Military Training Exercises, Pollution, and their Consequences for Health[1]

Gustavo J. Bobonis[2], Mark Stabile[3], and Leonardo Tovar[4]

November 2017

Abstract:

Militaries around the world perform training exercises in preparation for war. We study the relationship between *in utero* exposure to military exercises (bombing) and early-life health outcomes, combining data on naval bombing exercises in Vieques, Puerto Rico, and the universe of births from 1990-2003. Using a differences-in-differences design, we find that a one standard deviation increase in exposure to bombing activity leads to a 34 to 77 percent increase in the incidence of congenital anomalies. The evidence is generally consistent with the channel of environmental pollution; increases in arsenic levels in waters surrounding the live impact area.

Keywords: Infant health; military activity; environmental pollution; maternal stress.

JEL Codes I15, I14, O1

---

[1] This is a significant revision and extension of an earlier paper, circulating under the title "Bombs and Babies: U.S. Navy Bombing Activity and Infant Health in Vieques, Puerto Rico" (NBER Working Paper #2909). We thank Francesco Amodio, Michael Baker, Loren Brandt, Esther Duflo, Fred Finan, Jeanne Lafortune, Elaine Liu, Aprajit Mahajan, Ted Miguel, Teresa Molina, Ben Olken, 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, the CIREQ Montreal Applied Economics Conference 2016, and the NBER Environment and Energy Economics Spring 2017 Meeting 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.

[2] Corresponding author: Department of Economics and School of Public Policy and Governance, University of Toronto; Center for a New Economy; and BREAD. Address: 150 St. George St., Room 304, Toronto, Ontario, M5S 3G7, Canada. E-mail: gustavo.bobonis@utoronto.ca.

[3] INSEAD

[4] University of Toronto.

I. Introduction

Militaries around the world perform training exercises in preparation for war and, in general, they take place "at home". The U.S. is no exception. As of 2001, approximately 950 formerly used defense sites (FUDS) located across the country associated with former military training ranges contained defense-related hazards such as unexploded ordnance and other explosive wastes. These sites represent health hazards to local populations exposed to contaminants and military debris (U.S. General Accounting Office 1996, 2001).[5]

Surprisingly, there is very limited research documenting the impacts of these military training exercises on the livelihoods of nearby populations. Given that these training exercises continue to take place around the world (Korea, Japan, Iraq to name but a few), we would benefit from a better understanding of the potential consequences of these practices on health and socioeconomic outcomes of nearby populations -- often vulnerable groups in society.

This study exploits a case study to provide evidence regarding the effects of these military exercises on the health outcomes of nearby populations. 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 allows us to explore whether exposure to military training in fact has consequences for the health and safety of nearby populations, including the health at birth for children exposed *in utero*.[6,7]

---

[5] FUDS are located throughout the United States, on remote islands such as Pacific Atolls or the Aleutian Islands in Alaska, while others include urban settings such as Hunter's Point Naval Shipyard in San Francisco.

[6] We also focus on neonatal health outcomes for two additional reasons: due to data availability as well as the fact that newborn health can respond rapidly to environmental conditions, which is important for an empirical strategy based on the high frequency timing of the practices. 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

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 2003, to study the relationship between *in utero* 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 -- particularly for congenital anomalies. Our analysis of the bombing period reveals that a one standard deviation increase in exposure to bombing activity while *in utero* leads to three to seven per thousand point (34-77 percent) increase in the incidence of congenital anomalies. 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, 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

---

Ródenas-Serrano (2017). 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).

[7] 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.

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 mediate 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 6.9-8.0 per thousand (67-77 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) and provides additional support for the link between bombing and congenital anomalies found during the bombing period.

Our study makes several contributions to the health, conflict and human development literature. Prominent research on the effects of exposure to 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. [8] 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 both child policy and military policy. Infant health outcomes such as congenital anomalies and low birth weight are important predictors of child health (McCormick 1985; Pollack and Divon 1992; Almond, Chay, and Lee

[8] For instance, Camacho (2008), León (2012), and Quintana-Domeque and Ródenas-Serrano (2017).

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 in Section IV. In Section V we explore potential mechanisms, followed in Section VI by a series of robustness tests and a discussion of potential impacts on other health outcomes. The paper concludes in Section VII with a discussion of findings and their broad implications.

II. Background

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

Vieques is an island 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). 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, and 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.[9] 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.[10] The U.S. ATSDR has produced public health assessment studies on drinking groundwater (released in 2001), ingesting or touching soil (2003), breathing air (2003),

---

[9] 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.

[10] 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.

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.[11] 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 and López-Rivera 2004; Massol-Deyá et al 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 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

[11] 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).

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 total weight of ordnance used by the U.S. Navy and other parties for all military training exercises (including air-to-ground, ship-to-ground, and land-based activities) on a monthly basis is available for the period May 1985 - July 1999.[12] 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 2003, available from the Puerto Rico Statistics Institute. Specifically, we have data on approximately 855,429 births in the territory of P.R. with information on birth outcomes such as sex, month of conception, exact date of birth, gestation period, and detection of congenital anomalies, 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 for which the date of birth and the period of gestation, as well as the municipality of residence, are known.[13] After combining these data with the monthly tonnage of ordnance, we lose 50,081 observations

---

[12] 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. 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). 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).

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

(5.8 percent) and an additional 59 observations with missing information on maternal age or educational attainment. The remaining sample is composed of 805,348 births (94.1 percent of the population), with item non-response rates for our various outcomes of interest in the 0.2-0.3 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 13,170 municipality-by-month cells, covering 174 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.[14]

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. Also, 14.9 percent of infants are born prematurely, most of them being moderately or late preterm, but a substantial proportion (0.8 percent) are extremely preterm. Eleven (11) percent of live births are considered low weight births, and 1.3 percent of children have a low 5 minute Apgar score (defined as less than 7 out of 10). 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 on average 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

[14] Density plots of the distributions for both measures show that the measure of monthly ordnance is skewed to the right, with most of the observations in the 0-2 tons per month range. 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.

than those for the overall U.S. population during this time period.[15] The proportion of female live births is slightly higher in Vieques than in the rest of Puerto Rico (49.1 percent vs. 48.6 percent).

The average characteristics of mothers in Vieques are reasonably different from those in the rest of the sample: 37.1 percent of mothers in Vieques have only a high school degree versus 29.7 percent in the rest of Puerto Rico. Mothers are slightly younger (ages 23.8 versus 24.7, on average) and more of the mothers are giving birth as teenagers (14.2 percent versus 9.2 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) as further local controls.

III.B. Empirical Methodology

Our empirical strategy consists of two difference-in-differences designs. First, we use the end of practices in the year 2000 to compare outcomes for cohorts conceived following the end of naval practices to those conceived in the preceding period within the municipality using the health outcomes of newborns in other municipalities to control for period-specific effects. Second, we compare children having experienced distinct levels of exposure to these exercises within the municipality of Vieques over time up to the completion of the bombing once again 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:

---

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

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

where y_{jmt} is the proportion of children with a congenital anomaly, born to mothers residing in municipality *j*, conceived in the month *m* of year *t*; Ordnance_{mt} is either a pre-post dummy for the end of the exercises (specification 1), or the mean level of ordnance in the 9-month period between conception and birth (assuming a 40-week pregnancy) (specification 2); 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_{jmt}, 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. We also break down this 9-month period into trimesters to examine the effect at different gestation periods. Each specification includes controls for maternal characteristics at that municipality-month-year level. To interpret magnitudes of the effects in specification 2, we also report the magnitude of the predicted relationship given a one standard deviation increase in the explanatory variable of interest and each outcome 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 large time dimension of the data (174 or 118 months for specifications 1 and 2, respectively) 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 (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.

IV. Results

We start by examining trends in the incidence of congenital anomalies for births conceived by residents of Vieques (solid blue line) and those in the rest of Puerto Rico (dotted green line), from early 1989 until early 2003 (births in 1990-2003), together with the volume of ordnance during this time period (dotted red line) (see Figure 2). Due to the small cell sizes in the case of Vieques, we smooth the series by presenting 24-month moving averages of the outcomes for both Vieques and control municipalities. We observe a clear relationship between the volume of ordnance—and its abrupt end—and incidences of congenital anomalies among birth cohorts to Viequense mothers. In contrast, we see no relationship between ordnance levels and these across cohorts in the rest of Puerto Rico. This evidence strongly suggests that the military exercises represented health hazards and had negative consequences for newborns in the local population.

Next we present regression-based evidence of these effects, reported in Table 3. We estimate each specification both including and not including the local unemployment rates as controls. The first two columns report 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 6.9-8.0 per thousand decrease in the incidence of congenital anomalies, a 67-77 percent reduction relative to the baseline mean. The relationship is significant at the 1 percent level, with a permutation percentile rank of five and six out of 77 (approximate p-values = 0.065, 0.078).

Columns 3 and 4 report the effect using variation in bombing over the 1990-1999 period. Again, 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. A one standard deviation change in bombing ordnance is associated with a 3.4-3.6 per thousand point increase in the incidence of congenital anomalies, a 34.2-36.1 percent increase relative to the baseline mean. The relationship is significant at least at the 10 percent level, with a permutation percentile rank of eight and seven out of 77 (approximate p-values = 0.104, 0.091). 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). 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).

We next explore whether the relationship between bombing ordnance and newborn health 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. Results are reported in columns 5 and 6 of Table 3.

The relationship between bombing ordnance and congenital anomalies appears to be strongest and statistically significant (at 95 percent confidence) in the second and third trimesters, with robust permutation percentile rank approximate p-values in the 0.013-0.052 range. 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 7.6-8.9 per thousand point increase in the incidence of congenital anomalies, a 77.2-90.4 percent increase relative to the baseline mean.

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. The estimates are of similar magnitude independently of the lag structure used (one to four lags of the dependent variable); the results are reported in Appendix Table A1. Estimates looking at the effect of the end of the bombing suggest a reduction relative to the baseline mean of between

45 and 63 percent (Panel A). Estimates based on models using variation in bombing between 1990 and 1999 and allowing for trimester-specific effects are also quantitatively similar, and have similar levels of precision as those discussed above; these are reported in Panels B and C of the table. These various robustness checks imply that we find large and robust effects of bombing ordnance on congenital anomalies.

V. Potential Mechanisms

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 (Quintana-Domeque and Ródenas-Serrano 2017). There are several 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. Previous literature has shown a direct link between air pollution and infant health (Chay & Greenstone, 2003; Currie, Neidell, &

Schmieder, 2009). 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). For measures of dissolved oxygen, acidity, alkalinity and nitrogen, while average levels are within the range deemed safe by the Environmental Protection Agency, the maximum level reported exceeds the range (data available upon request). 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:

$$1(y_t > y^{EPA}) = \theta_B(\text{Ordnance}_t) + \varepsilon_{t,} \qquad (2)$$

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 4. 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.

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 et al 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 et al 2010). Therefore, it is certainly feasible that increased stress due to the bombings had negative effects on infant health in Vieques.

VI. Robustness Tests and Selection

Economic Downturns

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 (León 2012). While we control for unemployment levels in our baseline specification, here 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 (1), excluding maternal controls, to predict unemployment rates as a function of a) the end of naval practices in Vieques and b) the ordnance measure for all 9 months of pregnancy and separately for each trimester.

The estimates are reported in the first two columns of Table 5. If anything, the evidence is consistent with the naval activities leading to a short-term improvement in local economic conditions. We find a positive and significant relationship between the end of naval practices and the unemployment rate – a 3 percentage point / 0.2 log point increase in the unemployment rate – and a corresponding negative relationship between bombing levels and the unemployment rate – a one standard deviation increase in bombing activity predicts reductions in the unemployment rate in Vieques of 2.4 percentage points / 0.14 log points.

Given that these positive short-term fluctuations could lead to worse neonatal 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 include average unemployment rates as controls in our main specification above. As seen in Section IV, 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.[16]

Mother characteristics, and other possible selection effects

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 directly estimate the relationship between our main bombing variables in both specifications and mother and cohort characteristics. Specifically, we estimate linear models of the form:

$$x_{jmt} = \theta(Ordnance_{mt} \times Vieques_j) + \alpha_j + \gamma_{mt} + \varepsilon_{jmt,} \qquad (3)$$

where x_{jmt} is the average (or aggregate) characteristic for mothers 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.

Columns 3 and 4 of Table 5 reports results for estimates of cohort size effects. We find a 0.17 log point decrease in the number of live births following the ending of naval practices; this

[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.

is consistent with the short-term worsening of economic conditions in the municipality causing lower fertility rates. However, this relationship is not robust to estimating effects in levels. In this case, we estimate an increase of 6.5 births in the municipality (approximately 10 percent), (approximate p-value = 0.23). We also find no evidence of economically substantial and statistically significant variation in cohort sizes resulting from variation in the intensity of bombing during the 1990-1990 period (Panels B and C). The evidence is not conclusive regarding the importance of selection due to fertility in explaining our results.

Columns 5 through 11 of Table 5 reports results for estimates of selection on observable child or maternal characteristics. Our results show no consistent pattern of gender-based selection. We find a 4.0 percentage point drop in the probability of female births following the end of naval practices, statistically insignificant based on asymptotic DK estimates of standard errors, but with a percentile rank test approximate p-value < 0.001). In contrast, we find a 3.8 percentage point drop in the probability of a female birth given a one standard deviation increase in bombing activity. The latter estimate 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 6 through 8 report results for the educational attainment of mothers giving birth, broken down by high school dropouts, high school graduates, and those with some or completed higher education. There is a *positive* and significant relationship between bombing ordnance and mothers' educational attainment. The end of naval practices predicts a 7.4 percentage point increase in births by high school graduates, with a corresponding 8.6 decrease in the probability by mothers with tertiary education. Also, the second model predicts that a one standard deviation increase in ordnance is correlated with a significant 3.8 percentage increase in the probability the mother has commenced or completed tertiary 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.

Columns 9 through 11 of Table 5 report results on the differential correlation of naval practices in Vieques with mothers' age. There is, in general, no relationship between bombing ordnance and mothers' age for the bombing period between 1990-1999 although post bombing, mothers appear to be somewhat younger and more likely to be teenage mothers. Again, since the relationship between teenage pregnancies and children's health status at birth is negative, these correlations are indicative of positive selection based on maternal age.

Finally, 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 C of Table 5).

In addition to looking directly at the relationship between ordinance and these characteristics, we also re-estimate the linear models on child health outcomes (equation 1) excluding these maternal controls to assess the sensitivity of the estimates to these control variables. The estimates are reported in Table 6. We report estimates of the effects when we (i) exclude maternal age controls (columns 2 and 6), (ii) exclude maternal schooling attainment controls (columns 3 and 7), and (iii) exclude all maternal controls (columns 4 and 8). For purposes of comparability, we report our baseline estimates with maternal controls – with and without economic activity proxy controls – in columns 1 and 4, respectively. The estimates are remarkably stable. For instance, the model without controls (column 4) implies that the end of naval practices led to a 0.79 percentage point decrease in the incidence of congential anomalies (Panel A), and the effect of a one standard deviation change in average ordnance leads to a 6.7 per thousand point increase in the incidence risk, an estimated effect that is 0.05 per thousand points *smaller* in magnitude. In general, this sensitivity analysis suggests that there is a small degree of correlation between these observable characteristics and the incidence of congenital anomalies, and as a result the degree of selection on observables explains a minimal share of the relationship between the volume of ordnance and the risk of congenital anomalies.

Potential Impacts on Other Health Outcomes

Finally, we report estimates of impacts on other potential child health outcomes in addition to congenital anomalies. We examine a variety of other possible child health outcomes including premature births, birthweight, and APGAR scores; the results are reported in Table 7. Our estimates of the effects of the ordinance level between 1990-1999 suggests some evidence of a negative effect of bombing on neonatal health (Panels B and C). For example, we find an increase in the probability of extremely preterm birth and low APGAR scores using ordnance across all 9 months of pregnancy, and an increase in premature birth and low APGAR scores due to bombings during the first trimester of pregnancy. However, unlike with congenital anomalies, we do not find statistically significant evidence of improvements in child health in these areas following the ending of the bombing. Coupled with the evidence cited above on the link between environmental factors and congenital anomalies in particular, we therefore believe our inference is most robust to the effects of the bombings on congenital anomalies.

VII. Conclusion

We identify the relationship between frequent explosions and high-ordnance military exercises and child health at birth. Our results indicate that there is a negative effect of these exercises on health outcomes at birth. Our results showing an effect on congenital anomalies is most robust, with consistent effects across two identification strategies. Our analysis helps inform the literature regarding why stress and environmental factors may be important channels via which conflict affects human development and also speaks to the direct effect of military practice sessions on the local population – a practice that continues today by militaries around the world.

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 Ródenas-Serrano, 2017) and not inconsistent with estimates of conflict on child height (Bundervoet, Verwierp and Akresh, 2009). To our knowledge there are no other studies of the impacts of military preparation exercises on the health of the local population.

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 economics 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, and Salvanes 2007; Oreopoulos, Stabile, Roos, and Walid 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.

References

Al-Hadithi, T., J. K. Al-Diwan, A. M. Saleh, and N. P. Shabila (2012). Birth defects in Iraq and the plausibility of environmental exposure: A review. *Conflict and Health*, 6(3), 1-7.

Al-Sabbak, M., Sadik Ali, S., Savabi, O., Savabi, G., Dastgiri, S., & Savabieasfahani, M. (2012). Metal Contamination and the Epidemic of Congenital Birth Defects in Iraqi Cities. *Bulletin of Environmental Contamination and Toxicology*, 89(5), 937–944. http://doi.org/10.1007/s00128-012-0817-2

Alderman, H., Hoddinott, J., and Kinsey, B. (2006). Long Term Consequences of Early Childhood Malnutrition. *Oxford Economic Papers*, 58(3), 450–74.

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

Almond, D., Chay, K. Y., & Lee, D. S. (2005). The Costs of Low Birth Weight. *Quarterly Journal of Economics, 120*(3), 1031-1083.

ATSDR. (2001). *Public Health Assessment: Drinking Water Supplies and Groundwater Pathway Evaluation, Isla de Vieques Bombing Range, Vieques, Puerto Rico.* Atlanta: Agency for Toxic Substances and Disease Registry. Retrieved Aug. 2014, from http://www.atsdr.cdc.gov/HAC/PHA/reports/isladevieques_10162001pr/printview.html

ATSDR. (2003). *Public Health Assessment: Air Pathway Evaluation, Isla de Vieques Bombing Range, Vieques, Puerto Rico.* Atlanta: Agency for Toxic Substances and Disease Registry.

Barker, D. J. (1990). The Fetal and Infant Origins of Adult Disease. *BMJ, 301*(6761), 1111.

Barrios, T. Diamond, R., Imbens, G. W., & Kolesár, M. (2012). Clustering, Spatial Correlations, and Randomization Inference. *Journal of the American Statistical Association*, 107(498), 578-91.

Behrman, J., & Rosenzweig, M. (2004). Returns to Birthweight. *Review of Economics and Statistics, 86*(2), 586-601.

Bertrand, M., Duflo, E., & Mullainathan, S. (2004). How Much Should We Trust Differences-in-Differences Estimates? *Quarterly Journal of Economics*, 119(1), 249-75.

Beydoun, H., and Saftlas, A. (2008). Physical and Mental Health Outcomes of Prenatal Maternal Stress in Human and Animal Studies: A Review of Recent Evidence. *Paediatric and Perinatal Epidemiology* 22(5), 438–466.

Black, S., Devereux, P., & Salvanes, K. (2007). From the Cradle to the Labor Market? The Effect of Birth Weight on Adult Outcomes. *Quarterly Journal of Economics, 122*(1), 409-439.

Bundervoet, T., Verwimp, P., & Akresh, R.(2009). Health and Civil War in Rural Burundi. *Journal of Human Resources*, 44(2), 536-63.

Camacho, A. (2008, May). Stress and Birth Weight: Evidence from Terrorist Attacks. *The American Economic Review, 98*(2), 511-515.

Cameron, C. Gelbach, J., & Miller, D. (2008). Bootstrap-Based Improvements for Inference with Clustered Errors. *Review of Economics and Statistics*, 90(3), 414-27.

Carmichael, S. L., Shaw, G. M., Yang, W., Abrams, B., & Lammer, E. J. (2007). Maternal Stressful Life Events and Risks of Birth Defects. *Epidemiology* (Cambridge, Mass.), 18(3), 356–361. http://doi.org/10.1097/01.ede.0000259986.85239.87

Carmichael, S. L., Ma, C., Tinker, S., Rasmussen, S. A., Shaw, G. M., & the National Birth Defects Prevention Study. (2014). Maternal stressors and social support as risks for delivering babies with structural birth defects. *Paediatric and Perinatal Epidemiology*, 28(4), 338–344. http://doi.org/10.1111/ppe.12123

Chay, K., & Greenstone, M. (2003). The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession. *Quarterly Journal of Economics*, 118(3), 1121-1167.

Currie, J., Greenstone, M., & Moretti, E. (2011). Superfund Cleanups and Infant Health. *American Economic Review Papers and Proceedings*, 101(3), 435-41.

Currie, J., & Hyson, R. (1999). Is the Impact of Health Shocks Cushioned by Socioeconomic Status? The Case of Low Birth Weight. *American Economic Review Papers and Proceedings, 89*(2), 245-250.

Currie, J., Neidell, M., & Schmieder, J. F. (2009). Air Pollution and Infant Health: Lessons from New Jersey. *Journal of Health Economics, 28*, 688-703.

Currie, J., Ray, S. H., & Neidell, M. (2011). Quasi-Experimental Studies Suggest That Lowering Air Pollution Levels Benefit Infants' And Children's Health. *Health Affairs*,30(12), 2391-99.

Currie, J., & Schwandt, H. (2014). The 9/11 Dust Cloud and Pregnancy Outcomes: A Reconsideration. NBER Working Paper #20368.

Davis, J. S., Hayes-Conroy, J.S., & Jones, V.M. (2007). Military Pollution and Natural Purity: Seeing Nature and Knowing Contamination in Vieques, Puerto Rico. GeoJournal, 69(3).

de Weerrth, C., & Buitelaar, J. (2005). Physiological Stress Recreatiity in Human Pregnancy. A Review." *Neuroscience and Behavioral Review*, 29:295-312.

Dehejia, R., & Lleras-Muney, A. (2004). Booms, Busts, and Babies' Health. *Quarterly Journal of Economics, 119*, 1091-1130.

Driscoll, J. C., & Kraay, A. C. (1998). Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data. *Review of Economics and Statistics*, 80(4), 549-60.

Dustmann, C., and F. Fasani (2014). The Effect of Local Area Crime on Mental Health. *Economic Journal*, forthcoming.

EPA. (2013). *May 2013 Vieques Activities Update.* Environmental Protection Agency. Retrieved Aug. 2014, from http://www.epa.gov/region2/vieques/may2013viequesupdate_.pdf

Figueroa, N., Suarez, E., De La Torre, T., Torres, M., & Perez, J. (2009). *Incidencia y Mortalidad de Cancer en Vieques, 1990-2004.* San Juan: Registro Central de Cancer de Puerto Rico.

Fisher, R. A. (1925). *The Design of Experiments* (1st ed.) London: Oliver & Boyd.

Galdo, J. (2013). Long-Run Labor-Market Impacts of Early-Life Exposure to Civil War: Evidence from the Shining Path in Perú. *Economic Development and Cultural Change, 61*(4), 789-823.

Hadi, A. S. (1992). Identifying Multiple Outliers in Multivariate Data. *Journal of the Royal Statistical Society, Series B 54*, 761-771.

Hadi, A. S. (1994). A Modification of a Method for the Detection of Outliers in Multivariate Samples. *Journal of the Royal Statistical Society, Series B 56*, 393–396.

Hansen, D., Lou, H.C., and Olsen, J. (2000). Serious life events and congenital malformations: a national study with complete follow-up. *The Lancet*, 356(9233), 875-880.

Hopenhayn-Rich, C., Hertz-Picciotto, I., Browning, S., Ferreccio, C., Peralta, C. (1999). Reproductive and developmental effects associated with chronic arsenic exposure. In Chappel, W.R., Abernathy, C. O., & Calderon, R. L. (eds.), *Arsenic Exposure and Health Effects: Proceedings of the Third International Conference on Arsenic Exposure and Health Effects*, San Diego, California, 12-15 July, 1998, 115-64.

Imbens, G., & Kolesár, M. (2012). Robust Standard Errors in Small Samples: Some Practical Advice. NBER Working Paper No. 18478.

Kramer, M. S. (1987). Determinants of Low Birth Weight: Methodological Assessment and Meta-Analysis. *Bulletin of the World Health Organization, 65*(5), 663-737.

León, G. (2012). Civil conflict and Human Capital Accumulation: Long Term Consequences of Political Violence in Perú. *Journal of Human Resources, 47*(4), 991-1023.

Mansour, H., & Rees, D. I. (2012, Sept.). Armed Conflict and Birth Weight: Evidence from the al-Aqsa Infitada. *Journal of Development Economics, 99*(1), 190-199.

Massol-Deyá, A., Pérez, D., Pérez, E., Berríos, M., & Díaz, E. (2005). Trace Elements Analysis in Forage Samples from a U.S. Navy Bombing Range (Vieques, Puerto Rico). *International Journal of Environmental Research and Public Health, 2*(2), 263-266.

MacKinnon, J. G., & Webb, M. D. (2016). Wild Bootstrap Inference for Wildly Different Cluster Sizes. *Journal of Applied Econometrics*, forthcoming.

McCaffrey, K. (2009, Sept-Oct). Fish, Wildlife, and Bombs: The Struggle to Clean Up Vieques. *NACLA Report*, 35-41.

McCormick, M. C. (1985). The Contribution of Low Birth Weight to Infant Mortality and Childhood Morbidity. *New England Journal of Medicine*, 2(2), 263-266.

Miguel, E., Roland, G. (2011). The Long-Run Impact of Bombing Vietnam. *Journal of Development Economics* 96, 1-15.

Neyman, J. (1990). On the Application of Probability Theory to Agricultural Experiments: Essay on Principles--Section 9. *Statistical Science*, 5(4), 465-80.

Nordstrom, S., Beckman, L., & Nordenson, I. (1979). Occupational and environmental risks in and around a smelter in northern Sweden. *Hereditas*, 90, 291-6.

Oreopoulos, P., Stabile, M., Roos, L., & Walld, R. (2008). The Short, Medium, and Long Term Effects of Poor Infant Health. *Journal of Human Resources, 43*(1), 88-138.

Ortiz-Roque, C., & Lopez-Rivera, Y. (2004). Mercury Contamination in Reproductive Age Women in a Caribbean Island: Vieques. *Journal of Epidemiology and Community Health (1979-), 58*(9), 756-757.

Pollack, R., & Divon, M. (1992). Intrauterine Growth Retardation: Definition, Classification, and Etiology. *Clinical Obstetrics and Gynecology, 35*(1), 99-107.

Porter, J. W., Barton, J. V., & Torres, C. (2011). Ecological, Radiological, and Toxicological Effects of Naval Bombardment on the Coral Reefs of Isla de Vieques, Puerto Rico. In G. E. Machlis, T. Hanson, Z. Špirić, & J. E. McKendry, *Warfare Ecology: A New Synthesis for Peace and Security: Proceedings of the NATO Advanced Study Institute / Advanced Research Workshop* (pp. 65-122). Dordretch: Springer Netherlands.

Puerto Rico. (1999). *Informe de la Comisión Especial de Vieques al Gobernador de Puerto Rico, Hon. Pedro Rosselló.* San Juan.

Quintana-Domeque, C., & Ródenas-Serrano, P. (2017). The Hidden Costs of Terrorism: The Effects on Health at Birth. *Journal of Health Economics*, 56, 47-60.

Sotomayor, O. (2013). Fetal and Infant Origins of Diabetes and Ill Health: Evidence from Puerto Rico's 1928 and 1932 Hurricanes. *Economics and Human Biology, 11*(3), 281-293.

U.S. Navy. (1999). *The National Security Need for Vieques: A study prepared for The Secretary of the Navy.*

Wadhwa, P. D., Sandman, C. A., Porto, M., Dunkel-Schetter, C., & Garite, T. (1993, October). The Association between Prenatal Stress and Infant Birth Weight and Gestational Age at Birth: A Prospective Investigation. *American Journal of Obstetrics & Gynecology, 169*(4), 858-65.

Wargo, J. (2009). *Green Intelligence: Creating Environments that Protect Human Health.* New Haven: Yale University Press.

Zavala Zegarra, D. (2000). *Incidencia de Cancer en Vieques.* San Juan: Registro Central de Cancer de Puerto Rico.

Zhu, P., Tao, F., Hao, J., Sun, Y., & Jiang, X. (2010, July). Prenatal Life Events Stress: Implications for Preterm Birth and Infant Birthweight. *American Journal of Obstetrics & Gynecology, 203*(1), 1-8.

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

	Mean	**Std. Dev.**	**Min.**	**Max.**	**N**
	(1)	(2)	(3)	(4)	(5)
Volume of ordnance (monthly) [Hundreds of tons per month]	1.292	1.416	0.000	6.585	171
Volume of ordnance (9-month potential gestation period) [Hundreds of 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 (0.028)	13,170	0.005 (0.020)	170	0.010 (0.028)	13,000
Premature birth (< 37 weeks)	0.149 (0.113)	13,170	0.151 (0.128)	170	0.149 (0.113)	13,000
Extremely premature birth (< 28 weeks)	0.008 (0.051)	13,170	0.007 (0.026)	170	0.008 (0.051)	13,000
Low birth weight	0.110 (0.091)	13,170	0.113 (0.107)	170	0.110 (0.090)	13,000
Low APGAR score (5-min)	0.013 (0.045)	13,169	0.011 (0.031)	170	0.013 (0.045)	12,999
Panel B: Child and Mother Characteristics						
Female birth	0.486 (0.102)	13,170	0.491 (0.161)	170	0.486 (0.101)	13,000
High school graduate	0.298 (0.103)	13,170	0.371 (0.163)	170	0.297 (0.101)	13,000
Higher education (some/completed)	0.389 (0.127)	13,170	0.217 (0.134)	170	0.392 (0.126)	13,000
Mother's age	24.7 (1.4)	13,170	23.8 (2.1)	170	24.7 (1.3)	13,000
Teenage mother	0.093 (0.065)	13,170	0.142 (0.109)	170	0.092 (0.064)	13,000
Mother's age 40+	0.012 (0.024)	13,170	0.015 (0.043)	170	0.012 (0.023)	13,000

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 13,170 municipality-by-month cells.

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

	Dependent variable: Congenital anomaly (1/0)					
	All births, 1990-2003		All births, 1990-1999			
	(1)	(2)	(3)	(4)	(5)	(6)
End of Naval Practices × Vieques	-0.0080***	-0.0069***				
SE	(0.0024)	(0.0026)				
Permutation %-tile rank	5/77	6/77				
Approximate p-value	[0.065]	[0.078]				
Tons per month [Mths 1-9] × Vieques			0.0072*	0.0086**		
SE			(0.0041)	(0.0048)		
Permutation %-tile rank			8/77	7/77		
Approximate p-value			[0.104]	[0.091]		
Tons per month [Mths 1-3] × Vieques					-0.0003	0.0002
SE					(0.0018)	(0.0017)
Permutation %-tile rank					36/77	27/77
Permutation %-tile rank p-value					[0.468]	[0.351]
Tons per month [Mths 4-6] × Vieques					0.0041**	0.0047**
SE					(0.0018)	(0.0019)
Permutation %-tile rank					4/77	3/77
Permutation %-tile rank p-value					[0.052]	[0.039]
Tons per month [Mths 7-9] × Vieques					0.0054**	0.0059**
SE					(0.0023)	(0.0024)
Permutation %-tile rank					2/77	1/77
Permutation %-tile rank p-value					[0.026]	[0.013]
Mother Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Local Economic Activity Controls		Yes		Yes		Yes
Δ Outcome from One SD Δ in TPM	-	-	0.0034	0.0036	0.0076	0.0089
Outcome mean	0.010	0.010	0.010	0.010	0.010	0.010
N	13170	13170	9046	9046	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 and temporal dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. We also report the percentile rank of the coefficients from permutation exercises and its approximate p-value. Mother characteristics' controls include (averages of) indicators for high school graduate, higher education (some/completed), teenage pregnancy, mother's age at childbirth of 40 years or greater, and a linear maternal age control. 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.

Table 4: 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**	0.172**	0.183**	0.177**	0.176**
	(0.072)	(0.071)	(0.072)	(0.075)	(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	0.087	0.090	0.091
		(0.072)	(0.072)	(0.076)	(0.078)
Tons per month, Quarter *t-2*			0.003	0.004	0.005
			(0.071)	(0.073)	(0.076)
Tons per month, Quarter *t-3*				0.010	0.010
				(0.085)	(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 5: Correlates of Bombing Activity (Selection on Observables), 1990-2000

	Dependent variables:				
	Unempl. rate	ln(Unempl. rate)	Cohort size	ln(Cohort size)	Female birth
	(1)	(2)	(3)	(4)	(5)
	Panel A: End of Naval Practices, All Births 1990-2003				
End of Naval Practices × Vieques	3.16***	0.208***	6.50***	-0.168**	-0.040
	(0.689)	(0.044)	(2.06)	(0.080)	(0.028)
	[0.065]	[0.052]	[0.234]	[<0.001]	[<0.001]
	Panel B: Intensity of Bombing - Overall Effects, All Births 1990-1999				
Tons per month [Mths 1-9] × Vieques	- 5.03***	-0.296***	-0.08	0.004	-0.081*
	(1.13)	(0.064)	(2.10)	(0.087)	(0.042)
	[<0.001]	[<0.001]	[0.377]	[0.494]	[0.026]
	Panel C: Intensity of Bombing - Trimester-Specific Effects, All Births 1990-1999				
Tons per month [Mths 1-3] × Vieques	- 1.61***	-0.092***	0.71	-0.032	-0.041*
	(0.47)	(0.027)	(0.88)	(0.043)	(0.021)
	[<0.001]	[<0.001]	[0.416]	[0.078]	[<0.001]
Tons per month [Mths 4-6] × Vieques	- 2.09***	-0.122***	-0.55	-0.014	0.014
	(0.54)	(0.031)	(0.86)	(0.045)	(0.019)
	[<0.001]	[<0.001]	[0.247]	[0.338]	[0.208]
Tons per month [Mths 7-9] × Vieques	- 1.59***	-0.098***	-0.83	0.056	-0.026
	(0.42)	(0.027)	(0.72)	(0.044)	(0.023)
	[<0.001]	[<0.001]	[0.325]	[0.039]	[0.026]
Mother Characteristics	No	No	No	No	No
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
N	13170 / 9046		13170 / 9046		13170 / 9046

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

	Dependent variables:					
	High school dropout	High school Graduate	Higher education	Mother's age	Teenage Mother	Mother's age 40+
	(6)	(7)	(8)	(9)	(10)	(11)
	Panel A: End of Naval Practices, All Births 1990-2003					
End of Naval Practices × Vieques	0.013	0.074**	-0.086***	-1.01***	0.065***	0.001
	(0.033)	(0.034)	(0.027)	(0.37)	(0.022)	(0.009)
	[0.312]	[0.013]	[0.026]	[0.013]	[<0.001]	[0.364]
	Panel B: Intensity of Bombing - Overall Effects, All Births 1990-1999					
Tons per month [Mths 1-9] × Vieques	-0.028	-0.052	0.080**	-0.108	-0.049*	-0.008
	(0.035)	(0.041)	(0.034)	(0.512)	(0.025)	(0.009)
	[0.273]	[0.026]	[0.026]	[0.455]	[0.013]	[0.104]
	Panel C: Intensity of Bombing - Trimester-Specific Effects, All Births 1990-1999					
Tons per month [Mths 1-3] × Vieques	0.011	-0.023	0.012	-0.197	-0.008	-0.003
	(0.019)	(0.021)	(0.018)	(0.211)	(0.011)	(0.004)
	[0.260]	[0.013]	[0.195]	[0.078]	[0.130]	[0.078]
Tons per month [Mths 4-6] × Vieques	0.009	-0.046**	0.036*	0.034	-0.009	-0.005
	(0.019)	(0.018)	(0.020)	(0.233)	(0.010)	(0.004)
	[0.351]	[0.013]	[0.052]	[0.338]	[0.091]	[0.039]
Tons per month [Mths 7-9] × Vieques	-0.048***	0.005	0.043***	0.158	-0.032***	0.000
	(0.016)	(0.015)	(0.014)	(0.203)	(0.012)	(0.005)
	[<0.001]	[0.351]	[<0.001]	[0.143]	[0.013]	[0.494]
Mother Characteristics	No	No	No	No	No	No
Municipality Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N		13170 / 9046			13170 / 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. We also report the approximate p-value from the percentile rank of the coefficients from permutation exercises. 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: Robustness Tests

	Dependent variable: Congenital anomaly (1/0)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: End of Naval Practices, All Births 1990-2003							
End of Naval Practices × Vieques	-0.0080***	-0.0079***	-0.0075***	-0.0079***	-0.0069***	-0.0068**	-0.0063**	-0.0068**
	(0.0024)	(0.0024)	(0.0024)	(0.0023)	(0.0026)	(0.0026)	(0.0026)	(0.0026)
	[0.065]	[0.065]	[0.065]	[0.065]	[0.078]	[0.091]	[0.117]	[0.104]
	Panel B: Intensity of Bombing - Overall Effects, All Births 1990-1999							
Tons per month [Mths 1-9] × Vieques	0.0072*	0.0063	0.0074*	0.0067	0.0086**	0.0078*	0.0088**	0.0082*
	(0.0041)	(0.0042)	(0.0041)	(0.0042)	(0.0041)	(0.0042)	(0.0041)	(0.0042)
	[0.104]	[0.104]	[0.104]	[0.104]	[0.091]	[0.104]	[0.078]	[0.091]
	Panel C: Intensity of Bombing - Trimester-Specific Effects, All Births 1990-1999							
Tons per month [Mths 1-3] × Vieques	-0.0003	-0.0006	-0.0003	-0.0006	0.0002	-0.0001	0.0001	-0.0002
	(0.0018)	(0.0018)	(0.0018)	(0.0018)	(0.0017)	(0.0017)	(0.0017)	(0.0017)
	[0.468]	[0.364]	[0.468]	[0.364]	[0.351]	[0.505]	[0.390]	[0.519]
Tons per month [Mths 4-6] × Vieques	0.0041**	0.0038**	0.0041**	0.0039**	0.0047**	0.0044**	0.0047**	0.0045**
	(0.0018)	(0.0018)	(0.0018)	(0.0018)	(0.0019)	(0.0019)	(0.0019)	(0.0019)
	[0.052]	[0.052]	[0.052]	[0.052]	[0.039]	[0.039]	[0.039]	[0.039]
Tons per month [Mths 7-9] × Vieques	0.0054**	0.0051**	0.0041**	0.0055**	0.0059**	0.0056**	0.0061**	0.0060**
	(0.0023)	(0.0023)	(0.0018)	(0.0023)	(0.0024)	(0.0024)	(0.0024)	(0.0024)
	[0.026]	[0.039]	[0.013]	[0.026]	[0.013]	[0.026]	[0.013]	[0.013]
Mother Characteristics								
Education Controls	Yes	Yes			Yes	Yes		
Age Controls	Yes		Yes		Yes		Yes	
Municipality & Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local Economic Activity Controls					Yes	Yes	Yes	Yes
N	13170 / 9046				13170 / 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. We also report the approximate p-value from the percentile rank of the coefficients from permutation exercises.

Table 7: Bombing Activity and Other Health Outcomes at Birth, 1990-2003

	Dependent variables:			
	Premature birth	Extremely preterm birth	Low birth weight	Low APGAR score
	(1)	(2)	(3)	(4)
	Panel A: End of Naval Practices, All Births 1990-2003			
End of Naval Practices × Vieques	0.0182	-0.0032	-0.0221	0.0070
	(0.0200)	(0.0053)	(0.0284)	(0.0057)
	[0.182]	[0.416]	[0.130]	[0.208]
	Panel B: Intensity of Bombing - Overall Effects, All Births 1990-1999			
Tons per month [Mths 1-9] × Vieques	0.0175	0.0079*	0.0138	0.0103*
	(0.0209)	(0.0045)	(0.0206)	(0.0058)
	[0.156]	[0.013]	[0.130]	[0.065]
	Panel C: Intensity of Bombing - Trimester-Specific Effects, All Births 1990-1999			
Tons per month [Mths 1-3] × Vieques	0.0155*	0.0036	-0.0027	0.0063**
	(0.0088)	(0.0023)	(0.0081)	(0.0030)
	[<0.001]	[0.013]	[0.286]	[0.039]
Tons per month [Mths 4-6] × Vieques	0.0117	0.0009	0.0043	0.0033
	(0.0116)	(0.0015)	(0.0100)	(0.0039)
	[0.065]	[0.208]	[0.182]	[0.130]
Tons per month [Mths 7-9] × Vieques	-0.0106	0.0021	0.0151	-0.0006
	(0.0133)	(0.0023)	(0.0108)	(0.0031)
	[0.065]	[0.052]	[0.026]	[0.351]
Mother Characteristics	No	No	No	No
Municipality & Month-Year Fixed Effects	Yes	Yes	Yes	Yes
Δ Outcome from One SD Δ in TPM				
Panel B	0.008	0.004	0.006	0.005
Panel C	0.014	0.006	0.014	0.008
Outcome Mean	0.149	0.008	0.110	0.013
N	13170 / 9046		13170 / 9046	

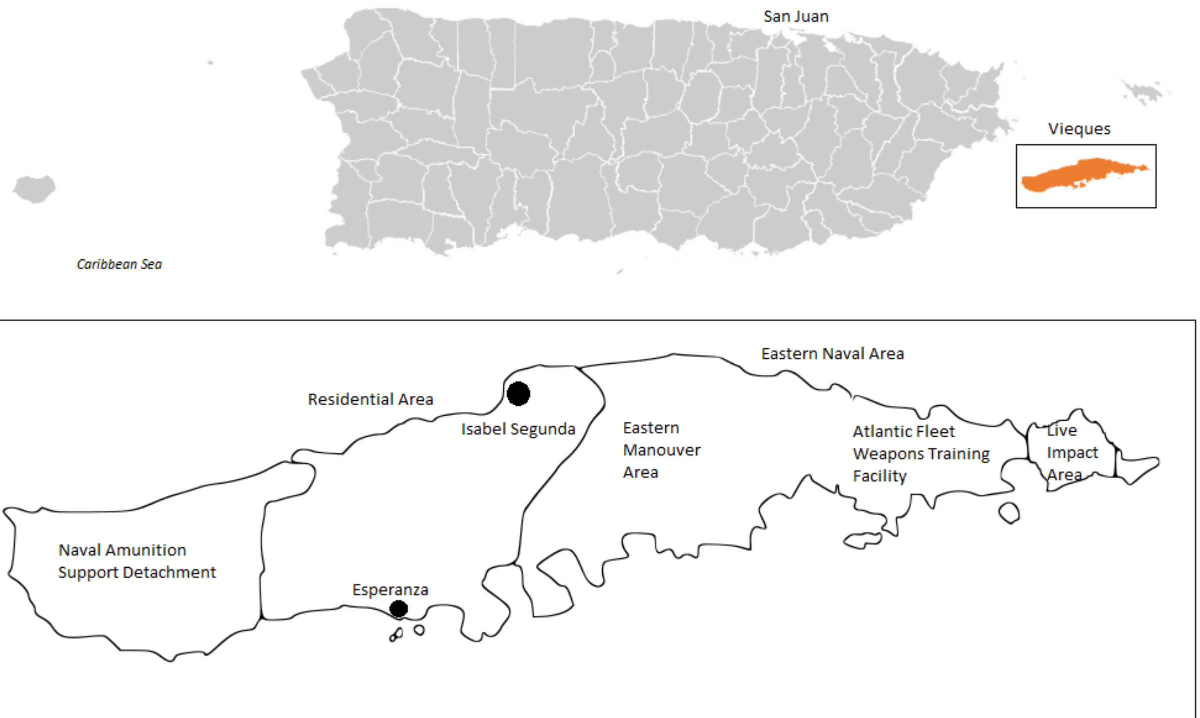
Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by panel and column) is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. We also report the approximate p-value from the percentile rank of the coefficients from permutation exercises. 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 A1: Bombing Activity and Health Outcomes at Birth, 1990-2003 – Lagged Dependent Variable

	Dependent variable: Congenital anomaly (1/0)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Panel A: End of Naval Practices, All Births 1990-2003							
End of Naval Practices × Vieques	-0.0063***	-0.0051**	-0.0050**	-0.0055**	-0.0055**	-0.0045*	-0.0046*	-0.0052**
	(0.0024)	(0.0023)	(0.0024)	(0.0026)	(0.0023)	(0.0024)	(0.0025)	(0.0026)
	Panel B: Intensity of Bombing - Overall Effects, All Births 1990-1999							
Tons per month [Mths 1-9] × Vieques	0.0071	0.0075	0.0069	0.0067	0.0084*	0.0087*	0.0079	0.0076
	(0.0047)	(0.0049)	(0.0050)	(0.0050)	(0.0048)	(0.0050)	(0.0050)	(0.0051)
	Panel C: Intensity of Bombing - Trimester-Specific Effects, All Births 1990-1999							
Tons per month [Mths 1-3] × Vieques	-0.0002	-0.0005	-0.0009	-0.0014	0.0001	-0.0001	-0.0006	-0.0011
	(0.0021)	(0.0023)	(0.0025)	(0.0026)	(0.0021)	(0.0023)	(0.0025)	(0.0026)
Tons per month [Mths 4-6] × Vieques	0.0034	0.0030	0.0023	0.0025	0.0039*	0.0035	0.0027	0.0029
	(0.0023)	(0.0023)	(0.0023)	(0.0023)	(0.0024)	(0.0023)	(0.0023)	(0.0023)
Tons per month [Mths 7-9] × Vieques	0.0053**	0.0055**	0.0056**	0.0057**	0.0058**	0.0059**	0.0059**	0.0061**
	(0.0024)	(0.0023)	(0.0024)	(0.0024)	(0.0024)	(0.0023)	(0.0024)	(0.0024)
Lags of dependent variable	1	2	3	4	1	2	3	4
Mother Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality & Month-Year FE's	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local Economic Activity Controls					Yes	Yes	Yes	Yes
N	13071 / 8958	12981 / 8872	12892 / 8787	12804 / 8703	13071 / 8958	12981 / 8872	12892 / 8787	12804 / 8703

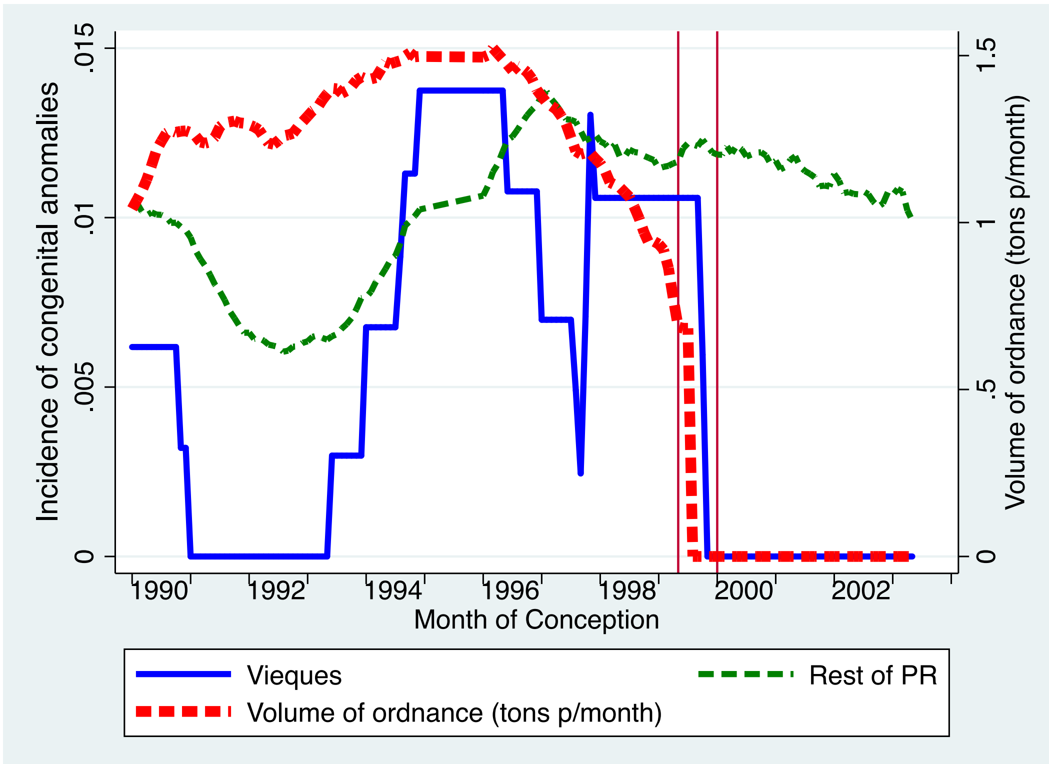
Notes: Coefficient estimates from municipality fixed effects regressions; each set of estimates (by panel and column) is from a different regression. Robust standard errors to general forms of cross-sectional (across municipalities) and temporal (within municipality) dependence (Driscoll and Kraay 1998) in parentheses; significant at (*) 90 percent, (**) 95 percent, (***) 99 percent confidence levels. We also report the approximate p-value from the percentile rank of the coefficients from permutation exercises.

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 Volume During Naval Exercises and Incidence of Congenital Anomalies, 1990-2003



Notes: Ordnance volume during naval exercises (bold dashed line); incidence of congenital anomalies by month of conception, for live births of mothers resident in Vieques (solid) and in the rest of PR (dashed line) (24-month moving average).