NBER WORKING PAPER SERIES

BOMBS AND BABIES:
US NAVY BOMBING ACTIVITY AND INFANT HEALTH IN VIEQUES, PUERTO RICO

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Working Paper 22909
http://www.nber.org/papers/w22909

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 2016

We thank Francesco Amodio, Michael Baker, Loren Brandt, Fred Finan, Jeanne Lafortune, Elaine Liu, Aprajit Mahajan, Ted Miguel, José Tessada, Tom Vogl, and seminar and conference participants at UC Berkeley, Toronto, Catholic University of Chile-Economic History and Cliometrics Lab Second Annual Conference 2014, the 11th Annual Workshop of the Households in Conflict Network, and the CIREQ Montreal Applied Economics Conference 2016 for helpful comments and suggestions. We would also like to thank Jordan Scantlebury for excellent research assistance, the Institute of Statistics of Puerto Rico, Dr. Heriberto Marín, and Dr. Arturo Massol Deyá for sharing administrative data and for their general support throughout, as well as the Canadian Institute for Advanced Research and the CONICYT/Programa de Investigación Asociativa (Project SOC 1102) for financial support. The views expressed in this document are those of the authors and do not necessarily represent those of the Center for a New Economy (CNE) or its sponsors. We are responsible for any errors that may remain. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 22909
December 2016
JEL No. I1,O0

ABSTRACT

We study the relationship between in utero exposure to military exercises and children's early-life health outcomes in a no-war zone. This allows us to document non-economic impacts of military activity on neonatal health outcomes. We combine monthly data on tonnage of ordnance in the context of naval exercises in Vieques, Puerto Rico, with the universe of births in Puerto Rico between 1990 and 2000; studying this setting is useful because these exercises have no negative consequences for local economic activity. We find that a one standard deviation increase in exposure to bombing activity leads to a three per thousand point (70 percent) increase in extremely premature births; a three to seven per thousand point – 34 to 77 percent – increase in the incidence of congenital anomalies; and a five per thousand point increase in low APGAR scores (38 percent). The evidence is generally consistent with the channel of environmental pollution. Given the well-documented relationship between neonatal health and later life outcomes, there is reason to believe that our substantial short-term effects may have longer-term consequences for this population.

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I. Introduction

From death to severe disability to economic deprivation, wars have strong negative consequences for civilians. They are frequently the victims of conflict, and the indirect consequences of war are often concentrated among vulnerable groups – the poor, women, children, and the elderly. There is also a growing consensus that conflict has strong long-term negative consequences for civilians' human capital accumulation, socioeconomic outcomes, and their livelihoods more generally. In particular, conflict can have negative consequences for children while *in utero*, and that these in turn have consequences for individuals' long-term health, educational, and economic outcomes.[5,6] While we know there are many harmful aspects to conflict, our understanding of which elements of conflict have the strongest effects on children, and in particular their health and human capital accumulation is more limited.

In what ways do wars harm human capital accumulation? To the extent that conflict disrupts economic activity and leads to the destruction of physical capital (e.g., Abadie and Gardeazabal 2003), this can affect households' access to or capacity to invest in human capital accumulation. Violent conflict also generates a disproportionate amount of stress, fear, and anxiety, which can have negative effects on physical and mental health (Becker and Rubinstein 2011; Dustmann and Fasani 2014). This in turn may have indirect negative effects on birth outcomes (e.g., Beydoun and Saftlas, 2008; Quintana-Domeque and Rodenas 2014). Finally, conflict can affect human development via environmental channels – air and water pollution, for instance (e.g., Al-Hadithi et al 2012; Brown 2012; Currie and Schwandt 2014). Understanding what drives these short-term and long-term outcomes can have implications for war's impacts on economic growth and inequality, as well as for conflict and post-conflict assistance. However, the work that separately identifies the channels through which violent conflict can affect short-term and long-term human development is scarce.

The central goal of this paper is to document the *non-economic* impacts of military activity on neonatal health outcomes. We take advantage of a unique setting that provides us with the opportunity to examine such relationships. Over the span of six decades (1941-2001), the U.S. Navy utilized two-thirds of the territory of Vieques, Puerto Rico, to host a range of military exercises (including ship-to-shore gun fire, air-to-ground bombing by naval aircraft, and Marine amphibious landing) 12.5 kilometres away from residential population. Studying this setting is useful because these exercises have no negative consequences for economic activity, allowing us to identify non-economic mechanisms through which this military activity impinges on early life outcomes (and hence potentially future economic activity). To do so, we combine monthly data on tonnage of ordnance used in these naval exercises with the universe of births in Puerto Rico between 1990 and 2000, to study the relationship between *in utero*

[5] Prominent examples of the research on the effects of conflict for early-life and long-term outcomes are Alderman, Hoddinott and Kinsey (2006), Bundervoet, Verwimp, and Akresh (2009), Camacho (2008), León (2012), Mansour and Rees (2012), Galdo (2013), and Quintana-Domeque and Rodenas (2014). A complementary literature analyzes how environmental factors that occur during the prenatal period have significant early life and long-term consequences; see Almond and Currie (2011) for a broad survey of the literature. Most epidemiological and medical research focuses on the role that nutrition plays for fetal development and early-life health outcomes (Kramer, 1987).

[6] 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. 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.

exposure to these military exercises and children's early-life health outcomes. Specifically, we compare newborns having experienced distinct levels of exposure to these exercises within the municipality over time while controlling for high frequency period-specific effects (using the health outcomes of newborns in other municipalities) to identify these effects.

The military exercises have significant negative consequences for early life outcomes. We find that a one standard deviation increase in exposure to bombing activity while *in utero* leads to a three per thousand point (70 percent) increase in extremely premature births; a three to seven per thousand point (34-77 percent) increase in the incidence of congenital anomalies; and a five per thousand point (38 percent) increase in low APGAR scores. We find direct support for the channel of environment pollution using data from U.S. Environmental Protection Agency (EPA) Discharge Monitoring Reports by the Atlantic Fleet Weapons Training Facility (U.S. Navy) of inorganic chemicals such as arsenic, cyanide, and lead, in waters surrounding the live impact area. In particular, we find strong evidence that bombing activity leads to short-term increases in arsenic levels above EPA limits in waters surrounding the live impact area: a one standard deviation increase in average ordnance levels leads to a 14 percentage point increase in this incidence risk, an effect that is 51.2 percent above the mean incidence risk. Given that arsenic exposure has been linked to increased frequency of spontaneous abortions and congenital malformations (Nordstrom et al. 1979; Hopenhayn-Rich et al. 1999, this evidence is suggestive of a link between water pollution resulting from the bombing activity and infant health outcomes. In contrast, we do not find evidence that possible disruptions in economic activity are a mechanism mediating these effects.

Finally, we examine whether following the end of naval practices in July 2000 had short-term consequences for infants' health outcomes. Using data on infant health outcomes up to the year 2003, we examine infant health outcomes for cohorts conceived following the end of naval practices to those conceived in the preceding period within the municipality. The sudden end of bombing practices is associated with a 7.5 per thousand (72 percent) decrease in the incidence of congenital anomalies. The evidence from this distinct episode confirms the hypothesis that reductions in environmental pollution and other environmental factors lead to a substantial reduction in the risk of congenital anomalies among the infant population (Currie, Greenstone, and Moretti 2011; Currie, Ray, and Neidell 2011).

Our study makes several contributions to the conflict and human development literature. Prominent research on the effects of conflict for early-life and long-term outcomes document a link that is most plausibly explained by economic channels and changes in stress as well as mental and physical health of the adult population.[7] We demonstrate that an important plausible channel in the context of certain conflicts is one of an environmental nature, consistent with a complementary literature that analyzes how environmental factors that occur during the prenatal period have significant early life and long-term consequences (Almond and Currie 2011). The study also has important implications for policy. Infant health outcomes such as congenital anomalies, low birth weight, and low Apgar scores are important predictors of child health (McCormick 1985; Pollack and Divon 1992; Almond, Chay,

[7] For instance, Camacho (2008), León (2012), and Quintana-Domeque and Rodenas (2014).

and Lee 2005) and long-term outcomes such as educational attainment, labor market outcomes, and adult health (Currie and Hyson 1999; Behrman and Rosenzweig 2004; Black, Devereux, and Salvanes 2007). Given the well-documented relationship between neonatal health and later life outcomes, there is reason to believe that our substantial short-term effects may have longer-term consequences for this population. Moreover, previous research has documented the effects of both maternal stress and environmental pollution on infant health (c.f. Currie et al 2009) and our evidence strongly suggests that at least one 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.

The paper is organized as follows. Section II provides background on U.S. Navy Activities in Vieques and the possible implications for health outcomes among the resident population. We follow with a description of the data and the empirical methodology in Section III. We present the central empirical results of the paper and robustness tests in Sections IV and V, respectively. In Section VI we explore potential mechanisms, followed by documenting the effects of the end of naval practices on infant health outcomes in Section VII. The paper concludes in Section VIII with a discussion of findings and their broad implications.

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 island hosted 9,301 habitants. 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, and 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 U.S. 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.[8] 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.[9] 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 the resident population has not been exposed to harmful levels of chemicals resulting from U.S. Navy training activities.[10] 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.

[8] 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.
[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. 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.
[10] 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).

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 definitive empirical evidence on the levels of physical and mental health among the population of Vieques during the period of interest, the limited documentation available suggests that pregnant women resident in the municipality may have been exposed to disruptive environmental factors that would have affected fetal development.

III. Data and Methodology

III.A. Data Description and Sample Selection Criteria

Data on tonnage of ordnance used in these naval exercises is available from Discharge Monitoring Reports submitted by the U.S. Department of the Navy's Atlantic Fleet Weapons Training Facility (Roosevelt Roads Base, Puerto Rico) to the U.S. Environmental Protection Agency (EPA). Information on ordnance used on a monthly basis is available for the period May 1985 - July 1999.[11]

Additional data on ordnance used in the naval exercises is 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).[12] 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 measures are available for the fiscal years 1983 to 1998 (October 1st - September 30th). From 1988 to 1999, between 1,359 and 2,667 tons of ordnance were used in training exercises, of which between 124 and 469 tons were considered high explosives.

We combine these data with the universe of birth records in Puerto Rico between 1990 and 2000, available from the Puerto Rico Statistics Institute. Specifically, we have data on approximately 695,722 births in the territory of P.R. with information on birth outcomes such as sex, month of conception, exact date of birth, gestation period, birth weight, APGAR scores (1-minute and 5-minute), and detection of congenital anomalies (by type), among other characteristics. In addition, we have data on the mother's municipality of residence at the time of birth, as well as a number of characteristics of the mother (i.e., age and educational attainment).

We use the sample of births of mothers resident in P.R. at the time of birth (N = 656,374) for which the date of birth and the period of gestation, as well as the municipality of residence, are known (N = 655,915, or 99.93

[11] These reports were made available in August 2001 to Dr. Arturo Massol Deyá via a Freedom of Information Act (FOIA) request to the U.S. Environmental Protection Agency. We thank Dr. Massol Deyá for sharing these reports with us.
[12] 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/

percent).[13] After combining these data with the monthly tonnage of ordnance, we lose 37,008 observations (from births in the year 2000) and an additional 39,317 observations with missing information on maternal age or educational attainment. The remaining sample is composed of 579,590 births, with item non-response rates for our various outcomes of interest in the 0.278-0.327 percent range. We first collapse the data to the municipality-by-month level and weight the observations by the number of live births in the month, a process that yields identical point estimates to the micro data. Our dataset is thus composed of 9,046 municipality-by-month cells, covering 117-118 months per jurisdiction.

Summary statistics on the ordnance measures are reported in Table 1. Monthly ordnance used in the exercises (in the complete 1985-1999 period) ranged from none (zero) to 658 tons; on average 129 tons of ordnance were used. The average tonnage of ordnance during each child's potential gestation period – our measure of interest – is similar, as it is a 9-month moving average of the monthly measure. It ranges from 16.7 to 277 tons of ordnance, and averages 130.6 tons per month. We also present density plots of the distributions for both measures (see Figure 2). The measure of monthly ordnance is quite skewed to the right, with most of the observations in the 0-2 tons per month range (Panel A). In contrast, the measure of ordnance exposure during each child's potential gestation period is more symmetrically shaped and in the 0-3 tons per month range (Panel B).

Table 2 reports summary statistics form the birth records data. Regarding child health outcomes at birth, one percent of live births are born with a congenital anomaly, and 1.3 percent of children have a low 5 minute Apgar score (defined as less than 7 out of 10) (Table 2). Also, the percentage of infants born preterm is 12.6 percent, most of them being moderately or late preterm (10.7 percent), but a substantial proportion (0.5 percent) are extremely preterm. 10 percent of live births are considered low weight births. These health indicators are similar for infants in Vieques than those in the rest of Puerto Rico: although the incidence of births with congenital anomalies is lower in Vieques than in the rest of Puerto Rico (0.5 percent vs. 1.0 percent), the remaining health measures are similar across these groups. These indicators are generally worse than those for the overall U.S. population during this time period.[14] The proportion of female live births is slightly higher in Vieques than in the rest of Puerto Rico (50.1 percent vs. 48.5 percent).

The average characteristics of mothers in Vieques are reasonably different from those in the rest of the sample. 34.4 percent of mothers in Vieques have only a high school degree versus 29.1 percent in the rest of the sample. Mother's age is slightly younger (24.0 versus 24.7) and more of the mothers are giving birth as teenagers (12.4 percent versus 9.5 percent).

Finally, we include municipality-level monthly employment and unemployment data estimates from the U.S. Bureau of Labor Statistics (BLS) Local Area Unemployment Statistics (LAUS) and annual crime statistics from the Puerto Rico Police Department as further local controls.

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[13] Among the sample of births with known date of birth and gestation period (N = 655,916), there is only one (1) observation for which we do not have information on the mother's municipality of residence.

[14] See National Center for Health Statistics, National Vital Statistics System. http://www.childstats.gov/americaschildren/health1.asp

III.B. Empirical Methodology

Our empirical strategy consists of comparing children having experienced distinct levels of exposure to these exercises within the municipality of Vieques over time, using the health outcomes of newborns in other municipalities to control for high frequency period-specific effects. This is essentially a differences-in-differences design with a continuous treatment.

Specifically, we estimate linear models of the form:

$$y_{ijmt} = \theta(\text{Ordnance}_{mt} \times \text{Vieques}_j) + X_{ijmt}\beta + \alpha_j + \gamma_{mt} + \varepsilon_{ijmt}, \quad (1)$$

where y_{ijmt} is the birth outcome for child *i*, born to mother residing in municipality *j*, conceived in the month *m* of year *t*; Ordnance_{mt} is the mean level of ordnance in the 9-month period between conception and birth (assuming a 40-week pregnancy); Vieques_j is an indicator variable for mother's residence in Vieques; α_j are municipality fixed effects; γ_{mt} are month-by-year fixed effects; and ε_{ijmt}, is the error term. The measure of ordnance encompasses the potential 9-month period instead of the actual gestation period, as ordnance levels can affect the duration of gestation potentially causing selection bias in our estimates. Each specification includes controls for the maternal characteristics shown above (in Section III.A). We also report the magnitude of the predicted relationship given 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.

Computing standard errors and making inferences is complicated in cases where there is only one treatment/intervention unit. The primary concern when using grouped data in differences in differences analysis is accounting for possible serial correlation (Bertrand, Duflo, and Mullainathan 2004). Although we use data from 77 municipalities, we cannot use either (i) a standard cluster robust variance estimator (CRVE) or (ii) inference based on the wild cluster bootstrap (Cameron, Gelbach, and Miller 2008) because the relevant degrees of freedom are the number of treatment units – which in this case is a single municipality (Imbens and Kolesar 2012; MacKinnon and Webb 2016). An additional concern is that ignoring spatial correlations that do not vanish between municipalities may lead to bias in standard errors (Barrios et al 2012).

As an alternative, we employ a number of different approaches for inference. First, we rely on the long time dimension of the data (118 months) to conduct inference based on asymptotics as the time dimension becomes large. Specifically, we estimate standard errors using a nonparametric covariance matrix estimator that produces standard errors that are robust to general forms of cross-sectional (spatial) and temporal dependence when the time dimension becomes large (Driscoll and Kraay 1998) (henceforth DK). Second, following the literature on randomization inference (Fisher 1925; Neyman 1990), we report the percentile rank of the coefficient from a permutation exercise where we estimate a placebo effect of the relationship for every municipality. Finally, as a robustness check we report heteroskedasticity-robust standard errors based on OLS estimates from models using lagged dependent variables to account for autocorrelation.

IV. Results

The first column of Table 3 reports the effects of bombing during the pregnancy period on being born with a congenital anomaly. We find a positive and significant effect of the average amount of ordnance in tons during the pregnancy period on the probability of being born with a congenital anomaly. We report the coefficient as well as the change in the probability of being born in low birth weight associated with a one standard deviation change in the bombing ordnance measure. Expressed in this fashion, a one standard deviation change in bombing ordnance is associated with a 3.4 per thousand point increase in the incidence of congenital anomalies, a 34 percent increase relative to the baseline mean. The relationship is significant at 10 percent confidence, with a permutation percentile rank of eight out of 77 (approximate p-value = 0.104). The magnitude of this impact is consistent with existing evidence on the consequences of reductions in environmental pollution from Superfund site clean-ups on neighbouring populations in the United States (Currie, Greenstone, and Moretti 2011).

Recent economic research has documented the relevance of Apgar scores in predicting short-term child health (Almond, Chay and Lee, 2005). We find a positive and significant relationship between bombing ordnance and the probability of having a low Apgar score. A one standard deviation change in ordnance increases the probability of having a low Apgar score by 4.8 per thousand (37.9 percent). The relationship is significant at 10 percent confidence, with a permutation percentile rank of five out of 77 (approximate p-value = 0.065). Once again there appears to be a strong and economically meaningful relationship between bombing levels and child health.

The third and fourth columns of Table 3 report results for premature birth measured as less than 37 weeks and then specifically at extremely (less than 28 weeks) preterm births separately. Although there is no significant relationship between bombing ordnance and premature birth in overall terms, we measure a relatively precise relationship with extremely preterm births. Overall, a one standard deviation change in ordnance leads to 3.7 per thousand point increase in extreme prematurity; the effect is over three quarters of the baseline rate (70.3 percent). The relationship is significant at the 10 percent significance level, with a permutation percentile rank of one out of 77 (approximate p-value = 0.013). Finally, we examine the relationship between bombing ordnance and the probability of being low birth weight (less than 2500g). We find no significant relationship in this case, consistent with recent literature on the relationship between polluted sites clean-ups (Currie, Greenstone, and Moretti 2011).

We next explore whether the relationship between bombing ordnance and child health outcomes differs for different trimesters of the pregnancy. Previous literature has documented that fetal exposures during different trimesters can have differing effects on child health. For example, Almond and Mazumder (2011) find that fasting during pregnancy for Muslims observing Ramadan, has negative effects on child health and that these effects are larger in the first and second trimester than the third. In our context, however, the mothers are exposed to bombing during the entire pregnancy, not just one trimester, but the amount of ordnance they are exposed to potentially differs across trimesters. In order to explore the relationship by trimester we include three separate measures of bombing ordnance in the regression models representing the exposure for the mother in each of the trimesters. The results are reported in Table 4.

The relationship between bombing ordnance and congenital anomalies appears to be strongest and statistically significant (at 95 percent confidence) in the second and third trimester, with robust permutation percentile rank approximate p-values of 0.052 and 0.026, respectively. The combined effect is positive and the proportional effects remain large: the marginal effect of a one standard deviation change in tons per month is a 7.6 per thousand point increase in the incidence of congenital anomalies, a 77.2 percent increase relative to the baseline mean. For Apgar scores and premature births, the relationship is strongest for the first and second trimester. In both cases the combined effect is positive and the proportional effects remain large. The marginal effects represent a 7.6 per thousand point increase in the incidence of low Apgar scores, a 59.6 percent increase relative to the baseline mean, and a 1.4 percentage point – 11.2 percent – increase in the incidence of premature births.

Finally, for the incidence of extremely premature births we find a relationship of similar magnitude as the overall effects reported above. A one standard deviation change in ordnance leads to 5.5 per thousand point increase in extreme prematurity. Although the relationship is insignificant at conventional confidence levels based on the DK standard errors, we have sufficient precision in the first and third trimesters (permutation percentile rank approximate p-values are 0.013 and 0.052, respectively).

In summary, the measured impacts are consistent with existing evidence on the consequences of comparable changes in environmental pollution on neighbouring populations in the United States ((Currie, Greenstone, and Moretti 2011; Currie and Schwandt 2014) as well as with effects of terrorist attacks on infant health (Quintana-Domeque and Rodenas 2014; Camacho, 2008).

V. Robustness Tests

V.A. Robustness to Sample Selection Concerns

Since the characteristics of mothers in Vieques are reasonably different from those in the rest of the sample. it is plausible that the estimated effects could be partially driven by sample selection. For instance, mothers with children with a worse underlying health status may be more likely to reside in Vieques during periods of more military activity, causing an upward bias in our estimates of interest. On the contrary, if bombing activity were to cause miscarriages or stillbirths, and pregnancies that terminated in these were more likely to be of children with worse underlying health conditions, this would cause our estimates to be biased downwards.

In order to evaluate these concerns, we take various steps to examine whether there is evidence of selection on observable characteristics. First, we aggregate the data at the municipality-month-year level to estimate a model of the relationship between the number of live births that were conceived in a given period in Vieques (relative to other municipalities in Puerto Rico) as a function of the amount of ordnance:

$$\ln(N_{jmt}) = \theta_B(\text{Ordnance}_{mt} \times \text{Vieques}_j) + \alpha_j + \gamma_{mt} + \varepsilon_{ijmt}, \quad (2)$$

where N_{jmt} captures the count of births to mothers resident in municipality *j* conceiving children in the *m,t* month-year period. Second, we estimate models analogous to equation (1) using the observable maternal characteristics as dependent variables. Specifically, we estimate linear models of the form:

$$x_{ijmt} = \theta(\text{Ordnance}_{mt} \times \text{Vieques}_j) + \alpha_j + \gamma_{mt} + \varepsilon_{ijmt}, \quad (3)$$

where x_{ijmt} is the maternal characteristic for mother *i* residing in municipality *j*, who conceived a child in month *m* of year *t*; and the other variables are defined as above. We also report analogous estimates of a model using the child's sex as the dependent variable. Finally, we re-estimate the linear models on child health outcomes (equation 1) excluding these maternal controls to assess their sensitivity to these control variables.

Appendix Table A1 reports estimates of equation (2). Again, we report the coefficient as well as the change associated with a one standard deviation change in the bombing ordnance measure. We find a small, negative, and statistically insignificant relationship between bombing during the pregnancy period and the number of births (in levels). The estimate implies that a one standard deviation increase in the average amount of ordnance leads to 0.12 (0.2 percent) fewer births, a minuscule decrease in live births. Similar results hold when we estimate the relationship in logs; the estimate implies that a one standard deviation increase in the average amount of ordnance leads to no fewer births. Panel B shows estimates based on models that allow for trimester-specific effects. Estimates from these lead to qualitatively similar results: a small and statistically insignificant relationship. The estimated relationship based on the model of live birth counts in levels implies that a one standard deviation increase in ordnance leads to 0.70 (1.1 percent) fewer births relative to the sample mean, whereas the model in logs implies a 1 percent increase in live births, both statistically insignificant at conventional confidence levels.

Panel A of Table 5 reports results for estimates of equation (3). Our results suggest that those children born are more likely to be boys. Our estimates imply that a one standard deviation increase in bombing ordnance is correlated with a 3.8 percentage point increase in the probability that the child is a boy.[15] The second and third columns report results for the educational attainment of mothers giving birth, broken down by high school graduates, and some/complete higher education studies (less than high school is the reference group). There is a *positive* and significant relationship between bombing ordnance and mothers' educational attainment. A one standard deviation increase in ordnance is correlated with a modest but significant 2.4 percentage point *decrease* in the proportion of mothers who are high school graduates. In contrast we find a 3.8 percentage point increase in the probability the mother has commenced or completed some higher education. Since the relationship between maternal educational attainment and their children's health status at birth is positive, this is indicative of positive selection based on educational attainment.

[15] This goes against our prior based on evidence that suggests that male foetuses are more vulnerable to detrimental influences *in utero* and therefore more likely to terminate prior to term (Kraemer 2000; Eriksson et al. 2010; Almond and Mazumder 2011; Dinkelman 2013).

Columns 4 through 6 of Table 5 report results on the differential correlation of average ordnance in Vieques with mothers' age. There is, in general, no relationship between bombing ordnance and mothers' age. However, this relationship with maternal age is non-monotonic, as the proportion of births to teenage mothers or to mothers 40 years and older (in Vieques) is decreasing in the average ordnance level. The point estimates imply that a one standard deviation increase in ordnance leads to a 2.3 percentage point decrease in the probability of a teenage birth, and a 0.4 percentage point decrease in the probability of birth to a mother 40 years and older. Again, since the relationship between teenage and older pregnancies and children's health status at birth is negative, these correlations are indicative of positive selection based on maternal age. We find very similar patterns for female births, maternal educational attainment levels, and mothers' age based on models that allow the relationship between bombing ordnance and child health outcomes to differ for different trimesters of the pregnancy (reported in Panel B of Table 5). In any case, given the small degree of correlation between these observable characteristics and congenital anomalies, the degree of selection on observables explains a very minor part of the relationship between the volume of ordnance and the risk of congenital anomalies. Estimates of the potential bias vary between reductions in the incidence of congenital anomalies by 0.2 per thousand to increases of 0.3 per thousand, an order of magnitude smaller than our preferred estimates of the overall effect.

The estimates of the child health outcomes effects (equation 1) excluding maternal characteristics controls are reported in Table 6. We report estimates of the effects when we (i) exclude maternal controls (columns 1,4,7), (ii) exclude maternal schooling attainment controls (column 2,5,8), and (iii) exclude all maternal controls (column 3,6,9). The estimates are remarkably stable. For instance, the model on congenital anomalies without controls implies that the effect of a one standard deviation change in average ordnance leads to a 3.2 per thousand point increase in the incidence risk, an estimated effect that is 0.2 per thousand points *smaller* in magnitude. None of these estimates are statistically distinguishable from one another. Estimates for all other health outcomes at birth show a qualitatively similar pattern of a statistically indistinguishable downward bias when excluding controls.[16]

V.B. Robustness to Inference Approach

Finally, as a robustness check we report heteroskedasticity-robust standard errors based on OLS estimates from models using lagged dependent variables to account for autocorrelation; see Appendix Table A2. OLS estimates of the effects on the incidence using lagged dependent variables to account for autocorrelation are of similar magnitude, independently of the lag structure used (one to three lags of the dependent variables). For estimates of congenital anomaly effects, the point estimates from the overall effects regressions imply estimates in the 3.3 to 3.5 per thousand range but are insignificant at conventional confidence levels (Panel A, columns 1-3). The estimates for low Apgar scores (columns 4-6) and extremely preterm births (columns 7-9) are quite stable and statistically significant at 90 percent confidence. Estimates based on models allowing for trimester-specific effects are

[16] As a further test of the effects of the bombing on the local environment (and potentially broader than health at birth) we investigate whether there is a relationship between yearly average ordinance and yearly crime statistics by municipality. We find no significant relationship between ordinance levels and reported crime.

also quantitatively similar, and have similar levels of precision as those discussed above; these are reported in Panel B of the table. These various robustness checks imply that we find large and robust effects of bombing ordnance on a variety of infant health outcomes.

VI. Discussion of Potential Mechanisms

There are a number of possible mechanisms by which these bombings could have affected mothers during pregnancy: the bombings could disrupt economic activity affecting households' access to or capacity to invest in human capital. They could cause maternal stress, fear, and anxiety, which can have negative effects on physical and mental health, and in turn have indirect negative effects on infant health outcomes at birth. The bombings could have a negative effect on the environment (air, soil and water) thereby affecting maternal and child health. In this section, we present and discuss the available evidence regarding these potential channels.

Environmental Pollution

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 3. To investigate the potential role of environmental contamination, we examine water pollution levels. The Discharge Monitoring Reports contain information regarding tests of water quality in the training area's Inner Range, the waters surrounding the live impact area. These reports contain information on tests to measure the levels of inorganic chemicals in the water (arsenic, cyanide, lead, among others) in addition to other characteristics of the waters in the range. We use the information available on a quarterly basis during the same period (May 1985 - July 1999). Appendix Table A3 reports the measures of water pollution available, summary statistics on these measures, as well as the maximum containment level or limit approved by the Environmental Protection Agency. For measures of dissolved oxygen, acidity, alkalinity and nitrogen, while average levels are within the range deemed safe, the maximum level reported exceeds the range. For many of the inorganic chemicals tested, average levels reported exceed the maximum level for safety.

Given that arsenic exposure has been linked to increased frequency of spontaneous abortions and congenital malformations (Nordstrom et al. 1979; Hopenhayn-Rich et al. 1999), we document the extent to which there is a relationship between the level of bombing activity and arsenic in the waters surrounding the live impact area. Specifically, we estimate time series models to measure the relationship between naval bombing activity and the incidence that maximum arsenic levels surrounding the live impact area are above permitted EPA limits, of the following linear form:

$$1(y_t > y^{EPA}) = \theta_B(\text{Ordnance}_t) + \varepsilon_t, \quad (4)$$

where y_t captures the maximum arsenic level measured in quarter *t*. We allow for leads and lags of the ordnance volume measure to evaluate the degree of correlation of arsenic pollution based on bombing activity in previous time periods. Standard errors are corrected for heteroskedasticity.

The estimates of the contemporaneous (same quarter) correlation are reported in Table 7. The estimates are remarkably stable. For instance, the model with the simple correlation implies that the effect of a one standard deviation change in average ordnance levels leads to a 14 percentage point increase in this incidence risk, an estimated effect that is 51.2 percent above the mean incidence risk. Estimates that allow for lags and leads of ordnance show a quantitatively similar pattern. This evidence is suggestive of a link between water pollution resulting from the bombing activity and infant health outcomes. However, a number of other chemicals were also present (although not correlated with bombing activity), and thus it is difficult to assess the role of arsenic in the etiology of these effects.

Economic Downturns and Health/Other Infrastructure

Although given our research context, we can rule out the destruction of physical capital as a determinant of these adverse infant health consequences (e.g., Abadie and Gardeazabal 2003), another plausible pathway is through disruption of economic activity affecting households' access to or capacity to invest in human capital (Leon 2012). To evaluate this possibility, we examine the relationship between naval bombing exercises and the municipal unemployment rate, using municipality-level monthly unemployment data estimates from the U.S. Bureau of Labor Statistics (BLS) Local Area Unemployment Statistics (LAUS). We estimate models analogous to equation (3) excluding maternal controls to predict unemployment rates as a function of the ordnance measure. Specifically, we estimate models for the unemployment rate in each month starting 3 months preceding conception until 16 months following conception.

The estimates are reported in Appendix Table A4. If anything, the evidence is consistent with the naval activities leading to a short-term improvement in local economic conditions. A one standard deviation increase in bombing activity predicts reductions in the unemployment rate in Vieques that range between 1.1 percentage points during the month preceding conception up to 2.8 percentage points in the second month following conception.

Because these positive short-term fluctuations could lead to worse infant health outcomes attributable both to selection (changes in the type of mothers who conceive based on local economic conditions) and to improvements in health behaviors during recessions (Dehejia and Lleras-Muney 2004), we re-estimate the linear models on child health outcomes (equation 1) including summary measures of average unemployment rates during the 9-month potential pregnancy period as covariates (in levels or in logs) to assess their sensitivity to these control variables. In some specifications, we also control for the average unemployment rate in the 9-month period preceding conception, for purposes of robustness.

The estimates are reported in Appendix Table A5. In spite of there being a relationship between local economic conditions and our measures of infant health – consistent with previous literature – our estimates are robust to specifications that control for maternal characteristics and these local economic conditions. This evidence is quite suggestive that in our context the link between bombing activity and infant health is not driven by a pernicious effect in economic activity.

Maternal Stress

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.

VII. End of Naval Practices and Infant Health

As mentioned above, the U.S. Navy reduced its operations in April 1999 and stopped practices in July 2000 (ATSDR, 2003, p. 13). We exploit this episode to examine whether the sudden and stark reduction in bombing activity had any short-term consequences for infants' health outcomes. Using data on infant health outcomes for the period 1990-2003, we examine infant health outcomes for cohorts conceived following the end of naval practices to those conceived in the preceding period within the municipality.

Our empirical strategy to study this consists of a differences-in-differences design: comparing children who were in utero not exposed to these exercises within the municipality of Vieques (conceived in August 2000 onwards) to those in utero at some point during naval exercises, using the health outcomes of newborns in other municipalities to control for period-specific effects. We estimate linear models of the form:

$$y_{ijmt} = \theta(Post_{mt} \times Vieques_j) + X_{ijmt}\beta + \alpha_j + \gamma_{mt} + \varepsilon_{ijmt}, \qquad (5)$$

where $Post_{mt}$ is the period following the end of naval practices in the municipality (July 2000 onwards).

The first column of Table 8 reports the effects of the end of bombing during the pregnancy period on the risk of birth with congenital anomalies. We find a large and significant effect: the sudden change in bombing practices is associated with a 7.5 per thousand decrease in the incidence of congenital anomalies, a 72 percent reduction relative to the baseline mean. The magnitude of this impact is consistent with the evidence above, as the end of practices led to a reduction in monthly ordnance of approximately 129 tons (the mean level of ordnance in the preceding period). In contrast, we do not find significant evidence that this episode led to significant improvements in Apgar scores or gestation periods (see columns 2-5). In sum, the evidence from this distinct episode confirms the hypothesis that reductions in environmental pollution and other environmental factors lead to a substantial reduction in the risk of congenital anomalies among the infant population and provides some additional comfort that our estimates of the effects of the bombing are causal.

VIII. Conclusion

We identify the relationship between frequent explosions and high-ordnance military exercises and child health at birth. Our results suggest that there is a negative effect of these exercises on live births, and their health outcomes at birth. Because we can rule out that these military exercises have short-term perverse economic effects, our analysis helps inform the literature regarding why stress and environmental factors may be important channels via which conflict affects human development.

While it is challenging to make exact comparisons with other bombing sites (active war zones), it is perhaps interesting to compare the magnitude of ordinance with those in war zones studied in the literature. Vieques experienced between 100,000 and 300,000 tons of ordinance versus approximately 454,000 in the Korean war and over 6 million in Vietnam (Miguel and Roland, 2011). There are, to our knowledge, few comparable estimates of the effects of bombing on health outcomes at birth. However, our estimates on APGAR scores and pre-term birth are consistent although larger than estimates of the effects of terrorism on health at birth (5/1000 increase in (extreme) prematurity versus 1/1000 in Quintana-Domeque and Rodenas, 2014) and not inconsistent with estimates of conflict on child height (Bundervoet, Verwierp and Akresh, 2009). While our estimates can been interpreted as the direct health effects of the bombing, other estimates are presumably some combination of direct effects of conflict on health and indirect effects through economic channels.

While previous literature looking at the longer-term effects of war on economic outcomes has found small economic impacts (c.f. Miguel and Roland, 2011), there is reason to suspect that in this case there may be longer lasting effects given the areas in which we find effects. Previous health economic research has documented a number of long term consequences related to being born in poor health 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). Therefore there is reason to believe that our findings of short-term effects on infant health in this context 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.

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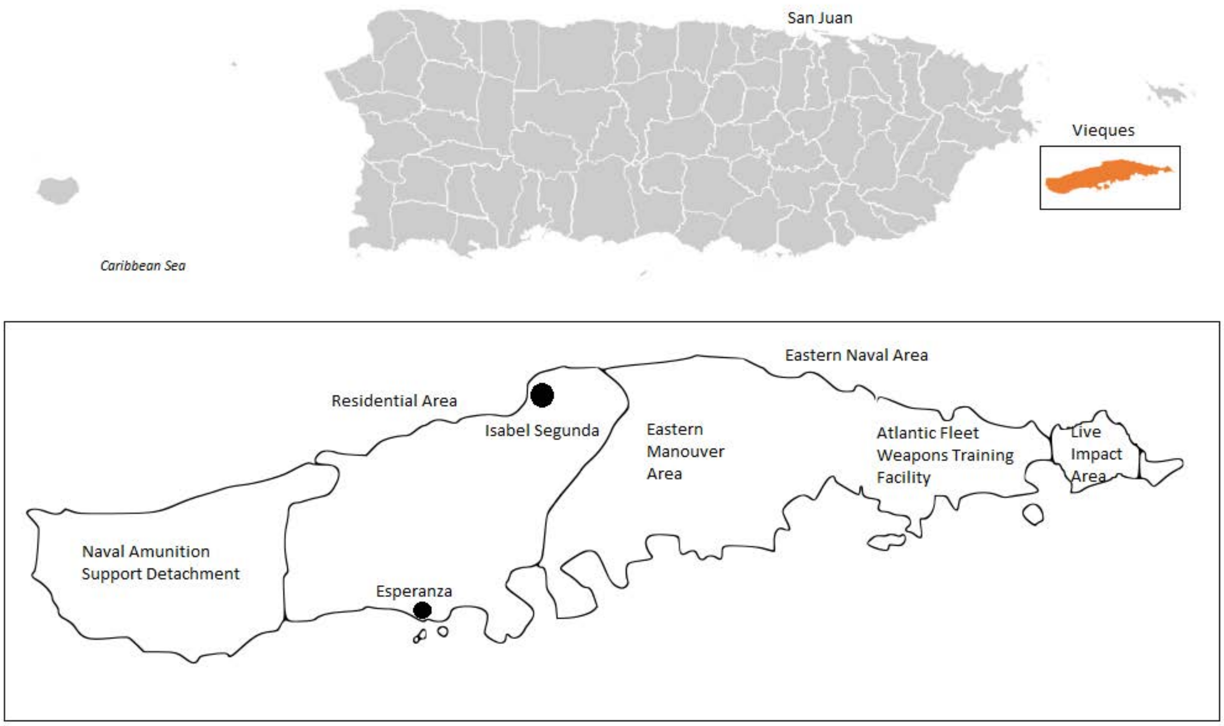
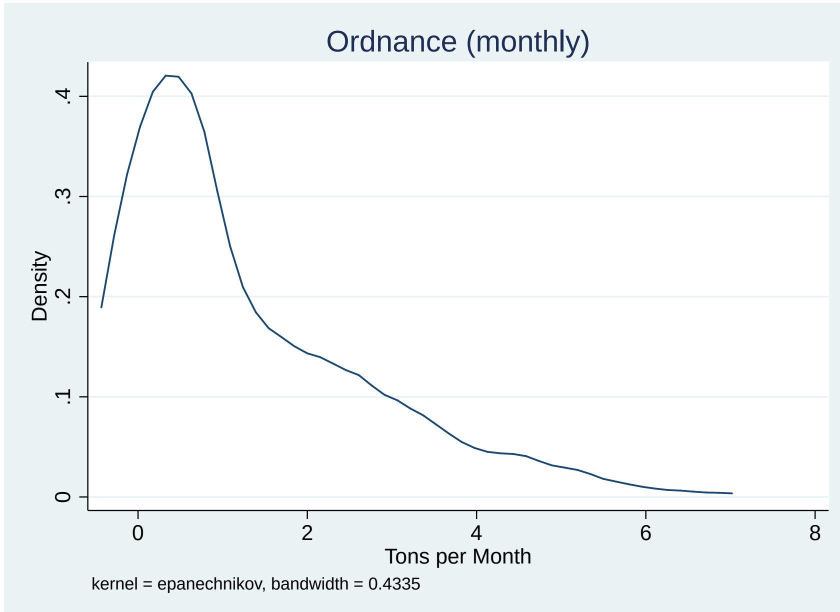
Figure 1: Map of Puerto Rico and Vieques with Former Division of Residential and Military Zones



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

Figure 2: Ordnance Used During Naval Exercises, 1985-1999

Panel A: Volume of Ordnance (Monthly)



Panel B: Volume of Ordnance (9-Month Period)

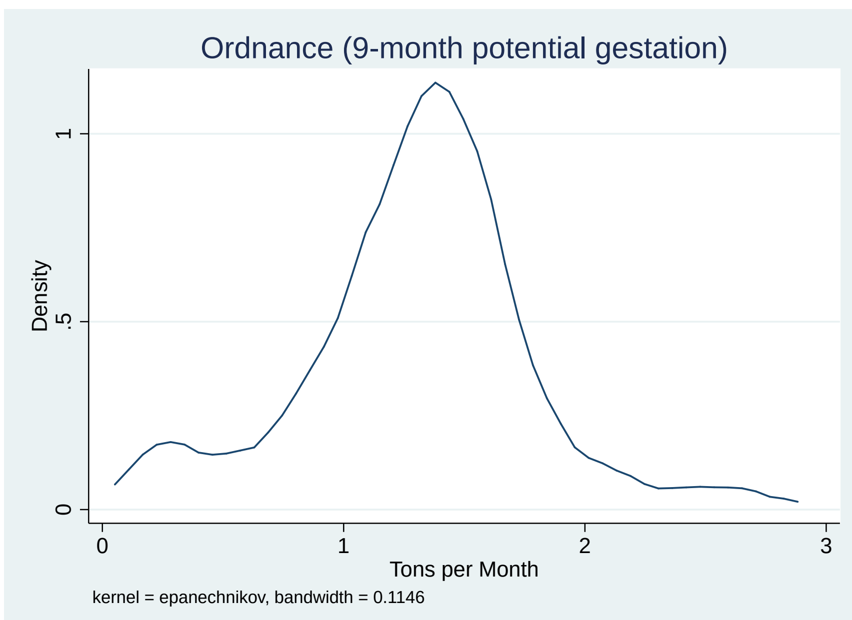


Table 1: Volume of Ordnance – Summary Statistics, 1985-1999

	Mean	Std. Dev.	Min.	Max.	N
	(1)	(2)	(3)	(4)	(5)
Volume of ordnance (monthly) [Tons per month]	1.292	1.416	0.000	6.585	171
Volume of ordnance (9-month potential gestation period) [Tons per month]	1.306	0.469	0.167	2.767	163

Notes: Reported are the sample mean, standard deviation, minimum and maximum of each variable; based on aggregated data at the month level for the period 1985-1999.

Table 2: Descriptive Statistics, Puerto Rico Natality Files, 1990-2000

Sample	All Residents		Vieques Residents		Other Residents	
	Mean / (SD)	N	Mean / (SD)	N	Mean / (SD)	N
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Neonatal Health Outcomes						
Congenital anomaly	0.010 (0.024)	9046	0.005 (0.017)	117	0.010 (0.024)	8929
Low APGAR score (5-min)	0.013 (0.025)	9045	0.012 (0.030)	117	0.013 (0.025)	8928
Premature birth (< 37 weeks)	0.126 (0.069)	9046	0.130 (0.091)	117	0.126 (0.069)	8929
Extremely premature birth (< 28 weeks)	0.005 (0.013)	9046	0.006 (0.021)	117	0.005 (0.012)	8929
Low birth weight	0.100 (0.058)	9046	0.102 (0.086)	117	0.100 (0.057)	8929
Panel B: Child and Mother Characteristics						
Female birth	0.486 (0.094)	9046	0.501 (0.153)	117	0.485 (0.093)	8929
High school graduate	0.292 (0.093)	9046	0.344 (0.139)	117	0.291 (0.092)	8929
Higher education (some/completed)	0.370 (0.119)	9046	0.226 (0.116)	117	0.372 (0.118)	8929
Mother's age	24.6 (1.2)	9046	24.0 (1.9)	117	24.7 (1.2)	8929
Teenage mother	0.095 (0.059)	9046	0.124 (0.089)	117	0.095 (0.059)	8929
Mother's age 40+	0.011 (0.020)	9046	0.013 (0.035)	117	0.011 (0.020)	8929

Notes: Reported are the sample mean and standard deviation of each variable; based on aggregated data at the municipality-by-month level and weighted by the number of live births in the month. The dataset is composed of 9,046 municipality-by-month cells.

Table 3: Bombing Activity and Health Outcomes at Birth, 1990-1999

Dependent variables:	Congenital anomaly	Low APGAR score	Premature birth	Extremely preterm birth	Low birth weight
	(1)	(2)	(3)	(4)	(5)
Tons per month [Mths 1-9] × Vieques	0.0072*	0.0103*	0.0175	0.0079*	0.0138
SE	(0.0041)	(0.0058)	(0.0209)	(0.0045)	(0.0206)
Permutation %-tile rank	8/77	5/77	12/77	1/77	10/77
Approximate p-value	0.104	0.065	0.156	0.013	0.130
Mother Characteristics	Yes	Yes	Yes	Yes	Yes
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Δ Outcome from One SD Δ in TPM	0.0034	0.0048	0.0082	0.0037	0.0065
Outcome mean	0.010	0.013	0.126	0.005	0.100
N	9046	9045	9046	9046	9046

Notes: Coefficient estimates from municipality fixed effects regressions; each reported coefficient is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Also, we report the percentile rank of the coefficient from a permutation exercise and its approximate p-value. Mother characteristics' controls include indicators for high school graduate, higher education (some or completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear control for the mother's age. The change in each of the outcome variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure (= coefficient estimate × 0.469).

Table 4: Trimester-Specific Bombing Activity and Health Outcomes at Birth, 1990-2000

Dependent variables:	Congenital anomaly (1)	Low APGAR score (2)	Premature birth (3)	Extremely preterm birth (4)
Tons per month [Mths 1-3] × Vieques	-0.0003	0.0063**	0.0155*	0.0036
SE	(0.0018)	(0.0030)	(0.0088)	(0.0023)
Permutation %-tile rank p-value	0.468	0.039	<0.001	0.013
Tons per month [Mths 4-6] × Vieques	0.0041**	0.0033	0.0117	0.0009
SE	(0.0018)	(0.0039)	(0.0116)	(0.0015)
Permutation %-tile rank p-value	0.052	0.130	0.065	0.208
Tons per month [Mths 7-9] × Vieques	0.0054**	-0.0006	-0.0106	0.0021
SE	(0.0023)	(0.0031)	(0.0133)	(0.0023)
Permutation %-tile rank p-value	0.026	0.351	0.065	0.052
Mother Characteristics	Yes	Yes	Yes	Yes
Municipality Fixed Effects	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes
Δ Outcome from One SD Δ in TPM	0.0076	0.0076	0.0141	0.0055
Outcome mean	0.010	0.013	0.126	0.005
N	9046	9045	9046	9046

Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by column) is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Also, we report the percentile rank of the coefficient from a permutation exercise and its approximate p-value. Mother characteristics' controls include indicators for high school graduate, higher education (some or completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear control for the mother's age. The change in each of the outcome variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume.

Table 5: Correlates of Bombing Activity (Selection on Observables), 1990-2000

Dependent variables:	Female birth	High school graduate	Higher educ. (some/completed)	Mother's age	Teenage mother	Mother's age 40+
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Overall Effects						
Tons per month [Mths 1-9] × Vieques	-0.0806*	-0.0517	0.0802**	-0.1079	-0.0489*	-0.0078
	(0.0418)	(0.0409)	(0.0339)	(0.5115)	(0.0253)	(0.0091)
Δ Outcome from One SD Δ in TPM	-0.0378	-0.0243	0.0376	-0.0506	-0.0229	-0.0037
Panel B: Trimester-Specific Effects						
Tons per month [Mths 1-3] × Vieques	-0.0412*	-0.0235	0.0121	-0.1965	-0.0079	-0.0034
	(0.0213)	(0.0211)	(0.0183)	(0.2115)	(0.0111)	(0.0041)
Tons per month [Mths 4-6] × Vieques	0.0142	-0.0457**	0.0362*	0.0342	-0.0093	-0.0050
	(0.0188)	(0.0179)	(0.0202)	(0.2332)	(0.0100)	(0.0035)
Tons per month [Mths 7-9] × Vieques	-0.0257	0.0048	0.0429***	0.1582	-0.0315***	-0.0004
	(0.0232)	(0.0153)	(0.0137)	(0.2030)	(0.0116)	(0.0046)
Δ Outcome from One SD Δ in TPM	-0.044	-0.054	0.076	-0.007	-0.040	-0.007
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Correlation coefficient	0.0042	0.0064*	0.0088***	0.0004	0.0090	0.0386
[Congenital anomaly]	(0.0038)	(0.0035)	(0.0028)	(0.0003)	(0.0054)	(0.0281)
Predicted change in cong. anomalies	-0.0002	-0.0002	0.0003	0.0000	-0.0002	-0.0001
Outcome mean	0.486	0.292	0.370	24.6	0.095	0.011
N	9046	9046	9046	9046	9046	9046

Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by panel and column) is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. The change in each of the variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure.

Table 6: Sensitivity of Bombing Activity Effects Estimates to Controls

Dependent variables:	Congenital anomaly			Low APGAR score			Extremely Preterm Birth		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Overall Effects									
Tons per month [Mths 1-9] × Vieques	0.0063	0.0074*	0.0067	0.0093	0.0096	0.0088	0.0080*	0.0079*	0.0079*
	(0.0042)	(0.0041)	(0.0042)	(0.0058)	(0.0060)	(0.0060)	(0.0046)	(0.0045)	(0.0046)
Δ Outcome from One SD Δ in TPM	0.0030	0.0035	0.0032	0.0043	0.0045	0.0041	0.0038	0.0037	0.0037
Panel B: Trimester-Specific Effects									
Tons per month [Mths 1-3] × Vieques	-0.0006	-0.0003	-0.0006	0.0059*	0.0064**	0.0060*	0.0036	0.0036	0.0037
	(0.0018)	(0.0018)	(0.0018)	(0.0032)	(0.0031)	(0.0033)	(0.0023)	(0.0023)	(0.0023)
Tons per month [Mths 4-6] × Vieques	0.0038**	0.0041**	0.0039**	0.0034	0.0034	0.0035	0.0010	0.0010	0.0010
	(0.0018)	(0.0018)	(0.0018)	(0.0040)	(0.0040)	(0.0040)	(0.0015)	(0.0015)	(0.0015)
Tons per month [Mths 7-9] × Vieques	0.0051**	0.0056**	0.0055**	-0.0010	-0.0014	-0.0017	0.0021	0.0020	0.0020
	(0.0023)	(0.0023)	(0.0023)	(0.0031)	(0.0033)	(0.0033)	(0.0023)	(0.0023)	(0.0023)
Δ Outcome from One SD Δ in TPM	0.007	0.008	0.007	0.007	0.007	0.007	0.006	0.006	0.006
Maternal Controls									
Age Controls	No	Yes	No	No	Yes	No	No	Yes	No
Education Controls	Yes	No	No	Yes	No	No	Yes	No	No
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Outcome mean	0.010	0.010	0.010	0.013	0.013	0.013	0.005	0.005	0.005
N	9046	9046	9046	9045	9045	9045	9046	9046	9046

Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by panel and column) is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Mother characteristics' controls include indicators for high school graduate, higher education (some or completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear control for the mother's age. The change in each of the variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure.

Table 7: Bombing Activity and Arsenic Pollution Levels in Water – Live Impact Area Inner Range Water, 1985-1999

Dependent variables:	Maximum Arsenic Levels Above EPA Limit				
	(1)	(2)	(3)	(4)	(5)
Tons per month, Quarter *t*	0.171** (0.072)	0.172** (0.071)	0.183** (0.072)	0.177** (0.075)	0.176** (0.078)
Δ Outcome from One SD Δ in TPM	0.14	0.14	0.15	0.15	0.14
Other Controls					
Tons per month, Quarter *t-1*		0.086 (0.072)	0.087 (0.072)	0.090 (0.076)	0.091 (0.078)
Tons per month, Quarter *t-2*			0.003 (0.071)	0.004 (0.073)	0.005 (0.076)
Tons per month, Quarter *t-3*				0.010 (0.085)	0.010 (0.087)
Tons per month, Quarter *t+1*					-0.011 (0.086)
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Outcome mean	0.275	0.280	0.286	0.292	0.292
N	51	50	49	48	48

Notes: Coefficient estimates from time series regressions; each set of estimates (by column) is from a different regression. Heteroskedasticity-robust standard errors in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. The change in each of the variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure (= coefficient estimate × 0.822).

Table 8: End of Naval Practices and Infant Health, Years 2000-2003

Dependent variables:	Congenital anomaly	Low APGAR score	Premature birth	Extremely preterm birth	Low birth weight
	(1)	(2)	(3)	(4)	(5)
End of Naval Practices × Vieques	-0.0075***	0.0070	0.0182	-0.0032	-0.0221
SE	(0.0024)	(0.0057)	(0.0200)	(0.0053)	(0.0284)
Permutation %-tile rank	6/77	16/77	14/77	32/77	10/77
Approximate p-value	0.078	0.208	0.182	0.416	0.130
Mother Characteristics	Yes	Yes	Yes	Yes	Yes
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Outcome mean	0.010	0.013	0.149	0.008	0.110
N	13170	13169	13170	13170	13170

Notes: Coefficient estimates from municipality fixed effects regressions; each reported coefficient is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Mother characteristics' controls include indicators for high school graduate, higher education (some or completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear control for the mother's age.

Appendix Table A1: Bombing Activity and Birth Counts, 1990-2000

Dependent variables:	Births	ln(Births)
	(1)	(2)
Panel A: Overall Effects		
Tons per month [Mths 1-9] × Vieques	-0.25	0.009
	(2.24)	(0.089)
Δ Outcome from One SD Δ in TPM	-0.12	0.00
Panel B: Trimester-Specific Effects		
Tons per month [Mths 1-3] × Vieques	0.68	-0.030
	(0.89)	(0.044)
Tons per month [Mths 4-6] × Vieques	-0.63	-0.012
	(0.87)	(0.049)
Tons per month [Mths 7-9] × Vieques	-0.91	0.056
	(0.80)	(0.044)
Δ Outcome from One SD Δ in TPM	-0.70	0.01
Municipality Fixed Effects	Yes	Yes
Month-Year Fixed Effects	Yes	Yes
Outcome mean	64.1	-
N	9046	9046

Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by panel and column) is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Mother characteristics' controls include indicators for high school graduate, higher education (some or completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear control for the mother's age. The change in each of the variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure.

Appendix Table A2: Sensitivity of Bombing Activity Effects Estimates to Lag Structure

Dependent variables:	Congenital anomaly			Low APGAR score			Extremely Preterm Birth		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Overall Effects									
Tons per month [Mths 1-9] × Vieques	0.0071	0.0075	0.0070	0.0098*	0.0111*	0.0104*	0.0084*	0.0088*	0.0089*
	(0.0047)	(0.0049)	(0.0050)	(0.0059)	(0.0062)	(0.0062)	(0.0048)	(0.0051)	(0.0052)
Δ Outcome from One SD Δ in TPM	0.0034	0.0035	0.0033	0.0046	0.0052	0.0049	0.0039	0.0041	0.0042
Panel B: Trimester-Specific Effects									
Tons per month [Mths 1-3] × Vieques	-0.0002	-0.0005	-0.0009	0.0067*	0.0083**	0.0077*	-0.0004	0.0002	0.0002
	(0.0021)	(0.0023)	(0.0025)	(0.0038)	(0.0042)	(0.0045)	(0.0039)	(0.0043)	(0.0045)
Tons per month [Mths 4-6] × Vieques	0.0034	0.0030	0.0023	0.0042	0.0052	0.0051	0.0096*	0.0099*	0.0100*
	(0.0023)	(0.0023)	(0.0023)	(0.0042)	(0.0043)	(0.0044)	(0.0052)	(0.0054)	(0.0054)
Tons per month [Mths 7-9] × Vieques	0.0053**	0.0055**	0.0056**	-0.0014	-0.0017	-0.0013	-0.0024	-0.0025	-0.0025
	(0.0024)	(0.0023)	(0.0024)	(0.0031)	(0.0031)	(0.0032)	(0.0044)	(0.0044)	(0.0045)
Δ Outcome from One SD Δ in TPM	0.007	0.007	0.006	0.008	0.010	0.010	0.006	0.006	0.006
Lags of dependent variable									
First lag	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Second lag		Yes	Yes		Yes	Yes		Yes	Yes
Third lag			Yes			Yes			Yes
Mother Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Outcome mean	0.010	0.010	0.010	0.013	0.013	0.013	0.005	0.005	0.005
N	8958	8958	8958	8957	8957	8957	8958	8958	8958

Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by panel and column) is from a different regression. Heteroskedasticity-robust standard errors in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Mother characteristics' controls include indicators for high school graduate, higher education (some or completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear control for the mother's age. The change in each of the outcome variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure.

Appendix Table A3: Water Pollution Levels – Live Impact Area Inner Range, 1985-1999

		Test Samples				
		Average of Samples		Max. of Samples		
Measures of water polution	**Max. Contaminant Level (MCL) / Limit**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**N**
	(1)	(2)	(3)	(4)	(5)	(6)
Dissolved oxygen	5 mg/l	0.020	0.141	0.059	0.238	50 / 51
Acidity	7.3 pH	-	-	0.173	0.382	52
Alkalinity	8.5 pH	-	-	0.173	0.382	52
Turbidity	10 NTU	0.000	0.000	0.038	0.192	53
Nitrogen	5 mg/l	0.019	0.137	0.075	0.267	53
Inorganic Chemicals						
Arsenic	0.015 mg/l	0.151	0.361	0.264	0.445	53
Barium	1 mg/l	0.019	0.137	0.038	0.192	53
Boron	4.8 mg/l	0.151	0.361	0.358	0.484	53
Cadmium	0.005 mg/l	0.792	0.409	0.849	0.361	53
Hexavalent chromium	0.05 mg/l	0.038	0.192	0.189	0.395	53
Total chromium	0.3 mg/l	0.000	0.000	0.058	0.235	52
Copper	0.5 mg/l	0.566	0.500	0.623	0.489	53
Cyanide	0.02 mg/l	0.173	0.382	0.288	0.457	52
Fluoride	1.3 mg/l	0.038	0.194	0.096	0.298	52
Iron	0.2 mg/l	0.481	0.505	0.635	0.486	52
Lead	0.015 mg/l	0.769	0.425	0.808	0.398	52
Mercury	0.001 mg/l	0.115	0.323	0.269	0.448	52
Phenolic substances	0.001 mg/l	0.314	0.469	0.471	0.504	51
Selenium	0.01 mg/l	0.300	0.463	0.380	0.490	50
Silver	0.002 mg/l	0.765	0.428	0.804	0.401	51
Sulfide	0.002 mg/l	0.980	0.140	0.980	0.140	51
Zinc	0.05 mg/l	0.529	0.504	0.627	0.488	51
Manganese	0.1 mg/l	0.118	0.325	0.216	0.415	51

Source: U.S. Environmental Protection Agency Discharge Monitoring Reports, Atlantic Fleet Weapons Training Facility, Roosevelt Roads Base, Puerto Rico

Appendix Table A4: Bombing Activity and Local Economic Activity

	Coef. estimate, Tons per month, months [*t*, *t+8*] x Vieques	Δ Outcome from One SD Δ in TPM	Proportional Effect		Coef. estimate, Tons per month, months [*t*, *t+8*] x Vieques	Δ Outcome from One SD Δ in TPM	Proportional Effect
	(1)	(2)	(3)		(4)	(5)	(6)
Dep. variables:							
Unemployment rate,							
Month *t-3*	-1.156 (1.423)	-0.54	-3.2%	Month *t+7*	-4.710*** (1.634)	-2.21	-13.0%
Month *t-2*	-1.741 (1.290)	-0.82	-4.8%	Month *t+8*	-4.579*** (1.524)	-2.15	-12.7%
Month *t-1*	-2.409* (1.305)	-1.13	-6.7%	Month *t+9*	-4.085*** (1.396)	-1.92	-11.3%
Month *t*	-3.514*** (1.307)	-1.65	-9.7%	Month *t+10*	-3.433** (1.399)	-1.61	-9.5%
Month *t+1*	-4.927*** (1.316)	-2.31	-13.6%	Month *t+11*	-2.892* (1.458)	-1.36	-8.0%
Month *t+2*	-5.675*** (1.338)	-2.66	-15.7%	Month *t+12*	-2.108 (1.440)	-0.99	-5.8%
Month *t+3*	-5.998*** (1.300)	-2.81	-16.6%	Month *t+13*	-1.911 (1.429)	-0.90	-5.3%
Month *t+4*	-5.489*** (1.413)	-2.58	-15.2%	Month *t+14*	-1.861 (1.394)	-0.87	-5.2%
Month *t+5*	-5.280*** (1.540)	-2.48	-14.6%	Month *t+15*	-1.789 (1.364)	-0.84	-5.0%
Month *t+6*	-5.127*** (1.563)	-2.41	-14.2%	Month *t+16*	-2.112 (1.316)	-0.99	-5.8%
Mother Characteristics					No		
Municipality Fixed Effects					Yes		
Month-Year Fixed Effects					Yes		
Outcome mean					16.9		
N					9046		

Notes: Coefficient estimates from municipality fixed effects regressions; each coefficient is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. The change in each of the variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure.

Appendix Table A5: Sensitivity of Bombing Activity Effects Estimates to Local Economic Activity Controls

Dependent variables:	Congenital anomaly				Low APGAR score				Extremely Preterm Birth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A: Overall Effects												
Tons per month [Mths 1-9] × Vieques	0.0079*	0.0073*	0.0086**	0.0076*	0.0093	0.0088	0.0080	0.0072	0.0079*	0.0085*	0.0077*	0.0083*
	(0.0042)	(0.0040)	(0.0041)	(0.0039)	(0.0059)	(0.0059)	(0.0060)	(0.0062)	(0.0046)	(0.0046)	(0.0046)	(0.0045)
Δ Outcome from One SD Δ in TPM	0.0037	0.0034	0.0040	0.0036	0.0044	0.0041	0.0037	0.0034	0.0037	0.0040	0.0036	0.0039
Panel B: Trimester-Specific Effects												
Tons per month [Mths 1-3] × Vieques	-0.0001	-0.0002	0.0002	-0.0001	0.0060*	0.0059*	0.0056*	0.0054*	0.0036	0.0037	0.0035	0.0037
	(0.0018)	(0.0018)	(0.0017)	(0.0018)	(0.0031)	(0.0031)	(0.0031)	(0.0031)	(0.0023)	(0.0023)	(0.0023)	(0.0023)
Tons per month [Mths 4-6] × Vieques	0.0044**	0.0042**	0.0047**	0.0043**	0.0029	0.0027	0.0024	0.0020	0.0009	0.0012	0.0008	0.0011
	(0.0018)	(0.0018)	(0.0019)	(0.0018)	(0.0040)	(0.0040)	(0.0040)	(0.0041)	(0.0016)	(0.0016)	(0.0016)	(0.0015)
Tons per month [Mths 7-9] × Vieques	0.0056**	0.0054**	0.0059**	0.0054**	-0.0009	-0.0011	-0.0014	-0.0017	0.0021	0.0023	0.0020	0.0023
	(0.0024)	(0.0023)	(0.0024)	(0.0023)	(0.0030)	(0.0030)	(0.0030)	(0.0031)	(0.0023)	(0.0023)	(0.0023)	(0.0023)
Δ Outcome from One SD Δ in TPM	0.008	0.008	0.009	0.008	0.007	0.006	0.006	0.005	0.006	0.006	0.005	0.006
Unemployment Rate Controls												
Months [1-9]	Levels	Levels	Ln	Ln	Levels	Levels	Ln	Ln	Levels	Levels	Ln	Ln
Months [[-9]-[-1]]		Levels		Ln		Levels		Ln		Levels		Ln
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Outcome mean	0.010	0.010	0.010	0.010	0.013	0.013	0.013	0.013	0.005	0.005	0.005	0.005
N	9046	9046	9046	9046	9045	9045	9045	9045	9046	9046	9046	9046

Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by panel and column) is from a different regression. Heteroskedasticity-robust standard errors in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. Mother characteristics' controls include indicators for high school graduate, higher education (some or completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear control for the mother's age. The change in each of the outcome variables from a one (1) standard deviation increase in the tons of ordnance per month is calculated as the product of the relevant coefficient estimate and the standard deviation of the ordnance volume measure.