

Bombs and Babies

The Relationship between U.S. Navy Bombing Activity and Infant Health in Vieques, Puerto Rico^{*}

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Abstract:

We study the relationship between exposure during pregnancy to frequent explosions from military exercises and children's early-life health outcomes in the context of Vieques, a small islet off the island of Puerto Rico (P.R.). Examining the relationship between annual variations in bombing activity with a subsequent year's reports of live births, still births, and low birth weight we find that there is a strong relationship between the exposure to exercises-based bombing activity and infant health outcomes. We find that a one standard deviation increase in bombing intensity increases the rate of low birth weight by 17 percent. Given the well-documented relationship between low birth weight and adult health there is reason to believe that our large short term effects may have longer term consequences for the population of Vieques.

Keywords: Infant health, pollution, maternal stress, military activity

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I. Introduction

Many factors can affect the development of a fetus during pregnancy. Most epidemiological and medical research focuses on the role that nutrition plays for fetal development and early-life health outcomes (Kramer, 1987). A complementary literature analyzes external environmental factors that may occur during the prenatal period (Almond & Currie, 2011). This emerging body of research supports the “fetal origins” hypothesis first articulated by David Barker (1990): the idea that numerous external environmental factors during the mother’s pregnancy can have important, long-lasting consequences on health outcomes.¹ In particular, there is a growing consensus that the relationship between events that interrupt normal living conditions – such as civil conflict, terrorist attacks, famines, and natural disasters – have strong negative consequences for the children of pregnant mothers’ early-childhood, but also for these individuals’ long-term health, educational, and economic outcomes.²

We study the relationship between exposure during pregnancy to frequent explosions from military exercises and children’s early-life health outcomes in the context of Vieques, a small islet off the island of Puerto Rico (P.R.) which served as the base for military exercises by the U.S. Navy during the second half of the twentieth century. Our research design relies on annual variation in bombing activity with a subsequent year’s reports of live births, still births, and low birth weight births to women resident in the municipality, relative to those in the remaining municipalities of Puerto Rico during the period 1998-1999.

The results from our study suggest that there is a strong relationship between the exposure to exercises-based bombing activity and infant health outcomes, even in a non-combat/non-conflict context like Vieques. We find that a one standard deviation increase in the intensity of ordnance used by the U.S. Navy in the Vieques live impact area – our main measure of activity – explains an increase in children’s low birth weight rate by 18.2 per thousand live births among children born to a Vieques resident, a 17 percent increase from the municipality average over this time period.

The study has important implications for policy. Low birth weight is an important predictor of child health (McCormick, 1985; Pollack & Divon, 1992; Almond, Chay, & Lee, 2005) and long-term outcomes such as educational attainment, labor market outcomes, and adult health (Currie & Hyson, 1999; Behrman & Rosenzweig, 2004; Black, Devereux, & Salvanes, 2007). Previous research has documented the effects of both maternal stress and environmental pollution on infant health (c.f. Currie et al 2009) and it is likely that some combination of these channels is responsible for the detrimental effects on child health that we find here. Since the shutdown of the U.S. Navy in Vieques in 2001 formalized the start of a negotiation between the Commonwealth of Puerto Rico and the U.S. for an ecological and economic restoration strategy for the island, these findings have implications to expand the discussion to address child health and child development dimensions.

II. Background

II.A. U.S. Navy Activities in Vieques

Vieques is an islet off the eastern end of Puerto Rico with approximately 350 square kilometers (Figure 1). In 2010, the small island hosted 9,301 habitants, less than 0.01 per cent of the 3.7 million residents in

¹ According to the fetal origins hypothesis, intrauterine exposure to environmental agents may program the fetus to have particular metabolic characteristics (Barker, 1990). The specific biological mechanisms that manifest in different health outcomes of fetuses depend on the level of exposure to environmental factors as well as nutritional and genetic factors.

² Prominent examples of the research on the effects of conflict for early-life and long-term outcomes are Camacho (2008), León (2012), Mansour and Rees (2012), Galdo (2013), and Quintana-Domeque and Rodenas (2014). See Almond and Currie (2011) for a broad survey of the literature.

Puerto Rico. Close to two-thirds of the Vieques territory served as part of the U.S. Navy Atlantic Fleet Weapons Training Area from 1941 to 2001. Military training and operations were conducted in the eastern end of the island, while the western end was used to store munitions. The central part, the “civilian area” (approximately 45 square kilometers), was designated to accommodate local civilian residents.

The eastern naval area hosted a range of military exercises including ship-to-shore gun fire, air-to-ground bombing by naval aircraft, and Marine amphibious landing. Over the span of six decades, naval operations averaged between 180 to 250 days each year (approximately 6,300 shelling days) with an annual estimate of 3-14 million pounds of live ordnance detonated and dropped within the live impact area (189-662 million pounds in total) (Porter, Barton, & Torres, 2011, p. 68). The live impact area encompasses an area of about 900 acres and is 12.5 kilometers away from residential population.

In addition to conventional weaponry, the composition of munitions used during bombardment exercises posed risks to the health of the population and ecology of the island. The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) notes that naval training involved handling of Napalm and Agent Orange at various stations within the eastern naval area (ATSDR, 2001). Despite serious concerns of the radiological and toxicological effects of depleted uranium once it vaporises in the air, over 250 rounds (88 lb) of ammunition tipped with depleted uranium were fired in 1999 (Wargo, 2009). According to a U.S. Congress report by the Department of Defense, biological weapons were tested in Vieques but no further details of the operation are publicly disclosed (Porter, Barton, & Torres, 2011).

The U.S. Navy reduced its operations in April 1999 following a widely publicized campaign when David Sanes, a civilian employee, was killed during a bombing accident. No military training exercises took place on Vieques for approximately thirteen months. In May 2000, the Navy resumed military training exercises but only with “practice” bombs and other non-explosive ordnance for a brief period of less than fifty days (ATSDR, 2003, p. 13). All military training exercises at Vieques officially ceased on May 1, 2003, when the Navy turned its lands over to the U.S. Fish and Wildlife Service.

Since various areas of the island remained contaminated by solid and hazardous waste resulting from decades of military activity, in 2005 the U.S. Environment Protection Agency (EPA) declared these lands a superfund site. This required the U.S. Navy to partner with the EPA, Fish and Wildlife Service and the Puerto Rico Environmental Quality Board to determine and implement cleanup actions. The effects of decontamination practices may pose further risks to Vieques residents and stress on pregnant women as these involve, among other things, detonating defective ordnance in the air.³ Current projections indicate that work at the site will be completed in 2022 for the land areas and in 2029 for the underwater effort (EPA, 2013).

II.B. Implications for Health Outcomes among the Resident Population

Most research efforts on the impacts of military activity on the health profile of the Vieques’ resident population (“Viequenses”) have focused on documenting the unusually high cancer incidence rates in the municipality. Reports produced by the Puerto Rico Department of Health have identified an upward trend since 1960 in cancer incidence rates in Vieques relative to the rest of Puerto Rico.⁴ The U.S. ATSDR has produced public health assessment studies on drinking groundwater (released in 2001), ingesting or touching soil (2003), breathing air (2003), and eating fish and shellfish (2003), and they all conclude that Viequenses have not been

³ McCaffrey (2009) highlights this and several environmentally degrading practices by the U.S. Navy during the cleanup process, including burning excess materials and waste and dumping toxic chemicals and substances in sensitive wetland areas.

⁴ See Zavala Zegarra (2000) for the period covering 1960-2004; and Figueroa, Suarez, De La Torre, Torres, and Perez (2009) for the period covering 1995-2004. The latter documents that Vieques residents were 26 per cent more likely to develop cancer in 1995-1999, and 19 per cent in 2000-2004 compared to residents in the rest of Puerto Rico.

exposed to harmful levels of chemicals resulting from U.S. Navy training activities.⁵ A small number of independent research studies have documented exposure of the population to higher levels of mercury, lead, copper, and nickel than those clinically recommended by the World Health Organization (Ortiz-Roque & Lopez-Rivera, 2004; Massol-Deya, Perez, Perez, Berrios, & Diaz, 2005). Although based on small samples, this literature is suggestive of an environmental link that can help explain the Vieques population's poor health profiles compared to those of residents of other municipalities in Puerto Rico.

The effects of naval aircraft and bombing exercises on the psychological and psychosocial profile of Vieques is an area that remains unexplored despite documented qualitative evidence that these activities disrupted regular life activities. According to the 1999 Special Commission on Vieques, officials from the P.R. Department of Education reported that “the vibrations caused by bombing practices shudder educational facilities, affecting the physical structure of buildings and interrupting classes”. The Department concluded that it is evident that “this sort of activity and the noise generated cause anxiety and concern among students and school staff in general” (Puerto Rico, 1999, p. 10). Even without empirical evidence on the levels of distress and mental well-being among Viequenses during the period of interest for this report, the limited documentation available suggests that pregnant women in Vieques may have been exposed to disruptive environmental factors that would have impacted fetal development in unintended ways.

III. Data and Methodology

III.A. Data Description and Summary Statistics

Data on bombing activity related to naval exercises in Vieques are based on a study prepared for the Secretary of the U.S. Navy in 1999, which was later reproduced in an ATSDR public health assessment of pollution via air pathways (2003, pp. 96-97).⁶ The dataset contains two measures of live-fire range utilization: (1) total weight of ordnance that the U.S. Navy and other parties used for all military training exercises, including air-to-ground, ship-to-ground, and land-based activities; and (2) total weight of high explosives used at the live impact area. The bombing measures are available for the fiscal years 1983 to 1998 (beginning on October 1st of the preceding year and ending on September 30th of the current year). From 1988 to 1999, between 1,359 and 2,667 tons of ordnance were used in military training exercises, of which between 124 and 469 tons were considered high explosives (summary statistics of these variables are reported in Table 1, Panel A).

We use infant health outcomes data by mother's municipality of residence and calendar year from annual vital statistics collected by the P.R. Department of Health for the period 1988-1999. This data cover the twelve-year period in the lead up to the shutdown of U.S. Navy operations in Vieques. These data contain the number of live births, number of still births, the number of low and very low birth weight births to mothers resident in each municipality, and population estimates in a calendar year. We construct three outcome variables based on these: (1) the number of live births per 100,000 inhabitants, (2) the low birth weight (< 2,500 grams) rate per thousand live births, and (3) the number of still births per thousand births.

Vital statistics also report a small subset of maternal and prenatal care characteristics: the number of teenage births, the number of births to single mothers, and the number of women receiving prenatal care during the first trimester of pregnancy. We construct rates of these measures per thousand live births. Finally,

⁵ The impartiality of ATSDR studies have been questioned by the academic community and journalists alike. For an analysis on the narrative and language used by different U.S. departments and agencies on handling the Vieques file see Davis, Hayes-Conroy, and Jones (2007).

⁶ The primary source of the data, U.S. Navy (1999), remains untraceable. We obtained the bombing data from charts reproduced in ATSDR (2003, pp. 96-97) using Engauge Digitizer 4.1, a software designed for optical plot reading and digital conversion. For more information on Engauge Digitizer, visit <http://digitizer.sourceforge.net/>

we use municipality-level annual (calendar year) unemployment rates from the P.R. Department of Labor. Following the removal of outliers, the final sample size is $n = 908$ municipality-year observations.⁷ Summary statistics of these additional variables are reported in Table 1, Panels B and C.

III.B. Empirical Methodology

We compare annual variation in bombing activity in a fiscal year with a subsequent calendar year's reports of live births, still births, and low birth weight births to women resident in the municipality of Vieques, relative to those in the remaining municipalities of Puerto Rico during the period 1998-1999. Specifically, we estimate linear models in which we regress the various outcomes on the interaction of the magnitude of ordnance used during naval exercises and an indicator variable for the Vieques municipality. Each specification includes controls for maternal characteristics (discussed in Section III.A) and prenatal medical care to separate other potential factors that could affect the outcomes of interest. All specifications include fixed effects for each calendar year and for each municipality to control for unobserved heterogeneity in health outcomes that vary over time and across jurisdictions, respectively. Therefore, our estimates are identified using variation within municipalities over time. We cluster standard errors at the municipality level, to allow for serial correlation in the error terms.

We also report the magnitude of the predicted relationship between a one standard deviation increase in the explanatory variable of interest and each outcomes variable (in proportional terms) by taking the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure.

IV. Results

Figure 2 shows the relationship between the level of ordnance in a fiscal year and rates of low birth weight births in the subsequent calendar year, for Vieques and the rest of Puerto Rico. The rate of low birth rate births tracks ordnance levels quite closely whereas the low birth weight rate in the rest of Puerto Rico is much flatter. This pattern is striking: low birth weight births spike in Vieques in the calendar year following high levels of explosive ordnance with little change in the LBW rate in other areas.

Our linear regression model estimates mirror the results depicted above (see Table 2, Panel A). Our models strongly suggest that bombing activity may have acted as an external factor affecting fetal development. Vieques experienced a decline in live births, and an increase in both the LBW and still births rate during this time period, significantly correlated with the levels of ordnance used in the live impact area. Specifically, a one standard deviation increase in total ordnance predicts a 1.7 percent reduction in the number of live births. More significantly, the measure predicts a 17.3 percent increase in the rate of low birth weight births (an increase of 18.2 per thousand live births), and a 37.0 percent increase in the still births rate (2.8 per thousand births).⁸ Analogous models using as the explanatory variable the level of high explosives have a similar relationship with the outcomes of interest (see Table 2, Panel B).

⁷ We conducted a multiple outlier detection test, following Hadi (1994; 1992), with the significance level for outlier cut-off at $p = 0.5$.

⁸ Estimates are robust to alternate specifications. In particular, these are robust to models that account for contemporaneous variation in municipality-level economic activity (i.e., municipality-level unemployment rates) (Dehejia & Lleras-Muney, 2004). In addition, the bombing activity-LBW rate relationship is qualitatively robust to a simulation exercise that accounts for the possibility that the reduction in the number of live births can increase the reported rate of low birth weight births (i.e., assuming that the live births predicted to not take place would all be non-LBW births). These are available from the authors upon request.

V. Discussion

Our paper uses a quasi-natural experiment to identify the relationship between frequent explosions and high-ordnance military exercises and infant health. Our results suggest that there is a negative effect of these exercises on both live births, still births and infant birth weight. There are a number of possible mechanisms by which these bombings could have affected mothers during pregnancy. It is feasible that the bombings increased stress levels or sleep deprivation among pregnant women. The medical literature indicates that prenatal stress increases levels of corticotrophin releasing hormone, which regulates the duration of pregnancy and fetal maturation. Increases in prenatal stress levels have been associated with a decrease in infant birth weight, an increased likelihood of LBW, and a decrease in gestational age at birth (Wadhwa, Sandman, Porto, Dunkel-Schetter, & Garite, 1993). Studies have also suggested that stress induced during the first trimester tend to have more significant effects on birth weight and preterm birth (Zhu, Tao, Hao, Sun, & Jiang, 2010). More recently, literature looking at terrorist bombings and mental health shows a strong relationship between the two (Dustmann & Fasani, 2014). Therefore, it is certainly feasible that increased stress due to the bombings had negative effects on infant health in Vieques.

Another plausible pathway is through contamination of the local environment. Increases in solid and hazardous waste, resulting in potential contamination of soil, water, and/or air may also have affected infant health. Again, previous literature has shown a direct link between air pollution and infant health (Chay & Greenstone, 2003; Currie, Neidell, & Schmieder, 2009). To the extent that air or water pollution directly increases and dissipates with the level of bombing, it would be consistent with the patterns between bombing levels and low birth rates shown in Figure 2. Given the additional previous evidence showing higher rates of cancer in Vieques relative to Puerto Rico,⁹ it is likely that more than one causal mechanisms is at play here.

Previous research has documented a number of long term consequences related to being born low birth weight, including long term effects on education, welfare receipt, earnings and adult health (Black, Devereux, & Salvanes, 2007; Oreopoulos, Stabile, Roos, & Walld, 2008). One study has even documented long-term consequences of fetal health on adults in Puerto Rico (Sotomayor, 2013). Given this body of research, there is reason to believe that our findings of short-term effects on infant health may have longer-term effects on educational attainment, labor force attachment, and adult health. Further study is required to better understand the mechanisms through which the bombings affected infant health and to inform public policy.

⁹ See Zavala Zegarra (2000) for the period covering 1960-2004; and Figueroa, Suarez, De La Torre, Torres, and Perez (2009) for the period covering 1995-2004.

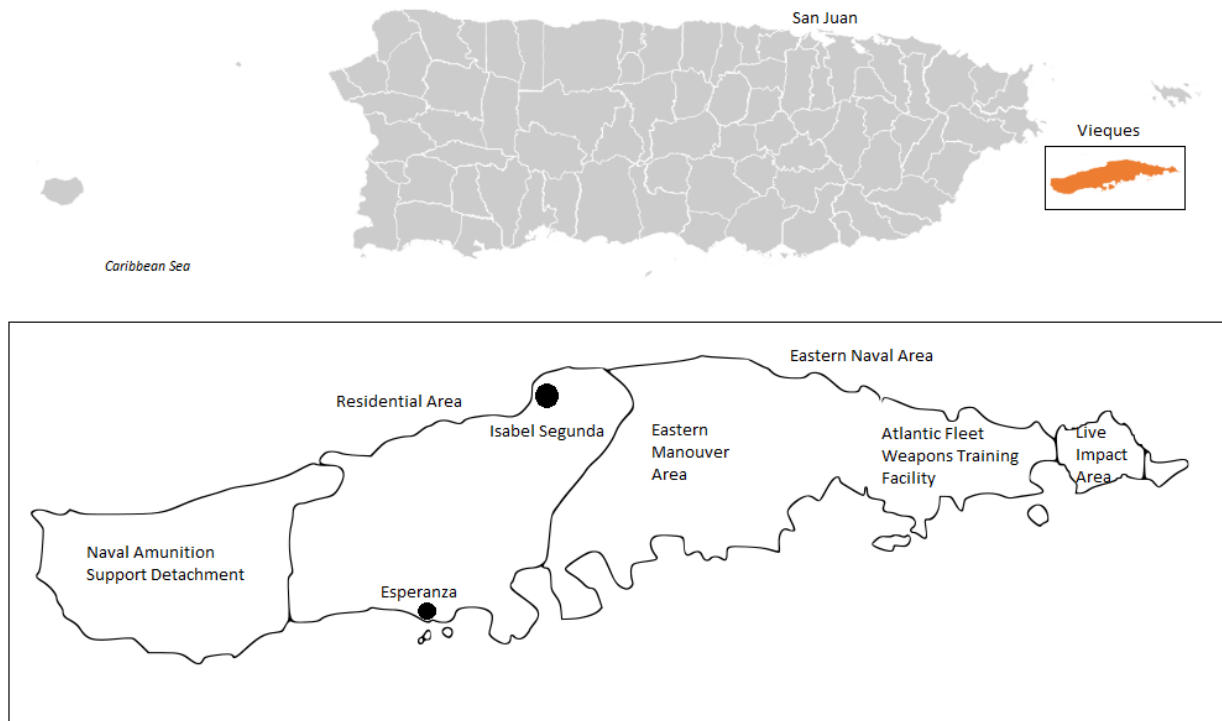
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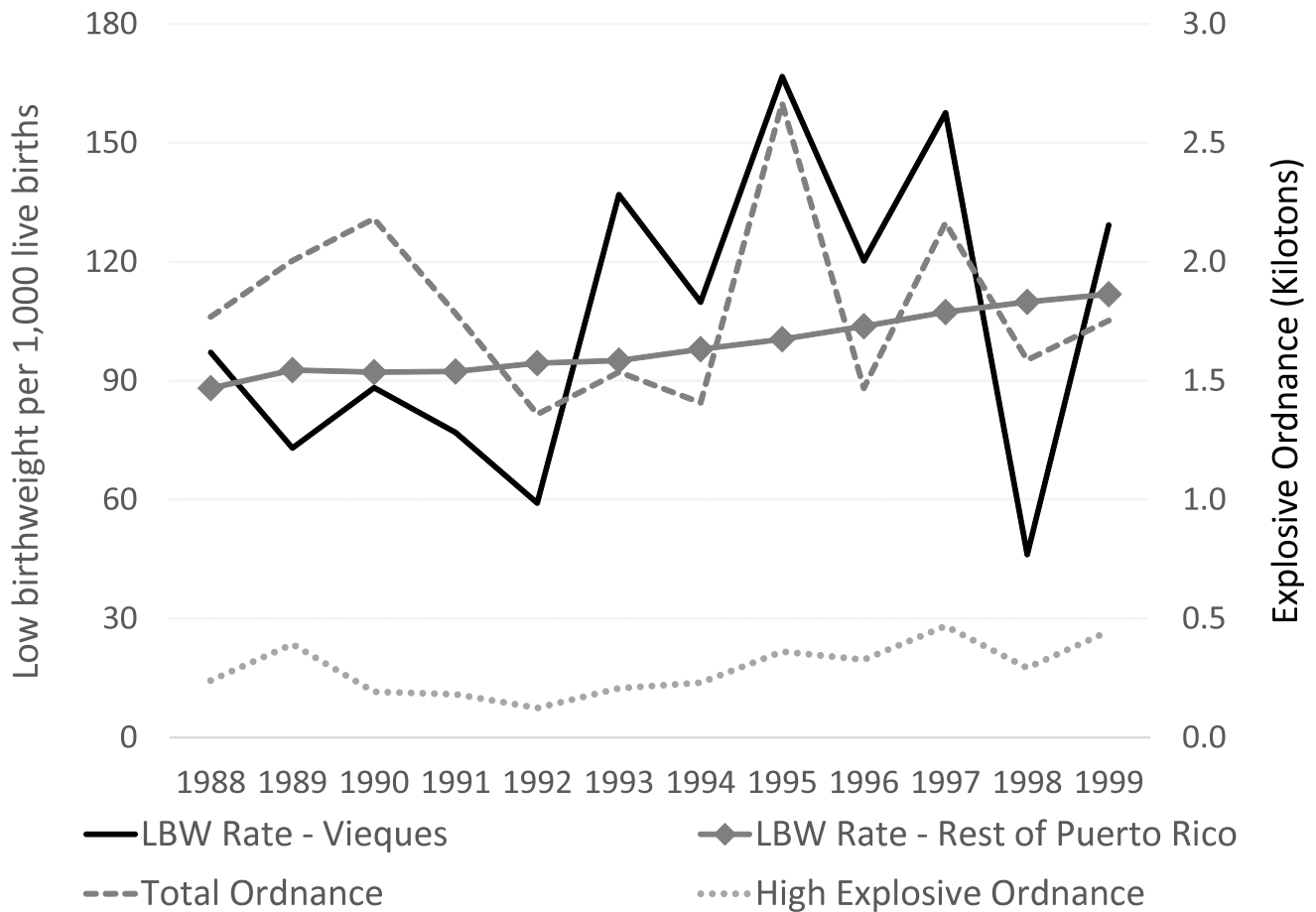
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Figure 1: Map of Puerto Rico and Vieques with Former Division of Residential and Military Zones



Notes: Map is for illustrative purposes only. Map may not be drawn to scale.

Figure 2: Ordnance Used During Naval Exercises and Low Birth Weight Rates, 1988-1999



Source: Vital Statistics from P.R. Department of Health; Bombing metrics from U.S. Navy (1999) included in ATSDR (2003, pp. 96-97)

Notes: Reported are low birth weight rates by calendar year t , and the one fiscal year lag of the volume of bombing activity (October 1st, year $t-2$ to September 30th, year $t-1$).

Table 1: Bombing Activity (in Vieques) and Infant Health and Other Indicators, 1988-1999

Variable	Description	Vieques		Rest of P.R.	
		Mean	S.D.	Mean	S.D.
Panel A: Bombing Activity					
Total ordnance used ¹	Kilotons of ordnance used at the live impact area in Vieques	1.8	0.4	--	--
High explosive ordnance used ¹	Kilotons of "high explosives" ordnance used at the live impact area in Vieques	0.3	0.1	--	--
Panel B: Natality and Neonatal Health Outcomes					
Live births	Number of live births per 100,000 habitants	19.0	2.8	18.0	2.5
Still births	Number of still births per 1,000 births	7.8	6.9	9.3	6.1
Low birth weight rate	Number of low birth weight (< 2,500 grams) births per 1,000 live births	105.1	38.3	98.9	18.5
Panel C: Maternal and Municipality Characteristics					
Teenage mother	Number of mothers aged between ten and nineteen per 1,000 live births	249.1	28.2	204.2	36.9
Single mother	Number of single mothers per 1,000 live births	544.1	86.5	403.9	99.7
Prenatal care	Number of pregnancies with prenatal care during the first trimester per 1,000 live births	595.2	63.8	767.8	74.9
Municipality unemployment rate	Municipality-level annual unemployment rate	15.8	3.6	17.9	5.0

Notes: ¹ Series are lagged by one year

Table 2: Relationship between Bombing Activity during Naval Exercises and Infant Health Outcomes, 1988-99

	Dependent variables:		
	Live births rate	Low birth weight rate	Stillbirths rate
	(1)	(2)	(3)
Panel A: Ordnance			
Ordnance_{t-1} × Vieques	-0.85*** (0.14)	47.01*** (1.57)	7.41*** (0.53)
Maternal controls	Yes	Yes	Yes
Municipality Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Percent change in outcome variable from 1 S.D. increase in ordnance	-1.7%	17.3%	37.0%
Panel B: High Explosives			
High Explosives_{t-1} × Vieques	-5.42*** (0.81)	123.60*** (7.32)	15.88*** (2.54)
Maternal controls	Yes	Yes	Yes
Municipality Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Percent change in outcome variable from 1 S.D. increase in high explosives	-3.16%	13.03%	22.71%
Observations	908	908	908
Dep. variable mean	19.0	105.1	7.8

Notes: Coefficient estimates from municipality fixed effects regressions; each reported coefficient is from a different regression. Robust standard errors in parentheses, clustered at the municipality level; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Maternal controls include the number of teenage mothers per thousand live births, the number of single mothers per thousand live births, and the number of pregnancies with prenatal care during the first trimester per thousand live births. The percent change in each outcomes variable from a one (1) standard deviation increase in the relevant explanatory variable is calculated by the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure: standard deviation (Ordnance_{t-1}) = 0.387; standard deviation (High Explosives_{t-1}) = 0.111.