columns (1) to (3) show that babies born in municipalities that are closer to the impending hurricane in 2004 tend to have better birth outcomes compared to those in more distant municipalities. There is a sizeable and statistically significant difference in average birth weight (3,315 g vs. 3,256 g, p-value<0.001). Columns (4) to (6) indicate that babies in Santa Catarina have a higher

[18]The extreme poverty ratio is defined as the proportion of individuals with household income per capita equal to or less than 70 Brazilian Reals per month (USD 41.3 PPP). This is the poverty line criteria for the Bolsa Familia Program, the main conditional cash transfer program in Brazil.

Table 2: Characteristics of affected and unaffected municipalities in 2000

	Within Santa Catarina			Santa Catarina vs. Brazil		
	< 100km	**100-200km**	**Diff**	**Catarina**	**Brazil**	**Diff**
	(1)	(2)	(3)	(4)	(5)	(6)
A. Municipality characteristics						
HH income per capita	574.56	507.83	66.73	526.39	341.23	185.16***
Illiteracy rate $\geq$ 15 y/o (%)	8.04	9.81	-1.77**	9.13	22.45	-13.33***
Infant mortality rate	21.44	22.71	-1.27	22.53	33.24	-10.71***
Fertility rate 15-49 y/o (%)	2.36	2.64	-0.28***	2.54	2.89	-0.35***
Urbanization rate (%)	57.59	50.38	7.22	51.87	58.86	-6.99***
Life expectancy	72.97	72.45	0.52	72.52	68.18	4.34***
Human development index	0.63	0.60	0.03**	0.61	0.52	0.09***
Extreme poverty ratio (%)	3.62	5.55	-1.93*	7.41	21.43	-14.02***
B. Newborn characteristics						
Birth weight	3313.55	3256.09	57.46***	3253.15	3231.08	22.07***
Low birth weight (<2,500g)	0.04	0.06	-0.02***	0.06	0.06	-0.00***
High birth weight (>4,000g)	0.07	0.06	0.01***	0.06	0.05	0.01***
Short gestational length (<37 wks)	0.04	0.05	-0.01***	0.05	0.06	-0.00***
Long gestational length (>41 wks)	0.01	0.01	-0.00*	0.01	0.01	-0.00***
Apgar score (0-10)	9.22	8.92	0.30***	9.15	9.17	-0.01*
Girls	0.48	0.48	-0.00	0.48	0.49	-0.00
White	0.94	0.94	0.00	0.95	0.57	0.39***
C. Mother characteristics						
Age	25.50	25.49	0.01	25.52	24.69	0.83***
Married	0.83	0.66	0.17***	0.76	0.64	0.12***
Completed HS	0.10	0.12	-0.01***	0.11	0.12	-0.00***
First birth	0.41	0.42	-0.01	0.40	0.39	0.01***
Birth = residential mun.	0.69	0.67	0.02**	0.76	0.79	-0.02***
Municipalities	43	44		293	5,272	
Births	11,619	13,157		83,032	2,224,118	

Notes: Columns (1) and (2) respectively present variable means for municipalities in Santa Catarina that are less than 100km or between 100 to 200km away from the hurricane. Column (3) presents the difference in means (column 1 - 2). Columns (4) and (5) respectively present variable means for municipalities within Santa Catarina and municipalities in Brazil (excluding Santa Catarina). Column (6) presents the difference in means (column 4 - 5). Data on municipality characterstics comes from the 2013 Human Development Atlas of the United Nations Development Program in Brazil, which uses Demographic Censuses to compute development indicators at the municipality level. Data on birth outcomes, child and mother characteristics comes from 2000 live birth statistics. Income per capita is measured in 2010 Brazilian Reals. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

average weight at birth compared to the rest of Brazil (3,253 g vs. 3,231 g, p-value<0.001).

Finally, in panel C, we compare the characteristics of mothers across municipalities and between Santa Catarina and the rest of Brazil. Columns (1) to (3) show that mothers in municipalities closer to the hurricane are more likely to be married (83% vs. 66%, p-value<0.001), less likely to have completed high school (10% vs. 12%, p-value<0.001), and 2 pp more likely to give birth in their municipality of residence (69% vs 67%, p-value<0.001). Columns (4) to (6) shows that mothers in Santa Catarina tend to be about 1 year older than in the rest of Brazil (25.5 vs 24.7, p-value<0.001), they are 12 pp more likely to be married (76% vs 64%, p-value<0.001), they are less likely to have completed high school (11% vs 12%, p-value<0.001), and 3 pp less likely to give birth in their municipality of residence (76% vs 79%, p-value<0.001).

These descriptive statistics suggest that municipalities closer to Catarina have better socioeconomic characteristics than distant municipalities. Under the assumption that municipalities with worse socioeconomic indicators are more vulnerable to hurricane damages, this suggests that the estimated impacts of the hurricane are likely to provide a lower bound of the effect on mothers and newborns residing in more economically vulnerable municipalities.

4 Empirical Strategy

Our main empirical strategy is a difference-in-difference-in-differences (DDD) strategy that exploits three sources of variation in exposure to the hurricane. The first two sources of variation are *temporal* variation based on the newborn's date of birth: (a) year of birth (2004 vs. 2003) and (b) season of birth (after March 28 vs. before). Since the hurricane hit the coast of Santa Catarina on March 28 2004, all babies born before this date are not exposed to the hurricane in utero. In contrast, babies born between March 28 and December

31 2004 are likely to be exposed in utero.[19] The third source of variation is *geographical* variation in exposure to the hurricane based on the mother's municipality of residence at the time of birth. We consider municipalities within 100 km of the hurricane center to be close to Catarina.[20]

Combining these sources of variation (i.e. temporal and geographical) provides us with our baseline specification to estimate the effect of in utero exposure to Catarina on birth outcomes. Our baseline specification uses the sample of babies born in 2003 or 2004 within 200 km of the hurricane center. The econometric model is given by equation (1):

$$\begin{aligned} y_{itmdp} = \alpha &+ \beta_{DDD}(Close_p \times Y2004_t \times Mar28_{dm}) + \beta_1(Y2004_t \times Mar28_{dm}) \\ &+ \beta_2(Close_p \times Y2004_t) + \beta_3(Mar28_{dm} \times Close_p) \\ &+ \beta_4(Mar28_{dm}) + \gamma X'_{itmdp} + \phi_p + \tau_t + \mu_m + \epsilon_{itmdp} \end{aligned} \tag{1}$$

where the dependent variable y_{itmdp} denotes the birth outcome for newborn i in year t, month m, and day d whose mother's municipality of residence is p. We focus on the following birth outcomes: : (a) birth weight (in grams), (b) a binary indicator for low birth weight (<2,500 g), (c) a binary indicator for high birth weight (>4,000 g), (d) a binary indicator for short gestational length (<37 weeks), (e) a binary indicator for long gestational length (<41 weeks), and (f) Apgar score within the first 5 minutes of birth. We multiply binary

[19] The Information System on Live Births before 2011 does not contain information on the date of the last menstrual period which can be used to measure the date of conception. To avoid introducing measurement error by counting backwards from the date of birth in measuring exposure by trimester, we focus our analysis on exposure during pregnancy. In a recent paper, Carrillo et al. (2020) also use data from the Information System on Live Births (ISLB) to investigate the impact of a mining dam collapse in Brazil on infant health, including birth weight and infant mortality. They use data from the years 2011-2016. For this period, the ISLB contains information on the date of the last menstrual period, which they use as a proxy for the date of conception. The availability of the data of the last menstrual period allows them to measure exposure to trimester of pregnancy without introducing measurement error by counting backwards from the date of birth.

[20] As discussed previously, there are two reasons for this definition of geographical proximity. First, among municipalities that reported damages from the hurricane, all of them are within 90 km from the hurricane position. Second, this distance cutoff is consistent with the empirical design used in previous studies (e.g. Currie and Rossin-Slater (2013)).

dependent variables (b–e) by 100 so that the effects can be interpreted as percentage point differences.

The main explanatory variables are defined as follows: $Close_p$ takes on a value of one if municipality p is less than 100 km away from the hurricane center and zero otherwise; $Y2004_t$ takes on a value of one if the baby is born in year 2004 and zero otherwise; $Mar28_{dm}$ takes on a value of 1 if the baby is born on or after March 28 (in any year) and zero otherwise.

The remaining variables include the vector X' which consists of mother and newborn characteristics: gender of the baby, race of the baby (white or other), age bins for the mother (in 5 year intervals), marital status of the mother (married or not), indicators for mother's educational attainment (completed high school or not), 3 indicators for parity at current birth (2nd birth, 3rd birth, or 4th birth and above), and an indicator for whether the mother's municipality of residence is the same as the municipality where the baby is born. We provide evidence below (Table B.2) that these mother and newborn characteristics are not affected by exposure to the hurricane. Finally, we include municipality fixed effects ϕ_p, year fixed effects τ_y, and calendar month fixed effects μ_m.[21] We cluster standard errors at the municipality level (87 municipalities).

The main coefficient of interest is our DDD estimand β_{DDD} which captures the effect of in utero exposure of the hurricane on birth outcomes. Given that Catarina is a macro-level shock and we do not have information on the manner and extent to which individual mothers are affected, it seems reasonable to interpret β_{DDD} as an intention-to-treat effect rather than a standard treatment effect.[22] The coefficient β_{DDD} is identified by the difference between two difference-in-differences (DD). The first DD is the difference in average birth outcomes between those born in the period March 28–December 31 2004 and those born in the period March 28–December 31 2003 in municipalities close to Catarina minus the same difference in

[21] The month fixed effects are not perfectly collinear with the indicator $Mar28_{dm}$ since there are four days in March (28, 29, 30, 31) for which $Mar28_{dm} = 1$. Instead of including $Close_p$, we use a set of municipality indicators; instead of including $Y2004_t$, we use a set of year of birth indicators.

[22] It is conceivable that even in municipalities exposed to Catarina, not all women were directly affected.

municipalities far from Catarina. The second DD is the difference in average birth outcomes between those born in the period January 1–March 27 2004 and those born in the period January 1–March 27 2003 in municipalities close to Catarina minus the same difference in municipalities far from Catarina.

Our strategy differs from most empirical strategies in the existing literature which typically use DD strategies and focus on two sources of variation: before/after the shock and geographical proximity to the shock. This DD method controls for year, regional effects, and (optionally) year-specific region effects. In addition to this, our DDD strategy also controls for season of birth effects, year-specific season of birth effects, as well as region-specific season of birth effects. Given the existing evidence on the determinants of season of birth (Buckles and Hungerman, 2013; Clarke et al., 2019), it is important to make sure that our estimates are not contaminated by year-specific season of birth or region-specific season of birth effects. In Appendix D, we compare standard-DD with DDD estimates and demonstrate the benefits of controlling for season of birth effects in a flexible manner.

Threats to Identification

Different trends across municipalities. The main identification assumption behind our baseline specification is that there are no contemporaneous shocks that affect the relative outcomes of those born before March 28 and those born after in the same municipality-years as the hurricane. This requires the difference in average birth outcomes among those born after March 28 and those born before in regions close to Catarina and the same difference in regions far from Catarina to evolve in a similar way across time. To check the reliability of this assumption, one can test for similar pre-trends in the outcomes of interest between municipalities close to and far from the hurricane. To that end, we extend our baseline model to include additional pre-hurricane years (2001 and 2002) and a post-hurricane year (2005). In these extended models, we maintain 2003 as the reference year to be consistent with the baseline model. The extended econometric model is given by equation (2):

$$\begin{aligned}
y_{itmdp} = \alpha &+ \sum_{\substack{t=2001 \\ t\neq 2003}}^{2005} \beta^t_{DDD}(Close_p \times Y2004_t \times Mar28_{dm}) \\
&+ \sum_{\substack{t=2001 \\ t\neq 2003}}^{2005} \beta^t_1(Y2004_t \times Mar28_{dm}) + \sum_{\substack{t=2001 \\ t\neq 2003}}^{2005} \beta^t_2(Close_p \times Y2004_t) \\
&+ \beta_3(Mar28_{dm} \times Close_p) + \beta_4(Mar28_{dm}) + \gamma X'_{itmdp} + \phi_p + \tau_t + \mu_m + \epsilon_{itmdp}
\end{aligned} \tag{2}$$

where $Year_t = 1$ if $Year_t = t$ and zero otherwise.

Differential mortality and compositional effects. Table B.2 in Appendix B presents estimates of a modified version of equation (2) where the dependent variable are potential "control" variables and we omit the vector of controls from the right hand side. The goal of this exercise is to assess whether the hurricane affected the composition of mothers giving birth and the characteristics of newborns. This will inform us as to whether the controls in X' are bad controls (Angrist and Pischke, 2008).

The reported estimates in Table B.2 provide no evidence that the hurricane affected mother or baby characteristics. Columns (1) and (2) show that the hurricane did not have any impact on the sex or ethnicity of newborns, suggesting that there was no differential mortality by sex or ethnicity. Columns (3) to (7) indicate that there are no compositional effects in terms of mother characteristics. The mothers of babies who were exposed to Catarina in utero are not more or less likely to have completed high school, not more or less likely to be married, do not have a higher or small number of births up to the current birth, and are not more or less likely to deliver their birth in the same municipality where they reside.

Endogenous mobility. Since our empirical strategy relies on geographical proximity to the hurricane to identify its effects, a concern is that mothers move municipalities as a result of the hurricane. While Table B.2 suggests that there is no evidence that babies who are exposed to the hurricane are more likely to be delivered in a different municipality than that of the mother's residence, it could be that the hurricane had different effects on mobility across mothers with different characteristics. In Table B.3, we assess the impact of the hurricane on mobility by mother subgroups, where mobility is measured by a binary indicator that equals one if the mother's residential municipality equals the newborn's birth municipality and zero otherwise. The results show that there is no differential impact on mobility depending on mother's age, education, marital status, or parity. The final few rows of the table indicate that mobility is similar across age, education, and parity groups. The one exception is that married women appear to be less likely than unmarried women to live and give birth in the same municipality (73.3% vs. 62.8%).

General equilibrium effects. Another concern is that the hurricane may result in general equilibrium effects that affect municipalities in different ways. For example, the hurricane may have affected the viability of certain industries (e.g. agriculture) in municipalities close to the hurricane. To investigate whether this is a cause for concern, we use annual data on employment and GDP and estimate difference-in-differences models where the main interaction of interest is the proximity of the municipality to the hurricane (<100 km or over 100 km) and the post-hurricane year (2004). In Table B.4, we fail to find that employment or GDP changed after the hurricane. Furthermore, the relative share of the industry, agricultural, and service sectors do not appear to differ before and after the hurricane. While this analysis is rather limited, it suggests that general equilibrium effects are not likely to be a relevant issue when interpreting our estimates.

5 Main Results

5.1 Impacts on Birth Outcomes

Main results. Table 3 presents the estimated impacts of the hurricane on six birth outcomes: birth weight (g), low birth weight (< 2,500 g), high birth weight (> 4,000 g), short gestational length (< 37 weeks), long gestational length (> 41 weeks), and Apgar score (0-10). All binary outcomes have been scaled such that the coefficient represents percentage point effects. We estimate the regression for all mothers and for two sub-samples of mothers, split by age (15-24 vs. 25-49). We use age 25 as the cutoff because this is the median age of mothers in the sample and also because it fits with the Brazilian government's demographic breakdowns in official statistics.[23]

The estimates indicate the hurricane had impacts on birth weight, but not on gestational length or the Apgar score. In terms of birth weight impacts, we document an average reduction of about 44 g [95% CI: -85, -4], which is equivalent to roughly 0.09 standard deviations. Interestingly, the effect is driven by the babies born to mothers aged 15–24, among whom birth weight decreased by an average of 83 g [95% CI: -136, -30] or about 0.17 standard deviations. Among babies born to mothers aged 25–49, there is no significant effect, with the estimated impact being -4.1 g [95% CI: -57, 49].

Among babies born to young mothers, we also find effects on low birth weight and high birth weight. The hurricane increased the likelihood of these babies being born with low birth weight by 3.4 pp [95% CI: 1.0, 5.8], equivalent to almost 50% effect of the pre-hurricane low birth weight prevalence among babies born to young mothers. The hurricane also decreased the likelihood of being born with high birth weight by 3.1 pp [95% CI: -5.2, -1.0], equivalent to almost 68% of the pre-hurricane high birth weight prevalence among this group.

[23]Brazilian public health authorities have expressed particular concerns with teenage and youth pregnancy. As a result, they established the age range 15–24 as a priority demographic group for the sexual and reproductive health policy in Brazil (Ministério da Saúde, 2013).

Table 3: Impact of hurricane on birth outcomes

	Birth weight (grams)			Low birth weight (<2500g)			High birth weight (>4000g)		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD	-43.52*	-82.98**	-4.12	1.13	3.39**	-1.07	-1.70	-3.06**	-0.30
	(20.06)	(26.79)	(26.48)	(0.92)	(1.23)	(1.12)	(0.93)	(1.06)	(1.60)
	[-83.39, -3.65]	[-136.23, -29.73]	[-56.76, 48.52]	[-0.70, 2.96]	[0.95, 5.83]	[-3.29, 1.16]	[-3.54, 0.15]	[-5.18, -0.95]	[-3.47, 2.88]
% Impact	-1.34%	-2.58%	-0.13%	17.64%	49.40%	-17.91%	-28.93%	-67.90%	-4.17%
Dep var mean	3250	3212	3285	6.391	6.864	5.949	5.864	4.511	7.13
Dep var SD	514.07	507.11	518.07	24.46	25.28	23.65	23.49	20.75	25.73
Adj. R-squared	0.040	0.039	0.034	0.008	0.008	0.007	0.015	0.012	0.014

	Short gestational length (<37 wks)			Long gestational length (>41 wks)			Apgar score (0-10)		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD	0.19	1.85	-1.41	-0.35	-0.23	-0.52	-0.03	0.02	-0.08
	(0.89)	(1.16)	(1.21)	(0.47)	(0.61)	(0.65)	(0.05)	(0.06)	(0.06)
	[-1.59, 1.96]	[-0.45, 4.15]	[-3.82, 1.01]	[-1.28, 0.58]	[-1.45, 0.99]	[-1.82, 0.78]	[-0.12, 0.07]	[-0.09, 0.13]	[-0.20, 0.05]
% Impact	3.56%	33.44%	-27.93%	-33.20%	-21.02%	-50.77%	-0.29%	0.23%	-0.83%
Dep var mean	5.276	5.539	5.03	1.066	1.106	1.028	9.085	9.053	9.114
Dep var SD	22.36	22.88	21.86	10.27	10.46	10.09	0.79	0.80	0.78
Adj. R-squared	0.009	0.010	0.007	0.008	0.011	0.007	0.097	0.096	0.099
Municipalities	87	87	87	87	87	87	87	87	87
Births	53,006	25,416	27,590	53,006	25,416	27,590	53,006	25,416	27,590

Notes: This table presents the estimated triple difference coefficients for the baseline model. Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. Birth weight is measured in grams. Low birth weight is defined as being born weighing less than 2,500 grams. High birth weight is defined as being born weighing over 4,000 grams. Babies with short gestational length are those with less than 37 completed weeks of gestation. Babies with long gestational length are those with over 41 completed weeks of gestation. All regressions include the following controls: gender of the baby, race of the baby (white or other), age bins for the mother (in 5 year intervals), marital status of the mother (married or not),indicators for mother's educational attainment (completed high school or not), 3 indicators for parity at current birth (2nd birth, 3rd birth, or 4th and above), and an indicator for whether the mother's municipality of residence is the same as the municipality where the baby is born. All regressions include municipality, month, and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Finally, while the magnitudes of the estimated effects on gestational length are non-negligible, the estimates are too noisy to make statistically significant claims.

Extensions on consistency and inference. Appendix B contains additional results that examine the consistency of our baseline estimates and their standard errors. Table B.5 shows that our results are robust to controlling for municipality-specific trends (linear year-month) trends. Table B.6 reveals that, after excluding pre-term babies, we still find significant effects among babies born to young mothers. The estimated effects for the following outcomes are attenuated when pre-term babies are excluded: birth weight (-65 g, 95% CI: -120, -11), low birth weight (1.9 pp, 95% CI: -0.3, 4.2), high birth weight (-3.1 pp, -5.4, -0.8). Overall, this suggests that the estimated effects reported in Table 3 are not just mechanically driven by potential decreases in gestational length, which we are not able to capture due to power issues.

In Table B.7, we augment equation (1) by including indicators (and its corresponding interactions) for being born between March 28–November 30 and an indicator for being born in December. This allows us to control for the fact that babies born at term in December 2004 are likely to be conceived after the hurricane, potentially contaminating the estimate effects due to selective fertility. When we include this additional indicator, we obtain similar results. Importantly, the adverse effects of the hurricane are driven by babies born between March 28 and November 30, rather than those born in December. Finally, in Table B.8, we compare our approximately clustered 95% confidence intervals with confidence intervals based on spatial heteroscedasticity and autocorrelation consistent errors (Conley, 1999) using different cutoff distances. The results indicate that our impacts are more precisely estimated with these alternative standard errors.

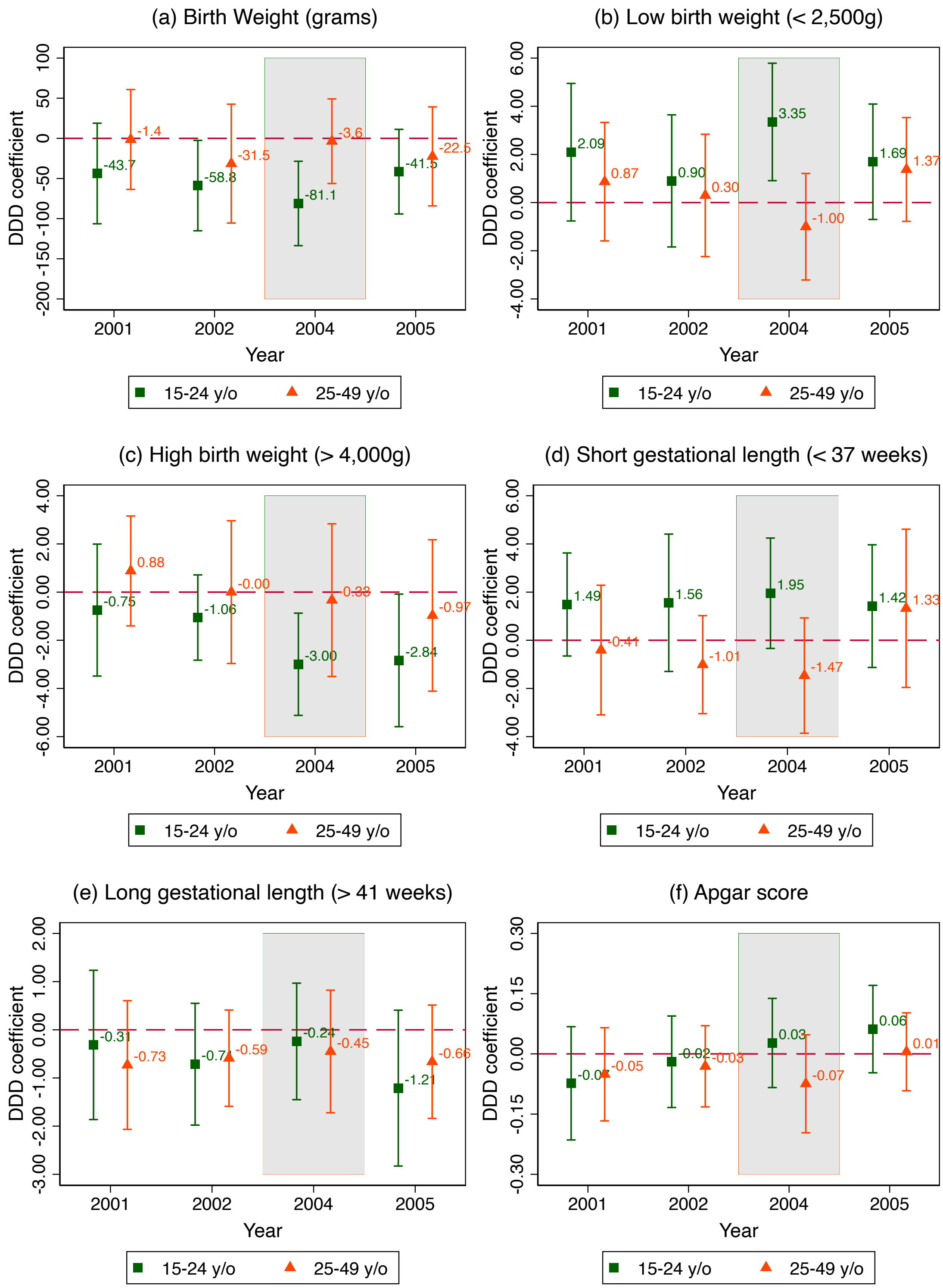
Extended Model. The main identifying assumption behind our DDD models is the parallel trends assumption, i.e., the evolution of average infant health outcomes would have been the same among babies that were *not* exposed to the hurricane and among babies exposed to the hurricane had they not been exposed to the hurricane. While this (counterfactual) assumption cannot be tested, we can test for pre-trends in the evolution of average infant health outcomes in the period *before* the hurricane (i.e., we can test for the absence of *placebo* effects). Figure 3 depicts the estimated coefficients of equation (2), displaying the "hurricane" effects reported in Table 3 (2004 vs. 2003) together with the additional "pre-hurricane" effects (2001 vs. 2003, 2002 vs. 2003) and "post-hurricane" effects (2005 vs. 2003). Table B.9 presents the corresponding β^t_{DDD} estimates from equation (2) where $t = 2001, 2002, 2004, 2005$.

Panels (a)–(c) of Figure 3 show two patterns. First, the documented impacts among babies born to young mothers on birth weight, low birth weight and high birth weight are driven by the difference between outcomes in 2004 (post-hurricane) vs. 2003 (pre-hurricane), replicating the findings in Table 3. Second, and more importantly, no effects are found when comparing pre-hurricane years (2001 vs. 2003 or 2002 vs. 2003). Moreover, and for the sake of comparison, we also report a comparison between a post-hurricane with a pre-hurricane year (2005 vs. 2003), but we remain agnostic about the interpretation since this is a post-treatment comparison and could be contaminated by selective fertility. Reassuringly, excluding the post-hurricane year does not appear to affect our findings (see Table B.10).

The estimates from the extended model suggest that our identification strategy seems reliable in allowing us to identify a causal effect of the hurricane on birth outcomes. We do not find much evidence of either pre-treatment effects or post-treatment effects on any birth outcome, at least as judged by the 95% confidence intervals. This is consistent with the parallel trends assumption required for identification of models in differences.

Different cutoff distances. Figures C.3 and C.4 in Appendix C plot the estimated β_{DDD} coefficient in equation (1) using different distances to the hurricane to define geographical proximity (from 50 km to 150 km). Reassuringly, our results do not appear to be contingent on our 100 km cutoff definition.

Figure 3: Impact of hurricane on birth outcomes (extended model)



5.2 Impacts on Live Births, Fetal Mortality, and Infant Mortality

Main results. Exposure to hurricane Catarina may increase fetal deaths because many of the bio-active mediators of maternal stress contribute to the pathophysiology of stillbirth (Silver and Ruiz, 2013). If the number of fetal deaths increases, the number of live births can be affected too. Moreover, exposure to Catarina can have an impact on infant mortality, via an increase in neonatal deaths (deaths within 28 days after birth) and/or an increase in post-neonatal deaths (deaths between 28 and 364 days after birth). We investigate the impacts of the hurricane on the fetal death rate, live birth rate, neonatal death rate and post-neonatal death rate by estimating the following equation:

$$\begin{aligned} R_{tmp} = \delta_0 &+ \delta_{DDD}(Close_p \times Y2004_t \times Apr_m) + \delta_1(Y2004_t \times Apr_m) \\ &+ \delta_2(Close_p \times Y2004_t) + \delta_3(Apr_m \times Close_p) \\ &+ \phi_p + \tau_t + \mu_m + \epsilon_{tmp} \end{aligned} \tag{3}$$

In equation (3), the unit of observation is denoted by the year (t), month (m), and municipality (p). The month refers to the birth month so that the dependent variable R_{ptm} is a particular rate for babies born in year t month m whose mothers reside in municipality p. Since we are aggregating at the monthly level and the hurricane occurred at the end of March, we define months such that the month of April is defined to include March 28 to March 31 so that the interaction $Y2004_t \times Apr_m$ appropriately captures the post-hurricane date. The fetal death rate is the number of deaths in that municipality-year-month divided by the sum of fetal deaths and live births in that unit, multiplied by 1,000. The live birth rate is the number of live births in that municipality-year-month divided by the population of women in that unit, multiplied by 1,000. The neonatal death rate is the number of deaths occurring within 28 days of births divided by the number of live births in that unit, multiplied by 1,000. The post-neonatal death rate is the number of deaths occurring between

28 and 364 days of births divided by the number of live births in that unit, multiplied by 1,000. When constructing these rates for different age groups, the definitions are adjusted accordingly (e.g. the unit is the municipality-year-month for women between 15 and 24 years old).

The first panel of Table 4 presents the estimated impacts of the hurricane on fetal deaths and live births. The estimates reveal a statistically significant and sizeable effect of being exposed to Catarina on the fetal death rate among babies born to young mothers. The fetal death rate increases by 16.7 [95% CI: 4.6, 28.9], over five times the pre-hurricane mean of 3 deaths per 1000 live births and fetal deaths. We do not find evidence that the hurricane had an impact on the live birth rate for either young or older mothers. In Table B.11 in Appendix B, we also assess the impact on live births by mothers' education and marital status. Across all mother subgroups, there is little evidence of selective fertility either before or after the hurricane.

The second panel of Table 4 investigates the impact of the hurricane on infant deaths. The estimates show a statistically and relevant effect on post-neonatal mortality, regardless of mother's age. The post-neonatal death rate increases by 4.2 per 1000 live births [95% CI: 0.1, 8.3] as a result of the hurricane. While we cannot reject zero impacts on the neonatal death rates of both 15-24 years-old and 25-49 years-old mothers, these are quite imprecisely estimated.

Additional robustness checks. Table B.12 shows that these results are robust to controlling for municipality-specific trends (linear year-month) trends. Figure 4 presents estimates from a modified version of equation (3) to allow for pre-hurricane and post-hurricane effects, analogous to equation (2). The corresponding estimates from these regressions can be found in Table B.13 of Appendix B. Both Figure 4 and Table B.13 show that to the extent that impacts on fetal and infant deaths are economically and statistically significant, such effects are driven by comparing death rates in 2004 with respect to outcomes in 2003. This supports

Table 4: Impact of hurricane on birth and death rates

	Fetal Death Rate			Live Birth Rate		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD	-0.93	16.74**	-27.16	0.09	-0.51	0.40
	(6.73)	(6.13)	(16.08)	(0.29)	(0.71)	(0.34)
	[-14.30, 12.45]	[4.56, 28.92]	[-59.13, 4.82]	[-0.49, 0.68]	[-1.93, 0.91]	[-0.28, 1.08]
Dep var mean	5.314	3.052	7.669	4.084	6.083	3.076
Dep var SD	28.429	17.509	51.425	1.659	3.502	1.663

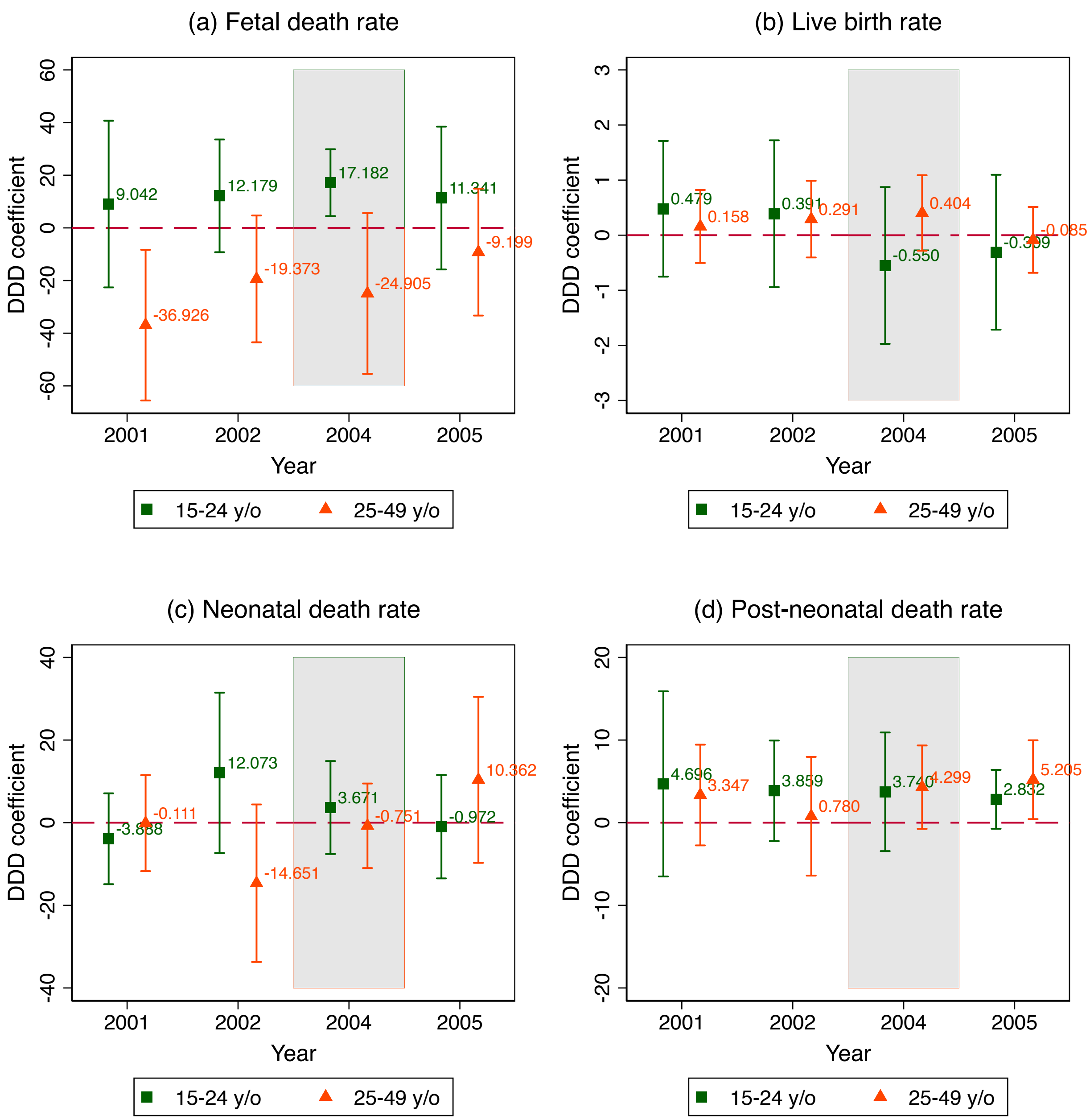
	Neonatal Death Rate			Post-neonatal Death Rate		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD	1.06	3.94	-0.75	4.21*	4.44	4.20
	(3.75)	(5.40)	(5.14)	(2.07)	(3.45)	(2.56)
	[-6.40, 8.51]	[-6.80, 14.67]	[-10.96, 9.46]	[0.11, 8.32]	[-2.41, 11.29]	[-0.89, 9.30]
Dep var mean	5.269	6.277	3.770	1.727	1.633	1.542
Dep var SD	24.294	36.249	22.557	13.767	19.797	14.418
Municipalities	87	87	87	87	87	87
Observations	2,037	1,897	1,932	2,037	1,897	1,932

Notes: This table presents the estimated effects of the hurricane on birth and death rates. Each observation is defined by a municipality, year, and 'adjusted' month. Adjusted months are the same as calendar months except that the month of April is defined to include March 28 to March 31 so that the post-hurricane dates are captured correctly. Fetal death rate is the number of fetal deaths divided by the number of resident live births plus fetal deaths (for the same unit) multiplied by 1,000. Birth rate is the number of live births divided by the number of women in that cohort in 2003 multipled by 1,000. Neonatal death rate is the number of deaths occuring within 28 days of births divided by the number of live births multiplied by 1,000. Post neonatal death rate is the number of deaths occuring between 28 and 364 days of birth divided by the number of live births multiplied by 1,000. All regressions include municipality, year, and 'adjusted'-month fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

the parallel trend assumption in the case of fetal and infant deaths. Lastly, Table B.14 presents estimates when babies born after the hurricane in 2005 are excluded from the analysis. The results are similar to the baseline results, confirming that the inclusion of babies born after the hurricane are not driving our results.

Adjusting for culling effects. The increase in fetal deaths among babies born to young mothers raises the issue of *survivor bias.* If experiencing adverse events in utero increases

Figure 4: Impact of hurricane on birth and death rates



fetal mortality and if there is positive selection of fetuses, such that the weakest are culled, then previous estimates of the impact on birth outcomes provide a lower bound estimate of the true impact.[24] To deal with this, we follow the bounding procedure of Lee (2009).[25] The idea is to estimate equation (2) using a sample of babies who would have survived regardless of the hurricane. To do this, we need to trim our main sample by the number of "extra" babies in non-exposed cohorts who would have died were they exposed to the hurricane.

We adopt two approaches to identify this group of babies who need to be trimmed from the main sample. The first approach involves inferring the size of the culling effect from our DDD estimate of the impact on fetal deaths. Our estimate suggests that the fetal death rate increased by five-fold among babies born to young mothers. In the non-exposed cohort of young mothers (i.e. those living in municipalities over 100 km away in the pre-hurricane period), the average number of live births per month is 13.3 while the average number of fetal deaths per month is 0.077. A five-fold increase in this number would result in 0.386 deaths per months. This means that the non-exposed cohort of young mothers would be 2.9% smaller if they were exposed to the hurricane. Under the assumptions that (a) the exposed cohort born to young mothers is 2.9% smaller compared to adjacent birth cohorts and that (b) among those exposed to the hurricane those with the lowest birth weight are least likely to survive, this method implies dropping babies in the bottom 3% of the birth weight distribution who are born to young mothers in the non-exposed cohort.[26]

The second approach to implement the bounding procedure is to use information on the the birth weight of babies who died at birth. In particular, using the fetal deaths data, we find that the average birth weight of babies born to young mothers between March 29 and December 2004 who died at birth is 1,773 g. We drop babies born to young mothers in the non-exposed cohort with birth weight below this threshold. Figure C.2 illustrates the distribution of birth weight for these two trimmed groups.

[24]Selection and scarring mechanisms are well acknowledged, described and illustrated by Almond (2006), Bozzoli et al. (2009) and Valente (2015).

[25]Recent papers that use this bounding exercise include Halla and Zweimuller (2014), Lin and Liu (2014), and Isen et al. (2017).

[26]The magnitude of our calculated culling effect is comparable to those in the existing literature. For instance, Lin and Liu (2014) find that the 1919 cohort is 3% smaller than the 1918 cohort due to the 1918 influenza pandemic.

Table B.15 presents the DDD estimates for the two trimmed samples. As expected, the estimated effects of birth outcomes for these two trimmed samples are even more adverse compared to the baseline sample without trimming. For example, after applying the first bounding method (trimming the bottom 3%), the DDD estimate suggests that birth weight reduced by 96 g (compared to 83 g in the non-trimmed sample) and the incidence of low birth weight increased by 4.1 pp (compared to 3.4 pp in the non-trimmed sample). After applying the second bounding method (trimming babies with birth weight below the average birth weight of babies who died at birth), the DDD estimate suggests that birth weight decreased by 91 g and the incidence of low birth weight increased by 3.7 pp. Overall, this bounding exercise suggests that our baseline results provide conservative estimates of the impact of the hurricane on birth outcomes.

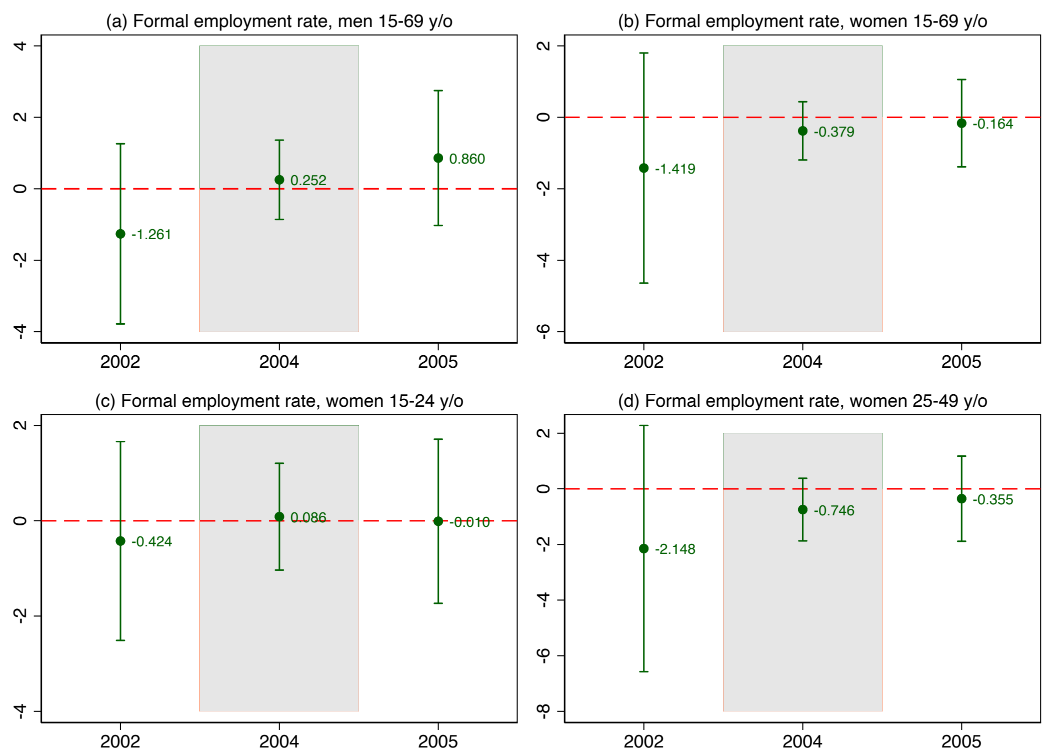
6 Mechanisms

Our baseline results provide evidence that exposure to hurricane Catarina in utero increased fetal deaths and led to a deterioration of birth outcomes. Furthermore, these effects are concentrated among babies born to young mothers. In Table B.16, we examine the characteristics of young mothers which might make their children more vulnerable to in utero exposure to Catarina. Young mothers are 18 pp less likely to be married than non-young mothers (58% vs. 76%, p-value<0.01), they are 11 pp less likely to have completed high school (9% vs. 20%, p-value<0.01), and are 17 pp less likely to be in the labor force (40% vs. 57%, p-value<0.01). Not surprisingly, the average number of births up to the current one is smaller among young mothers (1 fewer birth) than among older mothers (0.6 vs. 1.6, p-value<0.01). The percentage of mothers delivering their births in their municipality of residence is similar among the two groups (65% vs. 64%, p-value<0.01). These descriptive statistics suggest that younger mothers may be more economically vulnerable than older mothers.

6.1 Formal employment

We investigate whether employment, and hence income, may be an important mechanism behind our results. We use data on the number of formal workers across various demographic groups: men, women, young women, and older women. Since the employment data are only available at an annual level, we estimate DD models where the main interaction of interest is the proximity of the municipality to the hurricane (<100 km vs. $\geq$ 100 km) and the post-hurricane year (2004). The dependent variable is the number of formally employed workers in that cell divided by the population estimate in that cell multiplied by 100. Figure 5 and Table B.17 (Appendix B) present the estimates from these DD models. We fail to find evidence that that the hurricane affected formal employment rates for men or women (panels a and b), or for young or older women (panels c and d).

Figure 5: Impact of hurricane on formal employment rates



6.2 Healthcare use

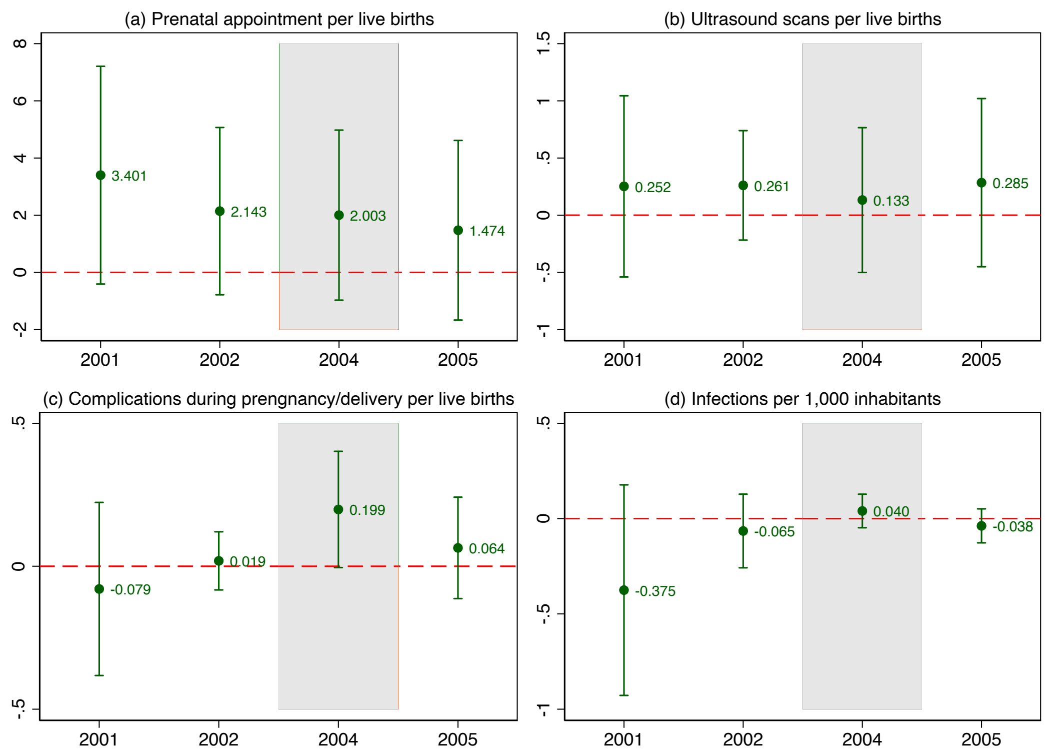
We also investigate whether the hurricane disrupted the access to healthcare services by examining the impact of the hurricane on healthcare utilization and hospital admissions. In doing so, we need to acknowledge one of the main limitations of this analysis: the data on healthcare services do not allow us to distinguish between healthcare utilization and hospital admissions rates for young and older mothers. Figure 6 and Table B.18 presents the estimates from these regressions. Panels (a) and (b) show no evidence that prenatal appointments or ultrasound appointments are affected by the hurricane. Panel (c) provides weak evidence that complications during pregnancy/delivery increased in 2004 compared to 2003, but this is statistically insignificant. Finally, panel (d) suggests that infection rates across the whole population were not affected by the hurricane.

6.3 Maternal stress

Overall, we are unable to directly pinpoint the mechanisms driving our results. We hypothesize that residual factors may be plausible explanations of the documented effects if young mothers are more susceptible to such factors. One candidate explanation is maternal stress. A growing body of literature shows that maternal stress is associated with neuroendocrine changes and disruptions to the immune system, events which are hypothesized to prematurely initiate the parturition pathway (Coussons-Read, 2013) and lead to the risk of pre-term birth and low birth weight (Brown et al., 2011). Furthermore, recent evidence suggests that lower maternal socioeconomic status during pregnancy and childhood is associated with higher levels of cortisol during *each* trimester of gestation (Enlow et al., 2019). Table B.16 demonstrates that younger mothers have characteristics that may leave them less financially and socially secure than older mothers. Therefore, although municipal-level GDP and employment statistics do not appear to be affected by the hurricane, younger mothers may nevertheless be more likely than older mothers to perceive the hurricane as a serious threat to their livelihoods, increasing maternal stress among this group.

In Table B.19, we show that the adverse effects of Catarina is concentrated among teenage mothers whose newborns see a 112 g drop in birth weight and a 5.34 pp increase in the probability of being low birth weight. The fact that the negative effects documented earlier among mothers aged 15 to 24 is concentrated among the subset of teenage mothers supports the hypothesis that younger mothers are more vulnerable to such shocks. This is consistent with the findings of Menclova and Stillman (2020) who find that babies born to teenage mothers tend to have worse birth outcomes after exposure to earthquakes, possibly due to the relative difficulty of dealing with the stress of the aftermath while pregnant.

Figure 6: Impact of hurricane on healthcare use and hospital admissions



7 Conclusion

The frequency and severity of natural disasters are on the rise. While several studies have investigated the impact of natural disasters on birth outcomes, the evidence on the effects of such events on birth outcomes and mortality remains mixed (Jeffers and Glass, 2020). In this paper, we study the effects of the first hurricane to hit Brazil on birth outcomes, birth rates, as well as fetal and infant mortality. This hurricane is particularly informative for at least two reasons: first, it was completed unexpected; second, it is similar to other recent hurricanes in the Americas in terms of wind speed, economic costs, and infrastructure damages.

Using a DDD framework, we find that exposure to Catarina in utero worsened birth outcomes of babies born to young mothers between 15 to 24 years old, which represent approximately 50% of our sample. In particular, birth weight decreased by 84 g, the probability of being low birth weight increased by 3.4 pp and the incidence of being high birth weight increased by 3.1 pp. Older mothers between 25 to 49 years old appear to be more resilient to the hurricane. Furthermore, we find that among babies born to young mothers, exposure to Catarina in utero increased the fetal death rate by 16.7 per 1000 live births and fetal deaths, five times the pre-hurricane mean. Among babies born to both younger and older mothers, the post-neonatal death rate increased by 4.2 per 1000 live births.

We do not find any evidence that employment or access to healthcare services were affected by the hurricane. The effects are concentrated among younger women, who are less likely to be married, less likely to have completed high school and less likely to be in the labor force. Given their characteristics, this group of women is more likely to be financially insecure, and maternal stress may be an important mechanism behind the documented declines in infant health. This is indeed consistent with recent evidence highlighting the relationship between socioeconomic status, stress, and birth outcomes (Brown et al., 2011; Coussons-Read, 2013; Enlow et al., 2019).

References

Aizer, Anna, Laura Stroud, and Stephen Buka (2016) "Maternal stress and child outcomes: Evidence from siblings," *Journal of Human Resources*, 51 (3), 523–555.

Almond, Douglas (2006) "Is the 1918 influenza pandemic over? Long-term effects of in utero influenza exposure in the post-1940 US population," *Journal of Political Economy*, 4 (114), 672—712.

Almond, Douglas, Kenneth Y Chay, and David S Lee (2005) "The costs of low birth weight," *The Quarterly Journal of Economics*, 120 (3), 1031–1083.

Almond, Douglas and Janet Currie (2011) "Killing me softly: The fetal origins hypothesis," *Journal of Economic Perspectives*, 25 (3), 153–72.

Andalón, Mabel, João Pedro Azevedo, Carlos Rodríguez-Castelán, Viviane Sanfelice, and Daniel Valderrama-González (2016) "Weather Shocks and Health at Birth in Colombia," *World Development* (82), 69–82.

Angrist, Joshua D and Jörn-Steffen Pischke (2008) *Mostly harmless econometrics: An empiricist's companion*: Princeton University Press.

——— (2010) "The credibility revolution in empirical economics: How better research design is taking the con out of econometrics," *Journal of Economic Perspectives*, 24 (2), 3–30.

Black, Sandra E, Paul J Devereux, and Kjell G Salvanes (2007) "From the cradle to the labor market? The effect of birth weight on adult outcomes," *The Quarterly Journal of Economics*, 122 (1), 409–439.

——— (2016) "Does grief transfer across generations? Bereavements during pregnancy and child outcomes," *American Economic Journal: Applied Economics*, 8 (1), 193–223.

Bobonis, Gustavo J, Mark Stabile, and Leonardo Tovar (2020) "Military training exercises, pollution, and their consequences for health," *Journal of Health Economics*, 73, 102345.

Bozzoli, Carlos, Angus Deaton, and Climent Quintana-Domeque (2009) “Adult height and childhood disease,” *Demography*, 46 (4), 647–669.

Bozzoli, Carlos and Climent Quintana-Domeque (2014) “The weight of the crisis: Evidence from newborns in Argentina,” *Review of Economics and Statistics*, 96 (3), 550–562.

Brown, Ryan et al. (2014) “The intergenerational impact of terror: Does the 9/11 tragedy reverberate into the outcomes of the next generation?” *Households in Conflict Network. https://econpapers. repec. org/paper/hicwpaper/165. htm.*

Brown, Stephanie J, Jane S Yelland, Georgina A Sutherland, Peter A Baghurst, and Jeffrey S Robinson (2011) “Stressful life events, social health issues and low birthweight in an Australian population-based birth cohort: challenges and opportunities in antenatal care,” *BMC Public Health*, 11 (1), 196.

Buckles, Kasey S and Daniel M Hungerman (2013) “Season of birth and later outcomes: Old questions, new answers,” *Review of Economics and Statistics*, 95 (3), 711–724.

Camacho, Adriana (2008) “Stress and birth weight: evidence from terrorist attacks,” *American Economic Review*, 98 (2), 511–15.

Carlson, Kyle (2015) “Fear itself: The effects of distressing economic news on birth outcomes,” *Journal of Health Economics*, 41, 117–132.

——— (2018) “Red Alert: Prenatal Stress and Plans to Close Military Bases,” *American Journal of Health Economics*, 4 (3), 287–320.

Carrillo, Bladimir, Daniel Da Mata, Lucas Emanuel, Daniel Lopes, and Breno Sampaio (2020) “Avoidable environmental disasters and infant health: Evidence from a mining dam collapse in Brazil,” *Health Economics*, 29 (12), 1786–1794.

Christopher, Kenneth E (2017) *The Effects of Hurricane and Tornado Disasters on Pregnancy Outcomes* Ph.D. dissertation, Walden University.

Clarke, Damian, Sonia Oreffice, and Climent Quintana-Domeque (2017) "On the value of birth weight," *HCEO Working Paper* (2017-018).

——— (2019) "The demand for season of birth," *Journal of Applied Econometrics*, 34 (5), 707–723.

Conley, Timothy G (1999) "GMM estimation with cross sectional dependence," *Journal of Econometrics*, 92 (1), 1–45.

Coussons-Read, Mary E (2013) "Effects of prenatal stress on pregnancy and human development: mechanisms and pathways," *Obstetric Medicine*, 6 (2), 52–57.

Currie, Janet and Douglas Almond (2011) "Human capital development before age five," in *Handbook of Labor Economics*, 4, 1315–1486: Elsevier.

Currie, Janet and Maya Rossin-Slater (2013) "Weathering the storm: Hurricanes and birth outcomes," *Journal of Health Economics*, 32 (3), 487–503.

Enlow, Michelle Bosquet, Georgios Sideridis, Yueh-Hsiu Mathilda Chiu, Farida Nentin, Elizabeth A Howell, Blake A Le Grand, and Rosalind J Wright (2019) "Associations among maternal socioeconomic status in childhood and pregnancy and hair cortisol in pregnancy," *Psychoneuroendocrinology*, 99, 216–224.

Figlio, David, Jonathan Guryan, Krzysztof Karbownik, and Jeffrey Roth (2014) "The effects of poor neonatal health on children's cognitive development," *American Economic Review*, 104 (12), 3921–55.

Grabich, Shannon C, Whitney R Robinson, Charles E Konrad, and Jennifer A Horney (2017) "Impact of hurricane exposure on reproductive health outcomes, Florida, 2004," *Disaster Med Public Health Prep*, 11 (4), 407–411.

Halla, Martin and Martina Zweimuller (2014) "Parental response to early human capital shocks: evidence from the Chernobyl accident," *IZA Working paper.*

Henry, Michael, Nekeisha Spencer, and Eric Strobl (2020) "The impact of tropical storms on households: evidence from panel data on consumption," *Oxford Bulletin of Economics and Statistics*, 82 (1), 1–22.

Isen, Adam, Maya Rossin-Slater, and W Reed Walker (2017) "Every breath you take, every dollar you'll make: The long-term consequences of the clean air act of 1970," *Journal of Political Economy*, 125 (3), 848–902.

Jeffers, Noelene K and Nancy Glass (2020) "Integrative review of pregnancy and birth outcomes after exposure to a hurricane," *Journal of Obstetric, Gynecologic & Neonatal Nursing*.

Kanter, Robert K (2010) "Child mortality after hurricane katrina," *Disaster Medicine and Public Health Preparedness*, 4 (1), 62–65.

Karbownik, Krzysztof and Anthony Wray (2019) "Long-run consequences of exposure to natural disasters," *Journal of Labor Economics*, 37 (3), 949–1007.

Kim, Bongkyun, Celeste K Carruthers, and Matthew C Harris (2017) "Maternal stress and birth outcomes: Evidence from the 1994 Northridge earthquake," *Journal of Economic Behavior & Organization*, 140, 354–373.

Kim, Ella J (2016) "The impacts of climate change on human health in the United States: A scientific assessment, by us global change research program," *Journal of the American Planning Association*, 82 (4), 418–419.

Lee, Chulhee (2014) "Intergenerational health consequences of in utero exposure to maternal stress: Evidence from the 1980 Kwangju uprising," *Social Science & Medicine*, 119, 284–291.

Lee, David S (2009) "Training, wages, and sample selection: Estimating sharp bounds on treatment effects," *The Review of Economic Studies*, 76 (3), 1071–1102.

Lin, Ming-Jen and Elaine M Liu (2014) "Does in utero exposure to illness matter? The 1918 influenza epidemic in Taiwan as a natural experiment," *Journal of Health Economics*, 37, 152–163.

Liu, Elaine M, Jin-Tan Liu, and Tzu-Yin Hazel Tseng (2015) "The impact of a natural disaster on the incidence of fetal losses and pregnancy outcomes," *Working Paper*.

Mansour, Hani and Daniel I Rees (2012) "Armed conflict and birth weight: Evidence from the al-Aqsa Intifada," *Journal of Development Economics*, 99 (1), 190–199.

McTaggart-Cowan, Ron, Lance F Bosart, Christopher A Davis, Eyad H Atallah, John R Gyakum, and Kerry A Emanuel (2006) "Analysis of hurricane Catarina (2004)," *Monthly Weather Review*, 134 (11), 3029–3053.

Menclova, Andrea Kutinova and Steven Stillman (2020) "Maternal stress and birth outcomes: Evidence from an unexpected earthquake swarm," *Health Economics*, 29 (12), 1705–1720.

Mendez-Figueroa, Hector, Suneet P Chauhan, Mary C Tolcher, Alireza A Shamshirsaz, Haleh Sangi-Haghpeykar, Ryan M Pace, Derrick M Chu, and Kjersti Aagaard (2019) "Peripartum outcomes before and after hurricane Harvey," *Obstetrics & Gynecology*, 134 (5), 1005–1016.

Ministério da Saúde (2013) "Saúde sexual e saúde reprodutiva," *Secretaria de Atenção à Saúde, Departamento de Atenção Básica*, 26.

Ornes, Stephen (2018) "Core Concept: How does climate change influence extreme weather? Impact attribution research seeks answers," *Proceedings of the National Academy of Sciences*, 115 (33), 8232–8235.

Persson, Petra and Maya Rossin-Slater (2018) "Family ruptures, stress, and the mental health of the next generation," *American Economic Review*, 108 (4-5), 1214–52.

Pezza, Alexandre Bernardes and Ian Simmonds (2005) "The first South Atlantic hurricane: Unprecedented blocking, low shear and climate change," *Geophysical Research Letters*, 32 (15).

——— (2008) "Large-scale factors in tropical and extratropical cyclone transition and extreme weather events," *Annals of the New York Academy of Sciences*, 1146 (1), 189–211.

Pezza, Alexandre Bernardes, Ian Simmonds, and Augusto Jose Pereira Filho (2009) "Climate perspective on the large-scale circulation associated with the transition of the first South Atlantic hurricane," *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 29 (8), 1116–1130.

Quintana-Domeque, Climent and Pedro Ródenas-Serrano (2017) "The hidden costs of terrorism: The effects on health at birth," *Journal of Health Economics*, 56, 47–60.

Rocha, Rudi and Rodrigo Soares (2015) "Water scarcity and birth outcomes in the Brazilian semi-arid," *Journal of Development Economics* (112), 72–91.

Rohrer, Julia M (2018) "Thinking clearly about correlations and causation: Graphical causal models for observational data," *Advances in Methods and Practices in Psychological Science*, 1 (1), 27–42.

Rosales-Rueda, Maria (2018) "The impact of early life shocks on human capital formation: Evidence from El Niño floods in Ecuador," *Journal of Health Economics*, 62, 13–44.

Silver, Robert M and R Jeanne Ruiz (2013) "Invited commentary: maternal stress and stillbirth—another piece of the puzzle," *American Journal of Epidemiology*, 177 (3), 228–229.

Simeonova, Emilia (2011) "Out of sight, out of mind? Natural disasters and pregnancy outcomes in the USA," *CESifo Economic Studies*, 57 (3), 403–431.

Smith, Adam B (2020) "2010–2019: A landmark decade of US. billion-dollar weather and climate disasters," *National Oceanic and Atmospheric Administration*.

Torche, Florencia (2011) "The effect of maternal stress on birth outcomes: exploiting a natural experiment," *Demography*, 48 (4), 1473–1491.

Valente, Christine (2015) "Civil conflict, gender-specific fetal loss, and selection: A new test of the Trivers–Willard hypothes," *Journal of Health Economics* (39), 31—50.

Zahran, Sammy, Ian M Breunig, Bruce G Link, Jeffrey G Snodgrass, Stephan Weiler, and Howard W Mielke (2014) "Maternal exposure to hurricane destruction and fetal mortality," *Journal of Epidemiology & Community Health*, 68 (8), 760–766.

Zahran, Sammy, Lori Peek, Jeffrey G Snodgrass, Stephan Weiler, and Lynn Hempel (2013) "Abnormal labor outcomes as a function of maternal exposure to a catastrophic hurricane event during pregnancy," *Natural Hazards*, 66 (1), 61–76.

Online Appendix (not for publication)

A Links to Data Sources

The main data sources used in this analysis are:

Live births

- Information: birth outcomes, sociodemographic characteristics of the child and the mother.
- Source: Information System on Live Births (Sistema de Informações sobre Nascidos Vivos – SINASC).
- Access: `http://www2.datasus.gov.br/DATASUS/index.php?area=0901&item=1&acao=28&pad=31655`.

Fetal and infant deaths

- Information: fetal and infant deaths by day of death and municipality of residence.
- Source: Information System on Deaths (Sistema de Informações sobre Mortalidade – SIM).
- Access: `http://www2.datasus.gov.br/DATASUS/index.php?area=0901&item=1&acao=26&pad=31655`

Healthcare services

- Information: at the municipality level on hospital admissions due to infections and complications during pregnancy; information on prenatal appointments and obstetric ultrasound scan appointments.
- Source: Hospital Information System (Sistema de Informações Hospitalares - SIH) and Outpatient Information System (Sistema de Informações Ambulatoriais – SIA).
- Access: SIH: `http://www2.datasus.gov.br/DATASUS/index.php?area=0202&id=11633`; SIA: `http://www2.datasus.gov.br/DATASUS/index.php?area=0202&id=19122`

GDP

- Information: municipality-year level data on GDP.
- Source: Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE).
- Access: `https://www.ibge.gov.br/estatisticas/downloads-estatisticas.html`

Employment

- Information: municipality-year level data on formal employment.
- Source: Annual Register of Social Information (Relação Anual de Informações Sociais-RAIS).
- Access: `http://bi.mte.gov.br/bgcaged/login.php` (Public access using login "basico" and password "12345678")

Damage reports

- Information: municipality-level data on damages due to Catarina.
- Source: Integrated System of Information on Disasters (Sistema Integrado de Informações sobre Desastres - S2iD) of Civil Defence.
- Access: `https://s2id-search.labtrans.ufsc.br/`

Development indicators

- Information: municipality-level data on development statistics.
- Source: The 2013 Human Development Atlas (Atlas do Desenvolvimento Humano 2013) of United Nations Development Programme in Brazil.
- Access: `https://www.br.undp.org/content/brazil/pt/home/idh0/atlas-do-desenvolvimento-humano/atlas-dos-municipios.html`

Natural disasters in the Americas

- Information: country-level data on natural disasters used to construct Figure C.1.
- Source: The Emergency Disasters Database (EM-DAT) maintained by the Centre for Research on the Epidemiology of Disasters (CRED).
- Access: `https://www.emdat.be/`

Population Estimates (2001–2005)

- Information: municipality-year level data, by gender and age groups.
- Source: DATASUS/Ministry of Health.
- Access: `http://tabnet.datasus.gov.br/cgi/deftohtm.exe?popsvs/cnv/popbr.def`

B Additional Tables

Table B.1: Damages to municipalities in Santa Catarina due to hurricane

	Quantity	**% of total**
	(1)	(2)
A. Municipalities		
Municipalities directly affected	21	7.2
Distance to hurricane (km)	28.2–88.8	(Mean=55.77)
Total number of municipalities	293	
B. Population affected		
Had to temporarily leave the dwelling	25,283	5.9
Need shelter	1,320	0.3
Injured or sick	421	0.1
Missing or dead	3	0.7 × 10ˆ3
Total population affected	27,025	6.4
Population of affected muncipalities (2000, IBGE)	425,444	
C. Damages to infrastructure		
Dwellings	71,646	11.1
Public buildings	434	0.1
Private buildings	9,350	1.5
Total buildings damaged	81,430	12.7
Domiciles in affected municipalities (2000, IBGE)	643,208	
D. Direct costs of damages (in 1000 USD PPP)		
Buildings/infrastructure	91,781	2.36
Environment	8,772	0.23
Crops	103,284	2.65
Livestock	2,243	0.06
Other Economic Losses	55,057	0.13
Essential services	16,578	0.43
Total cost	227,715	5.84
GDP of affected municipalities (2003, IBGE)	3,895,940	

Notes: Data on damages comes from the Assessment Reports of Civil Defense (Relatórios de Avaliação de Danos - AVADAN) that can be accessed in the following here: `https://s2id.mi.gov.br/`. Data on population, domiciles, and GDP comes from the 2000 Demographic Census of the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE). Essential services include transportation, communication, water supply, electricity supply, sewage, garbage. Costs of damages and GDP are deflated to 2005 using the General Price Index (IGP-DI, FGV), and converted to USD PPP (World Development Indicators-WDI).

Table B.2: Impact of hurricane on baby and mother characteristics (extended model)

	Girl	**White**	**15-24 y/o**	**Completed HS**	**Married**	**First birth**	**Same mun**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DDD (2001)	-0.025	0.000	0.029	-0.008	0.021	0.011	-0.038
	[-0.057, 0.007]	[-0.018, 0.019]	[-0.006, 0.064]	[-0.041, 0.024]	[-0.032, 0.075]	[-0.194, 0.215]	[-0.078, 0.001]
DDD (2002)	-0.023	0.003	0.026	-0.004	0.039	0.104	-0.017
	[-0.061, 0.015]	[-0.015, 0.022]	[-0.016, 0.068]	[-0.028, 0.020]	[-0.014, 0.091]	[-0.187, 0.395]	[-0.063, 0.028]
DDD (2004)	-0.005	0.004	0.001	-0.016	-0.007	0.077	-0.002
	[-0.039, 0.029]	[-0.015, 0.024]	[-0.037, 0.039]	[-0.051, 0.020]	[-0.111, 0.098]	[-0.091, 0.245]	[-0.049, 0.044]
DDD (2005)	-0.027	0.002	0.010	0.020	0.016	0.029	-0.004
	[-0.061, 0.007]	[-0.017, 0.020]	[-0.034, 0.054]	[-0.020, 0.061]	[-0.041, 0.073]	[-0.136, 0.195]	[-0.045, 0.037]
% Impact (2004)	-1.07%	0.45%	0.18%	-10.15%	-0.86%	6.79%	-0.37%
Dep var mean	0.487	0.941	0.483	0.155	0.759	1.133	0.654
Dep var SD	0.500	0.236	0.500	0.362	0.428	1.450	0.476
Municipalities	87	87	87	87	87	87	87
Births	133,513	133,513	133,513	133,513	133,513	133,513	133,513

Notes: This table presents estimated triple-difference coefficients for our selection equations. *Same mun* denotes whether the mother's municipality of residence is the same as the municipality where the baby is born. All regressions include municipality, month, and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.3: Impact of hurricane on mother's mobility (extended model)

	Age 15-24	Age 25-49	No HS	Completed HS	Not married	Married	Parity<1	Parity≥1
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DDD (2001)	-0.056	-0.018	-0.044*	0.013	-0.045	-0.031	-0.013	-0.047*
	(0.030)	(0.017)	(0.018)	(0.047)	(0.045)	(0.019)	(0.024)	(0.019)
	[-0.116, 0.003]	[-0.051, 0.015]	[-0.081, -0.007]	[-0.080, 0.106]	[-0.134, 0.045]	[-0.068, 0.006]	[-0.061, 0.035]	[-0.085, -0.008]
DDD (2002)	-0.032	-0.004	-0.019	-0.019	0.042	-0.026	0.054	-0.054*
	(0.024)	(0.026)	(0.021)	(0.053)	(0.034)	(0.025)	(0.034)	(0.021)
	[-0.080, 0.016]	[-0.054, 0.047]	[-0.060, 0.021]	[-0.123, 0.086]	[-0.025, 0.109]	[-0.076, 0.023]	[-0.013, 0.122]	[-0.097, -0.012]
DDD (2004)	0.002	-0.003	0.001	-0.032	0.012	-0.002	0.048	-0.030
	(0.031)	(0.021)	(0.023)	(0.036)	(0.042)	(0.025)	(0.032)	(0.025)
	[-0.059, 0.064]	[-0.045, 0.038]	[-0.045, 0.047]	[-0.103, 0.039]	[-0.070, 0.095]	[-0.052, 0.047]	[-0.016, 0.113]	[-0.080, 0.019]
DDD (2005)	-0.001	-0.002	0.006	-0.058	0.015	-0.019	0.042	-0.030
	(0.025)	(0.023)	(0.021)	(0.054)	(0.030)	(0.028)	(0.026)	(0.025)
	[-0.051, 0.049]	[-0.048, 0.044]	[-0.035, 0.047]	[-0.166, 0.050]	[-0.045, 0.075]	[-0.076, 0.037]	[-0.010, 0.095]	[-0.079, 0.018]
% Impact	0.38%	-0.48%	0.15%	-4.88%	1.69%	-0.36%	7.32%	-4.65%
Dep var mean	0.655	0.653	0.653	0.658	0.733	0.628	0.659	0.650
Dep var SD	0.475	0.476	0.476	0.474	0.442	0.483	0.474	0.477
Municipalities	87	87	87	87	87	87	87	87
Births	64,015	69,498	113,622	19,891	44,137	89,376	55,956	77,557

Notes: The dependent variable is a binary indicator that equals 1 if the mother's municipality of residence is the same as the municipality where the baby is born and zero otherwise. All regressions include municipality, month, and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.4: Impact of hurricane on employment and GDP

	ln employed	ln GDP	Share relative to total GDP: Industry	Agriculture	Services
	(1)	(2)	(3)	(4)	(5)
DDD (2002)	-0.035	-0.046	0.655	-1.126	0.464
	(0.040)	(0.023)	(0.465)	(0.727)	(0.551)
	[-0.114, 0.044]	[-0.091, 0.000]	[-0.269, 1.580]	[-2.571, 0.319]	[-0.632, 1.560]
DDD (2004)	0.000	0.015	0.300	0.073	-0.130
	(0.024)	(0.027)	(0.489)	(0.815)	(0.637)
	[-0.047, 0.048]	[-0.038, 0.068]	[-0.673, 1.273]	[-1.546, 1.692]	[-1.396, 1.136]
DDD (2005)	0.030	0.007	-0.175	0.451	-0.464
	(0.030)	(0.027)	(0.586)	(0.777)	(0.640)
	[-0.030, 0.089]	[-0.046, 0.061]	[-1.340, 0.990]	[-1.094, 1.996]	[-1.737, 0.809]
Dep var mean	7.130	11.109	20.673	30.178	42.178
Dep var SD	1.440	1.173	14.569	20.842	12.565
Adj. R-squared	0.993	0.994	0.981	0.980	0.970
Municipalities	87	87	87	87	87
Observations	348	348	348	348	348

Notes: This table examines the effect of the hurricane on the number of employed formal workers, GDP, and the share of various sectors as a proportion of GDP. All regressions include municipality and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.5: Impact of hurricane on birth outcomes (w/ municipality specific year-month trends)

	Birth weight (grams)			**Low birth weight (<2500g)**			**High birth weight (>4000g)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD	-41.79*	-79.20**	-4.79	1.13	3.49**	-1.10	-1.56	-2.96**	-0.13
	(20.29)	(27.32)	(26.93)	(0.92)	(1.22)	(1.12)	(0.93)	(1.08)	(1.60)
	[-82.13, -1.45]	[-133.52, -24.88]	[-58.33, 48.75]	[-0.69, 2.96]	[1.07, 5.90]	[-3.33, 1.13]	[-3.40, 0.28]	[-5.11, -0.81]	[-3.32, 3.05]
% Impact	-1.29%	-2.47%	-0.15%	17.73%	50.79%	-18.47%	-26.66%	-65.57%	-1.88%
Dep var mean	3250	3212	3285	6.391	6.864	5.949	5.864	4.511	7.13
Dep var SD	514.07	507.11	518.07	24.46	25.28	23.65	23.49	20.75	25.73
Adj. R-squared	0.040	0.040	0.034	0.008	0.007	0.007	0.015	0.012	0.015

	Short gestational length (<37 wks)			**Long gestational length (>41 wks)**			**Apgar score (0-10)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD	0.18	1.92	-1.44	-0.36	-0.29	-0.51	-0.03	0.02	-0.08
	(0.89)	(1.16)	(1.21)	(0.49)	(0.63)	(0.67)	(0.05)	(0.06)	(0.06)
	[-1.60, 1.95]	[-0.39, 4.23]	[-3.85, 0.96]	[-1.33, 0.61]	[-1.54, 0.95]	[-1.84, 0.82]	[-0.13, 0.06]	[-0.09, 0.13]	[-0.20, 0.04]
% Impact	3.32%	34.60%	-28.71%	-33.64%	-26.63%	-49.56%	-0.35%	0.23%	-0.89%
Dep var mean	5.276	5.539	5.03	1.066	1.106	1.028	9.085	9.053	9.114
Dep var SD	22.36	22.88	21.86	10.27	10.46	10.09	0.79	0.80	0.78
Adj. R-squared	0.009	0.010	0.006	0.012	0.017	0.009	0.103	0.102	0.105
Municipalities	87	87	87	87	87	87	87	87	87
Births	53,006	25,416	27,590	53,006	25,416	27,590	53,006	25,416	27,590

Notes: This table presents the estimated triple difference coefficients for the baseline model, modified to include municipality specific year-month trends (in addition to municipality, month, and year fixed effects). Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. Birth weight is measured in grams. Low birth weight is defined as being born weighing less than 2,500 grams. High birth weight is defined as being born weighing over 4,000 grams. Babies with short gestational length are those with less than 37 completed weeks of gestation. Babies with long gestational length are those with over 41 completed weeks of gestation. All regressions include the following controls: gender of the baby, race of the baby (white or other), age bins for the mother (in 5 year intervals), marital status of the mother (married or not),indicators for mother's educational attainment (completed high school or not), 3 indicators for parity at current birth (2nd birth, 3rd birth, or 4th and above), and an indicator for whether the mother's municipality of residence is the same as the municipality where the baby is born. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.6: Impact of hurricane on birth outcomes (excluding preterm babies)

	Birth weight (grams)			Low birth weight (<2500g)			High birth weight (>4000g)		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD	-33.79	-65.21*	-2.48	0.15	1.93	-1.54	-1.71	-3.13**	-0.21
	(21.11)	(27.35)	(27.03)	(0.79)	(1.13)	(0.94)	(0.99)	(1.16)	(1.68)
	[-75.74, 8.17]	[-119.57, -10.84]	[-56.22, 51.25]	[-1.41, 1.71]	[-0.31, 4.18]	[-3.41, 0.32]	[-3.67, 0.25]	[-5.44, -0.82]	[-3.55, 3.14]
% Impact	-1.02%	-2.00%	-0.07%	4.37%	53.53%	-47.69%	-27.74%	-65.82%	-2.76%
Dep var mean	3301	3266	3334	3.419	3.612	3.239	6.17	4.751	7.492
Dep var SD	455.81	443.37	464.77	18.17	18.66	17.71	24.06	21.27	26.33
Adj. R-squared	0.045	0.042	0.039	0.005	0.004	0.005	0.016	0.012	0.015
Municipalities	87	87	87	87	87	87	87	87	87
Births	50,234	24,018	26,216	50,234	24,018	26,216	50,234	24,018	26,216

Notes: This table presents the estimated triple difference coefficients for the baseline model, excluding preterm babies. Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. Birth weight is measured in grams. Low birth weight is defined as being born weighing less than 2,500 grams. High birth weight is defined as being born weighing over 4,000 grams. Babies with short gestational length are those with less than 37 completed weeks of gestation. Babies with long gestational length are those with over 41 completed weeks of gestation. All regressions include the following controls: gender of the baby, race of the baby (white or other), age bins for the mother (in 5 year intervals), marital status of the mother (married or not),indicators for mother's educational attainment (completed high school or not), 3 indicators for parity at current birth (2nd birth, 3rd birth, or 4th and above), and an indicator for whether the mother's municipality of residence is the same as the municipality where the baby is born. All regressions include municipality, month, and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.7: Impact of hurricane on birth outcomes (inc. indicator for Dec)

	Birth weight (grams)			**Low birth weight (<2500g)**			**High birth weight (>4000g)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD (Mar28-Nov)	-44.82*	-85.65**	-4.80	0.98	3.42**	-1.38	-1.60	-3.11**	-0.08
	[-84.69, -4.95]	[-140.85, -30.45]	[-56.58, 46.99]	[-0.75, 2.70]	[0.88, 5.96]	[-3.40, 0.65]	[-3.57, 0.38]	[-5.27, -0.96]	[-3.34, 3.18]
DDD (Dec)	-28.35	-53.03	4.38	2.51	2.97	1.90	-2.54	-2.40	-2.28
	[-127.15, 70.46]	[-176.74, 70.67]	[-123.50, 132.26]	[-2.00, 7.01]	[-2.13, 8.07]	[-4.24, 8.04]	[-5.48, 0.41]	[-6.10, 1.29]	[-7.28, 2.71]
% Impact	-1.38%	-2.67%	-0.15%	15.31%	49.81%	-23.18%	-27.21%	-69.00%	-1.12%
Dep var mean	3250	3212	3285	6.391	6.864	5.949	5.864	4.511	7.13
Dep var SD	514.07	507.11	518.07	24.46	25.28	23.65	23.49	20.75	25.73
Adj. R-squared	0.040	0.039	0.034	0.008	0.008	0.007	0.015	0.012	0.014

	Short gestational length (<37 wks)			**Long gestational length (>41 wks)**			**Apgar score (0-10)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD (Mar28-Nov)	0.25	2.18	-1.59	-0.27	-0.14	-0.42	-0.02	0.02	-0.07
	[-1.66, 2.16]	[-0.34, 4.70]	[-4.08, 0.90]	[-1.19, 0.66]	[-1.38, 1.10]	[-1.73, 0.88]	[-0.12, 0.07]	[-0.09, 0.13]	[-0.18, 0.05]
DDD (Dec)	-0.58	-1.85	0.35	-1.15	-1.11	-1.41	-0.06	0.06	-0.17
	[-3.57, 2.41]	[-5.90, 2.21]	[-4.54, 5.23]	[-2.59, 0.30]	[-2.98, 0.77]	[-3.23, 0.40]	[-0.20, 0.08]	[-0.11, 0.22]	[-0.39, 0.04]
% Impact	4.76%	39.41%	-31.56%	-24.97%	-12.48%	-41.16%	-0.25%	0.20%	-0.72%
Dep var mean	5.276	5.539	5.03	1.066	1.106	1.028	9.085	9.053	9.114
Dep var SD	22.36	22.88	21.86	10.27	10.46	10.09	0.79	0.80	0.78
Adj. R-squared	0.009	0.011	0.007	0.008	0.011	0.007	0.097	0.096	0.099
Municipalities	87	87	87	87	87	87	87	87	87
Births	53,006	25,416	27,590	53,006	25,416	27,590	53,006	25,416	27,590

Notes: This table presents estimates of a modified version of the baseline equation that includes additional indicators and interactions for babies born in December 2004. Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. Controls and fixed effects are the same as in the baseline model. Standard errors are clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.8: Robustness to spatial and serial correlation using Conley (1998) spatial HAC errors

	Birth weight (grams)			**Low birth weight (<2500g)**			**High birth weight (>4000g)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
DDD (Baseline)	-43.519*	-82.979**	-4.12	1.127	3.391**	-1.065	-1.696	-3.063**	-0.298
	[-83.39,-3.65]	[-136.23,-29.73]	[-56.76,48.52]	[-0.70,2.96]	[0.95,5.83]	[-3.29,1.16]	[-3.54,0.15]	[-5.18,-0.95]	[-3.47,2.88]
Cutoff distances									
25km	[-78.33,-8.71]	[-129.27,-36.69]	[-53.46,45.22]	[-0.63,2.88]	[1.11,5.67]	[-3.34,1.21]	[-3.45,0.06]	[-5.26,-0.87]	[-2.88,2.28]
50km	[-72.74,-14.30]	[-129.60,-36.36]	[-48.07,39.83]	[-0.35,2.61]	[1.24,5.54]	[-3.02,0.89]	[-3.31,-0.08]	[-5.19,-0.94]	[-2.52,1.93]
75km	[-69.91,-17.13]	[-128.89,-37.06]	[-45.64,37.40]	[-0.15,2.40]	[1.30,5.48]	[-2.69,0.56]	[-3.18,-0.22]	[-5.12,-1.00]	[-2.34,1.74]
100km	[-66.80,-20.24]	[-128.04,-37.92]	[-43.11,34.87]	[-0.09,2.35]	[1.33,5.45]	[-2.50,0.37]	[-3.08,-0.31]	[-5.10,-1.03]	[-2.11,1.52]

	Short gestational age (<37 wks)			**Long gestational age (>41 wks)**			**Apgar score (0-10)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
DDD (Baseline)	0.188	1.852	-1.405	-0.354	-0.232	-0.522	-0.027	0.021	-0.075
	[-1.59,1.96]	[-0.45,4.15]	[-3.82,1.01]	[-1.28,0.58]	[-1.45,0.99]	[-1.82,0.78]	[-0.12,0.07]	[-0.09,0.13]	[-0.20,0.05]
Cutoff distances									
25km	[-1.40,1.77]	[-0.22,3.93]	[-3.87,1.06]	[-1.25,0.54]	[-1.49,1.03]	[-1.63,0.59]	[-0.12,0.06]	[-0.09,0.13]	[-0.19,0.04]
50km	[-1.03,1.41]	[0.00,3.70]	[-3.50,0.69]	[-1.25,0.54]	[-1.41,0.94]	[-1.59,0.55]	[-0.11,0.06]	[-0.09,0.13]	[-0.19,0.04]
75km	[-0.82,1.20]	[0.32,3.38]	[-3.24,0.43]	[-1.29,0.58]	[-1.38,0.92]	[-1.57,0.53]	[-0.11,0.05]	[-0.09,0.13]	[-0.18,0.03]
100km	[-0.68,1.06]	[0.50,3.21]	[-3.11,0.30]	[-1.32,0.61]	[-1.41,0.95]	[-1.57,0.53]	[-0.10,0.04]	[-0.08,0.12]	[-0.17,0.02]
Observations	53,006	25,416	27,590	53,006	25,416	27,590	53,006	25,416	27,590

Notes: This table compares standard 95% confidence intervals (in square brackets) with confidence intervals based on spatial heteroscedasticity and autocorrelation consistent errors (Conley, 1999). We use different cutoffs for neighboring municipalities: 25km, 50km, 75km,, and 100km. Controls and fixed effects are the same as in the main paper. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.9: Impact of hurricane on birth outcomes (extended model)

	Birth weight (grams)			**Low birth weight (<2500g)**			**High birth weight (>4000g)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD (2001)	-24.39	-43.74	-1.43	1.54	2.09	0.87	0.02	-0.75	0.88
	[-75.31, 26.53]	[-106.37, 18.88]	[-63.65, 60.78]	[-0.74, 3.83]	[-0.76, 4.95]	[-1.59, 3.33]	[-1.71, 1.76]	[-3.49, 1.99]	[-1.40, 3.16]
DDD (2002)	-46.65	-58.82*	-31.46	0.65	0.90	0.30	-0.56	-1.06	-0.00
	[-97.22, 3.91]	[-115.11, -2.53]	[-105.48, 42.56]	[-1.30, 2.61]	[-1.84, 3.64]	[-2.24, 2.84]	[-2.22, 1.11]	[-2.83, 0.71]	[-2.96, 2.96]
DDD (2004)	-42.71*	-81.12**	-3.57	1.16	3.35**	-1.00	-1.66	-3.00**	-0.33
	[-82.36, -3.05]	[-133.65, -28.59]	[-56.26, 49.12]	[-0.67, 2.99]	[0.91, 5.79]	[-3.21, 1.21]	[-3.49, 0.16]	[-5.12, -0.87]	[-3.50, 2.84]
DDD (2005)	-34.14	-41.52	-22.46	1.64	1.69	1.37	-1.89	-2.84*	-0.97
	[-79.42, 11.13]	[-94.22, 11.18]	[-84.13, 39.20]	[-0.14, 3.43]	[-0.70, 4.09]	[-0.78, 3.53]	[-3.89, 0.11]	[-5.59, -0.08]	[-4.11, 2.17]
% Impact (2004)	-1.31%	-2.53%	-0.11%	18.14%	48.78%	-16.86%	-28.33%	-66.43%	-4.67%
Dep var mean	3250	3212	3285	6.391	6.864	5.949	5.864	4.511	7.13
Dep var SD	514.07	507.11	518.07	24.46	25.28	23.65	23.49	20.75	25.73
Adj. R-squared	0.039	0.040	0.034	0.008	0.008	0.009	0.015	0.012	0.013

	Short gestational length (<37 wks)			**Long gestational length (>41 wks)**			**Apgar score (0-10)**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD (2001)	0.59	1.49	-0.41	-0.53	-0.31	-0.73	-0.06	-0.07	-0.05
	[-1.40, 2.58]	[-0.65, 3.62]	[-3.10, 2.28]	[-1.55, 0.49]	[-1.86, 1.24]	[-2.07, 0.60]	[-0.17, 0.05]	[-0.21, 0.07]	[-0.17, 0.07]
DDD (2002)	0.35	1.56	-1.01	-0.65	-0.71	-0.59	-0.03	-0.02	-0.03
	[-1.43, 2.13]	[-1.30, 4.41]	[-3.05, 1.02]	[-1.50, 0.20]	[-1.98, 0.55]	[-1.59, 0.41]	[-0.12, 0.07]	[-0.13, 0.09]	[-0.13, 0.07]
DDD (2004)	0.25	1.95	-1.47	-0.33	-0.24	-0.45	-0.03	0.03	-0.07
	[-1.51, 2.01]	[-0.34, 4.24]	[-3.86, 0.93]	[-1.25, 0.60]	[-1.45, 0.97]	[-1.72, 0.82]	[-0.12, 0.07]	[-0.08, 0.14]	[-0.20, 0.05]
DDD (2005)	1.44	1.42	1.33	-0.95	-1.21	-0.66	0.03	0.06	0.01
	[-0.89, 3.78]	[-1.13, 3.96]	[-1.96, 4.61]	[-2.08, 0.18]	[-2.83, 0.41]	[-1.84, 0.51]	[-0.05, 0.12]	[-0.05, 0.17]	[-0.09, 0.10]
% Impact (2004)	4.72%	35.25%	-29.16%	-30.64%	-21.81%	-43.79%	-0.28%	0.30%	-0.82%
Dep var mean	5.276	5.539	5.03	1.066	1.106	1.028	9.085	9.053	9.114
Dep var SD	22.36	22.88	21.86	10.27	10.46	10.09	0.79	0.80	0.78
Adj. R-squared	0.007	0.007	0.007	0.006	0.007	0.006	0.083	0.086	0.080
Municipalities	87	87	87	87	87	87	87	87	87
Births	133,513	64,015	69,498	133,513	64,015	69,498	133,513	64,015	69,498

Notes: This table presents the estimated triple difference coefficients for the extended model, where 2003 is the omitted year. Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. Controls and fixed effects are the same as in the baseline model. Standard errors are clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. Observations: all=26,553; 15-25 y/o=12,836; 25-49 y/o=13,717. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.10: Impact of hurricane on birth outcomes (excluding those born in 2005)

	Birth weight (grams)			Low birth weight (<2500g)			High birth weight (>4000g)		
	All mothers	15-24 y/o	25-49 y/o	All mothers	15-24 y/o	25-49 y/o	All mothers	15-24 y/o	25-49 y/o
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD (2001)	-24.82	-43.76	-1.68	1.56	2.09	0.88	0.03	-0.73	0.89
	[-75.83, 26.20]	[-106.48, 18.96]	[-64.11, 60.75]	[-0.74, 3.86]	[-0.79, 4.96]	[-1.58, 3.34]	[-1.72, 1.77]	[-3.49, 2.02]	[-1.39, 3.18]
DDD (2002)	-46.48	-58.38*	-31.36	0.64	0.88	0.27	-0.53	-1.03	0.03
	[-97.33, 4.37]	[-114.91, -1.86]	[-105.72, 43.00]	[-1.33, 2.61]	[-1.88, 3.64]	[-2.28, 2.82]	[-2.20, 1.14]	[-2.81, 0.76]	[-2.93, 3.00]
DDD (2004)	-42.92*	-80.69**	-3.67	1.13	3.29**	-1.03	-1.66	-2.96**	-0.30
	[-82.80, -3.04]	[-133.50, -27.88]	[-56.57, 49.22]	[-0.70, 2.97]	[0.84, 5.74]	[-3.24, 1.18]	[-3.48, 0.16]	[-5.10, -0.82]	[-3.47, 2.88]
% Impact (2004)	-1.32%	-2.51%	-0.11%	17.73%	47.95%	-17.32%	-28.31%	-65.60%	-4.17%
Dep var mean	3250	3212	3285	6.391	6.864	5.949	5.864	4.511	7.13
Dep var SD	514.07	507.11	518.07	24.46	25.28	23.65	23.49	20.75	25.73
Adj. R-squared	0.040	0.040	0.034	0.008	0.008	0.008	0.015	0.012	0.013

	Short gestational length (<37 wks)			Long gestational length (>41 wks)			Apgar score (0-10)		
	All mothers	15-24 y/o	25-49 y/o	All mothers	15-24 y/o	25-49 y/o	All mothers	15-24 y/o	25-49 y/o
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD (2001)	0.58	1.42	-0.37	-0.53	-0.29	-0.76	-0.06	-0.07	-0.05
	[-1.40, 2.57]	[-0.73, 3.56]	[-3.07, 2.34]	[-1.55, 0.48]	[-1.83, 1.25]	[-2.09, 0.57]	[-0.17, 0.05]	[-0.20, 0.07]	[-0.16, 0.07]
DDD (2002)	0.33	1.46	-0.95	-0.66	-0.71	-0.61	-0.03	-0.02	-0.03
	[-1.46, 2.12]	[-1.40, 4.33]	[-3.00, 1.11]	[-1.51, 0.19]	[-1.98, 0.56]	[-1.60, 0.38]	[-0.12, 0.07]	[-0.13, 0.10]	[-0.13, 0.07]
DDD (2004)	0.24	1.93	-1.42	-0.34	-0.24	-0.47	-0.03	0.03	-0.07
	[-1.53, 2.02]	[-0.36, 4.23]	[-3.83, 0.99]	[-1.26, 0.59]	[-1.44, 0.96]	[-1.76, 0.83]	[-0.13, 0.07]	[-0.09, 0.14]	[-0.20, 0.05]
% Impact (2004)	4.64%	34.92%	-28.26%	-31.70%	-21.82%	-45.26%	-0.29%	0.29%	-0.82%
Dep var mean	5.276	5.539	5.03	1.066	1.106	1.028	9.085	9.053	9.114
Dep var SD	22.36	22.88	21.86	10.27	10.46	10.09	0.79	0.80	0.78
Adj. R-squared	0.006	0.007	0.006	0.006	0.006	0.006	0.095	0.097	0.093
Municipalities	87	87	87	87	87	87	87	87	87
Births	107,052	51,748	55,304	107,052	51,748	55,304	107,052	51,748	55,304

Notes: This table presents the estimated triple difference coefficients for the extended model, excluding babies born in 2005. 2003 is the omitted year. Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. Controls and fixed effects are the same as in the baseline model. Standard errors are clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. Observations: all=26,553; 15-25 y/o=12,836; 25-49 y/o=13,717. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.11: Impact of hurricane on fertility by mother characteristics

	Low educ	High educ	Married	Not married
	(1)	(2)	(3)	(4)
DDD (2001)	0.046	-0.168	0.054	-0.165
	(0.074)	(0.127)	(0.080)	(0.148)
	[-0.10, 0.19]	[-0.42, 0.08]	[-0.10, 0.21]	[-0.46, 0.13]
DDD (2002)	0.033	-0.110	0.086	-0.232
	(0.053)	(0.091)	(0.054)	(0.159)
	[-0.07, 0.14]	[-0.29, 0.07]	[-0.02, 0.19]	[-0.54, 0.08]
DDD (2004)	0.026	-0.166	-0.010	-0.063
	(0.050)	(0.117)	(0.109)	(0.144)
	[-0.07, 0.12]	[-0.40, 0.06]	[-0.22, 0.20]	[-0.34, 0.22]
DDD (2005)	-0.119	-0.024	-0.045	-0.224*
	(0.062)	(0.125)	(0.054)	(0.113)
	[-0.24, 0.00]	[-0.27, 0.22]	[-0.15, 0.06]	[-0.45, -0.00]
Dep var mean	22.521	4.090	20.333	6.557
Dep var SD	46.387	13.722	41.283	20.101
Municipalities	87	87	87	87
Observations	5,220	5,220	5,220	5,220

Notes: This table presents the estimated effects of the hurricane on births by mother subgroup. Each observation is defined by a municipality, year, and 'adjusted' month for that subgroup. Adjusted months are the same as calendar months except that the month of April is defined to include March 28 to March 31 so that the post-hurricane dates are captured correctly. All regressions include municipality, year, and 'adjusted'-month fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.12: Impact of hurricane on births and deaths (w/ municipality specific year-month trends)

	Fetal Death Rate			Live Birth Rate		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD	-0.28 [-13.71, 13.15]	15.73* [3.67, 27.80]	-27.76 [-61.89, 6.38]	0.07 [-0.53, 0.68]	-0.55 [-1.99, 0.89]	0.39 [-0.31, 1.09]
Dep var mean	5.314	3.052	7.669	4.084	6.083	3.076
Dep var SD	28.429	17.509	51.425	1.659	3.502	1.663
	Neonatal Death Rate			**Post-neonatal Death Rate**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD	1.04 [-6.60, 8.68]	4.59 [-6.50, 15.68]	-1.07 [-11.77, 9.63]	4.18 [-0.00, 8.36]	5.20 [-2.05, 12.45]	4.24 [-0.96, 9.44]
Dep var mean	5.269	6.277	3.770	1.727	1.633	1.542
Dep var SD	24.294	36.249	22.557	13.767	19.797	14.418
Municipalities	87	87	87	87	87	87
Observations	2,037	1,897	1,932	2,037	1,897	1,932

Notes: This table presents the estimated effects of the hurricane on birth and death rates using the baseline model, modified to include municipality specific year-'adjusted' month trends (in addition to municipality, 'adjusted'-month, and year fixed effects). Each observation is defined by a municipality, year, and 'adjusted' month. Adjusted months are the same as calendar months except that the month of April is defined to include March 28 to March 31 so that the post-hurricane dates are captured correctly. Fetal death rate is the number of fetal deaths divided by the number of resident live births plus fetal deaths (for the same unit) multiplied by 1,000. Birth rate is the number of live births divided by the number of women in that cohort in 2003 multipled by 1,000. Neonatal death rate is the number of deaths occuring within 28 days of births divided by the number of live births multiplied by 1,000. Post neonatal death rate is the number of deaths occuring between 28 and 364 days of birth divided by the number of live births multiplied by 1,000. All regressions include municipality, year, and 'adjusted'-month fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.13: Impact of hurricane on birth and death rates (Extended model)

	Fetal Death Rate			Live Birth Rate		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD (2001)	-15.51	9.04	-36.93*	0.27	0.48	0.16
	[-36.89, 5.88]	[-22.61, 40.69]	[-65.54, -8.31]	[-0.29, 0.83]	[-0.75, 1.71]	[-0.50, 0.82]
DDD (2002)	-0.62	12.18	-19.37	0.32	0.39	0.29
	[-11.09, 9.85]	[-9.23, 33.59]	[-43.45, 4.70]	[-0.31, 0.95]	[-0.94, 1.72]	[-0.40, 0.99]
DDD (2004)	-0.52	17.18**	-24.90	0.08	-0.55	0.40
	[-13.87, 12.82]	[4.48, 29.88]	[-55.44, 5.63]	[-0.50, 0.67]	[-1.97, 0.87]	[-0.28, 1.09]
DDD (2005)	7.25	11.34	-9.20	-0.16	-0.31	-0.09
	[-8.50, 23.00]	[-15.79, 38.47]	[-33.30, 14.90]	[-0.77, 0.45]	[-1.71, 1.10]	[-0.68, 0.51]
Dep var mean	5.314	3.052	7.669	4.084	6.083	3.076
Dep var SD	28.429	17.509	51.425	1.659	3.502	1.663
	Neonatal Death Rate			**Post-neonatal Death Rate**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD (2001)	-2.36	-3.89	-0.11	4.39	4.70	3.35
	[-11.75, 7.02]	[-14.88, 7.10]	[-11.73, 11.51]	[-2.37, 11.14]	[-6.51, 15.90]	[-2.75, 9.44]
DDD (2002)	-3.70	12.07	-14.65	0.95	3.86	0.78
	[-16.84, 9.44]	[-7.33, 31.48]	[-33.71, 4.41]	[-4.43, 6.32]	[-2.22, 9.94]	[-6.40, 7.96]
DDD (2004)	1.11	3.67	-0.75	4.16*	3.74	4.30
	[-6.34, 8.56]	[-7.58, 14.92]	[-10.98, 9.48]	[0.05, 8.28]	[-3.44, 10.92]	[-0.75, 9.35]
DDD (2005)	7.56	-0.97	10.36	4.24*	2.83	5.21*
	[-8.51, 23.62]	[-13.48, 11.54]	[-9.73, 30.45]	[0.88, 7.60]	[-0.73, 6.39]	[0.44, 9.97]
Dep var mean	5.269	6.277	3.770	1.727	1.633	1.542
Dep var SD	24.294	36.249	22.557	13.767	19.797	14.418
Municipalities	87	87	87	87	87	87
Observations	4,830	4,830	4,830	4,830	4,830	4,830

Notes: This table presents the estimated effects of the hurricane on birth and death rates. Each observation is defined by a municipality, year, and 'adjusted' month. Adjusted months are the same as calendar months except that the month of April is defined to include March 28 to March 31 so that the post-hurricane dates are captured correctly. Fetal death rate is the number of fetal deaths divided by the number of resident live births plus fetal deaths (for the same unit) multiplied by 1,000. Birth rate is the number of live births divided by the number of women in that cohort in 2003 multipled by 1,000. Neonatal death rate is the number of deaths occuring within 28 days of births divided by the number of live births multiplied by 1,000. Post neonatal death rate is the number of deaths occuring between 28 and 364 days of birth divided by the number of live births multiplied by 1,000. All regressions include municipality, year, and 'adjusted'-month fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.14: Impact of hurricane on birth and death rates (excluding those born in 2005)

	Fetal Death Rate			Live Birth Rate		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD (2001)	-15.53	9.43	-37.01*	0.25	0.45	0.15
	[-36.92, 5.86]	[-22.30, 41.15]	[-65.74, -8.28]	[-0.31, 0.82]	[-0.78, 1.68]	[-0.51, 0.82]
DDD (2002)	-0.55	12.64	-19.35	0.31	0.36	0.28
	[-11.05, 9.96]	[-8.81, 34.08]	[-43.42, 4.72]	[-0.32, 0.93]	[-0.96, 1.68]	[-0.41, 0.98]
DDD (2004)	-0.47	18.14**	-25.09	0.07	-0.57	0.40
	[-13.83, 12.89]	[5.55, 30.73]	[-55.84, 5.65]	[-0.51, 0.65]	[-2.00, 0.85]	[-0.28, 1.08]
Dep var mean	5.314	3.052	7.669	4.084	6.083	3.076
Dep var SD	28.429	17.509	51.425	1.659	3.502	1.663
	Neonatal Death Rate			**Post-neonatal Death Rate**		
	All mothers	**15-24 y/o**	**25-49 y/o**	**All mothers**	**15-24 y/o**	**25-49 y/o**
	(1)	(2)	(3)	(4)	(5)	(6)
DDD (2001)	-2.28	-3.58	-0.26	4.41	4.87	3.38
	[-11.67, 7.10]	[-14.57, 7.41]	[-11.87, 11.35]	[-2.34, 11.16]	[-6.42, 16.15]	[-2.71, 9.48]
DDD (2002)	-3.53	12.13	-14.69	0.96	4.01	0.81
	[-16.68, 9.62]	[-7.32, 31.57]	[-33.83, 4.44]	[-4.42, 6.33]	[-2.11, 10.12]	[-6.36, 7.99]
DDD (2004)	1.33	3.69	-0.67	4.18*	3.96	4.35
	[-6.11, 8.77]	[-7.42, 14.80]	[-10.87, 9.54]	[0.07, 8.29]	[-3.15, 11.08]	[-0.71, 9.40]
Dep var mean	5.269	6.277	3.770	1.727	1.633	1.542
Dep var SD	24.294	36.249	22.557	13.767	19.797	14.418
Municipalities	87	87	87	87	87	87
Observations	3,877	3,877	3,877	3,877	3,877	3,877

Notes: This table presents the estimated effects of the hurricane on birth and death rates. Each observation is defined by a municipality, year, and 'adjusted' month. Adjusted months are the same as calendar months except that the month of April is defined to include March 28 to March 31 so that the post-hurricane dates are captured correctly. Fetal death rate is the number of fetal deaths divided by the number of resident live births plus fetal deaths (for the same unit) multiplied by 1,000. Birth rate is the number of live births divided by the number of women in that cohort in 2003 multipled by 1,000. Neonatal death rate is the number of deaths occuring within 28 days of births divided by the number of live births multiplied by 1,000. Post neonatal death rate is the number of deaths occuring between 28 and 364 days of birth divided by the number of live births multiplied by 1,000. All regressions include municipality, year, and 'adjusted'-month fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.15: Robustness to survivor bias using Lee (2009) bounding methodology

	BW	LBW	HBW	Preterm	LGA	Apgar
	(1)	(2)	(3)	(4)	(5)	(6)
Baseline (No trimming)						
DDD	-82.98**	3.39**	-3.06**	1.85	-0.23	0.02
	[-136.23, -29.73]	[0.95, 5.83]	[-5.18, -0.95]	[-0.45, 4.15]	[-1.45, 0.99]	[-0.09, 0.13]
Dep var mean	3212	6.864	4.511	5.539	1.106	9.053
Dep var SD	507.11	25.28	20.75	22.88	10.46	0.80
Municipalities	87	87	87	87	87	87
Births	25,416	25,416	25,416	25,416	25,416	25,416
Trim obs with birthweight below 3rd percentile of birthweight distribution (2,200g)						
DDD	-95.74***	4.05***	-3.17**	2.50*	-0.25	0.03
	[-150.61, -40.87]	[2.03, 6.07]	[-5.35, -0.99]	[0.43, 4.57]	[-1.52, 1.01]	[-0.07, 0.14]
Dep var mean	3257	3.976	4.651	3.269	1.141	9.08
Dep var SD	442.31	19.54	21.06	17.78	10.62	0.75
Municipalities	87	87	87	87	87	87
Births	24,791	24,791	24,791	24,791	24,791	24,791
Trim obs with birthweight below average birthweight of babies who died during birth (1,773g)						
DDD	-90.31**	3.69**	-3.11**	2.13	-0.24	0.03
	[-147.13, -33.50]	[1.15, 6.24]	[-5.24, -0.97]	[-0.24, 4.50]	[-1.47, 1.00]	[-0.08, 0.13]
Dep var mean	3234	5.733	4.566	4.439	1.12	9.07
Dep var SD	468.63	23.25	20.87	20.60	10.52	0.76
Municipalities	87	87	87	87	87	87
Births	25,171	25,171	25,171	25,171	25,171	25,171

Notes: This table presents estimated triple-difference coefficients for the baseline model using the bounds estimator of Lee (2009). Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. In the second panel, we drop babies that satisfy the following three conditions: (i) are born to young mothers, (ii) are born in cohorts excluding the treatment cohort, (iii) are born with birthweight below z, where z corresponds to the 3rd percentile of the birthweight distribution for young mothers in the treatment cohort. In the third panel, we drop babies that satisfy the following three conditions: (i) are born to young mothers, (ii) are born in cohorts excluding the treatment cohort, (iii) are born with birthweight below z, where z corresponds to the average birthweight of babies that died during birth and are born to young mothers in the treatment cohort. Controls and fixed effects are the same as in the baseline model. Standard errors in parentheses, clustered at the municipality level. Means and standard deviation of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.16: Characteristics of young and old mothers

	15-24 y/o	**25-49 y/o**	**Difference**
	(1)	(2)	(3)
Married	0.58	0.76	-0.18***
Completed HS	0.09	0.20	-0.11***
In labor force	0.40	0.57	-0.17***
Birth = residential mun.	0.65	0.64	0.01***
Parity	0.60	1.60	-1.00***
Observations	64,015	69,498	

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.17: Impact of hurricane on formal employment rates

	Male & Female 15-69	**Male 15-69**	**Female 15-69**	**Female 15-24**	**Female 25-49**
	(1)	(2)	(3)	(4)	(5)
DD (2002)	-1.345	-1.261	-1.419	-0.424	-2.148
	(1.119)	(1.268)	(1.620)	(1.049)	(2.226)
	[-3.569, 0.880]	[-3.782, 1.260]	[-4.639, 1.800]	[-2.511, 1.662]	[-6.573, 2.277]
DD (2004)	-0.058	0.252	-0.379	0.086	-0.746
	(0.418)	(0.558)	(0.410)	(0.564)	(0.566)
	[-0.888, 0.773]	[-0.857, 1.362]	[-1.194, 0.435]	[-1.034, 1.206]	[-1.871, 0.380]
DD (2005)	0.370	0.860	-0.164	-0.010	-0.355
	(0.687)	(0.950)	(0.615)	(0.866)	(0.770)
	[-0.996, 1.737]	[-1.027, 2.748]	[-1.386, 1.058]	[-1.733, 1.712]	[-1.885, 1.176]
Dep var mean	20.742	25.188	16.217	15.695	20.564
Dep var SD	11.061	14.693	8.731	10.601	10.570
Adj. R-squared	0.925	0.930	0.823	0.915	0.781
Municipalities	87	87	87	87	87
Observations	348	348	348	348	348

Notes: This table examines the effect of the hurricane on formal employment rates. The dependent variable is the number of formally employed workers in that cell divided by the population estimate in that cell multiplied by 100. Each observation is at the municiality-year level. All regressions include municipality and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviation of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.18: Impact of hurricane on health appointments and hospital admissions

	Public health service appointments			Hospital admissions	
	Prenatal	**Ultrasound**	**Gynecological**	**Complications during birth**	**Infections for all**
	(1)	(2)	(3)	(4)	(5)
DD (2001)	3.401	0.252	-4.021	-0.079	-0.375
	(1.916)	(0.399)	(2.662)	(0.152)	(0.278)
	[-0.407, 7.209]	[-0.540, 1.045]	[-9.312, 1.270]	[-0.382, 0.223]	[-0.928, 0.177]
DD (2002)	2.143	0.261	-0.664	0.019	-0.065
	(1.471)	(0.241)	(1.244)	(0.051)	(0.097)
	[-0.783, 5.068]	[-0.218, 0.740]	[-3.136, 1.808]	[-0.083, 0.121]	[-0.258, 0.128]
DD (2004)	2.003	0.133	0.870	0.199	0.040
	(1.496)	(0.318)	(2.450)	(0.102)	(0.044)
	[-0.971, 4.977]	[-0.501, 0.766]	[-4.000, 5.740]	[-0.005, 0.402]	[-0.048, 0.128]
DD (2005)	1.474	0.285	1.970	0.064	-0.038
	(1.580)	(0.370)	(2.372)	(0.089)	(0.045)
	[-1.667, 4.615]	[-0.451, 1.020]	[-2.746, 6.686]	[-0.113, 0.242]	[-0.127, 0.051]
Dep var mean	8.083	1.287	6.198	0.899	0.424
Dep var SD	8.634	1.526	16.160	0.545	0.661
Adj. R-squared	0.404	0.331	0.645	0.474	0.566
Municipalities	87	87	87	87	87
Observations	435	435	435	435	435

Notes: This table examines the effect of the hurricane on public health service appointments (columns 1-3) and hospital admissions (columns 4-5). Dependent variables in columns (1) to (4) are defined as the number of appointments or admissions divided by the number of live births. Infection rate in column 5 refers to the number of infections per 1,000 inhabitants. Each observation is at the municiality-year level. All regressions include municipality and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviation of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table B.19: Impact of hurricane on birth outcomes by young, prime-age, and old mothers

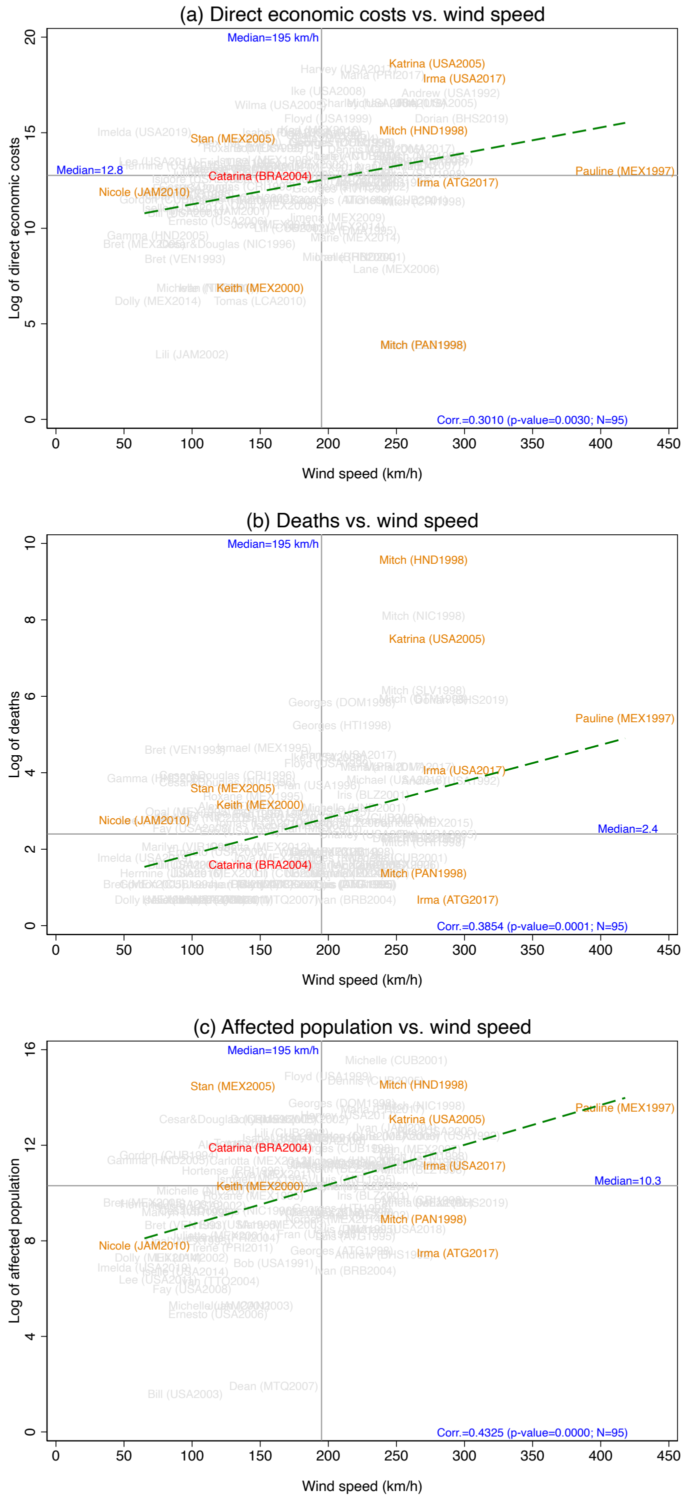
	Birth weight (grams)			Low birth weight (<2500g)			High birth weight (>4000g)		
	15-19 y/o	20-39 y/o	40-49 y/o	15-19 y/o	20-39 y/o	40-49 y/o	15-19 y/o	20-39 y/o	40-49 y/o
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD	-112.09*	-20.45	-168.15	5.31*	0.05	-0.75	-2.48	-1.46	-6.09
	(45.70)	(25.00)	(153.43)	(2.09)	(1.07)	(6.63)	(1.39)	(1.06)	(7.69)
	[-202.95, -21.24]	[-70.15, 29.25]	[-473.72, 137.42]	[1.16, 9.45]	[-2.09, 2.18]	[-13.95, 12.44]	[-5.25, 0.29]	[-3.56, 0.65]	[-21.41, 9.22]
% Impact	-3.54%	-0.63%	-5.21%	64.12%	0.78%	-8.60%	-70.23%	-22.76%	-83.21%
Dep var mean	3168	3271	3226	8.274	5.849	8.723	3.529	6.404	7.321
Dep var SD	516.28	509.59	571.31	27.55	23.47	28.24	18.45	24.48	26.07
Adj. R-squared	0.028	0.036	0.035	0.005	0.007	0.012	0.007	0.014	0.022

	Short gestational length (<37 wks)			Long gestational length (>41 wks)			Apgar score (0-10)		
	15-19 y/o	20-39 y/o	40-49 y/o	15-19 y/o	20-39 y/o	40-49 y/o	15-19 y/o	20-39 y/o	40-49 y/o
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DDD	4.52	-0.89	-0.34	-0.33	-0.30	-1.53	-0.01	-0.04	0.12
	(2.58)	(0.93)	(6.81)	(0.85)	(0.48)	(1.86)	(0.08)	(0.05)	(0.17)
	[-0.60, 9.65]	[-2.73, 0.95]	[-13.91, 13.23]	[-2.01, 1.36]	[-1.26, 0.66]	[-5.24, 2.17]	[-0.17, 0.16]	[-0.14, 0.06]	[-0.21, 0.46]
% Impact	71.97%	-17.88%	-5.17%	-25.97%	-29.75%	-163.97%	-0.08%	-0.40%	1.36%
Dep var mean	6.287	4.985	6.542	1.254	1.018	.9346	9.018	9.103	9.039
Dep var SD	24.28	21.76	24.75	11.13	10.04	9.63	0.84	0.77	0.95
Adj. R-squared	0.011	0.008	-0.010	0.013	0.008	0.073	0.087	0.100	0.054
Municipalities	87	87	77	87	87	77	87	87	77
Births	10,092	41,608	1,301	10,092	41,608	1,301	10,092	41,608	1,301

Notes: This table presents the estimated triple difference coefficients for the baseline model. Coefficients for regressions with binary outcome variables (low birth weight, high birth weight, short gestational length, long gestational length) have been multiplied by 100. Birth weight is measured in grams. Low birth weight is defined as being born weighing less than 2,500 grams. High birth weight is defined as being born weighing over 4,000 grams. Babies with short gestational length are those with less than 37 completed weeks of gestation. Babies with long gestational length are those with over 41 completed weeks of gestation. All regressions include the following controls: gender of the baby, race of the baby (white or other), age bins for the mother (in 5 year intervals), marital status of the mother (married or not),indicators for mother's educational attainment (completed high school or not), 3 indicators for parity at current birth (2nd birth, 3rd birth, or 4th and above), and an indicator for whether the mother's municipality of residence is the same as the municipality where the baby is born. All regressions include municipality, month, and year fixed effects. Standard errors in parentheses, clustered at the municipality level. Means and standard deviations of dependent variables are measured in 2003 before the hurricane. 95% confidence interval in square brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

C Additional Figures

Figure C.1: Relationship between damages and wind speed of hurricane



Source: EM-DAT (1991-2019)

Figure C.2: Distribution of birth weight for various control groups when implementing Lee (2009) bounding procedure

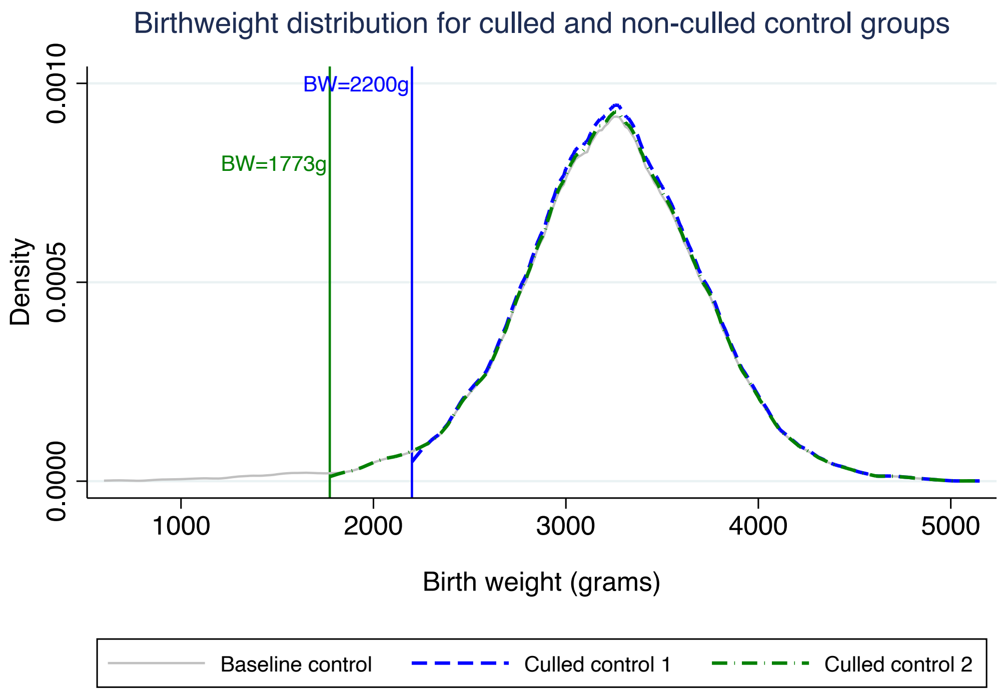


Figure C.3: Robustness check for different cutoff distances for mothers 15-24 y/o

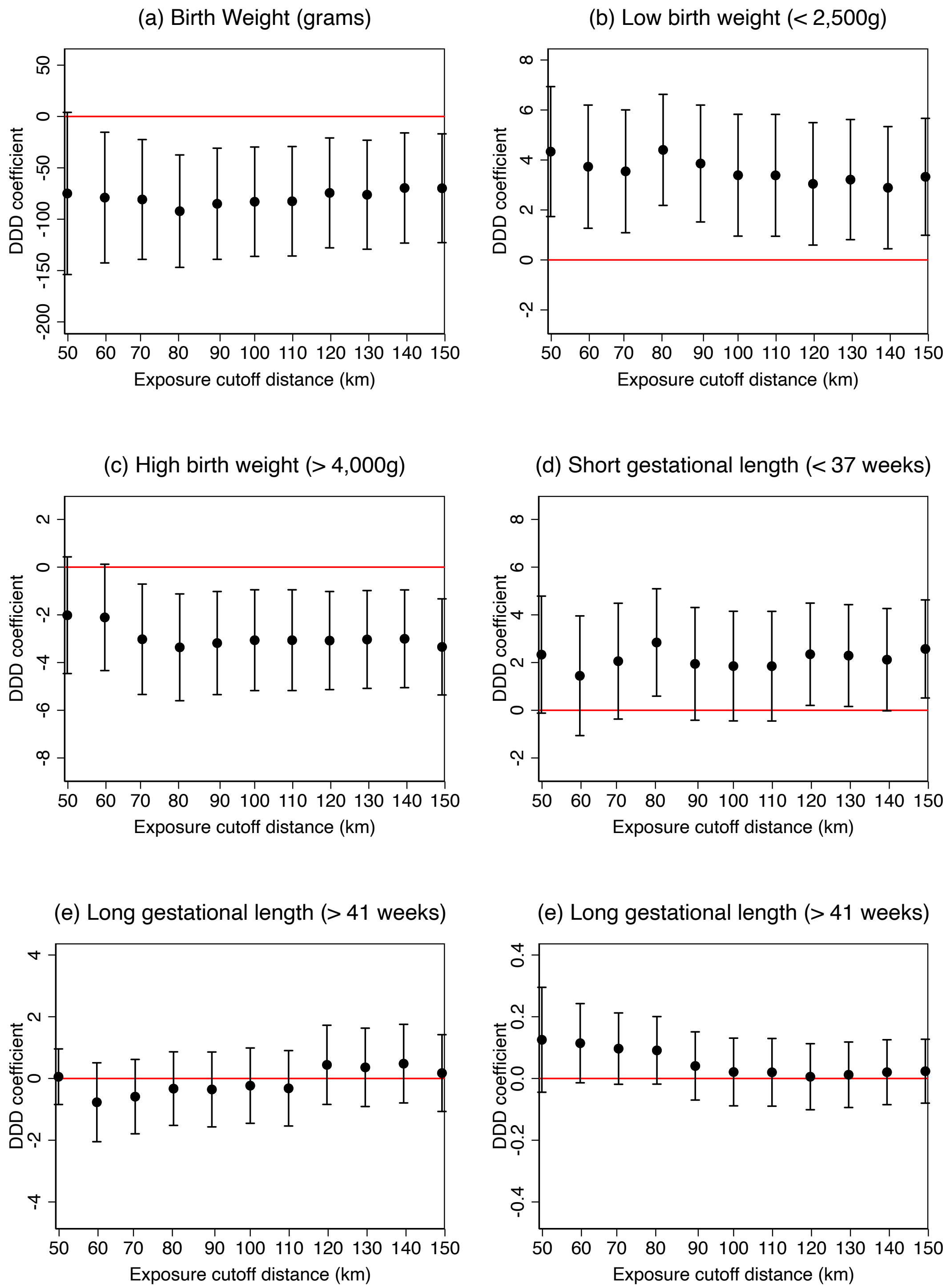


Figure C.4: Robustness check for different cutoff distances for mothers 25-49 y/o

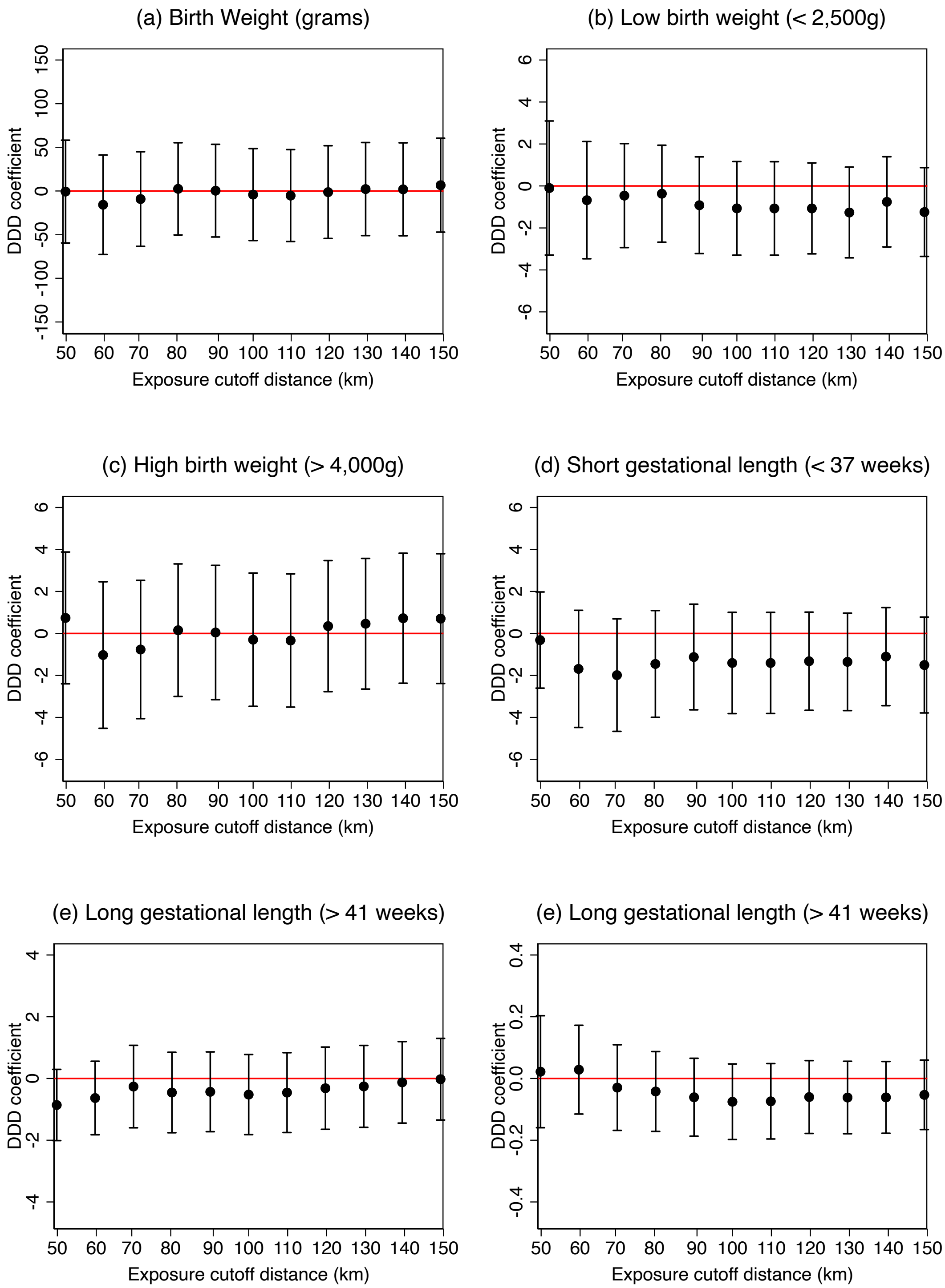


Figure C.5: Robustness check for different cutoff distances for mothers 15-24 y/o

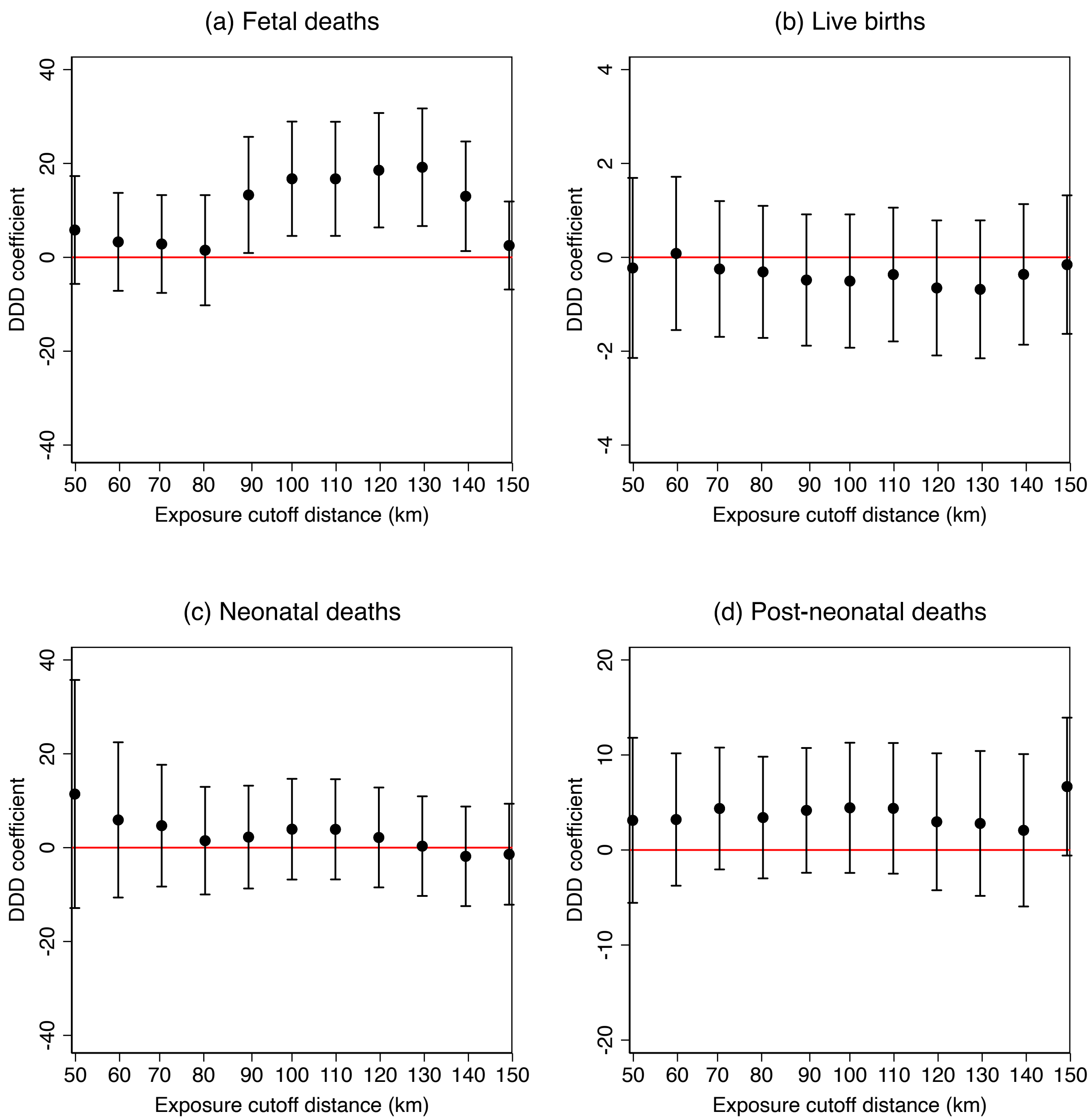
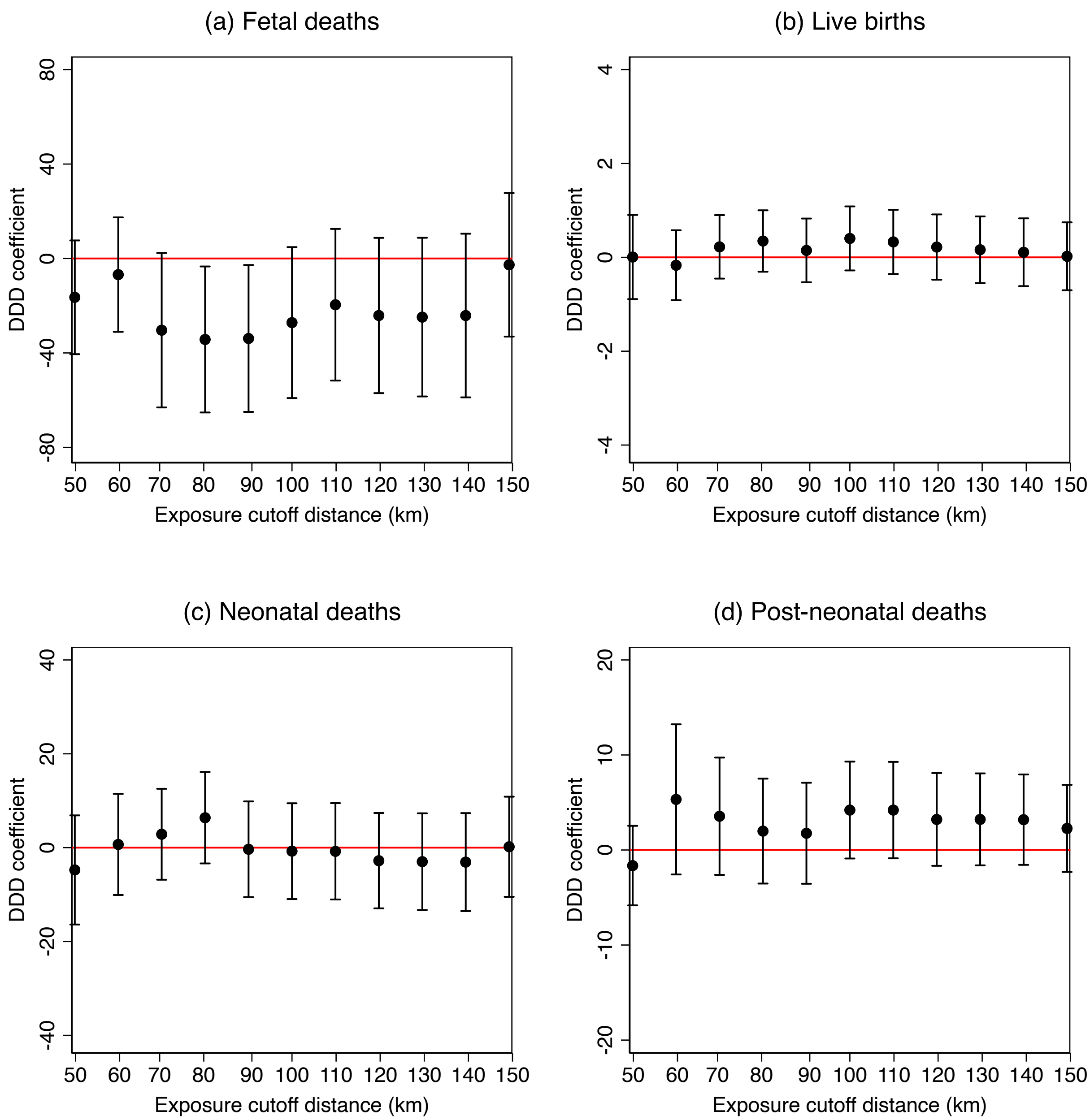


Figure C.6: Robustness check for different cutoff distances for mothers 25-49 y/o



D Comparison of DDD and DD methods

In this appendix, we compare estimates from a difference-in-differences (DD) and difference-in-difference-in-differences specification. When making this comparison, we simplify our specification by removing the set of fixed effects and controls in equation (1). With this simplification in mind, a natural DD specification in our context is given by the following equation:

$$y_{itmdp} = a_0 + a_1 Post_{tdm} + a_2 Close_p + a_{DD} Close_p \times Post_{dm} + u_{itmdp}, \tag{4}$$

where $Post_{tdm}$ equals 1 if baby i is born on or after March 28 2004 and zero otherwise, $Close_p$ equals 1 if municipality p is within 100 km of the hurricane center, and b_{DD} is the DD coefficient of interest. The corresponding simplified DDD specification is given by the following equation:

$$\begin{aligned} y_{itmdp} = {} & b_0 + b_1 Mar28_{dm} + b_2 Yr2004_t + b_3 Close_p \\ & + b_4 (Close_p \times Mar28_{dm}) + b_5 (Close_p \times Yr2004_t) + b_6 (Mar28_{dm} \times Yr2004_t) \\ & + b_{DDD} (Mar28_{dm} \times Yr2004_t \times Close_p) + \epsilon_{itmdp}, \end{aligned} \tag{5}$$

Equations (4) and (5) show that the DD and DDD models are equivalent if $b_1 = b_2 = b_4 = b_5 = 0$. If this is the case, then there are no advantages to using the more complex DDD model.

We estimate equations (4) and (5) separately for three groups of mothers (all mothers, young mothers, and older mothers) and plot the estimated a_{DD} and b_{DDD} coefficients for each group in Figure D.1. For each group, we report the F-statistic and corresponding p-value from testing the constraint required for the DD and DDD models to be equivalent. For most birth outcomes, the DD and DDD specifications yield different estimates, particularly for the group of young mothers. For example, using the DD specification suggests that Catarina had no significant effect on the birth weight of babies born to young mother (4.5 g) whereas the simplified DDD specification suggests that on average birth weight of this group fell by 77.6 g. Furthermore, the constraint test rejects the hypothesis that these models are equivalent for young mothers for three out of our six birth outcome variables.

In Figure D.2, we extend this analysis by adding the set of fixed effects and controls included in the baseline equation (year, month, municipality fixed effects and sociodemographic characteristics) to equations (4) and (5).[27] The differences between the DD and DDD estimates are also evident, highlighting the importance of allowing for season of birth effects, region-specific season of birth effects, and year-specific season of birth effects.

[27]In this case, the $Close_p$ drops out as it is collinear with the vector of municipality fixed effects.

Figure D.1: DDD vs DD, excluding municipality, month, year fixed effects and sociodemographic controls

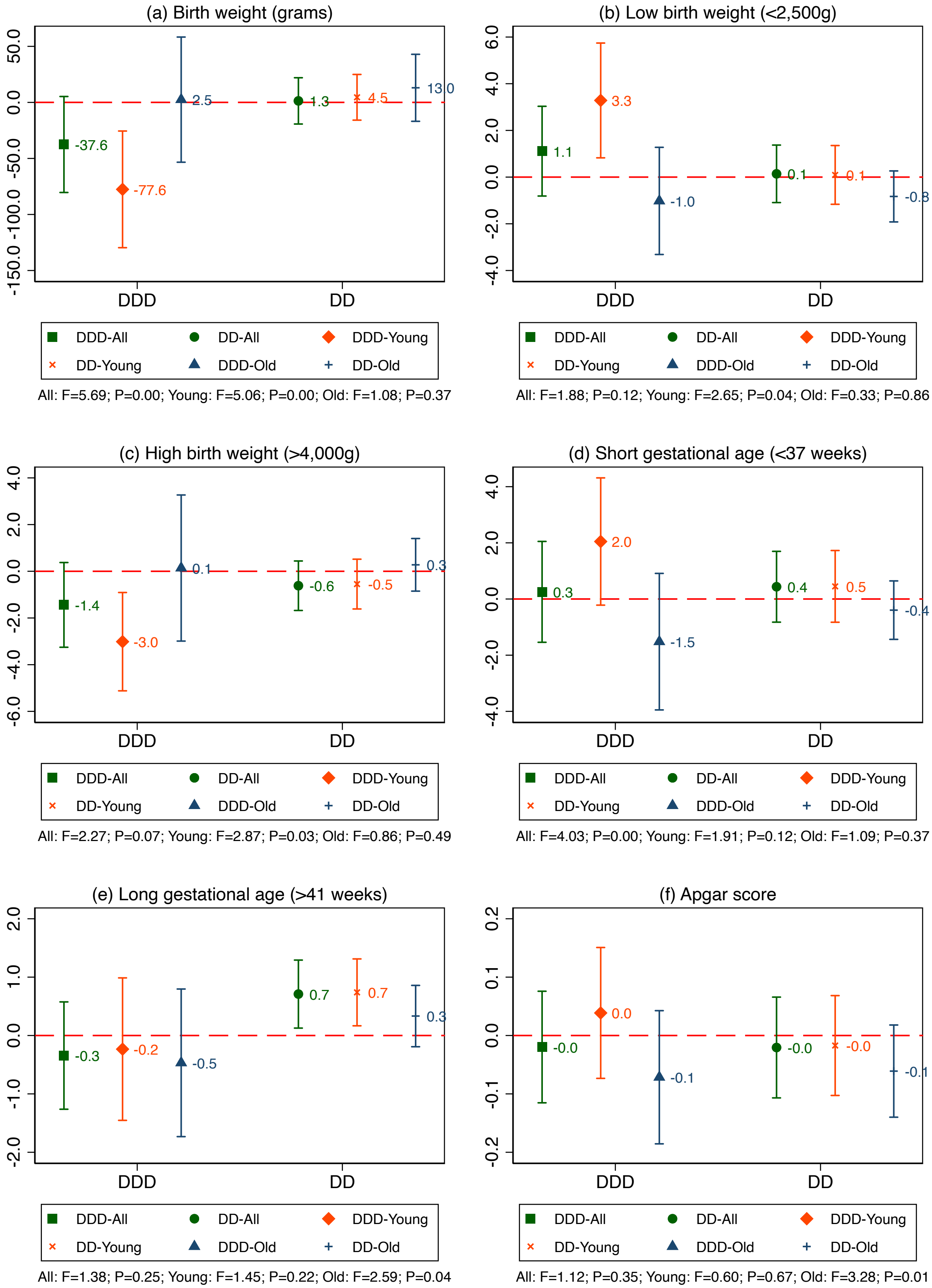


Figure D.2: DDD vs DD including municipality, month, year fixed effects and sociodemographic controls