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Public Health in the First Mortality Transition in the Tropics

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Abstract

This paper assesses the role of public health in Puerto Rico during one of the fastest mortality transitions in history and the first outside of Europe and Western offshoots. Using newly digitized, municipal-level data from 1923 to 1945 in an event study framework, I show that public health units (PHUs, or county health departments) were responsible for most of the reduction in infant and tuberculosis mortality and one-third of the decline in general mortality during the first half of the transition—and did so without significantly increasing public expenditures. PHUs also reduced stillbirths and maternal mortality but had no effect on malaria mortality. More per capita nurses and midwives, but not sanitary inspectors, are associated with steeper declines in infant and maternal mortality, suggesting the importance of, e.g., home visits, prenatal clinics, and occupational licensing. These results challenge the emphasis in the literature on postwar economic growth as the catalyst for improvements in health and provide evidence of the efficacy of anti-tuberculosis measures (e.g., quarantine and contact tracing) before modern medicine. More broadly, this paper provides a window into historical public health in Latin America, since most countries subsequently established local health departments but did not publish reliable vital statistics.

Keywords: public health; economic history; Puerto Rico; United States

JEL Classification Numbers: I15, I18, F54, N32, N36

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1 Introduction

The decline in mortality rates over the past two centuries ranks among the most significant achievements in history, greatly contributing to human welfare across the world. Life expectancy more than doubled, and children die at rates far below historical averages (Lee, 2003). There is an ongoing debate in the social sciences regarding the relative contributions of public health and economic growth to this process prior to modern medicine (Anderson et al., 2020b; Cutler and Miller, 2005), and the conclusions from this strand of research have important implications for parts of the developing world where contagious and infectious diseases are more prevalent and infant mortality remains high. In particular, such research may provide insight for combating tuberculosis (TB) without antibiotics, since TB remains a leading cause of death worldwide, and drug-resistant forms of the disease have emerged in recent years (Reid et al., 2019).

In this paper, I assess the role of public health in the mortality transition in Puerto Rico. Despite a GDP per capita less than one-fifth of the US level and a predominately agrarian society, Puerto Rico completed the first mortality transition outside of Europe and Western offshoots, doing so with public health administered primarily by native doctors and nurses and funded mostly by domestic taxes.[1] The mortality transition in Puerto Rico ranks among the most successful: between 1930 and 1960, life expectancy increased by 28.8 years—a rate unprecedented, and still nearly unsurpassed, in world history—and achieved parity with the United States (see Fig. 1).[2] Puerto Rico overcame a high disease burden typical of the tropics, where health outcomes are worse even after controlling for per capita income (Sachs, 2001), and one of the highest rates of TB mortality in the world (Yelton, 1946), leading a former commissioner of health to declare that "the progress of Puerto Rico in public health

1 Sixty percent of the labor force was employed in agriculture and 78 percent of the population resided in rural areas in 1920 (Vázquez Calzada, 1978). Urban areas were defined by the Census as cities, towns, and villages with 2,500 or more inhabitants. Comparisons of GDP per capita are based on data from Devereux (2019) and Bolt et al. (2018).

2 Excluding recoveries from large, negative health shocks (e.g. war), the only countries with a larger increase in life expectancy over any thirty-year period are Libya after the discovery of oil reserves (29.7 years, 1955-85) and Russia under Stalin (30.3 years, 1930-60).

has no parallel in any other country" (Bourne and Bourne, 1966, p. 81).

Using newly digitized, municipal-level data from 1923 to 1945 in an event study framework, I estimate the decline in mortality attributable to public health units (PHU), or subdivisions of the Department of Health designed to improve local coordination of public health education, control of communicable diseases, and child hygiene, primarily through preventative care and education. I exploit temporal and municipal variation in the rollout of the program to identify the effect of PHUs on mortality, as a unit opened in each municipality between 1926 and 1937. I estimate that PHUs were responsible for most of the decline in infant and TB mortality and about one-third of the decline in overall mortality during the initial phase of the mortality transition. PHUs also reduced stillbirths and maternal mortality but, consistent with the historical record, had no effect on malaria mortality. Using a cross-section of personnel from 1935, I find that more per capita nurses and midwives, but not sanitary inspectors, are associated with steeper declines in infant and maternal mortality, suggesting the importance of, e.g., home visits, prenatal clinics, and occupational licensing. The effect on infant mortality was also larger in rural areas, which previously lacked access to professional health services, while the effect on TB mortality was larger in urban areas, where TB was more prevalent and where anti-TB efforts were focused. The results are robust to estimators which allow for heterogeneity in treatment effects over time or across municipalities (Borusyak and Jaravel, 2018; de Chaisemartin and D'Haultfoeuille, 2020) and to controlling for time-varying demographic characteristics (i.e. shares of population female, nonwhite, younger than 5, and literate), municipality-specific linear trends, municipality characteristics linear trends, and the existence of a public water system.

Modeled after county health departments in the American South, PHUs were a joint effort by municipalities, the Puerto Rico Department of Health, and the Rockefeller Foundation. As the objectives of the Department of Health expanded beyond sanitary police and the suppression of epidemics, officials recognized the inefficiency of having every activity controlled by a separate arm of the insular government in the capital, San Juan (Pons, 1952). The PHU was implemented to unify control over health work under a full-time medical officer who could more effectively identify and respond to local problems. Puerto Rico prioritized the establishment and expansion of PHUs with the confidence that they, "more than anything else," could resolve ongoing public health problems (Governor of Puerto Rico, 1932, p. 6). In 1938-39, the first fiscal year in which all municipalities were served, PHUs gave 25,873 public lectures to 717,057 attendees, made 164,623 nurse home visits, and medically examined 170,576 school children—for a population of 1.8 million (Commissioner of Health, 1939). Remarkably, these accomplishments occurred during the Great Depression, when aid from outside sources was steadily diminishing, and without significantly increasing public expenditures (Payne, 1942). The Department of Health continued the rollout of PHUs despite a shrinking budget, including a 29 percent cut from 1931-32 to 1933-34, by simplifying its organization and eliminating unnecessary expenses. A back-of-the-envelope calculation indicates that the benefits of PHUs exceeded costs by a ratio of 22 to 1.

The mortality data introduced in this paper offer a glimpse into historical public health outside of Europe and Western offshoots. Data this granular and consistently reported are rare for a developing country from this time period (Preston, 1980). Even today, roughly 70 percent of the world's population lives in areas without complete registration of deaths (defined as more than 90 percent) (Mahapatra et al., 2007). As a US territory, Puerto Rico published reliable vital statistics, unlike most countries and territories in Africa, Asia, and Latin America.[3] After Puerto Rico, practically all countries of Latin America adopted public health units to deal with problems at the local level, so these data allow for a window into public health in Latin America more broadly (Bravo, 1958). Puerto Rican infant mortality data from 1927 to 1943 are used by McEniry (2011, 2014), but the present analysis builds on the data with additional outcome variables and years covered and is the first effort to explain changes in mortality. These data complement county-level mortality data for the

[3] According to Vázquez Calzada (1984, p. 174), the Civil Registration collected "very complete" death records from 1888 forward—that is, preceding US rule. However, an analysis of vital statistics in the 1899 US Census report concludes that the official mortality rate was severely understated (Davis, 1900).

United States digitized by Hoehn-Velasco (2018) for 1910 to 1936 and Bailey et al. (2018) for 1915 to 2007.

This paper builds on several strands of literature. First, this paper contributes to an ongoing debate on the contributions of public health and economic growth in the mortality transition prior to modern medicine (Anderson et al., 2020b; Costa, 2007; Cutler and Miller, 2005; Fogel, 2004; McKeown, 1979). Studying Puerto Rico enriches the discussion by introducing evidence from outside of Europe and Western offshoots. I also bring a debate on Puerto Rico into the wider literature: because the decrease in mortality accelerated while growth of GDP per capita and labor productivity ranked among the fastest rates in the world (Baumol and Wolff, 1996), there is disagreement about whether public health mattered (Davis, 1953; Molina and Noam, 1964; Stolnitz, 1953; Vázquez Calzada, 1984). While not ruling out the importance of economic growth, this paper highlights the role played by PHUs in Puerto Rico and confirms that the large reduction in mortality began during the Great Depression, prior to the postwar economic expansion.

More narrowly, this paper contributes to a debate regarding the efficacy of anti-TB efforts before the advent of antibiotics. Such research may be especially consequential because public health officials are increasingly searching for historical solutions to address the crisis of drug-resistant TB (Dheda and Migliori, 2012). In 2017, 1.6 million people died from TB, mostly in developing countries (Reid et al., 2019). Evidence of large reductions in TB caused by PHUs is consistent with Bauernschuster et al. (2019), Hollingsworth (2014), and Hansen et al. (2020) but stands in contrast to Anderson et al. (2019a) and Clay et al. (2020), who conclude that early efforts to combat TB in the United States found limited success. Pinpointing the measures that mattered is difficult because PHUs carried out many activities, but the confluence of this investigation with Hollingsworth (2014) and Hansen et al. (2020) suggests that quarantines, contact tracing, and instructions on how to prevent transmission may have been effective.

Two related studies are Hoehn-Velasco (2018, 2020), which find that county health departments led to a modest reduction in mortality in the rural, but not urban, United States from 1910 to 1933, and both papers follow the research design of Bailey and Goodman-Bacon (2015) in studying community health centers. Although county health departments were the inspiration for PHUs, the estimated effect on mortality in Puerto Rico is larger than that found in the continental United States. This paper also complements studies on public health efforts led by nurses (e.g., home visits and clinics for new mothers, as in Puerto Rico) (Bhalotra et al., 2017; Bütikofer et al., 2019; Moehling and Thomasson, 2014; Wüst, 2012) and the training and licensing of midwives (Anderson et al., 2020a; Kotsadam et al., 2017; Lazuka, 2018; Pettersson-Lidbom, 2015) in the United States and Scandinavia in the early 20th century, since in Puerto Rico more nurses and midwives per capita are associated with greater declines in infant and maternal mortality.

More generally, this investigation follows research on historical public health in the United States (Alsan and Goldin, 2019; Anderson et al., 2019a, 2020a, 2019b; Clay et al., 2019; Ferrie and Troesken, 2008; Kitchens, 2013; Komisarow, 2017; Olmstead and Rhode, 2004), including investments made by the Rockefeller Foundation (Bleakley, 2007). This paper also resembles research on Cuba, whose economic trajectory and semi-colonial status before the communist revolution tracked Puerto Rico. Díaz-Briquets (1981) and McGuire and Frankel (2005) link Cuba's early mortality transition to its proximity and close political and economic ties to the United States, starting with extensive sanitary reforms under US occupation and followed by infrastructure investments facilitated by the expansion of the sugar industry.

In addition, this paper contributes to research on the effectiveness of foreign aid in general (Easterly, 2006; Sachs, 2005) and health sector aid in specific (Mishra and Newhouse, 2009; Williamson, 2008; Wilson, 2011). Although Puerto Ricans were responsible for most PHU funding and personnel, the International Health Board of the Rockefeller Foundation played a key role in transplanting the model of county health departments from the United States to the island. The foundation assisted in the training of nurses, partially funded several units, and advised all units, assigning American physician George C. Payne to serve as the

Director of Public Health Units. Since PHUs also were financially supported by the federal government while Puerto Rico was under direct US rule, this study builds on the history of colonial medicine (Greene et al., 2013; Lowes and Montero, 2018; MacLeod and Lewis, 1988), a precursor to Western aid to the developing world, especially in US territories (Amador, 2015; Anderson, 2006; Moralia, 2009; Sullivan, 1988).

Finally, this paper follows several studies challenging the pessimistic view of changes in living conditions in Puerto Rico between the Spanish-American War in 1898 and US entry into World War II in 1941 (Ayala and Bergad, 2002, 2020; de Jesús Toro, 1982; Devereux, 2019; Marein, 2020a,b,c). Previous work on public health emphasizes improvements in health outcomes starting in the 1940s, noting that the fastest growth in life expectancy coincided with the eradication of malaria, the introduction of antibiotics, and improvements in material living standards during the postwar economic expansion (Molina and Noam, 1964; Rigau-Pérez, 2000; Vázquez Calzada, 1984).[4] In contrast, this paper stresses that the large increase in life expectancy commenced prior to the postwar expansion and chronicles the evolution of public health in the interwar period. González (2015) and McEniry (2014) cover aspects of progress in public health in this era, and Ramírez de Arellano (1981) recounts the politics of public health from 1926 to 1940 with extensive archival evidence. This paper provides the most detailed description of the activities of public health units, "the backbone of the field organization for public health services," and is the first to quantify the impact of the program (Commissioner of Health, 1942, p. 13).

[4] Davis (1953, pp. 117-118) is an exception, noting that the five leading causes of death all experienced sharp declines after 1932 and that "Puerto Rico has telescoped into a few years the health progress made in advanced countries over several decades." Commissioner of Health Juan A. Pons, quoted in Bourne and Bourne (1966), also recognized improvements after 1930.

2 Public Health Units in Puerto Rico

2.1 Program Overview

After a wave of public health investments and a steep drop in mortality following annexation by the United States in 1898, Puerto Rico experienced little change in mortality between 1910 and 1930 in spite of continued investment in rural sanitation, public waterworks and sewerage, and vaccinations (see Fig. 2) (Vázquez Calzada, 1984). As the Department of Health expanded the scope of its activities in the early 1920s to address ongoing problems, officials perceived certain defects in the operation of local health work, with each activity controlled by a separate bureau in San Juan and without coordination within municipalities (Pons, 1952). In 1925, a representative of the International Board of Health of the Rockefeller Foundation suggested that Puerto Rico might adopt the system of county health departments found in the United States to address local challenges, and the assistant secretary of health concurred after visiting a number of such departments. The new organizations were to be called public health units and would serve as the local subdivision of the Department of Health, making the public health services of the insular government readily available to each community. The purpose of the PHU was to unify the control of those activities related to the prevention of disease and the conservation of health in a local organization under a trained health officer. PHU policies were fixed by the Department of Health but varied in emphasis in accordance with changing local needs. Public health officials recognized PHUs as the "most effective and adequate means for the administration of public health matters" (Chaves, 1937a, p. 27).

Included in the work of each unit were the study and control of transmissible diseases; health education; medical inspection of school children; health promotion by special prenatal, infant, preschool and tuberculosis clinics; and the control of general sanitation, including inspection of food and drugs, supervision of construction and plumbing, and rural sanitation (Chaves, 1938c). Some activities undertaken by PHUs had previously been performed by multiple agencies operating under central control but lacking local coordination, but the rapid advance of the objectives of the Department of Health motivated the creation of a new institution for carrying out the more complicated procedures of modern health work. For example, prior to the opening of the first PHU, public health nursing was effectively nonexistent, as nurses were only employed in hospitals for bedside care (Chaves, 1938b). Physical examinations of schoolchildren, likewise, were conducted in few municipalities before 1926 but were universal by 1937 (Arbona, 1937).

Table 1 summarizes the significant accomplishments of PHUs in fiscal year 1938-39, the first full year in which all municipalities were served by a PHU. Among its various activities, PHUs gave 25,873 public lectures to 717,057 attendees, made 164,623 nurse home visits, and medically examined 170,576 school children, for a total population of approximately 1.8 million. About one in four prenatal cases received care in PHUs that year, and children regularly attended clinics for years past infancy (Arbona, 1940). PHUs were a central health institution with a footprint spanning much of society and even helped to erode distrust of modern health care by providing free, first-time access to professional services (Colombán Rosario and Carrión, 1938). Buildings for the operation of units were located in town centers, but their catchment areas included both the urban and rural populations within their territories (Ramírez de Arellano, 1981). Nurses made house calls in the rural hinterland by car, horse, and/or foot, and X-ray traveling units diagnosed TB cases in zones without a fixed X-ray unit. In Arecibo, and perhaps elsewhere, clinics were routinely conducted in rural districts to serve those far away from the town (Chaves, 1938a).

PHUs coordinated all the health efforts of the community, including insular and municipal as well as public and private efforts. For example, PHUs organized the spread of tuberculosis hospitals and special programs on malarial control, with contributions from the local landowners and sugar company. Perhaps the most important complement to PHUs were milk stations, which commenced operations in 1930 and aimed at educating mothers in infant feeding and care and provided them with milk of good quality at a nominal cost. The

Department of Health estimated that mortality among infants attending the stations was 57 percent lower than general infant mortality over the island (Governor of Puerto Rico, 1932). Milk stations were nominally independent of PHUs but in practice were integrated with PHU services like prenatal care and screening for tuberculosis (González, 2015). In fact, milk stations were often housed in the same facility as PHUs: in 1938-39, 65 of the 68 milk stations were in PHUs, but this proportion varied over time.

Initially, municipalities were responsible for a quarter of their PHU budgets, with the Rockefeller Foundation covering another quarter and the Department of Health covering a half, and the share borne by municipalities was to grow over time. Other sources of PHU funding included the US Public Health Service, the Federal Emergency Relief Administration, and the Puerto Rico Reconstruction Administration. Earlier PHUs served single municipalities, but it soon became apparent that many small municipalities could not afford their own units. Consequently, the island was divided into districts consisting of one to four municipalities based on population, means of communication, and similarity in health problems (Chaves, 1938a). Each district had one or more full-time health officers and an allotment of office personnel, while each municipality had its own nurses and inspectors.

2.2 PHU Interventions

The leading causes of death in this era were infectious and parasitic diseases, accounting for approximately 60 percent of all mortality at the beginning of the study period (see Table 2). Consistent with the mortality transition in other settings (Lee, 2003), general mortality in Puerto Rico declined because of a reduction in deaths from infectious and parasitic diseases (see Table 3). Trends in mortality rates from chronic and degenerative disease and external causes remained flat, while the share of all deaths caused by infectious and parasitic diseases fell to 48 percent in the late 1940s (Rivera de Morales, 1970; Vázquez Calzada, 1978). Below I discuss interventions that could have been responsible for decreases in the six outcomes examined in this paper: infant mortality, TB mortality, maternal mortality, malaria mortality, general mortality, and stillbirths.

2.2.1 Infant and Maternal Mortality

PHUs provided extensive guidance on child hygiene and nutrition. Clinics instructed mothers how to properly bathe and clothe the baby; take care of the eyes, mouth, teeth, skin, and genital organs; and prepare baby formula and keep utensils clean (Nochera, 1940). Nurses tracked the health of children under the care of milk stations through daily visits with mothers, advising mothers when to bring the child to a doctor or examining the child at home and seeking medical attention when needed (Garrido Morales, 1937). Milk stations had a duty to encourage breastfeeding at least until a child reached nine months (Garrido Morales, 1937), and breastfeeding is associated with lower rates of mortality from diarrhea and enteritis, pneumonia, and bronchitis in developing countries (Lamberti et al., 2013; World Health Organization, 2000). In 1930, a survey in the Santurce neighborhood of San Juan found that the majority of infant deaths occurred in children who were not breastfed, and in almost all of these cases the children "had been given herb teas in dirty bottles... [or] dirty pacifiers..."; in cases of breastfed children, the mother "had not been careful to keep her breasts clean" (Fernós Isern and Rodríguez Pastor, 1930, p. 163). Children admitted to a milk station were examined by the medical officer of the PHU, who prescribed a milk formula in accordance with the age and health of the child.

In addition, some PHU efforts combated both infant and maternal mortality. PHUs administered an intensive program of midwife supervision launched by the Bureau of Infant Hygiene (Van Horn, 1940). After discovering in 1931 that all children who died of infantile tetanus had been attended at birth by unlicensed midwives "under conditions where cleanliness and asepsis were entirely absent," the Bureau took charge of the instruction, supervision, and licensing of assistant midwives (Robert de Romeu, 1938, p. 56). The effect of occupational licensing on maternal mortality is theoretically ambiguous. Licensure should push low-quality providers out of the market and raise the quality of those who remain, but it may also increase the price of and reduce access to midwifery services (Anderson et al., 2020a). In Puerto Rico, however, the Health Department was created a new professional category, the assistant midwife, to differentiate them from midwives who had nursing degrees and had taken at least one year in a recognized school for midwives (del Río, 1938). Their strategy intended to maintain the accessibility of midwifery services while teaching assistant midwives the rudimentary principles of obstetrics and the care of mother and child at home. The law compelled midwives to attend classes once a week at PHUs until a license was granted. By 1938, licensed midwives attended 85 percent of all registered births. PHUs also distributed sterile umbilical dressings to midwives free of charge and required midwives to purchase antiseptic solutions and germicidal soaps.

The 1931 licensing law applied to entire island, but the arrival of PHUs in a community may have provided additional benefits. First, a nearby PHU would make courses on midwifery more accessible, leading to the decline of clandestine services. Second, prenatal clinics allowed for the early detection and treatment of contagious diseases and pregnancy complications, such as pre-eclampsia (Vilar Isern, 1942).

Finally, PHUs sought to eliminate uncinariasis (hookworm infection), which leads to iron-deficiency anemia and in pregnancy is associated with preterm labor, low neonatal weight, and increased newborn and maternal mortality (Camaschella, 2015; Hotez et al., 2004). Hookworm infection had been practically universal in rural communities, and expectant mothers were tested and treated at prenatal clinics. Sanitary inspectors from the PHUs visited homes to show people how to construct latrines; by 1939, practically every rural home had a latrine, and those unwilling to build a latrine were brought before justices of the peace and forced to conform with the sanitary regulations (Washburn, 1939).

2.2.2 Tuberculosis

Pulmonary tuberculosis, a disease caused by bacteria that spread from person to person through the air, was the leading cause of death among adults and was considered by the

Department of Health to be the "most serious health problem faced by the people of Puerto Rico..." (Commissioner of Health, 1933, p. 26), "unrivalled as Public Enemy Number One" (Rodriguez Pastor, 1944, p. 447). Nearly one-half of all deaths between the ages of 19 and 35 was caused by TB. According to the Chief of Tuberculosis, no country in Latin America had done as much to combat TB, and perhaps only Argentina and Uruguay had a system of TB dispensaries that could compare to that of the PHUs (Rodríguez Pastor, 1933).

PHUs provided education in the modes of spread of the disease and the essential features of prevention through clinics, an extensive house-to-house campaign, and the distribution of pertinent literature (Garrido Morales, 1935). Additionally, the Department of Health operated a closed system of treatment "from which the patient [could not] escape..." (Coryllos, 1937, p. 59). PHUs served as case-finding agencies, screening schoolchildren and attendees at their clinics and conducting house-to-house searches to direct those in contact with a TB patient to testing. All high school students underwent fluoroscopic examinations of the chest, since this age group was more susceptible to TB than younger children (Arbona, 1939). From the PHU, patients were sent to one of several anti-tuberculosis centers to confirm the diagnosis with an X-ray or sputum examination and subsequently relocated to the nearest TB hospital.[5] Hospitalization served to isolate infected persons to control transmission of the disease, and the island-wide anti-TB campaign launched in 1934 tripled the number of hospital beds available for tuberculosis patients (Rodríguez Pastor and Janer, 1953). Patients with active TB could undergo surgical procedures to collapse the lung and promote cavity closure, including induced pneumothorax or, if necessary, thoracoplasty or pneumonolysis at the hospital in Río Piedras. Cases that became negative were discharged, referred to their respective anti-tuberculosis center, and sent back to their hometowns to remain "under continuous supervision" by their PHU (Coryllos, 1937, p. 59). Transportation to the nearest anti-tuberculosis center to continue treatment was provided as needed.

[5] Since available funds were limited, tuberculosis hospitals admitted all types of cases of tuberculosis, serving as sanatoriums in addition to hospitals (Malaret, 1937a).

2.2.3 Malaria

PHUs provided anti-malarial drugs to those attending their clinics, participated in the destruction of larvae and other mosquito-control work, and employed special malaria inspectors to take surveys, draw blood samples, and treat cases in homes in areas where the disease was most prevalent (Malaret, 1937b). However, because of a lack of funds and trained field force, such activities by and large represented a continuation of the work that had started years ago rather than a new campaign. Prior to World War II, a malariologist in the Department of Health opined, "...it can readily be inferred that the number of inhabitants actually benefited is so reduced that it hardly affects the seriousness of the malaria conditions in the country at large" (Arbona, 1942, p. 257). The eradication of malaria did not begin in earnest until 1940, when the United States expanded its military presence in Puerto Rico and tasked the Office of Malaria Control in War Areas and the Works Project Administration with fighting the disease in areas near military installations (Miranda Franco and Casta Vélez, 1997).

2.2.4 Mortality from All Causes

Much of the decline in mortality from all causes can be attributed to decreases in infant, maternal, and TB mortality, addressed above. Several other activities may have further lowered overall mortality either through the direct reduction of disease transmission or by improving the ability to overcome disease. Child hygiene clinics and the school hygiene program offered advice to older children regarding a properly balanced diet, exercise, dental care, and hygiene (Nochera, 1940). The clinics also immunized children against smallpox, diphtheria, and typhoid. Teachers were encouraged to report any case of possible communicable disease among their students to the health officer of the local PHU (Arbona, 1937). The departments of health and education made a concerted effort to treat all children with hookworm infection in municipalities where PHUs had been established after examining the feces of urban schoolchildren through third grade and all rural schoolchildren each year (Chaves, 1937b). PHUs instructed students to wear shoes and use latrines to avoid contracting the infection and contaminating the soil. Inspectors enforced sanitary regulations for the building of houses, pure water supply for communities, and the latrine system and worked to root out the adulteration of milk, food, and drugs (Robert de Romeu, 1937).

2.2.5 Stillbirths

Several PHU activities could have contributed to the decline in stillbirths. First, syphilis tests were required in all prenatal clinics, with free treatment provided for all positive cases (Quintero, 1940). Presently, syphilis causes most infectious stillbirths in developing countries where it is prevalent, with 40 percent of fetuses dying in utero when maternal syphilis is left untreated (Goldenberg et al., 2010). Second, PHUs lessened the burden of pulmonary tuberculosis, which is associated with an elevated risk of perinatal death (Jana et al., 1994). Finally, PHUs may have brought down the number of stillbirths resulting from malaria by reducing morbidity through the anti-malarial measures described above. *Plasmodium falciparum* and *Plasmodium vivax* malaria in pregnancy both increase stillbirth risk, and both strains were prevalent in Puerto Rico (Moore et al., 2017). When detected and treated during pregnancy, *P. vivax* malaria is not associated with stillbirth, while *P. falciparum* malaria is associated with stillbirth to a lesser extent than when left untreated.

3 Mortality Data and Health Unit Openings

I document the rollout of PHUs using annual reports of the Commissioner of Health and histories of PHUs written by a director of PHUs (Chaves, 1942). The dataset includes information on fiscal year of inauguration as well as a list of municipalities with PHUs and those municipalities with corresponding subunits, since the island was divided into districts consisting of one to four municipalities with shared health officers. In all but two municipalities, a PHU remained open through the end of the study period once it commenced operations. In Loíza and Trujillo Alto, PHU services were extended from neighboring communities for one year, ceased for several years, and eventually resumed. I assign the later date of inauguration to both municipalities but explore the robustness of results to dropping these municipalities in the appendix. Finally, there are discrepancies in the inauguration dates for a few municipalities, most importantly for several of the largest cities and towns (San Juan, Ponce, Mayagüez, and Aguadilla). I rely on the earliest opening date found in annual reports of the Commissioner of Health, but I demonstrate in the appendix that the regression results are robust to assigning inauguration dates based on Chaves (1942).

Figure 3 shows the number of PHUs openings by fiscal year and illustrates the rollout of PHUs over time and space from 1926 until all municipalities, save the sparsely populated island of Culebra, had a unit in 1937. Río Piedras was selected as the site of a demonstration unit because it was considered characteristic of the northeastern coast of the island; contained urban and rural populations; allowed for easy communication with the central office in neighboring San Juan; was rapidly gaining in wealth and importance; was home to the university and various health facilities; and had municipal authorities willing to cooperate and fund the PHU (Martínez Rivera, 1943).[6] The second unit opened in 1927 in Yabucoa, to represent the sugar region, followed in 1929 by Adjuntas, to represent the coffee region, and Cayey, to represent the tobacco region.[7] The extension of PHUs to the entire island was expedited in 1931 by a grant from the Puerto Rico Child Health Committee (Payne, 1942), and PHUs rapidly spread throughout the 1930s with constant pressure from municipal authorities who wanted their communities to be included (Chaves, 1942).

I link data on PHU operations to annual, municipal-level mortality data that I digitized from annual reports of the Commissioner of Health for 1923 to 1945. Several years of missing data were supplemented with monthly data extracted from the *Porto Rico Review of Public Health and Tropical Medicine* or quarterly data from the *Puerto Rico Health Bulletin.* Mortality rates are reported by fiscal year through 1929 and by calendar year thereafter.

[6] Río Piedras was annexed by San Juan in 1951.

[7] PHUs also opened in fiscal year 1928-29 in Caguas, Cataño, and San Juan.

Annual data are available for all municipalities for the following years: overall mortality (1923-45), infant mortality (1924-45), stillbirths (1924-45), tuberculosis mortality (1923-45, except 1930), malaria mortality (1924-45, except 1927 and 1930), and maternal mortality (1924-1945, except 1927, 1929, and 1930).[8] Mortality from tuberculosis in 1930 and from malaria in 1927 and 1930 are interpolated. All outcomes are measured by place of occurrence. The data include the entire population, as the municipalities (*municipios*) are analogous to counties in the United States and cover the whole territory. I exclude the island municipality of Culebra, due to missing data and its small population (e.g. 847 in 1930), and aggregate data for Bayamón and Cataño throughout the sample because Cataño split off of Bayamón in 1927 and hence did not report its own data in years prior.

Figure 4 displays annual data on overall and infant mortality, which were regarded as reliable since all deaths were required by law to be registered (Hardy and Kramer, 1941).[9] A renewed decline in mortality rates coincided with the rollout of PHUs. Mortality from all causes returned to normal levels after the 1918-19 influenza pandemic and then fluctuated throughout the 1920s and early 1930s, with an uptick in 1928 resulting from Hurricane San Felipe. From 1933 forward, there was a general decline in overall mortality, from 22.6 in 1933 to 14.1 in 1945—a decrease of 38 percent. The infant mortality rate followed a similar pattern, averaging around 150 deaths before age one per 1,000 live births throughout the 1920s before starting a general decline in the early 1930s. Between 1933 and 1943, the infant mortality rate fell by 32 percent, from 139.4 to 95.3. Similarly, the stillbirth rate hovered around 85 per 1,000 total births through 1930, dropped mechanically to 71.0 in 1931 after a new law required stillbirths to be registered only if the fetus had advanced to the fifth

[8] Other forms of mortality are not frequently reported at the municipal-level in official reports, so I cannot use such outcomes in placebo tests. Instead, in the online appendix I show that the estimated effect of PHUs is much more negative than would be expected from a placebo intervention in which treatment timing is randomly assigned.

[9] The completeness of death registration stemmed from the tendency to bury the dead in cemeteries, resulting from the accessibility of cemeteries and the customs and religious beliefs of the vast majority of the population (Janer, 1945; Rodríguez Pastor and Janer, 1953; Vázquez Calzada, 1984). Consistent with its reputation for reliable death records, Puerto Rico was immediately admitted to the US Death Registration Area after its vital statistics system was centralized in 1931.

month of uterogestation, then declined almost continuously to a low of 56.2 in 1943, or a decrease of 21 percent following the new registration law. Lastly, maternal mortality stayed around 6.8 deaths per 1,000 live births in 1920s, fell to 5.9 in 1931 and below 5.0 by the late 1930s—around the time that sulfa drugs became widely available (Jayachandran et al., 2010; Thomasson and Treber, 2008)—and plummeted to 3.0 in 1945, a reduction of 57 percent from the 1920s.

Annual data on mortality rates for specific diseases are less reliable, especially before the creation of the Bureau of Vital Statistics in 1931 centralized and standardized data collection. Physicians often had to guess the cause of death in the absence of sound diagnostic practices and frequently signed death certificates without ever having seen the deceased, relying instead on information provided by friends and relatives (Commissioner of Health, 1926). Diagnoses were even less certain outside of major cities due to shortages of doctors. Still, in Figure 4 I present mortality rates specific to tuberculosis and malaria, two of the deadliest diseases at the time and diseases which were targeted by PHUs. Tuberculosis mortality exhibited an upward trend over the first half of the sample, rising by 62 percent between 1923 and 1933, but fell steadily thereafter and decreased by 39 percent by 1945. Malaria mortality likewise increased, from 1.05 deaths per 1,000 inhabitants in 1921 to 2.04 deaths in 1931. Mortality from malaria then decreased by 79 percent through 1945, with much of the decline occurring during World War II, when the United States escalated its anti-malarial campaign to protect troops stationed on the island (Miranda Franco and Casta Vélez, 1997). Note, however, that the apparent increases in deaths from tuberculosis and malaria, respectively, up to 1931 are likely due to improvement in cause of death certification rather than the spread of those diseases. For instance, tuberculosis mortality paralleled overall mortality beginning with the centralization of data collection in 1931-32, casting doubt on the reliability of figures for previous years (Rodríguez Pastor and Janer, 1953).

Measurement error for mortality rates should be of little concern because it likely works against finding that PHUs significantly decreased mortality rates. In the case of classical measurement error, regression coefficients will be unbiased but standard errors will be inflated. Alternatively, it is conceivable that the underreporting of vital statistics is correlated with the timing of PHU openings, as heightened attention to local problems and the coordination of activities island-wide may have improved record-keeping. The revision and centralization of the vital statistics system in 1931 may have had a similar impact (Janer, 1958). In either case, the opening of a public health unit would artificially increase mortality rates and attenuate the estimated effect of PHUs.[10]

4 Event Study Framework

My empirical strategy exploits temporal variation in the establishment of PHUs to quantify their effect on mortality rates. A key assumption of my approach is that the timing of PHU establishment is uncorrelated with other determinants of changes in mortality. In Table 4, I predict the order of PHU establishment with socio-demographic characteristics of municipalities and find that early adopters tended to be more urbanized and have higher initial mortality rates.[11] The result is not surprising because mortality rates were higher in urban areas, and more developed municipalities had greater resources to fund PHUs. Indeed, the largest cities and towns were among that earliest adopters, including Río Piedras in 1926-27, Caguas and San Juan in 1928-29, Mayagüez and Ponce in 1929-30, and Arecibo in 1930-31. Health dispensaries operated by the American Red Cross, the precursors to PHUs, had operated in San Juan since 1921 (Chaves, 1942). To account for these potential threats to internal validity, I include linear trends interacted with the share of the population in urban areas in 1930 and the average mortality rate from 1923 to 1926 in a robustness check

[10] Eriksson et al. (2018) determine that estimates of infant mortality in the US South before 1950 were biased upward because of severe underregistration of births and that underreporting of infant deaths was a minor issue. Births in Puerto Rico were also underreported, so it is plausible that published infant mortality rates decreased over time as birth registration improved. However, in Appendix C.3, I show that the results from the event study are nearly identical if the infant mortality rate is replaced with the ratio of infant deaths to population, which is unaffected by changes in birth registration.

[11] These results are corroborated by a Cox proportional hazards model. Other indicators of development, such as share of the labor force in agriculture and the number of physicians per capita, are excluded from the model because they are highly correlated with the urban share.

in Appendix C.[12] Importantly, pre-program trends in overall mortality do not predict the rollout of PHUs.

To identify the effect of PHUs on mortality rates, I start with the following event-study specification:

$$ln(Mortality_{mt}) = \theta_m + d_t + \sum_{k\neq -1} \gamma_k PHU_{mk} + \mathbf{X'_{mt}}\beta + \varepsilon_{mt} \quad (1)$$

where $Mortality_{mt}$ is one of five mortality rates (overall mortality, infant mortality, TB mortality, malaria mortality, or stillbirths) in municipality m in year t.[13] Maternal mortality is not included in the event study because of consecutive missing years of data but is considered in a difference-in-differences specification in Section 5.3. Overall mortality rates are the number of deaths, excluding stillbirths, per 1,000 inhabitants; TB and malaria mortality rates are the number of deaths per 100,000 inhabitants; the infant mortality rate is the number of deaths, excluding stillbirths, before age 1 per 1,000 live births; and stillbirth rates are the number of stillbirths per 1,000 total births. θ_m are municipality fixed effects to control for any time-invariant municipal characteristics correlated with the outcome variable, while d_t are year fixed effects to control for time-varying, territory-wide characteristics. $\mathbf{X_{mt}}$ is a vector of time-varying controls measured at the municipal level included in robustness checks. In various specifications, the vector may include linear trends interacted with municipality characteristics (urban share and pre-program mortality); an indicator variable equal to one if a municipality has a public water system and zero otherwise; municipality-specific time trends; and the fraction of the population that was female, nonwhite, younger than 5, and literate, linearly interpolated from the 1920, 1930, 1940, and 1950 censuses. Standard errors are clustered by municipality to allow for arbitrary correlation of errors within municipalities. Standard errors adjusted for spatial

12 Data on the share of the labor force employed in agriculture is not easily accessible for 1920 or 1930.

13 TB and malaria mortality are coded as $ln(1 + Mortality_{mt})$, where $Mortality_{mt}$ is measured per 100,000 inhabitants, since some values of $Mortality_{mt}$ are equal to zero. Results are robust to coding the dependent variable as $asinh(Mortality_{mt})$. Two observations report zero stillbirths, and I compute the stillbirth rate as if there were one stillbirth in both cases.

autocorrelation, regardless of the distance cutoff or time lag, are generally smaller than clustered standard errors, so they are relegated to Appendix C.12 (Colella et al., 2019; Conley, 1999). Observations are weighted by municipality population in 1935.

PHU_{mk} is the event study indicator variable equal to one if the PHU in municipality m is k years away from its inaugural year ($k = 0$) and zero in all other years.[14] Treatment is defined as being served by a PHU irrespective of the location of the PHU headquarters. In other words, treatment is assumed to be equivalent for municipalities with a unit and those with a subunit, or branch. Official reports offer no indication that municipalities with subunits were treated differently. The coefficients on PHU_{mk} characterize the effects of PHUs, relative to the year prior to PHU inauguration, $k = -1$, which is omitted.

I balance the panel by including leads and lags for all event-time periods for which there is an observation from each municipality. Observations more than four years (or three years for infant mortality and stillbirths) before or more than seven years after the establishment of a PHU are captured by dummies. The coefficients γ_k for $k < -1$ reveal the changes in the mortality rate in the four (three) years preceding the opening of its PHU, after controlling for aggregate trends and time-invariant municipality characteristics that affect mortality, and allow me to directly assess whether the timing of PHUs is exogenous to trends or shocks in mortality preceding inauguration. The parameters of interest are γ_k for $k > -1$, which measure the effect of PHUs on mortality in each year for seven years following the opening of a PHU.

Identification of the average treatment effect in this framework rests on a parallel trends assumption, requiring that mortality in treated municipalities would have followed a parallel path as untreated municipalities if not for PHUs. This assumption is reasonable given that

[14] Once again, mortality rates are reported by fiscal year through 1929 and by calendar year thereafter, but PHU treatment is reported by fiscal year over the entire sample. Mortality rates for fiscal year $t/t+1$ are coded as Year t, but a PHU opening in $t/t+1$ is coded as opening in $t+1$. This coding scheme means that, for data from 1927 to 1929, municipalities in Event Year 0 were treated for the entire year and had already been treated between 0 and 12 months in the previous year, depending on the month of PHU opening within the fiscal year. For data from 1930 to 1945, municipalities in Event Year 0 were treated at least 6 months and up to 12 months that year and had already been treated between 0 and 6 months in the previous year.

public health work developed “slowly and gradually” until 1926 (Chaves, 1937a, p. 27), and there were no striking changes in general or infant mortality between 1910 and 1930 (Vázquez Calzada, 1978, 1984). If, however, municipalities with the steepest (flattest) decline in mortality in the pre-period also were the first to open PHUs, the estimated effect of PHUs would be overstated (understated). This form of endogenous treatment, however, is unlikely because the earliest adopters were municipalities handpicked as test cases to represent the various regions of the island. Major urban centers also opened PHUs early, and Appendix C.7 presents results which allow for differential linear trends based on municipal socioeconomic characteristics. After 1932, the Health Department sought to extend PHUs to all municipalities as rapidly as possible, and did so partly by branching out from existing units, so treatment timing over the latter half of the sample is quasi-random (Chaves, 1942; Martínez Rivera, 1943). A related threat to identification is that municipalities were treated in response to a local mortality shock, such that the estimated effect of PHUs may capture mean reversion. This form of endogenous treatment, too, is unlikely in that there is no indication in any government report that areas with worsening disease environments were prioritized. In any case, an advantage of the event study framework is that it allows for direct observation of mortality trends preceding the opening of a PHU, and there is no evidence of pre-trends or mortality shocks preceding treatment.

5 Public Health Units and Mortality

5.1 Baseline Results

The results from the baseline event study specification are presented in Figure 5a. There is neither a discernible trend nor any spike in any outcome preceding PHU entry that is not captured by controls. All estimates of γ_k prior to treatment are small in magnitude and statistically indistinguishable from zero. This evidence strengthens the validity of the empirical strategy, confirming that the estimated treatment effects do not capture the mere continuation of falling mortality or mean reversion after a negative health shock. The absence of pre-trends lends credence to, but cannot prove, the assumption that mortality rates would have followed parallel trends in treated and untreated municipalities if not for PHUs.

Overall mortality subsequently dropped by approximately four percent in the first year following the opening of a PHU, significant at the 5 percent level. The treatment effect increased in magnitude over several years until leveling out around 10 percent. Likewise, the infant mortality rate fell by more than six percent in the first year, and the effect of PHUs grew over the next several years. Seven years after opening, PHUs reduced infant mortality by more than 12 percent. In general, the size of the effect of PHUs is roughly the same for overall and infant mortality, but the effect is more precisely estimated in the case of overall mortality. This can be explained by (classical) measurement error in infant mortality because less than 90 percent of births but almost 100 percent of deaths were registered in this era (Vázquez Calzada, 1968).

There is also some evidence that PHUs reduced the rate of stillbirths. The estimated effect of PHUs is equal to zero in the year of inauguration but turns negative thereafter. PHUs are estimated to have brought down the stillbirth rate by around four percent after one year and by ten percent after six years, but in no year is the estimated effect close to statistical significance at conventional levels. Nonetheless, the consistently negative effect is noteworthy given the presumed high degree of measurement error in the dependent variable, as there is no universally accepted definition for when a fetal death is called a stillbirth versus a miscarriage (Tavares Da Silva et al., 2016). Moreover, it is not surprising that PHUs are found to have no negative effect on stillbirths until year 1 even though there is a negative effect on total and infant mortality in year 0. Whereas improved health services can have an immediate effect on those already living, we should expect the effect on the unborn to materialize later.

Lastly, the results in Figure 6a show that the effect of PHUs on TB mortality was delayed but large: TB mortality dropped by about four percent in the inaugural year, 11 percent after one year, and between 16 and 23 percent in subsequent years. After the opening year, the estimated effect is statistically significant at either the 1 or 5 percent level in all years. The effect is comparable to that of TB dispensaries in Denmark (Hansen et al., 2020), where TB mortality declined by around 19 percent and began to fall 17-19 months after the introduction of a dispensary. In contrast, PHUs did not significantly affect malaria mortality. Although malaria mortality appears to fall after PHU inauguration, the decline was temporary, statistically insignificant, and not robust to alternative specifications, discussed in detail below.

5.2 Alternative Specifications

The specification above is standard in the literature but suffers from a major limitation. Difference-in-differences (DiD) models that impose restrictions on the dynamics of treatment effects estimate an average of treatment effects that severely overweighs short-run effects and weighs long-run effects negatively (Borusyak and Jaravel, 2018). When treatment effects vary over time, already-treated units act as controls, and changes in their treatment effects over time get subtracted from the DiD estimate (Goodman-Bacon, 2019). In the extreme case, a DiD coefficient could be positive even if all treatment effects are negative. Binning the endpoints of the event window with "before" and "after" dummies may inadvertently bias estimates of γ_k. For example, if long-run treatment effects are not constant, then the estimated effect for event-years after the event window will be unreliable. Through the wrong choice of unit and time fixed effects, the short-run effects will be biased.

I follow Borusyak and Jaravel (2018) to resolve this issue, starting with a model which imposes no restrictions on the dynamics of treatment effects. Terms corresponding to the year prior to PHU inauguration, $k_1 = -1$, and the earliest event-year in the sample, k_2, are dropped to be able to identify non-linear pre-trends.[15] The results from this specification

[15] The formal test of pre-trends is invariant to the choice of k_1 and k_2. Dropping periods far away from each other decreases the likelihood of observing a linear pre-trend (which is impossible to detect) and distracting attention from nonlinearities in pre-trends, making the graph of coefficients more useful.

appear in Figures 5b and 6b and should be used only to evaluate pre-trends since treatment effects are not estimated efficiently. Visual inspection of graphs for all outcomes offers no indication of trends preceding PHU openings, and coefficients before year 0 are generally quite close to zero. An F-test of the hypothesis that all leads of the treatment indicators are equal to zero renders the following p-values: 0.27, overall mortality; 0.10, infant mortality; 0.23, stillbirths; 0.36, TB mortality; and 0.40, malaria mortality. The relatively low p-value for infant mortality is the product of a large spike 12 years prior to the opening of a PHU, for which only 22 municipalities have data, and jumps up to $p = 0.61$ when that event-year is excluded from the F-test. The anomalous spike should, therefore, be of little concern. Stillbirths, likewise, exhibit negative spikes 13 and 12 years prior to PHU inauguration before following a flat path with coefficients near zero.

The results of the F-tests for all four outcomes justify imposing an assumption of no pre-trends and collapsing the model to a semi-dynamic specification without leads but with a full set of lags. Imposing this assumption increases the efficiency of the estimates of treatment effects when the restriction is true, and removing restrictions on the dynamics of treatment effects post-treatment eliminates bias stemming from the weighting problem described above, making the semi-dynamic model my preferred specification.

The results of the semi-dynamic model are displayed in the odd-numbered columns of Table 5, with treatment effects for event-years more than seven years after program adoption not shown. The coefficients estimated from the semi-dynamic and dynamic specifications are comparable. PHUs brought down mortality from all causes by four percent in their inaugural year, significant at the 5 percent level, and the effect grew to an 11 percent reduction after several years (95% CI: [-19.4%, -2.5%]). This reduction represents about 30 percent of the decline in mortality between 1923 and 1945 or more than half of the decline before US entry into World War II, during which the federal government launched an anti-malarial campaign to protect troops on the island and saved at least a thousand lives annually by the war's end (Miranda Franco and Casta Vélez, 1997).[16] Counterfactual estimates derived from the semi-dynamic model suggest that PHUs saved 3,430 lives in 1940 alone.[17]

PHUs also reduced infant mortality by seven percent in the first year, significant at the 1 percent level, and the effect grew to more than 18 percent by year 7 (95% CI: [-29.4%, -5.45%]). In other words, PHUs were responsible for about one-half of the decrease in infant mortality by 1945 and saved the lives of 1,766 infants under one year old in 1940, or 51 percent of all lives saved by PHUs that year. Stillbirths likewise fell by five percent in the first year with a PHU and by 25 percent after seven years (95% CI: [-45.6%, 4.5%]). The estimated effect on stillbirths is generally statistically insignificant or marginally significant. Still, given the high degree of measurement error in the dependent variable, this evidence is suggestive that PHUs may have helped to reduce stillbirths as well. The redefinition of stillbirths in 1931 and the severe extrapolation of estimated treatment effects for this outcome (discussed below) make it difficult to determine precisely the share of the decline in stillbirths attributable to PHUs, but PHUs seem to be the most important factor since stillbirths fell by 21 percent from 1931 to 1943. The central role of PHUs in reducing stillbirths is not surprising since, to reiterate, prenatal clinics universally tested for and treated syphilis, and 40 percent of fetuses die in utero when maternal syphilis is left untreated (Goldenberg et al., 2010). Importantly, stillbirths averted are in addition to the reduction in general mortality, which excludes stillbirths.

Finally, the semi-dynamic model indicates once more that PHUs significantly reduced mortality from TB but not malaria. The estimated effect of PHUs on TB mortality is smaller than in the previous section and often statistically insignificant or marginally significant. According to this model, PHUs reduced TB mortality by seven percent in Year 1 and 16 percent in Year 7 (95% CI: [-36.6%, 11.2%]). Because of improvement in the cause

[16] Estimates for share of reduced mortality attributable to PHUs are based on linear combinations of coefficient estimates for event-years 5 through 7 and three-year averages of mortality rates at the beginning and end of the sample period.

[17] Counterfactual estimates are derived by comparing estimated mortality with and without (i.e. setting all treatment dummies to zero) treatment.

of death certification, it is difficult to measure the share of the decline in TB mortality caused by PHUs. However, PHUs appear to have been responsible for at least half of the overall reduction, as TB mortality declined by 31 percent from the centralization of the vital statistics system through 1945.[18] PHUs prevented 907 fatalities from TB in 1940, accounting for more than one-quarter of all deaths averted by PHUs that year. For malaria mortality, the event study coefficients exhibit no consistent pattern, alternating between positive and negative.

A downside to the semi-dynamic model is that it is not robust to heterogeneous treatment effects across units or calendar time periods, as spurious trends may emerge from extrapolation of short-run effects. For instance, long-run effects of PHUs on stillbirths estimated from the semi-dynamic model exceed the total decline in stillbirths observed over the sample period. The simplest way to estimate treatment effects without extrapolation is to run the semi-dynamic regression separately for each event-year, $k \geq 0$, using all observations from that event-year as well as all untreated observations, $k < 0$. These regressions cannot suffer from extrapolation of treated observations because no other treatment effects are included in the estimation sample.

Results from this semi-parametric specification are displayed in the even-numbered columns of Tables 5. Point estimates and statistical significance are similar in the two semi-dynamic specifications, indicating that extrapolation was not severe in the parametric specification. After seven years, PHUs lowered overall mortality by almost 10 percent and infant mortality, TB mortality, and stillbirths by around 20 percent.

5.3 Nurses, Sanitary Inspectors, and Assistant Midwives

PHUs carried out a wide range of activities, making it difficult to know which efforts were responsible for reducing mortality. Official reports do not contain municipal-level information on the personnel employed or services provided by health units over time. However, in this

18 The record-high TB mortality in 1933 is partly the result of a hurricane that struck in September 1932 (Rodríguez Pastor and Janer, 1953).

section I use data on the full-time personnel employed by PHUs in 54 municipalities in 1935 to describe how the effect of PHUs varied with the number of nurses and sanitary inspectors per capita. I also incorporate data on the number of licensed midwives per capita in 1935-36 to comment on occupational licensing in relation to infant and maternal mortality.

Exercises based on these data are descriptive and should be interpreted with caution for several reasons. First, it is plausible that these snapshots are not representative of municipal-level inputs over time. Second, personnel per capita may not be randomly assigned, and municipalities with more nurses, sanitary inspectors, or midwives may have dedicated more resources to complementary aspects of their public health programs that are not captured by these variables. Third, in the case of nurses and sanitary inspectors per capita, the analysis is based on a sample of already-treated municipalities.

To assess whether the effect of PHUs varied with the number of nurses or sanitary inspectors per capita, I run a modified form of the semi-dynamic model by adding a full set of lags interacted with the number of nurses and inspectors per capita in 1935, respectively, as reported by Mountin et al. (1937). Fifty-four municipalities are included in the sample, and those municipalities without a PHU in 1935 are excluded. The number of public health nurses per 10,000 inhabitants ranged from 0.3 to 2.6, and the average municipality had 1.0 (median=1.2, s.d.=0.6). The number of sanitary inspectors per 10,000 inhabitants ranged from 0 to 2.0, and the average municipality had 0.7 (median=0.8, s.d.=0.4).

The top panel of Table 6 reports results from the triple-differences specification. The coefficients reported are a linear combination of coefficients from event-years 0 through 7. Municipalities with more nurses per capita experienced larger decreases in infant mortality, such that one additional nurse per 10,000 inhabitants is associated with 10 percent lower infant mortality. There is no evidence that changes in any type of mortality varied by per capita number of sanitary inspectors. While we still do not know exactly which PHU activities mattered most, these results suggest that the services of nurses may have been more important than those of sanitary inspectors for reducing infant mortality. However, municipalities maintained a sanitation service prior to opening PHUs, so the null results for sanitary inspectors may reflect that PHUs merely continued these services (Mountin et al., 1937).

These results are consistent with recent research on other historical contexts. The following public health programs significantly reduced infant mortality: United States, 1924 to 1929, interventions funded by the Sheppard-Towner Act that provided one-on-one contact and opportunities for follow-up care, such as health clinic and home visits by nurses (Moehling and Thomasson, 2014); Denmark, 1937 to 1949, a universal home-visiting program that advocated breastfeeding and diffused knowledge on nutrition (Wüst, 2012); Sweden, 1931 to 1933, a program providing information and support to mothers, with an emphasis on nutrition and sanitation, while monitoring infant care through home visits and clinics (Bhalotra et al., 2017); and Norway, 1936 to 1945, health care centers providing free and universal medical checkups for infants and advice to mothers on adequate infant care and nutrition (Bütikofer et al., 2019). Therefore, it is not surprising that health units in Puerto Rico with more nurses per capita had a larger effect on infant mortality since public health nurses dedicated three-fourths of their time to child health (Ramírez de Arellano, 1981).

To test whether the effect of PHUs on infant mortality varied with the use of midwives at childbirth, I run a similar set of regressions using the number of licensed assistant midwives per capita as reported in the 1935-36 Commissioner of Health report. A 1931 law required midwives to be licensed by the Health Department, but 4,653 documented births were attended by non-authorized persons in fiscal year 1935-36. More than 80 percent of all deliveries in Puerto Rico were attended by assistant midwives (Van Horn, 1940). Although PHUs trained and licensed assistant midwives, the 1931 law did not only apply to municipalities with health units; therefore, the regressions include an interaction of the number of midwives per capita and an indicator variable equal to one for all years starting in 1931. The number of assistant midwives per 1,000 inhabitants ranged from 0.9 to 3.6, and the average municipality had 1.9 (median=1.7, s.d.=0.6).

The bottom panel of Table 6 reveals that each additional midwife per 1,000 inhabitants is associated with a 13 percent drop in infant mortality. The number of midwives is also significantly negatively related to general mortality, though the magnitude of the coefficient is only half as large. Midwives could have reduced general mortality by preventing infant as well as maternal mortality, discussed below. Decreases in stillbirths and TB mortality, which are unrelated to the work of midwives, did not vary with the number of midwives.

Once again, these findings are consistent with recent research. In the United States, from 1900 to 1940, licensed midwives are associated with a modest reduction in infant mortality from diarrhea, perhaps by encouraging breastfeeding and by carrying an effective treatment at their disposal (Anderson et al., 2020a). In Sweden, from 1881 to 1930, midwives significantly reduced neonatal mortality, likely by following hygiene instructions and monitoring the health of the mothers and newborns for three weeks after birth (Lazuka, 2018). In Puerto Rico, most of the decline in infant mortality in the 1930s resulted from a higher probability of survival in the first month of life (Wegman et al., 1942), and assistant midwives were trained in proper hygiene for childbirth and visited for ten consecutive days after birth to wash and monitor the mother and baby (Robert de Romeu, 1939).

Finally, I examine PHUs in relation to maternal mortality in a difference-in-differences specification since data are missing for 1923, 1927, 1929, and 1930.[19] The coefficient on the 1931 midwives interaction term reveals that each additional midwife per 1,000 inhabitants is associated with 35 percent lower maternal mortality, significant at the 1 percent level ($p = 0.003$). PHUs without the midwife licensure law are associated with a 21 percent decline in maternal mortality ($p = 0.037$), perhaps through the monitoring and education of mothers at prenatal clinics. However, an estimate for a treatment dummy

[19] Note that I only consider changes in maternal mortality in relation to midwives because the universal application of the midwife licensure law allows me to flexibly observe the correlation between midwives and maternal mortality over time (see Appendix C.14). By contrast, a triple-differences result for, e.g., PHUs and nurses per capita, cannot be estimated flexibly in an event study or generalized DiD model due to missing years of data. Negative weighting in static DiD models make coefficients difficult to interpret (Abraham and Sun, 2019; Borusyak and Jaravel, 2018; de Chaisemartin and D'Haultfoeuille, 2020; Goodman-Bacon, 2019).

from a staggered rollout should be viewed with caution due to problems caused by negative weighting (de Chaisemartin and D'Haultfoeuille, 2020) (see Appendix C.10).

A negative association between assistant midwives per capita is consistent with trends in causes of maternal mortality. Deaths from complications of childbirth that could be affected by the work of midwives, such as puerperal sepsis, gradually declined after 1931, but deaths from puerperal hemorrhage, for which an assistant midwife could do little to help, stayed about the same (Robert de Romeu, 1939). These results are also supported by recent studies on other historical contexts. The training and licensing of midwives significantly reduced maternal mortality in the United States from 1900 to 1940 (Anderson et al., 2020a), in Norway from 1887 to 1921 (Kotsadam et al., 2017), and in Sweden from 1830 to 1894 (Pettersson-Lidbom, 2015). Notably, in Sweden a doubling of trained midwives is found to lead to a 20 to 40 percent reduction in maternal mortality, an effect comparable in magnitude to that found in this paper.

5.4 Heterogeneity by Socioeconomic Characteristics

The diversity of municipalities motivated the decentralization of public health, recognizing that officials in San Juan were not equipped to identify and respond to challenges elsewhere on the island. For instance, the adult literacy rate in 1920 in the capital and primary urban center, San Juan, stood at 74 percent, while in the town of Cidra, located in the rural, mountainous interior, the rate was just 28 percent. More relevant to this investigation, municipalities differed in their exposure to disease and access to professional health care: tuberculosis was nearly twice as high in urban as in rural areas (Rodríguez Pastor and Janer, 1953), and more than half of all physicians were located in just five municipalities (Mountin et al., 1937). Given such diversity, and with coordination of policy at the local level, the effect of PHUs should be expected to vary across municipalities.

Table 7 provides evidence of treatment heterogeneity based on a modified form of the semi-dynamic model. Heterogeneous treatment effects are assessed by including a full set of lags interacted with a time-invariant municipal characteristic, and coefficients reported are linear combinations of coefficients from event-years 0 through 7. PHUs were more effective in municipalities with higher pre-treatment mortality rates for each of the four outcomes, implying convergence in mortality, perhaps as a result of convergence in hygienic knowledge and access to health services. Larger effects in areas with higher mortality parallels, e.g., Bailey and Goodman-Bacon (2015) and Hansen et al. (2020).

The results in Table 7 suggest that PHUs were more effective at reducing general mortality in more developed areas, but this result is not robust to excluding San Juan from the regression or not weighting observations by municipal population (results not shown). There is weak evidence that PHUs more successfully reduced infant mortality in municipalities with less access to professional health services, as proxied by the number of doctors per capita, and in municipalities with higher shares of the labor force in agriculture. Prenatal and postpartum clinics at the health units were targeted at poor and indigent mothers (Commissioner of Health, 1942), and dozens of rural dispensaries opened by the Puerto Rico Reconstruction Administration in 1936 were subsumed by PHUs in 1938 (Ramírez de Arellano, 1981). The steeper decline in infant mortality in rural areas is, therefore, not surprising and comports with Hoehn-Velasco (2018), who finds that county health departments were more effective at reducing infant mortality in rural counties in the United States in the early 20th century. Lastly, PHUs more successfully reduced the burden of tuberculosis in municipalities with more physicians per capita, lower shares of agricultural employment, greater shares of the population in urban areas, and higher literacy rates. This result is not surprising since TB mortality was much higher in urban areas and anti-TB efforts were concentrated in the largest cities and towns.[20]

[20] For example, the anti-TB centers, which handled diagnoses and pneumothorax treatment, were located in the following municipalities: San Juan (population rank in 1935: 1), Ponce (2), Mayagüez (3), Arecibo (4), Caguas (6), Bayamón (8), Aguadilla (9), Guayama (15), and Fajardo (36) (Commissioner of Health, 1938).

6 Cost-Benefit Analysis

Remarkably, the reduction in mortality brought about by PHUs came at little additional cost to taxpayers. According to the chief of the Bureau of Public Health Units:

> [T]he greatest expansion and development of the improved organization occurred during financial depression, when the Insular income was at a low level and aid from outside sources was steadily diminishing... [and] it was accomplished, not by increasing public-health expenditures, but by redistributing them for greater effectiveness. (Payne, 1942, p. 270)

Indeed, the financial resources commanded by the Department of Health did not markedly grow until after the rollout of PHUs (see Fig. 7). The constraints imposed by the Great Depression—including a 29 percent ($518,109) budget cut from 1931-32 to 1933-34—prompted the department to simplify its organization and eliminate unnecessary expenses, such as by cutting most salaries by 10 percent (Commissioner of Health, 1934; Ramírez de Arellano, 1981). Yet, the department carried out, and even expanded, its ordinary activities. For instance, from 1931-32 to 1933-34, total and per capita costs fell at the insular psychiatric hospital, TB hospital, leper hospital, quarantine hospital, charity schools, blind asylum, institute for blind children, and the Ponce District Hospital, yet no institution severely cut back on its number of patients (Commissioner of Health, 1939).

Appropriations for health units doubled throughout the 1930s and constituted about one-fifth of total insular health expenditures over the decade (see Table 8). Before World War II, expenditures on PHUs made by the Department of Health averaged approximately $0.25 per capita ($4.61 in 2020 dollars). However, these numbers understate total PHU costs because they fail to account for contributions from municipalities, the Rockefeller Foundation, and external sources. The Rockefeller Foundation assigned a supervisor to the health units and contributed financially—for example, $14,000 to PHUs in specific and $72,000 to the Health Department in general in 1931-32—to the training of nurses and support of the PHUs (Commissioner of Health, 1932). Other notable contributions include $25,000 from the US Public Health Service in 1934-35 toward the payment of salaries; about $35,000 annually throughout the early 1930s from the Puerto Rico Child Health Committee, also to help cover salaries; and $325,000 from the Puerto Rico Reconstruction Administration in 1937 and 1938 for the construction of 24 new buildings (Commissioner of Health, 1935, 1939).[21] Still, the Department of Health covered most expenses.

To assess whether the benefits of PHUs exceeded their costs, I convert estimates of lives saved from Section 5 to dollars using estimates of the Value of Statistical Life (VSL) and the elasticity of value of life with respect to per capita GNP for the United States in 1940 from Costa and Kahn (2004). Using the full range of VSL ($76,370-106,690 in 1940 USD) and elasticity (1.5-1.7) estimates, I estimate VSL for Puerto Rico in 1940 under the assumptions that preferences over life and income were the same in the United States and Puerto Rico and that income in the United States was five times the level in Puerto Rico (Devereux, 2019).[22] Program costs are assumed to be twice the total expenditures of the Department of Health on public health units, since initially the department was supposed to cover half of all costs. This assumption is conservative since contributions from the Rockefeller Foundation, as well as other external sources, fell far short of matching one-half of Health Department expenditures.[23] Mountin et al. (1937, p .34) reports that the Health Department accepted "major administrative and financial responsibility" for PHUs but that in "most cases" there was "some participation by the municipalities."

A back-of-the-envelope calculation indicates that the benefits of PHUs exceeded costs by a ratio of 22 to 1 from 1931-32 to 1938-39 (see Table 9). Using 95-percent confidence intervals for the estimated effects of PHUs to derive lower and upper bounds, the benefit-cost ratio

[21] The Department of Health also received federal funds for activities not directly related to PHUs, such as $431,500 for the construction of four district hospitals (Commissioner of Health, 1938).

[22] VSL values are converted to 1940 dollars using the Bureau of Labor Statistics historical Consumer Price index (2020).

[23] More accurately, the Rockefeller Foundation was supposed to cover initially one-fourth of total PHU costs, with the Department of Health covering one-half and municipalities one-fourth. The Rockefeller Foundation was only financially committed to four early PHUs, however (Ramírez de Arellano, 1981).

ranges from 4:1 to 42:1.[24] Lower elasticity values (e.g., Viscusi and Aldy, 2003), accounting for the disproportionate impact on infant mortality and the possibility that VSL is higher for children (Hammitt and Haninger, 2010), and less conservative cost estimates would push the ratio higher.[25] The analysis also does not account for stillbirths averted, since severe extrapolation of estimated treatment effects precludes accurate estimation of stillbirths averted and stillbirths are not included in the general mortality rate. Even accounting for expenditures on complementary medical services—since PHU services were primarily preventative—the evidence is clear that the benefits of PHUs far exceeded their costs. Most importantly, the benefit-cost estimate is 15:1 after incorporating TB hospital costs borne by the insular government, which were approximately equal to insular expenditures on health units over this period.

7 Conclusion

This paper studies the effect of public health units (county health departments) on mortality during the early years of the mortality transition in Puerto Rico, the first outside of Europe and Western offshoots and one of most successful in world history. Using a novel data set of annual, municipal-level vital statistics from 1923 to 1945, I exploit the staggered rollout in an event study framework, assuming that municipalities would have followed parallel trends if not for PHUs. Health units accounted for most of the decline in infant and tuberculosis mortality and about one-third of the decline in general mortality through 1945. In 1940 alone, I estimate that PHUs saved 3,430 lives, including 907 from TB and 1,766 infants. PHUs also reduced maternal mortality and stillbirths but had no effect on malaria mortality. Evidence of the successful reduction of TB mortality is particularly important given the ongoing debate about the efficacy of anti-TB efforts prior to antibiotics and the crisis of drug-resistant TB in the modern developing world.

[24] Using the full range of VSL estimates from Costa and Kahn (2004) in addition to 95-percent confidence intervals for the estimated effects, the benefit-cost ratio ranges from 3:1 to 57:1.

[25] The data are not rich enough to adjust for differences in mortality reduction across the age distribution.

While it is difficult to know which PHU services made a difference, the fact that reductions in infant and maternal mortality were steeper with more nurses and midwives per capita, but unrelated to the number of sanitary inspectors, suggests that efforts led by nurses (e.g. home visits and prenatal clinics) and the licensing of midwives may have been more important than the enforcement of sanitary regulations or improvements in rural sanitation. That rural areas experienced larger decreases in infant mortality also indicates that PHUs were successful in their goal of reaching segments of the population that otherwise lacked access to professional health services and information about hygiene and disease transmission.

This paper contributes to a debate about the relative importance of public health and economic growth in the global mortality transition. While not ruling out the importance of rising income, I demonstrate that public health units were instrumental in reducing mortality during the initial phase of the mortality transition in Puerto Rico. Of course, regionally high public health expenditures were made possible by consistent economic growth following US annexation in 1898, and economic factors may have become more important after 1945 when the upward trends in both per capita income and life expectancy accelerated. Still, public health set in motion sustained decreases in mortality.

Bringing evidence from Latin America into the discussion is an important step in looking beyond Europe and Western offshoots. The study of Puerto Rico is possible because of its affiliation with the United States, which produced extensive administrative records and vital statistics at US standards. US military interventions in Latin America in the 20th century may have generated comparable records, allowing for wider study of the region. Notably, Cuba and Panama received American public health investments and also spent time under American jurisdiction. The European colonization of Africa and Asia may likewise have left behind materials to be explored.

Discussions of Latin American development tend to exclude Puerto Rico because its special relationship with the United States supposedly makes it unlike independent countries (e.g., Bulmer-Thomas, 2003). Yet, after Puerto Rico, practically all countries of Latin

America adopted public health units to deal with problems at the local level, so this investigation provides a window into public health in Latin America more broadly (Bravo, 1958). Local health services in Puerto Rico and throughout much of Latin America were realized with the technical and financial aid of the Rockefeller Foundation, the US federal government, and other external partners, such as the Puerto Rico Child Health Committee and the Pan-American Sanitary Bureau. In any case, most public health efforts in Puerto Rico were carried out by Puerto Ricans trained on the island, and health units were implemented not through new transfers from the mainland but primarily by redistributing public health expenditures for greater effectiveness (Payne, 1942). The success of the program, the emphasis on administrative reform, and the reliance on low-tech but labor-intensive measures makes Puerto Rico a useful example for countries with limited resources.

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A Tables

Table 1: Selected Activities of Public Health Units in Fiscal Year 1938-39

Public Health Education:	
Health Talks	25,873
Attendance	717,057
Home Visits Made by Nurses	164,623
Persons Receiving Specific Immunization or Treatment:	
Vaccination Against Smallpox	48,162
Immunization Against Typhoid Fever	44,252
Immunization Against Diphtheria	8,247
Treatment for Uncinariasis	207,640
Clinical Consultations:	
Tuberculosis Clinics	6,968
Prenatal Clinics	52,718
Infant Hygiene Clinics	61,035
Preschool Clinics	28,323
Number of School Children Examined	170,576

Source: *Report of the Commissioner of Health of Puerto Rico for the Fiscal Year 1938-39*

Table 2: Leading Causes of Death, 1931-32

(a) All deaths

Causes of Death	Death Rate per 100,000 population	Percent of all deaths
1. Diarrhea and Enteritis	408.2	18.3
2. Tuberculosis	297.3	13.4
3. Pneumonia	232.5	10.4
4. Malaria	174.9	7.8
5. Nephritis	137.4	6.2

(b) Deaths under one year of age

Causes of Death	Death Rate per 1,000 live births	Percent of all deaths
1. Diarrhea and Enteritis	39.6	29.9
2. Pneumonia	15.3	11.6
3. Bronchitis	7.9	6.0
4. Tetanus	5.8	4.4
5. Malaria	5.8	4.4

Source: *Thirty-Second Annual Report of the Governor of Puerto Rico*

Table 3: Mortality Rates per 100,000 Inhabitants for the Principal Infectious and Parasitic Diseases, 1931-1949

Years	Diarrhea/ Enteritis	TB	Malaria	Pneu- monia	Bron- chitis	Uncin- ariasis	Influenza	Tetanus	Total
1931-34	388.0	300.7	180.3	188.4	51.2	33.9	29.8	21.1	1193.4
1935-39	426.4	280.2	117.0	169.7	41.6	16.6	24.1	8.1	1083.6
1940-44	348.0	235.6	85.8	142.5	23.4	12.5	23.0	7.3	879.2
1945-49	201.7	185.9	21.9	108.7	13.7	1.9	10.1	6.3	550.3

Source: Vázquez Calzada (1978)

Table 4: The Correlates of Public Health Unit Openings

	(1)	(2)
Urban share	-0.88***	-0.80***
	(0.19)	(0.11)
Average mortality, 1923-1926	-0.93***	-1.16***
	(0.28)	(0.29)
Change in mortality, 1923-1926	-0.32	-0.26
	(0.24)	(0.28)
Constant	1933.84***	1933.36***
	(0.26)	(0.29)
Weighted by population	N	Y
Observations	75	75
R-squared	0.33	0.49

Notes: The dependent variable is the fiscal year of PHU inauguration (e.g. 1926-27 coded as 1927). All explanatory variables are standardized to have a mean equal to zero and a standard deviation equal to one. $Urbanshare_m$ is equal to the share of the population of municipality m living in urban areas (places with 2,500 or more inhabitants) in 1930. $AverageMortality_{1923-1926}$ is the mean of deaths per 1,000 inhabitants from 1923 to 1926. $ChangeInMortality_{1923-26,m}$ is equal to $ln(Mortality_{1926,m}/Mortality_{1923,m})$.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports. Population data come from the US Census.

Table 5: The Effect of Public Health Units on Mortality Rates
(Semi-Dynamic Specifications)

DV:	Mortality		IMR		Stillbirths		TB		Malaria	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Year 0	-0.04**	-0.04*	-0.06**	-0.06**	-0.05	-0.05	0.00	-0.00	-0.05	0.03
	(0.02)	(0.02)	(0.03)	(0.03)	(0.05)	(0.06)	(0.04)	(0.04)	(0.10)	(0.13)
Year 1	-0.03	-0.02	-0.05	-0.05	-0.10	-0.10	-0.08*	-0.06	-0.07	-0.05
	(0.02)	(0.02)	(0.04)	(0.04)	(0.07)	(0.08)	(0.04)	(0.04)	(0.14)	(0.17)
Year 2	-0.08***	-0.06**	-0.09**	-0.09**	-0.11	-0.09	-0.13**	-0.10*	-0.14	-0.11
	(0.03)	(0.03)	(0.04)	(0.04)	(0.09)	(0.09)	(0.05)	(0.05)	(0.15)	(0.17)
Year 3	-0.10***	-0.10***	-0.11**	-0.10*	-0.17*	-0.17	-0.13*	-0.12*	0.02	-0.01
	(0.03)	(0.03)	(0.05)	(0.05)	(0.10)	(0.11)	(0.07)	(0.07)	(0.19)	(0.21)
Year 4	-0.10**	-0.09**	-0.11**	-0.10*	-0.19	-0.19	-0.12	-0.12	0.16	0.24
	(0.04)	(0.04)	(0.05)	(0.05)	(0.11)	(0.12)	(0.09)	(0.09)	(0.20)	(0.23)
Year 5	-0.10***	-0.09***	-0.14**	-0.08	-0.21	-0.21*	-0.14	-0.17*	0.17	0.26
	(0.04)	(0.03)	(0.06)	(0.06)	(0.13)	(0.12)	(0.10)	(0.09)	(0.24)	(0.24)
Year 6	-0.10**	-0.10**	-0.15**	-0.19**	-0.26*	-0.36**	-0.13	-0.17	-0.01	0.30
	(0.04)	(0.05)	(0.06)	(0.08)	(0.15)	(0.16)	(0.12)	(0.13)	(0.25)	(0.34)
Year 7	-0.12**	-0.09*	-0.20***	-0.21**	-0.28*	-0.22	-0.17	-0.22	-0.00	0.53
	(0.05)	(0.05)	(0.07)	(0.08)	(0.16)	(0.15)	(0.14)	(0.13)	(0.28)	(0.45)
Semi-parametric	N	Y	N	Y	N	Y	N	Y	N	Y

Notes: The dependent variables are log mortality rates. The coefficients are weighted least-squares estimates. Dummy variables for event years beyond Year 7 are included but not shown in the table. Standard errors are clustered by municipality. Even-numbered columns are estimated each as one regression, with 1,725 observations for general and TB mortality and 1,650 observations each for infant mortality, stillbirths, and malaria mortality. Even-numbered columns are estimated as separate regressions for each outcome and event-year, with 888 observations for each regression with general and TB mortality and and 813 observations for each regression of infant mortality, stillbirths, and malaria mortality.

Table 6: Changes in Mortality by Personnel Per Capita

Dependent variables:	Death	IMR	Stillbirths	TB
PHU	-0.12***	-0.07	-0.06	-0.19
	(0.04)	(0.06)	(0.09)	(0.14)
PHU×Nurses$_{1935}$	-0.02	-0.10**	-0.05	0.07
	(0.02)	(0.05)	(0.05)	(0.07)
Observations	1,242	1,188	1,188	1,242

Dependent variables:	Death	IMR	Stillbirths	TB
PHU	-0.12**	-0.16**	-0.10	-0.18
	(0.05)	(0.09)	(0.09)	(0.18)
PHU×Inspectors$_{1935}$	-0.01	-0.00	-0.01	0.06
	(0.05)	(0.06)	(0.05)	(0.11)
Observations	1,242	1,188	1,188	1,242

Dependent variables:	Death	IMR	Stillbirths	TB	Maternal
PHU	-0.11***	-0.17***	-0.16*	-0.13*	-0.24**
	(0.03)	(0.04)	(0.09)	(0.07)	(0.11)
$1[t \geq 1931]$	-0.07**	-0.14***	0.04	-0.05	-0.45***
×Midwives$_{1935-36}$	(0.03)	(0.04)	(0.08)	(0.06)	(0.15)
Observations	1,725	1,650	1,650	1,725	1,425

Notes: The dependent variables are log mortality rates. The coefficients are weighted least-squares estimates. Standard errors are clustered by municipality. $Nurses_{m,1935}$ and $Inspectors_{1935}$ represent the number of nurses and inspectors, respectively, per 10,000 inhabitants in 1935 in municipality m. $Midwives_{m,1935-36}$ represents the number of licensed assistant midwives per 1,000 inhabitants in 1935-36. Coefficients on $Nurses_{m,1935}$, $Inspectors_{1935}$, $Midwives_{m,1935-36}$ and come from triple-differences estimated as a full set of lags interacted with the personnel variable. The coefficients reported are a linear combination of coefficients estimated separately for event-years 0 to 7 in a semi-dynamic model. The number of nurses and sanitary inspectors per capita is interacted with a PHU treatment dummy; the number of midwives per capita is interacted with a dummy equal to one in all years starting with 1931, since the licensing of assistant midwives started that year. See Sections 5.2 and 5.3 for more details. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports. Data on nurses and sanitary inspectors come from Mountin et al. (1937), and data on midwives come from the 1935-36 Commissioner of Health report. The top two panels exclude 21 untreated municipalities.

Table 7: Treatment Heterogeneity of Public Health Units by Municipal Characteristics

Dependent variable:	Mortality	IMR	Stillbirths	TB
	(1)	(2)	(3)	(4)
PHU	-0.04	-0.06	-0.04	0.05
	(0.04)	(0.05)	(0.09)	(0.07)
PHU$\times Y_{1924-26}$	-0.06***	-0.11***	-0.18***	-0.12***
	(0.01)	(0.02)	(0.04)	(0.03)
PHU	-0.06*	-0.15**	-0.17	0.02
	(0.04)	(0.06)	(0.12)	(0.06)
PHU×Physicians	-0.01**	0.02*	0.00	-0.07***
	(0.01)	(0.01)	(0.01)	(0.01)
PHU	-0.07**	-0.16***	-0.13	-0.01
	(0.03)	(0.06)	(0.10)	(0.06)
PHU×Agricultural Employment	-0.01	-0.03*	0.03	0.07**
	(0.02)	(0.02)	(0.02)	(0.03)
PHU	-0.05	-0.15**	-0.18	0.02
	(0.04)	(0.06)	(0.13)	(0.06)
PHU×Urban share	-0.02**	0.02	0.01	-0.08***
	(0.01)	(0.02)	(0.02)	(0.02)
PHU	-0.06*	-0.16***	-0.16	-0.01
	(0.03)	(0.06)	(0.12)	(0.05)
PHU×Literacy	-0.02*	0.03	-0.01	-0.07***
	(0.01)	(0.02)	(0.02)	(0.02)

Notes: The dependent variables are log mortality rates. The coefficients are weighted least-squares estimates. Standard errors are clustered by municipality. $Y1924-26$ represents the average value of the dependent variable (not in log form) for municipality m from 1924 to 1926. $Physicians_m$ is the number of physicians (public or private) serving m in 1935. $AgriculturalEmployment_m$ is the percent of the labor force in m employed in agriculture in 1935. $Urbanshare_m$ is the share of the population of m in 1930 living in urban areas (defined as towns with at least 2,500 inhabitants). $Literacy_m$ is the share of the adult population literate in 1920. Each cross-section of municipality characteristics is standardized to have a mean equal to zero and a standard deviation equal to one. Municipality characteristics are multiplied by a treatment indicator variable m in year t in each regression. Coefficients on municipality characteristics come from triple-differences estimated as a full set of lags interacted with the municipal characteristic. The coefficients reported are a linear combination of coefficients estimated separately for event-years 0 to 7 in a semi-dynamic model. Horizontal lines delineate separate series of regressions. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports. Data on physicians per capita is found is Mountin et al. (1937), and data on population density and agricultural employment are derived from the 1920 and 1935 censuses, respectively.

Table 8: Expenditures on PHUs by the Insular Department of Health, 1931-32 to 1938-39

Fiscal Year:	31-32	32-33	33-34	34-35	35-36	36-37	37-38	38-39
Appropriations ($1000s)	253	236	228	306	377	385	454	519
Share of insular health costs	0.14	0.16	0.18	0.21	0.20	0.19	0.15	0.15
Municipalities covered	28	34	38	54	64	71	77	77
Population covered (1000s)	872	986	1,073	1,335	1,528	1,641	1,745	1,767
Per capita cost ($)	0.29	0.24	0.21	0.23	0.25	0.23	0.26	0.29

Source: Puerto Rico Department of Health

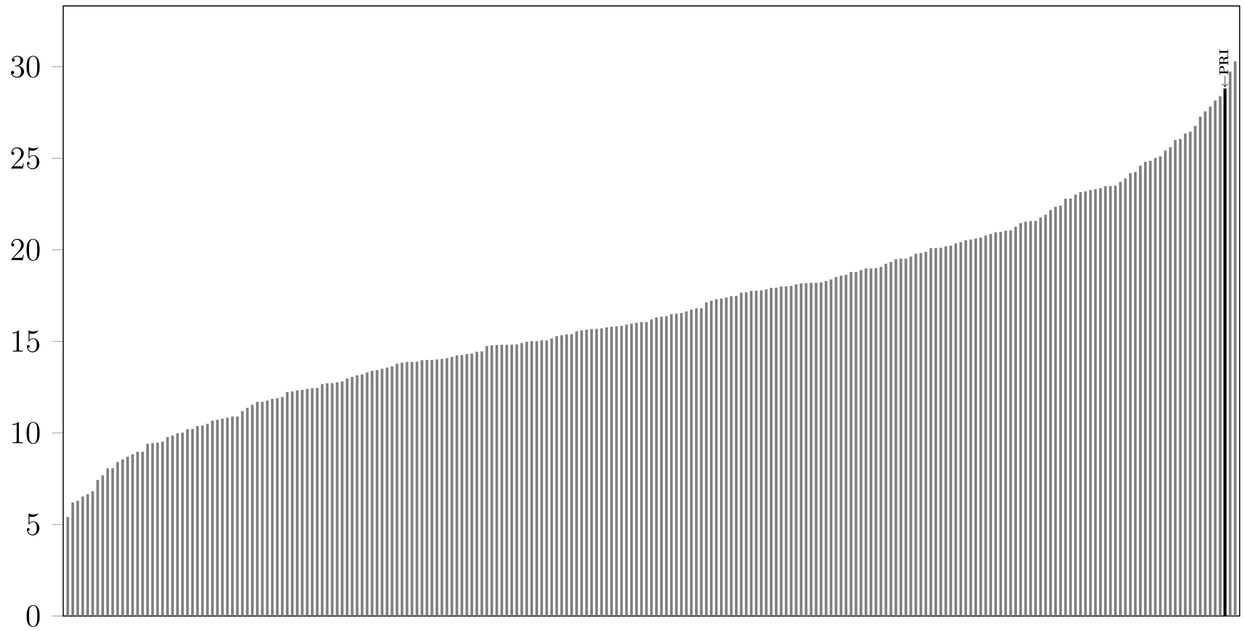
Table 9: Cost-benefit Analysis, 1931/32-1938/39

	Estimate	Lower bound	Upper bound
Deaths averted	17,731	3,263	33,324
Value of statistical life (thousands of 1940 dollars)	7.0	7.0	7.0
Benefits (thousands of 1940 dollars)	123,580.4	22,744.4	232,254.5
Program costs (thousands of 1940 dollars)	5,582.6	5,582.6	5,582.6
Rate of return (benefit-cost ratio)	22:1	4:1	42:1

Notes: Value of statistical life for Puerto Rico in 1940 is derived from estimates for the US in 1940 for 18- to 30-year-old men from Costa and Kahn (2004). Lower and upper bound estimates of deaths averted are based on the 95 percent confidence intervals of treatment effects by event-year from Section 5. Program costs are assumed to be twice the total spent by the Department of Health on public health units. All monetary values were converted to 1940 dollars using the Bureau of Labor Statistics historical Consumer Price index (2020).

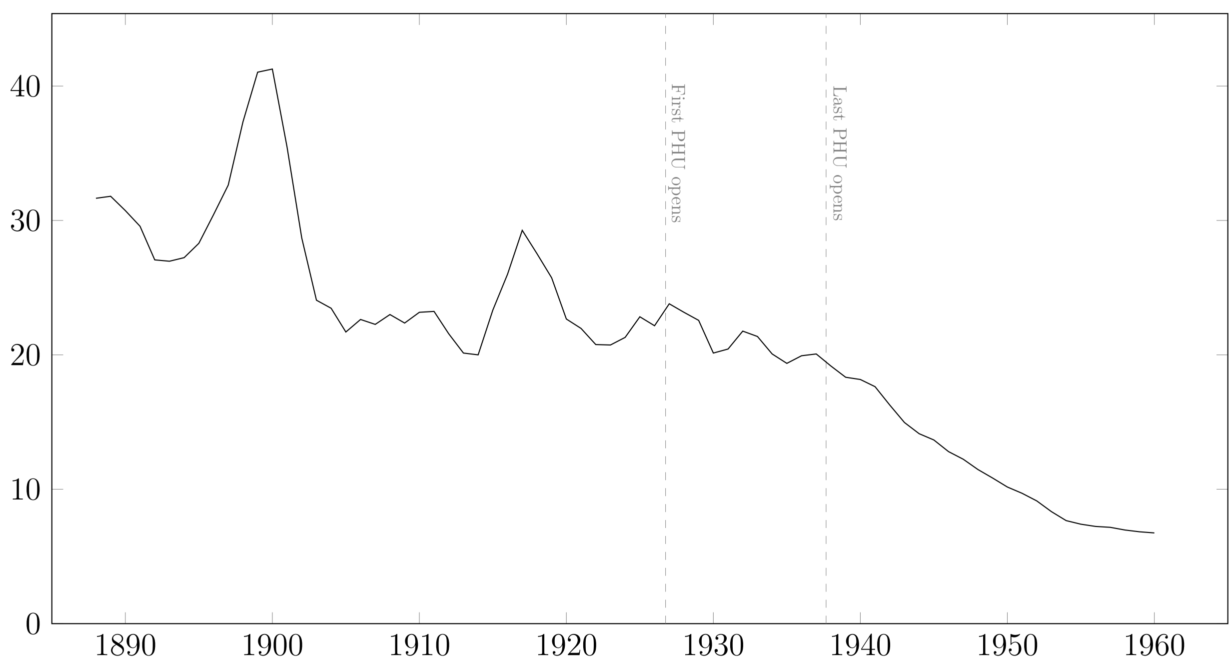
B Figures

Figure 1: The Largest Improvement in Life Expectancy
Over 30 Years by Country



Sources: Astorga et al. (2005); Roser et al. (2020); Vázquez Calzada (1978)
Notes: Each bar represents the largest increase in life expectancy from birth in years over any thirty year period from 1543-2019 for which data are available for all countries and territories included in Roser et al. (2020). Recoveries from large, negative health shocks, such as war, are excluded.

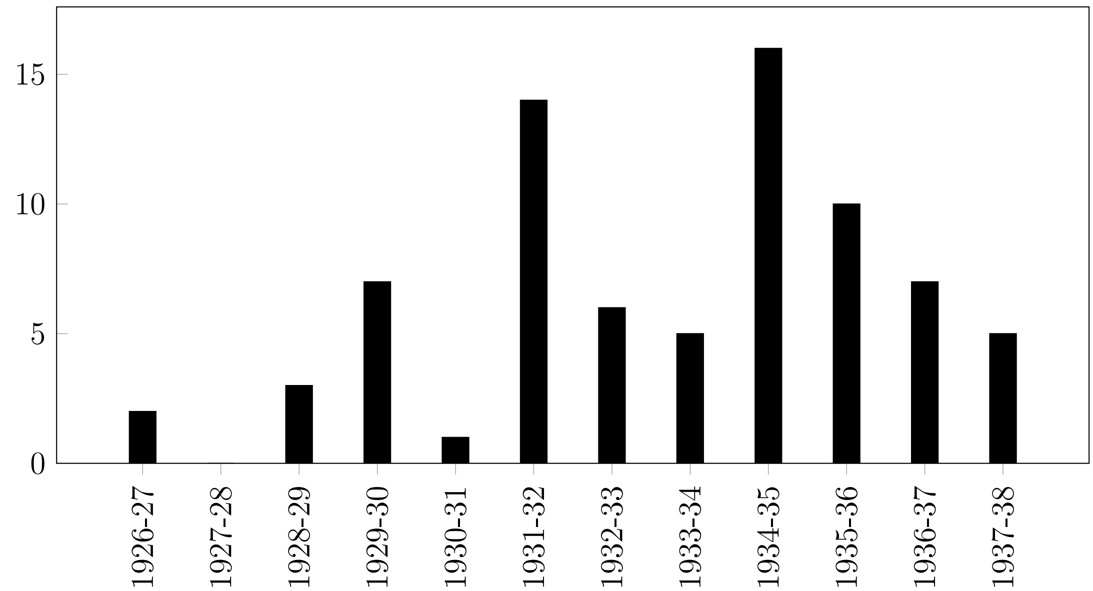
Figure 2: Deaths Per 1,000 Inhabitants in Puerto Rico, 1888-1960 (3-Year Moving Average)



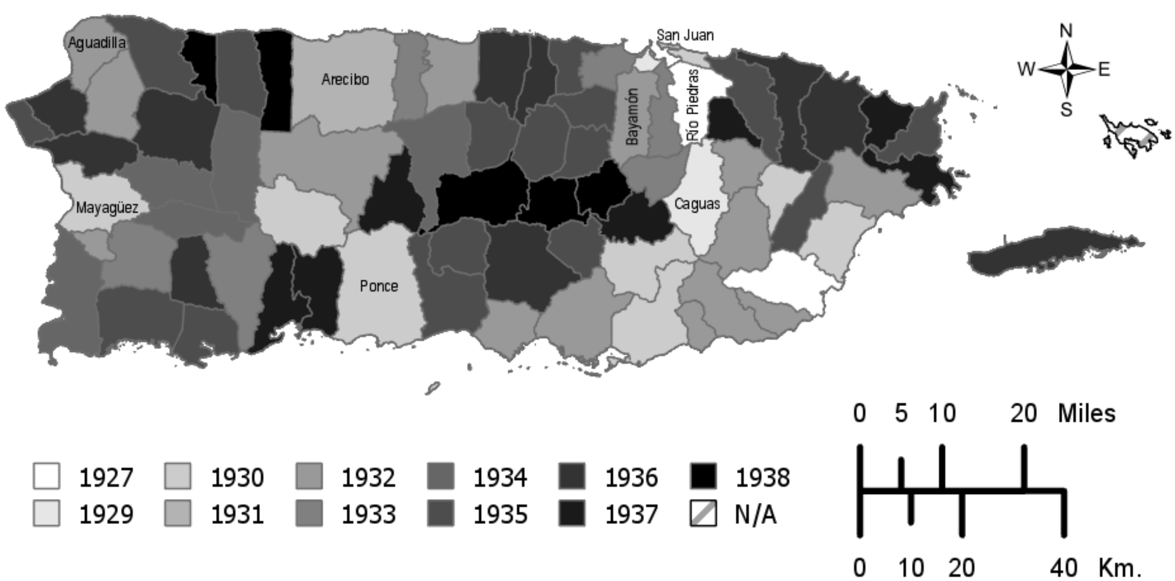
Source: Puerto Rico Department of Health

Figure 3: The Roll-out of Public Health Units

(a) Number of Public Health Units by Fiscal Year of Inauguration



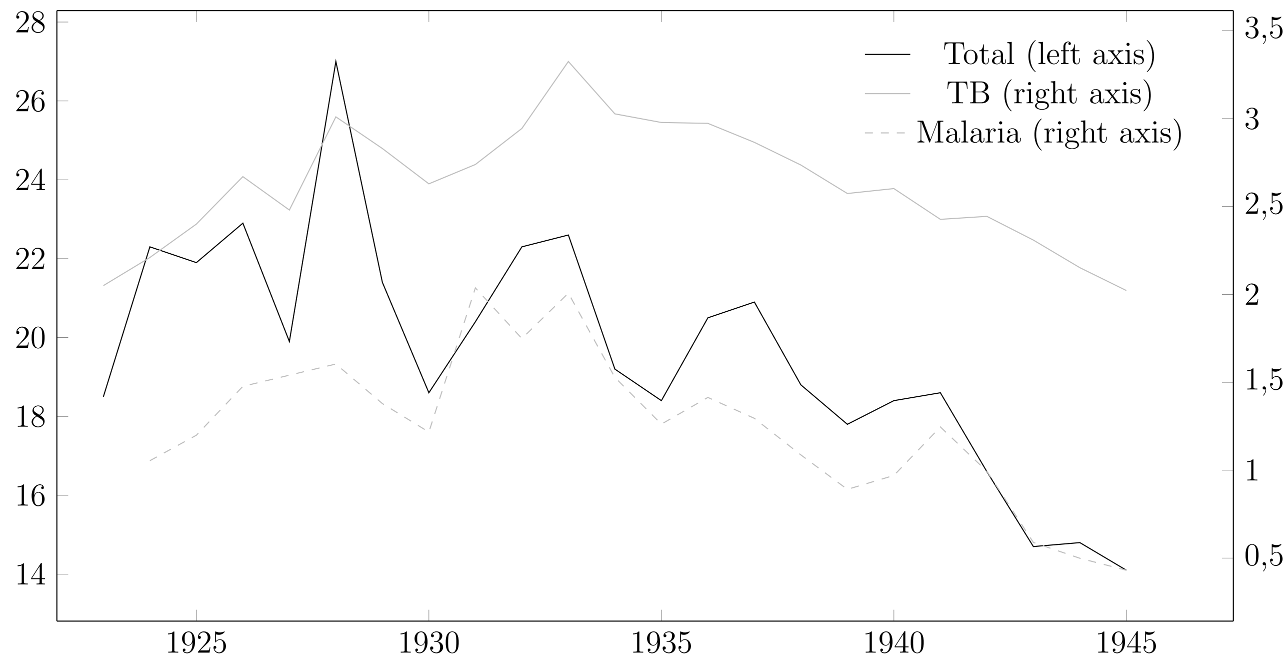
(b) The Roll-out of Public Health Units by Municipality



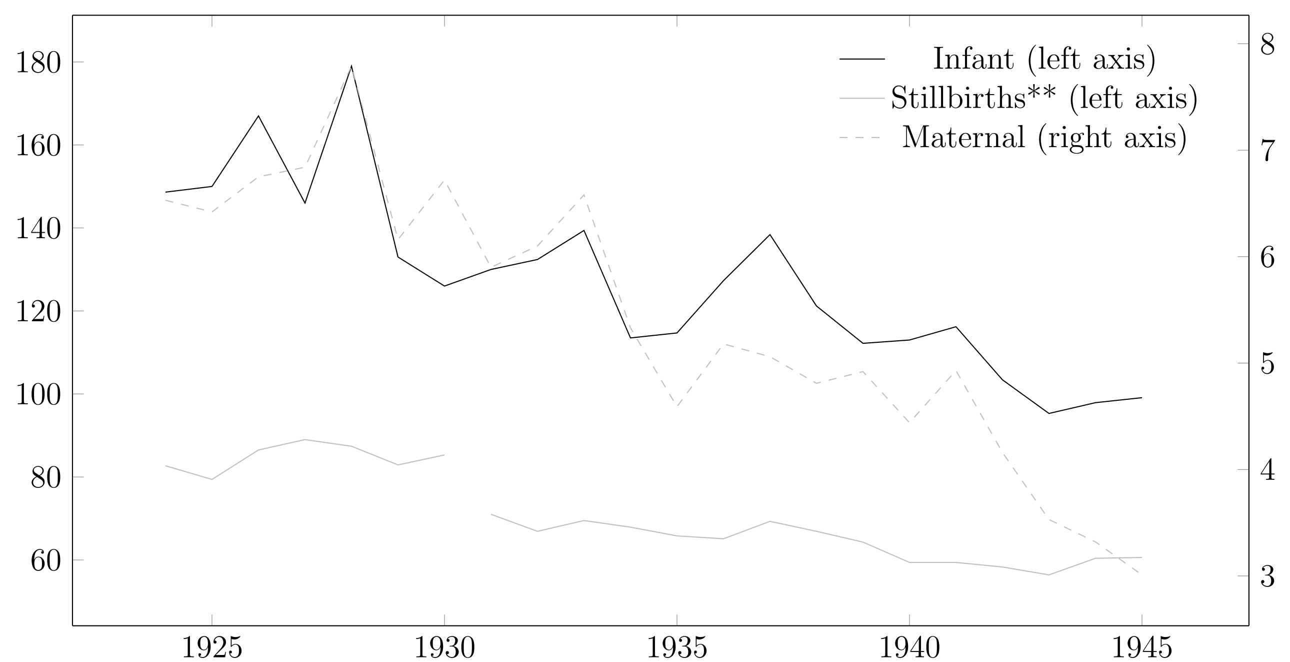
Notes: There are inconsistencies in reporting of PHU openings between 1928-32. Several units, typically with only a part-time director or without rural coverage, were no longer counted as PHUs in later reports. These figures are based on the earliest opening date found in annual reports of the Commissioner of Health. Results based on dates from Chaves (1942) are found in Appendix C.2. Panel (a) does not include the opening of additional subunits within a municipality.
Source: Annual reports of the Commissioner of Health and Chaves (1942).

Figure 4: Mortality Rates, 1923-1945

(a) Deaths per 1,000 inhabitants



(b) Deaths per 1,000 births*

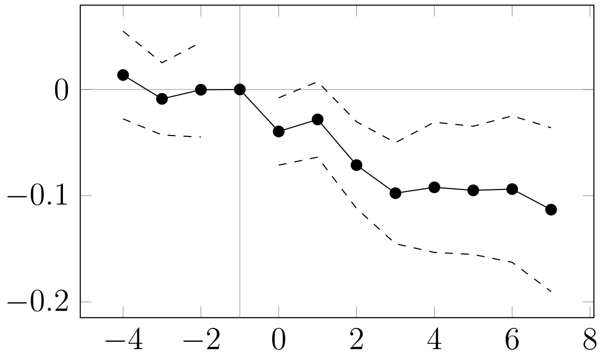


Notes: Data are reported by fiscal year (e.g. 1924-25 corresponds to 1924) before 1930.
*Infant mortality is per 1,000 live births; maternal mortality and stillbirths are per 1,000 total births.
**Beginning in 1930, stillbirths were required to be registered only if the fetus had advanced to the fifth month of uterogestation, while previously all stillbirths were to be registered.
Sources: Annual reports of the Commissioner of Health of Puerto Rico, *Puerto Rico Review of Public Health and Tropical Medicine*, and the *Puerto Rico Health Bulletin*.

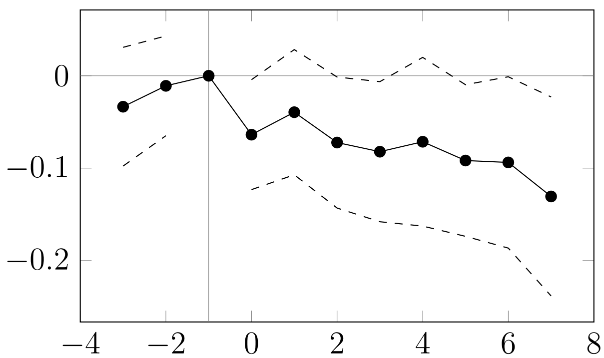
Figure 5: The Effect of Public Health Units on Mortality Rates

(a) Baseline Specification

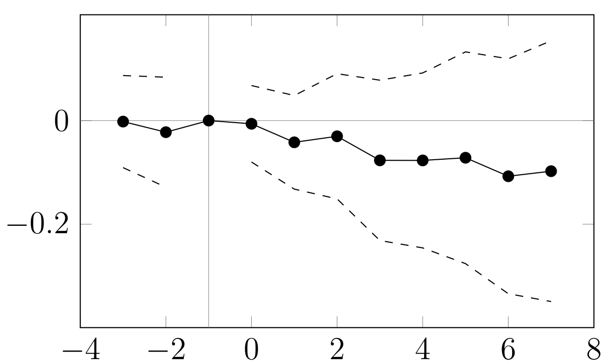
Mortality



Infant Mortality

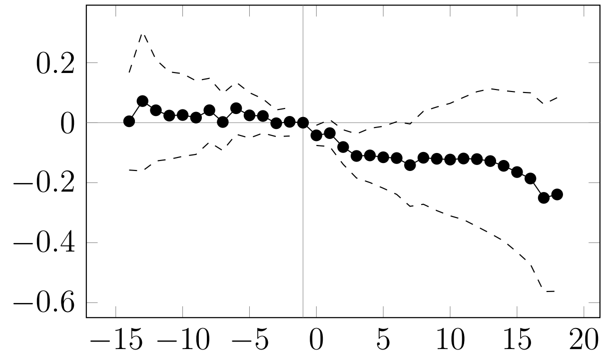


Stillbirths

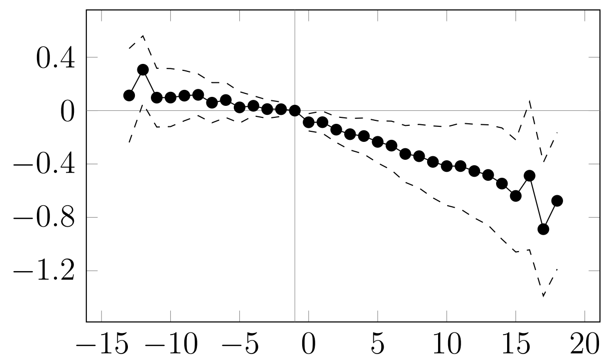


(b) Dynamic Specification

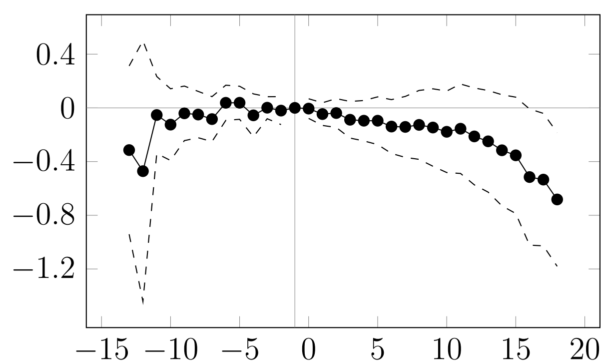
Mortality



Infant Mortality



Stillbirths

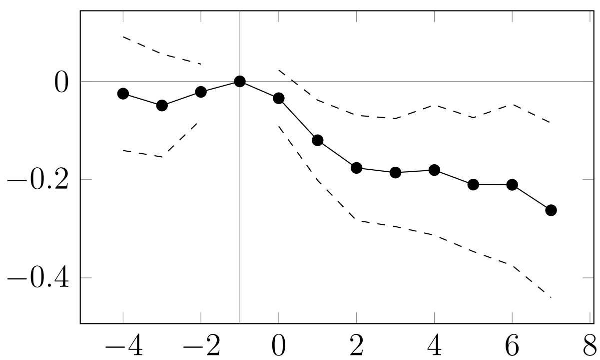


Notes: Dependent variables are log mortality rates. Coefficients are weighted least-squares estimates. Dashed lines are 95 percent confidence intervals and are based on standard errors clustered by municipality. The year prior to the establishment of the PHU is omitted, as is the first event-year in Panel B. Sample includes 75 municipalities and 1,725 municipality-year observations for mortality and 1,650 for infant mortality and stillbirths. In Panel A, event-years outside of the window are captured by "before" and "after" dummies.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from annual reports of the Commissioner of Health and Chaves (1942).

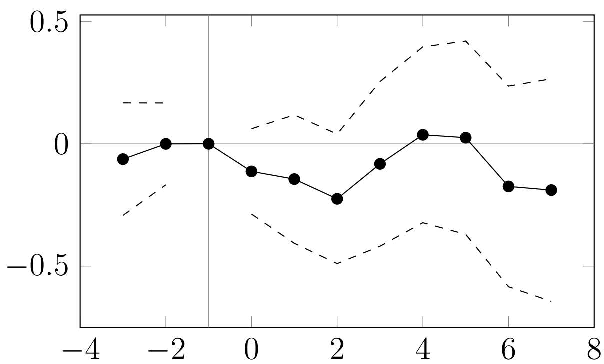
Figure 6: The Effect of Public Health Units on Mortality Rates by Cause of Death

(a) Baseline Specification

Tuberculosis

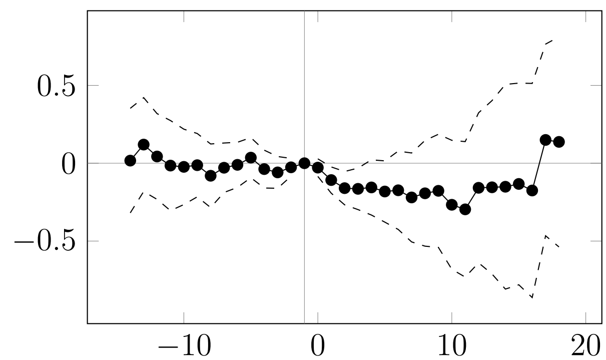


Malaria

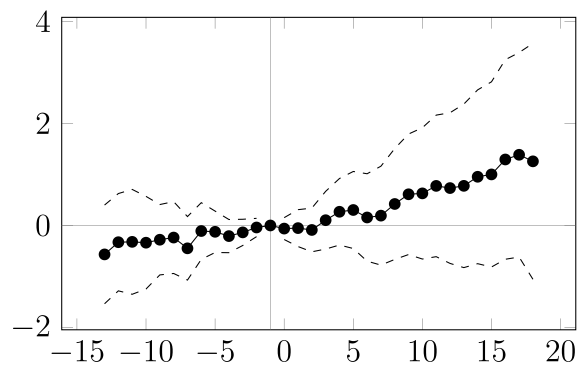


(b) Dynamic Specification

Tuberculosis

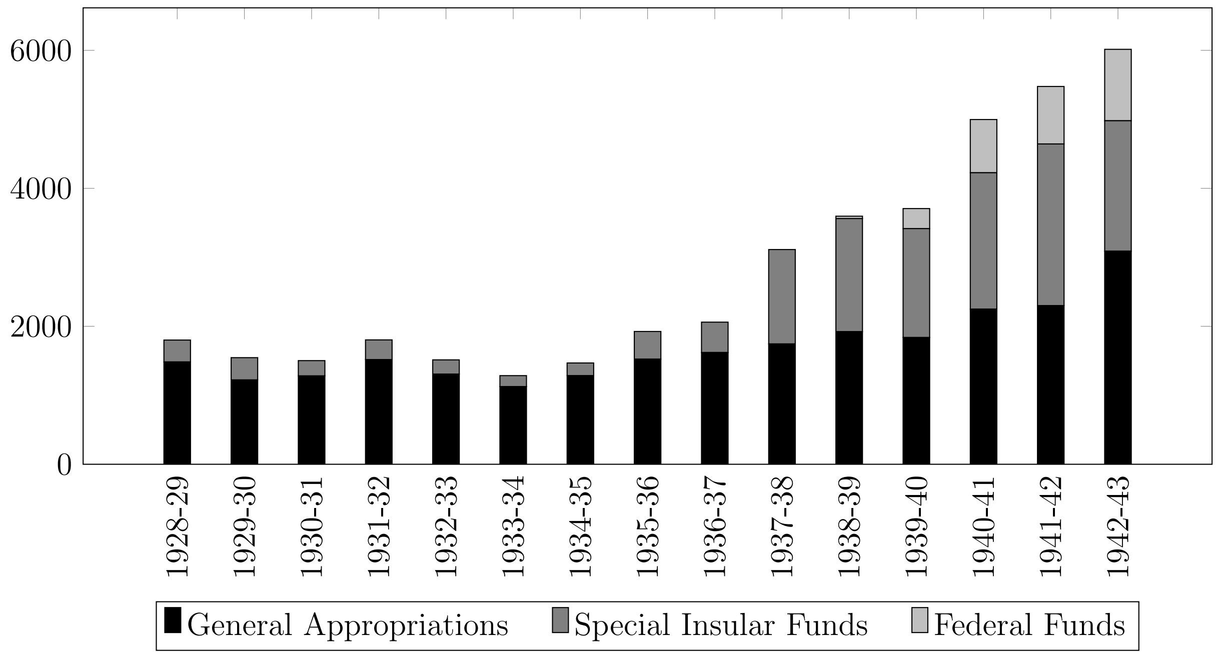


Malaria



Notes: Dependent variables are log mortality rates. Coefficients are weighted least-squares estimates. Dashed lines are 95 percent confidence intervals and are based on standard errors clustered by municipality. The year prior to the establishment of the PHU is omitted, as is the first event-year in the sample in Panel B. Sample includes 75 municipalities and 1,725 municipality-year observations for TB mortality and 1,650 municipality-year observations for malaria mortality. In Panel A, event-years outside of the designated window are captured by "before" and "after" dummies.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from annual reports of the Commissioner of Health and Chaves (1942).

Figure 7: Resources of the Department of Health, 1928-29 to 1942-43
(Thousands of dollars)



Source: *Report of the Commissioner of Health of Puerto Rico for the Fiscal Year 1942-43*

C Robustness Checks

The regression results described in Section 5 suggest that PHUs played a major role in the decline in mortality rates in Puerto Rico through the end of World War II. In this subsection, I explore the robustness of the results to several tweaks to the data and econometric model.

C.1 Random Placebo Test

The evidence from the event study that PHUs significantly reduced mortality applies to four different outcome variables, so it is unlikely that the results are spurious. Nonetheless, in this section I consider the possibility that the relationship between PHUs and mortality is spurious by performing random placebo tests. In each of 2,500 simulations, municipalities are randomly assigned an inaugural treatment year between 1927 and 1938, and the placebo treatment is used to re-estimate Equation 1. Figure A2 shows the distribution of coefficients from these simulations, with the coefficient derived from the true rollout marked by the vertical dashed line. Each distribution is centered near zero, and the percent of placebo coefficients to the left of the dashed lines is 0.16% for mortality, 0.12% for TB mortality, 1.44% for infant mortality, and 12.88% for stillbirths. Hence, the estimated effect of PHUs is much more negative than would be expected from a placebo intervention and the results are unlikely to be spurious for overall, TB, and infant mortality. In the case of stillbirths, the true coefficient is to the far left of the distribution, but the test leaves open the possibility that the negative effect found in Section 5 is spurious. Of course, the estimated effect of PHUs on stillbirths is not statistically significant in this specification, anyway.

C.2 PHU Dates of Inauguration

As discussed in Section 3, there are discrepancies in the inauguration dates for a few municipalities between official sources. In Section 5, PHU dates are based on the earliest opening date found in annual reports of the Commissioner of Health. In this section, I re-estimate Equation 1 to assess the sensitivity of the results to different ways of coding of PHU_{mk}. The pattern of results does not change, and the findings in this paper are not specific to the decisions made regarding PHU dates of inauguration.

Department of Health reports revised the year of inauguration to a later date for a few municipalities because earlier lists of PHUs had included semi-units, in which health officers were part-time employees, and units that did not provide rural coverage.[26] The discrepancies were due to the fact that in several towns "many changes had been made so that the skeleton of the new organization existed but the program was not complete..." (Commissioner of Health, 1932, p. 65). In any case, as seen in Tables A1-A4, the results for overall mortality, infant mortality, stillbirths, and TB mortality remain strong when semi-units are defined as untreated and municipalities without rural coverage are defined as untreated. Likewise, the results are robust to dates based on histories of PHUs written by a former director of PHUs (Chaves, 1942), which report later dates for semi-units and units without rural coverage, including when two obvious errors are fixed.[27] The same pattern of results also emerge when the inauguration date for Aguadilla is switched from 1931-32 to 1929-30 since Aguadilla had a health dispensary and was included in the list of municipalities with the skeleton of a PHU prior to 1932; Loíza and Trujillo Alto are dropped, since they each briefly had a PHU, spent several years without a PHU, and later regained the PHU; and when the aggregated data for Cataño and Bayamón are treated according to the date of inauguration of the PHU in Cataño, the smaller of the municipalities, rather than the date for Bayamón.

[26] The following municipalities were reported to have semi-units before 1931-32: Humacao, Juncos, and Mayagüez. The following municipalities were reported to have PHUs with no rural coverage before 1931-32: Humacao, Mayagüez, and Ponce. Additionally, San Juan was reported to have a PHU as early as 1928-29 (Governor of Puerto Rico, 1929) and Guayama in 1929-30 (Commissioner of Health, 1932), but later documents report 1931-32 as the year of inauguration for both municipalities. Guayama supposedly had a dispensary and unit organization nominally in place in 1929 but did not fully attempt its program until 1930.

[27] The PHUs in Manatí opened in 1931-32, not 1932-33 (Commissioner of Health, 1932), and in Sabana Grande in 1935-36, not 1934-35 (Commissioner of Health, 1936).

C.3 Underregistration of Births

Births were underreported in Puerto Rico throughout the period under investigation. The US Bureau of the Census in 1931 made tests of the completeness of birth registration in Puerto Rico to determine whether the island was eligible for admission to the US birth registration area. Registration was found to be poor, and the tests were discontinued (Eliot, 1933). Tests of completeness of birth registration based on the 1940 and 1950 censuses concluded that 86 and 96 percent of births, respectively, were registered (Vázquez Calzada, 1968). Puerto Rico was not admitted to the US birth registration area until 1943.

Infant mortality rates suffer from an upward bias stemming from underregistration of births, and the official infant mortality rate may have declined over time as a result of improvements in birth registration. If underregistration varied across municipalities—as in the US, where underreporting was more severe in the South and among blacks—estimates may be biased even in a panel setting with specifications that include location fixed effects and place-specific linear time trends (Eriksson et al., 2018).

To assess whether the decline in the official infant mortality rate following PHU openings is the product of improvements in birth registration, I here use the ratio of infant deaths to population as the dependent variable. Unlike births, nearly all deaths were believed to be reported even prior to the creation of the Bureau of Vital Statistics in 1931 (Janer, 1945). Likewise, intercensal population counts, though obviously imprecise, are untainted by underregistration of births because they are extrapolations of growth trends between censuses, including the 1935 special census. Therefore, the ratio of infant deaths to population has the advantages of being highly correlated with the infant mortality rate ($\rho = 0.92$) but uncorrelated with improvements in birth registration.

The results using this dependent variable appear in Figure A3 and are nearly identical to results based on the infant mortality rate. Parallel pre-trends demonstrate that changes in infant mortality were not different in other municipalities leading up to program adoption and support the assumption that infant mortality would likewise have followed a parallel trend in the absence of a PHU. The ratio of infant deaths to population then falls by seven or eight percent, depending on the specification, in the first year with a PHU, significant at the 5 percent level. The effect of PHUs then grows over time. Hence, the estimated reduction in infant mortality resulting from PHUs is not driven by differential changes in birth registration.

C.4 Additional Years of Data

The main analysis includes data starting in 1923 because data for 1922 are not available in government publications. In this section, I consider results based on data starting in 1920 and exclude data from 1918 and 1919 to avoid influence from the influenza pandemic. Data for 1922 are interpolated, as are data for 1923 for infant mortality, stillbirths, and malaria mortality. Overall, the results in Figures A4 and A5 mirror the main results, but there are two issues that ought to be addressed. First, although none of the coefficients are statistically significant, the leads in the baseline specification for infant mortality exhibit an upward trend for the period from 7 to 3 years preceding PHU inauguration. These coefficients are likely biased, as there is no evidence of a trend, or even negative coefficients, before PHU inauguration in the dynamic specification. Second, malaria mortality trends downward following treatment in the baseline specification. However, this result is not robust, as evidenced by the results of the dynamic specification, so the conclusion remains that PHUs did not significantly reduce malaria mortality.

C.5 Unweighted Observations

All regressions up to this point weighted observations by municipality population in 1935, generating results which generalize to the island population. In this section, I re-estimate Equation 1 without weighting observations to determine whether the main results were driven by a few large municipalities. The results are strikingly similar to those from the weighted regressions, indicating that PHUs played a major role in reducing all measured forms of mortality other than malaria mortality (see Col. 1, Tables A5-A8). In the case of overall mortality, there is some evidence of a significant change in mortality preceding PHU inauguration, as the point estimate on the lead variable two years prior equals -0.04 and is statistically significant at the 10 percent level. Still, the body of evidence supports the conclusion that PHUs reduced mortality across municipalities.

C.6 Municipality-Specific Time Trends

A common practice in analyses using an event study framework is to relax the assumption of common trends by allowing for unit-specific time trends. Following the guidance of Goodman-Bacon (2019) and Borusyak and Jaravel (2018), I do not include municipality-specific time trends in the main analysis. Unit-specific linear trends tend to absorb time-varying treatment effects that are necessarily larger at the end of the panel, and in these cases they over control. Nonetheless, such trends are included as a robustness check, and the main results are unaffected (see Col. 2, Tables A5-A8).

C.7 Municipality Characteristics Time Trends

A key assumption of my empirical strategy is that the timing of PHU establishment is uncorrelated with changes in other determinants of mortality. In Section 4, I find that municipalities that opened PHUs earlier tended to be more urbanized and have higher initial mortality rates. Municipality fixed effects in all specifications account for time-invariant municipal characteristics correlated with the outcome variable, so selection into treatment does not bias estimates unless it is correlated with trends in mortality. In this section, I consider this potential threat to identification by including linear trends interacted with the share of the population living in urban areas (places of 2,500 or more inhabitants) in 1930 and the average mortality rate from 1923 to 1926.[28] As seen in Column 3 of Tables A5-A8,

[28] The average mortality rate from 1923 to 1926 is the mortality rate (overall, infant, TB, or stillbirths) corresponding to the dependent variable in each regression. Infant mortality and stillbirth rates are available only for 1924 to 1926.

the results are unaffected for overall, infant, and TB mortality.

C.8 Census Controls

Time-varying municipal characteristics were not frequently reported throughout the sample period. In this section, I extract several variables from the the 1920, 1930, 1940, and 1950 censuses of Puerto Rico and linearly impute intercensal years. Following Anderson et al. (2019a), these variables are the fraction of the population that was female, nonwhite, younger than 5, and literate.[29] The fraction of the population that was under 5 is endogenous to infant mortality, and is significantly negatively correlated with changes in the infant mortality rate. The fractions female (due to the prevalence of puerperal mortality) or literate (due to changes in incentives to invest in human capital) may also be endogenous to mortality. In any case, results for Equation 1 appear in Column 4 of Tables A5-A8 and demonstrate, once again, that PHUs significantly reduced overall, TB, and infant mortality, and may have reduced stillbirths.

C.9 Controlling for a Public Water System

Improvements in water purification played a crucial role in the mortality transition in the United States (Alsan and Goldin, 2019; Anderson et al., 2019b, 2020c; Cutler and Miller, 2005; Ferrie and Troesken, 2008). Puerto Rico likewise invested in centralized water purification in the early 20th century, including during the period of analysis in this paper. Although the work of public health units involved the enforcement of sanitary regulations, PHUs were not responsible for the provision of drinking water. In Column 5 of Tables A5-A8, I control for improvements in drinking water by including an indicator variable equal to one if a municipality has a public water source and zero otherwise, derived from years of construction as reported in the 1939-40 annual report of the commissioner of health.

[29] Anderson et al. (2019a) uses the fraction of the population younger than 18, but I use the fraction under 5 because it is reported in the census report for each of the four censuses.

The coefficient on the public water dummy (not shown) is negative for all forms of mortality but is never close to statistically significant, and its inclusion does not change any of the main results.

C.10 Heterogeneous Treatment Effects

The event study design imposes the assumption that treatment effects depend only on the time relative to treatment, meaning that treatment effects are homogeneous across municipalities and calendar years. Violations of this assumption may bias coefficient estimates by negatively weighting some difference-in-differences comparisons when the "control group" is treated in both periods (Abraham and Sun, 2019; Borusyak and Jaravel, 2018; de Chaisemartin and D'Haultfoeuille, 2020; Goodman-Bacon, 2019). In extreme cases, the estimand may be negative (positive) while all average treatment effects are positive (negative). The homogeneity assumption may be unrealistic, as PHUs might have a more pronounced effect in areas which previously lacked public health services, for example. PHUs may have also had a larger effect in certain calendar years due to interactions with other programs. For instance, TB clinics in PHUs may have been more effective after the commencement of the island-wide anti-TB campaign in 1934 (Rodríguez Pastor and Janer, 1953).

To relax the assumption of homogeneity in treatment effects, I present results from an estimator proposed by de Chaisemartin and D'Haultfoeuille (2020) that is valid even if the treatment effect is heterogeneous over time or across municipalities. The estimand identifies the effect of the treatment in the groups that switch treatment, at the time when they switch, by comparing them to those that do not become treated at that time. For each event-time period, the estimand is the average of the instantaneous treatment effect at the time when a municipality starts receiving the treatment, across all municipalities. The estimator relies on a variant of the standard common trends assumption. The results from this estimator closely follow the main results in terms of magnitude and statistical significance, strongly supporting the conclusions drawn above (see Col. 6, Tables A5-A8).

C.11 Spillovers between Municipalities

Although PHUs were intended to improve local coordination of public health efforts at the municipal level, it is possible that PHUs could have had spillover effects on mortality in neighboring municipalities. Knowledge about infant hygiene, for example, may have diffused informally across society. None of the government documents reviewed for this study mentioned that services were limited to inhabitants of the municipality in which the PHU was located, so PHUs may have also directly served inhabitants of nearby municipalities. In the case of TB, the reduction in morbidity in one municipality may reduce morbidity in nearby municipalities by slowing the spread of disease.

Table A9 reports results from controlling for the opening of a dispensary in an adjacent municipality.[30] There is no evidence to suggest that PHUs had spillover effects into neighboring municipalities for any of the outcome variables. The point estimates for the effect of a PHU in an adjacent municipality are all close to zero and have no consistent sign across types of mortality. This is not surprising since modern forms of transportation were still inaccessible for most families in this era, so PHUs likely served the inhabitants of their municipality exclusively.[31]

C.12 Spatial Autocorrelation

Spatial data tend to be autocorrelated, and t-statistics may be too large in regressions with spatially autocorrelated residuals (Kelly, 2019). Clustering standard errors is invalid in

[30] The coefficients are derived from linear combinations of coefficients for event-years 0 through 7 in a fully dynamic event study specification. The regressions include a full set of indicator variables equal to 1 if there is a PHU in a municipality neighboring m in event-year k, and 0 otherwise, alongside the event study indicators for a PHU located in m. Results from a static two-way fixed effects estimator—which is not shown in the table due to concerns about negative weighting—likewise fail to find any evidence that PHUs had spillover effects into neighboring municipalities.

[31] For instance, nearly one-half of rural homes in the interior of the island were located more than three miles from a paved or dirt road (Mountin et al., 1937).

the presence of non-negligible spatial autocorrelation since residuals in neighboring clusters will tend to be correlated. Hence, the regression results based on clustering at the municipal level do not account for spatial autocorrelation.

Table A10 presents results for Equation 1 with standard errors adjusted for arbitrary dependence of the errors across observations in space and across time periods as in Colella et al. (2019), building on Conley (1999). I present results for a distance cutoff of 30 km. and that allow for dependence across all time periods. These results are conservative in that different parameters generally produce smaller standard errors. Still, the standard errors from this procedure are smaller than the clustered standard errors presented in the body of the paper. All of the main results of the paper hold after adjusting for spatial autocorrelation.

C.13 Static Difference-in-Differences

In difference-in-differences (DiD) settings with staggered adoption (e.g. the rollout of PHUs in Puerto Rico), the DiD coefficient in two-way (unit and time) fixed effects models does not have a clear causal interpretation under treatment effect heterogeneity. The DiD coefficient represents a weighted average of dynamic effects where some of the weights can be negative; in extreme cases, the DiD coefficient could be negative (positive) even though the treatment effect on each cohort is positive (negative) (Abraham and Sun, 2019; Borusyak and Jaravel, 2018; de Chaisemartin and D'Haultfoeuille, 2020; Goodman-Bacon, 2019). Using the `twowayfeweights` Stata package in a DiD model under the common trends assumption, I find that 32 percent of weights are negative; the DiD coefficient does not represent an average treatment effect and is uninterpretable (de Chaisemartin and D'Haultfoeuille, 2020).

Still, "static" DiD models, with a treatment dummy instead of leads and lags around the treatment event, are common in social science research. For comparison, I present results from a static model in the first row of Table A11 while stressing that these results are difficult to interpret and do not summarize the treatment effect. The PHU indicator variable is lagged one period when the stillbirth rate is the dependent variable since the event study revealed that the effect was delayed. Across the board the effect is negative, and it is statistically at the 1 percent level for overall mortality and at the 10 percent level for TB and malaria mortality. When the treatment indicator is lagged one period for TB, the effect is significant at the 1 percent level and the coefficient is larger ($\hat{\beta} = -0.12$).

In the second and third rows of Table A11 I provide alternative "static" DiD coefficients by manually averaging the coefficients from the baseline ("capped") and semi-dynamic specifications. In particular, the coefficient derived from the semi-dynamic specification has the advantages of summarizing the treatment effects for the first eight years with a PHU while avoiding the problem of negative weighting (from dynamic treatment effects only) by estimating treatment effects flexibly.

The baseline model suggests that PHUs significantly reduced overall and TB mortality at the 1 percent level and infant mortality at the 5 percent level. The semi-dynamic specification suggests that PHUs significantly reduced overall and infant mortality at the 1 percent level. Based on the semi-dynamic model, the average reduction in mortality in the first eight years of treatment were as follows: 8 percent for overall mortality, 11 percent for TB mortality, 11 percent for infant mortality, and 16 percent for stillbirths. Except in the case of malaria mortality, the coefficients are negative and quite large across specifications and outcome variables, strengthening the conclusion that PHUs significantly reduced these forms of mortality.

C.14 Infant Mortality, Maternal Mortality, and Midwives (Alternative Specification)

Results based on a difference-in-differences model in Section 5.3 indicate that infant and maternal mortality are negatively associated with assistant midwives per capita starting in 1931. In this section I test the robustness of that result with a generalized difference-in-difference model to determine when these negative relationships emerged.

Figure A1 displays results from a generalized difference-in-difference model which includes a series of interactions between year fixed effects and the number of assistant midwives per 1,000 inhabitants in 1935. The interaction term for 1924 is omitted. The pattern of coefficients over time suggests that the negative association between midwives per capita and infant mortality emerged in fiscal year 1929-30, just prior to the 1931 law mandating that assistant midwives be licensed. Coefficients trend downwards again in 1932 after briefly moving back up around zero. Still, the negative association before 1931 raises concern that the relationship between midwives per capita and infant mortality is driven by an omitted variable. However, in the second row of the first column, midwives per capita is replaced with the share of births attended by authorized persons—a proxy for the the impact of midwives, since midwives delivered 85 percent of infants—and a negative relationship between authorized births and infant mortality arises after the 1931 law. Hence, the evidence is suggestive, but not conclusive, that infant mortality is related to the licensing of midwives in 1931.

The right column of Figure A1 displays results for maternal mortality. The pattern of coefficients suggests that the negative association between midwives per capita and maternal mortality did not emerge until 1931, although the two years preceding the law are missing. The negative association remains through the remainder of the sample period but increases in magnitude in 1937 and subsequent years, around the time when sulfa drugs became widely available and reduced maternal mortality (Jayachandran et al., 2010; Thomasson and Treber, 2008). While midwives probably did not administer sulfa drugs, midwives might have recognized abnormal symptoms and known to call the attention of a physician. In any case, results for 1937 to 1945 do not drive the significant correlation between midwives per capita and maternal mortality: excluding later years in the difference-in-differences model, an additional midwife per 1,000 inhabitants is associated with 23 percent lower maternal mortality ($p = 0.035$). Results based on the share of births attended by authorized persons follow a similar pattern, albeit weaker.

D Additional Tables

Table A1: Robustness Checks: PHU Dates of Inauguration (Overall Mortality)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Year -4	0.02	0.01	0.01	0.01	0.01	0.00	0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year -3	-0.01	0.00	-0.01	-0.01	-0.01	-0.01	-0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year -2	-0.01	-0.01	-0.03	-0.03	-0.00	-0.03*	-0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year 0	-0.04**	-0.04***	-0.05**	-0.05***	-0.04**	-0.05***	-0.04***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
Year 1	-0.03*	-0.04*	-0.05**	-0.06**	-0.03*	-0.06**	-0.04**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year 2	-0.07***	-0.06***	-0.07***	-0.07***	-0.08***	-0.07***	-0.07***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year 3	-0.09***	-0.09***	-0.08***	-0.08***	-0.10***	-0.09***	-0.10***
	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.03)	(0.02)
Year 4	-0.09***	-0.09***	-0.08**	-0.08**	-0.10***	-0.09***	-0.10***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year 5	-0.09***	-0.09***	-0.09**	-0.09**	-0.10***	-0.10**	-0.11***
	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)
Year 6	-0.09**	-0.09**	-0.08**	-0.08**	-0.09***	-0.09**	-0.11***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)
Year 7	-0.11***	-0.11***	-0.10**	-0.10**	-0.12***	-0.10**	-0.13***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
PHU Dates	Semi-unit $\neq$ PHU	No rural $\rightarrow$ no PHU	Chaves	Chaves w/ 2 fixes	Aguadilla 1929-30	Drop Loíza, Truj. Alto	Bayamón 1929-30
Obs.	1,725	1,725	1,725	1,725	1,725	1,679	1,725

Notes: The dependent variable is the log mortality rate. The coefficients are weighted least-squares estimates. The year prior to the establishment of the PHU is omitted. Event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A2: Robustness Checks: PHU Dates of Inauguration (Infant Mortality)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Year -3	-0.02	0.00	0.00	0.00	-0.04	-0.00	-0.03
	(0.04)	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)
Year -2	-0.00	-0.00	-0.00	-0.01	-0.02	-0.01	-0.02
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year 0	-0.07**	-0.06**	-0.07*	-0.06*	-0.07**	-0.08**	-0.06**
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year 1	-0.05	-0.05	-0.05	-0.05	-0.05	-0.06	-0.05
	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)
Year 2	-0.07**	-0.07*	-0.05	-0.05	-0.08**	-0.06	-0.08**
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Year 3	-0.08**	-0.08**	-0.08*	-0.08*	-0.09**	-0.10**	-0.08**
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)
Year 4	-0.08	-0.09*	-0.08	-0.07	-0.08*	-0.10*	-0.08*
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
Year 5	-0.10**	-0.12***	-0.12**	-0.12**	-0.10**	-0.14***	-0.10**
	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)	(0.05)	(0.04)
Year 6	-0.10*	-0.11**	-0.09	-0.09*	-0.10**	-0.12**	-0.10**
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
Year 7	-0.14**	-0.15**	-0.12*	-0.11*	-0.13**	-0.14**	-0.13**
	(0.06)	(0.06)	(0.07)	(0.06)	(0.05)	(0.07)	(0.05)
PHU Dates	Semi-unit ≠ PHU	No rural → no PHU	Chaves	Chaves w/ 2 fixes	Aguadilla 1929-30	Drop Loíza, Truj. Alto	Bayamón 1929-30
Obs.	1,650	1,650	1,650	1,650	1,650	1,606	1,650

Notes: The dependent variable is the log infant mortality rate. The coefficients are weighted least-squares estimates. The year prior to the establishment of the PHU is omitted. Event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. Significance levels are denoted by * $p < .10$, ** $p < .05$, *** $p < .01$.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A3: Robustness Checks: PHU Dates of Inauguration (Stillbirths)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Year -3	0.02	0.03	0.04	0.05	-0.00	0.01	-0.01
	(0.05)	(0.05)	(0.06)	(0.06)	(0.04)	(0.05)	(0.04)
Year -2	-0.01	0.01	0.01	0.01	-0.02	-0.01	-0.03
	(0.05)	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)	(0.05)
Year 0	0.01	0.03	0.00	0.00	-0.01	0.01	-0.00
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Year 1	-0.02	-0.04	-0.05	-0.04	-0.04	-0.03	-0.04
	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
Year 2	-0.02	-0.04	-0.06	-0.06	-0.02	-0.02	-0.03
	(0.06)	(0.06)	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)
Year 3	-0.07	-0.08	-0.13	-0.13	-0.08	-0.09	-0.08
	(0.08)	(0.08)	(0.09)	(0.09)	(0.08)	(0.08)	(0.08)
Year 4	-0.07	-0.07	-0.11	-0.12	-0.08	-0.05	-0.08
	(0.09)	(0.09)	(0.10)	(0.10)	(0.08)	(0.08)	(0.08)
Year 5	-0.07	-0.07	-0.11	-0.12	-0.06	-0.04	-0.08
	(0.11)	(0.11)	(0.13)	(0.13)	(0.10)	(0.10)	(0.10)
Year 6	-0.09	-0.09	-0.11	-0.11	-0.10	-0.03	-0.11
	(0.12)	(0.12)	(0.14)	(0.14)	(0.11)	(0.11)	(0.11)
Year 7	-0.09	-0.08	-0.13	-0.14	-0.10	-0.03	-0.10
	(0.13)	(0.13)	(0.16)	(0.16)	(0.13)	(0.12)	(0.13)
PHU Dates	Semi-unit $\neq$ PHU	No rural $\rightarrow$ no PHU	Chaves	Chaves w/ 2 fixes	Aguadilla 1929-30	Drop Loíza, Truj. Alto	Bayamón 1929-30
Obs.	1,650	1,650	1,650	1,650	1,650	1,606	1,650

Notes: The dependent variable is the log stillbirth rate. The coefficients are weighted least-squares estimates. The year prior to the establishment of the PHU is omitted. Event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A4: Robustness Checks: PHU Dates of Inauguration (Tuberculosis Mortality)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Year -4	-0.03	-0.03	-0.01	-0.01	-0.02	-0.00	-0.03
	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Year -3	-0.06	-0.05	-0.04	-0.04	-0.05	-0.05	-0.04
	(0.05)	(0.05)	(0.06)	(0.06)	(0.05)	(0.06)	(0.05)
Year -2	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.01
	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year 0	-0.03	-0.03	-0.05	-0.04	-0.04	-0.06	-0.03
	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)
Year 1	-0.11**	-0.11**	-0.14**	-0.14**	-0.12***	-0.14**	-0.12***
	(0.04)	(0.05)	(0.06)	(0.06)	(0.04)	(0.06)	(0.04)
Year 2	-0.16***	-0.16***	-0.19***	-0.18***	-0.17***	-0.20***	-0.17***
	(0.06)	(0.06)	(0.07)	(0.07)	(0.05)	(0.07)	(0.05)
Year 3	-0.18***	-0.18***	-0.19**	-0.18**	-0.18***	-0.20***	-0.17***
	(0.06)	(0.06)	(0.07)	(0.07)	(0.06)	(0.07)	(0.06)
Year 4	-0.18**	-0.17**	-0.17**	-0.17**	-0.18***	-0.19**	-0.17**
	(0.07)	(0.07)	(0.08)	(0.08)	(0.07)	(0.08)	(0.07)
Year 5	-0.19***	-0.20***	-0.21**	-0.20**	-0.21***	-0.23**	-0.21***
	(0.07)	(0.07)	(0.09)	(0.09)	(0.07)	(0.09)	(0.07)
Year 6	-0.20**	-0.20**	-0.20*	-0.19*	-0.21**	-0.22**	-0.20**
	(0.08)	(0.09)	(0.10)	(0.10)	(0.08)	(0.10)	(0.08)
Year 7	-0.25***	-0.24***	-0.24**	-0.24**	-0.26***	-0.25**	-0.25***
	(0.09)	(0.09)	(0.11)	(0.11)	(0.09)	(0.11)	(0.09)
PHU Dates	Semi-unit $\neq$ PHU	No rural $\rightarrow$ no PHU	Chaves	Chaves w/ 2 fixes	Aguadilla 1929-30	Drop Loíza, Truj. Alto	Bayamón 1929-30
Obs.	1,725	1,725	1,725	1,725	1,725	1,679	1,725

Notes: The dependent variable is the log TB mortality rate. The coefficients are weighted least-squares estimates. The year prior to the establishment of the PHU is omitted. Event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A5: Robustness Checks: Alternative Specifications (Overall Mortality)

	(1)	(2)	(3)	(4)	(5)	(6)
Year -4	-0.00	0.02	0.02	0.01	0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Year -3	-0.02	-0.01	-0.01	-0.01	-0.01	-0.03
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year -2	-0.03*	0.00	0.00	-0.00	-0.00	0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year -1						0.01
						(0.03)
Year 0	-0.04**	-0.04**	-0.04**	-0.04**	-0.04**	-0.04*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year 1	-0.03	-0.03*	-0.03	-0.03*	-0.03	-0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year 2	-0.06**	-0.08***	-0.07***	-0.07***	-0.07***	-0.06**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Year 3	-0.08***	-0.10***	-0.09***	-0.10***	-0.10***	-0.09***
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Year 4	-0.06*	-0.10***	-0.09***	-0.10***	-0.09***	-0.06*
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year 5	-0.07*	-0.10***	-0.09***	-0.10***	-0.10***	-0.09***
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year 6	-0.07	-0.10***	-0.08**	-0.10***	-0.09***	-0.07
	(0.05)	(0.03)	(0.03)	(0.03)	(0.03)	(0.06)
Year 7	-0.09*	-0.12***	-0.10***	-0.12***	-0.11***	-0.11
	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.07)
Robustness Check	Un-weighted	Muni-trends	X_i-trends	Census Controls	Public Water	Hetero. TE

Notes: The dependent variables are log mortality rates. Except in columns 6, the year prior to the establishment of the PHU is omitted, and event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. All regressions include 1,725 observations. Columns 1-5 are derived from Equation 1. Column 1 is unweighted. Column 2 includes municipality-specific linear trends. Column 3 includes linear trends interacted with municipality characteristics (urban share and pre-program mortality). Column 4 includes controls for the fraction of the population that was female, nonwhite, younger than 5, and literate, linearly interpolated from the 1920, 1930, 1940, and 1950 censuses. Column 5 includes an indicator variable equal to one if municipality m has a public water source in year t and zero otherwise. Column 6 allows for treatment effects to vary across municipalities and calendar years and is estimated with the Stata command *did_multiplegt* from de Chaisemartin and D'Haultfoeuille (2020). Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A6: Robustness Checks: Alternative Specifications (Infant Mortality)

	(1)	(2)	(3)	(4)	(5)	(6)
Year -3	0.00	-0.03	-0.03	-0.03	-0.03	-0.02
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year -2	-0.01	-0.01	-0.01	-0.01	-0.01	0.02
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year -1						0.01
						(0.04)
Year 0	-0.06*	-0.07**	-0.06**	-0.06**	-0.06**	-0.08**
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)
Year 1	-0.05	-0.04	-0.04	-0.04	-0.04	-0.07*
	(0.05)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)
Year 2	-0.10*	-0.08**	-0.07**	-0.07**	-0.07**	-0.12**
	(0.05)	(0.03)	(0.03)	(0.04)	(0.04)	(0.05)
Year 3	-0.13**	-0.09**	-0.08**	-0.08**	-0.08**	-0.13**
	(0.06)	(0.04)	(0.04)	(0.04)	(0.04)	(0.06)
Year 4	-0.12*	-0.08*	-0.07	-0.07	-0.07	-0.14**
	(0.06)	(0.04)	(0.04)	(0.05)	(0.05)	(0.06)
Year 5	-0.17***	-0.10**	-0.10**	-0.10**	-0.10**	-0.17***
	(0.06)	(0.04)	(0.04)	(0.04)	(0.04)	(0.06)
Year 6	-0.14**	-0.10**	-0.08**	-0.10**	-0.10**	-0.23**
	(0.06)	(0.05)	(0.04)	(0.05)	(0.05)	(0.11)
Year 7	-0.20***	-0.14**	-0.12**	-0.14**	-0.13**	-0.26**
	(0.07)	(0.05)	(0.05)	(0.06)	(0.05)	(0.11)
Robustness Check	Un-weighted	Muni-trends	X_i-trends	Census Controls	Public Water	Hetero. TE

Notes: The dependent variables are log mortality rates. Except in columns 6, the year prior to the establishment of the PHU is omitted, and event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. All regressions include 1,650 observations. Columns 1-5 are derived from Equation 1. Column 1 is unweighted. Column 2 includes municipality-specific linear trends. Column 3 includes linear trends interacted with municipality characteristics (urban share and pre-program mortality). Column 4 includes controls for the fraction of the population that was female, nonwhite, younger than 5, and literate, linearly interpolated from the 1920, 1930, 1940, and 1950 censuses. Column 5 includes an indicator variable equal to one if municipality m has a public water source in year t and zero otherwise. Column 6 allows for treatment effects to vary across municipalities and calendar years and is estimated with the Stata command *did_multiplegt* from de Chaisemartin and D'Haultfoeuille (2020). Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A7: Robustness Checks: Alternative Specifications (Stillbirths)

	(1)	(2)	(3)	(4)	(5)	(6)
Year -3	0.04	0.01	0.01	-0.00	-0.01	0.06
	(0.07)	(0.05)	(0.04)	(0.04)	(0.04)	(0.10)
Year -2	0.03	-0.01	-0.02	-0.02	-0.03	-0.04
	(0.05)	(0.06)	(0.05)	(0.05)	(0.05)	(0.05)
Year -1						0.04
						(0.06)
Year 0	-0.00	-0.01	-0.01	-0.01	-0.00	-0.02
	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)
Year 1	-0.06	-0.05	-0.05	-0.04	-0.04	-0.05
	(0.06)	(0.04)	(0.05)	(0.05)	(0.04)	(0.05)
Year 2	-0.08	-0.04	-0.03	-0.03	-0.03	-0.05
	(0.08)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Year 3	-0.13	-0.09	-0.08	-0.07	-0.07	-0.10
	(0.11)	(0.07)	(0.08)	(0.08)	(0.07)	(0.07)
Year 4	-0.13	-0.09	-0.08	-0.07	-0.07	-0.11
	(0.13)	(0.07)	(0.08)	(0.08)	(0.08)	(0.08)
Year 5	-0.14	-0.08	-0.07	-0.07	-0.06	-0.19
	(0.16)	(0.08)	(0.10)	(0.10)	(0.10)	(0.13)
Year 6	-0.15	-0.11	-0.09	-0.10	-0.10	-0.33
	(0.18)	(0.09)	(0.11)	(0.11)	(0.11)	(0.24)
Year 7	-0.18	-0.09	-0.08	-0.09	-0.09	-0.11
	(0.20)	(0.10)	(0.12)	(0.12)	(0.12)	(0.17)
Robustness Check	Un-weighted	Muni-trends	X_i-trends	Census Controls	Public Water	Hetero. TE

Notes: The dependent variables are log mortality rates. Except in columns 6, the year prior to the establishment of the PHU is omitted, and event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. All regressions include 1,650 observations. Columns 1-5 are derived from Equation 1. Column 1 is unweighted. Column 2 includes municipality-specific linear trends. Column 3 includes linear trends interacted with municipality characteristics (urban share and pre-program mortality). Column 4 includes controls for the fraction of the population that was female, nonwhite, younger than 5, and literate, linearly interpolated from the 1920, 1930, 1940, and 1950 censuses. Column 5 includes an indicator variable equal to one if municipality m has a public water source in year t and zero otherwise. Column 6 allows for treatment effects to vary across municipalities and calendar years and is estimated with the Stata command *did_multiplegt* from de Chaisemartin and D'Haultfoeuille (2020). Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin.* Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A8: Robustness Checks: Alternative Specifications (Tuberculosis Mortality)

	(1)	(2)	(3)	(4)	(5)	(6)
Year -4	-0.10	-0.04	-0.02	-0.03	-0.02	-0.05*
	(0.09)	(0.06)	(0.06)	(0.06)	(0.06)	(0.03)
Year -3	-0.16	-0.06	-0.05	-0.05	-0.05	-0.02
	(0.10)	(0.06)	(0.05)	(0.05)	(0.05)	(0.04)
Year -2	-0.05	-0.03	-0.02	-0.02	-0.02	0.05
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)
Year -1						0.02
						(0.03)
Year 0	-0.06	-0.03	-0.03	-0.03	-0.04	-0.04
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Year 1	-0.17***	-0.11**	-0.12***	-0.12***	-0.12***	-0.12**
	(0.06)	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)
Year 2	-0.21***	-0.16***	-0.18**	-0.17***	-0.18***	-0.14**
	(0.08)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Year 3	-0.17**	-0.16**	-0.19***	-0.18***	-0.19***	-0.17***
	(0.07)	(0.06)	(0.05)	(0.06)	(0.06)	(0.06)
Year 4	-0.14*	-0.16*	-0.18***	-0.17**	-0.18***	-0.12
	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)	(0.10)
Year 5	-0.20**	-0.18**	-0.21***	-0.20***	-0.21***	-0.19*
	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)	(0.11)
Year 6	-0.17	-0.18*	-0.20**	-0.19**	-0.21**	-0.22
	(0.10)	(0.10)	(0.08)	(0.08)	(0.08)	(0.15)
Year 7	-0.26**	-0.23**	-0.25***	-0.24***	-0.27***	-0.28
	(0.12)	(0.11)	(0.09)	(0.09)	(0.09)	(0.20)
Robustness Check	Un-weighted	Muni-trends	X_i-trends	Census Controls	Public Water	Hetero. TE

Notes: The dependent variables are log mortality rates. Except in columns 6, the year prior to the establishment of the PHU is omitted, and event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are clustered by municipality. All regressions include 1,725 observations. Columns 1-5 are derived from Equation 1. Column 1 is unweighted. Column 2 includes municipality-specific linear trends. Column 3 includes linear trends interacted with municipality characteristics (urban share and pre-program mortality). Column 4 includes controls for the fraction of the population that was female, nonwhite, younger than 5, and literate, linearly interpolated from the 1920, 1930, 1940, and 1950 censuses. Column 5 includes an indicator variable equal to one if municipality m has a public water source in year t and zero otherwise. Column 6 allows for treatment effects to vary across municipalities and calendar years and is estimated with the Stata command *did_multiplegt* from de Chaisemartin and D'Haultfoeuille (2020). Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A9: The Effect of PHUs on Mortality Rates Controlling for Neighboring Units

Dependent variables:	Death	IMR	Stillbirths	TB
PHU	-0.10**	-0.20***	-0.12	-0.17**
	(0.04)	(0.05)	(0.11)	(0.07)
Neighboring PHU	-0.04	0.03	-0.03	0.02
	(0.03)	(0.07)	(0.12)	(0.10)
Observations	1,702	1,628	1,628	1,702

Notes: The dependent variables are log mortality rates. The coefficients are weighted least-squares estimates. Standard errors are clustered by municipality. Coefficients are derived from a linear combination of coefficients estimated separately for event-years 0 to 7 from the dynamic specification . See Sections 5.2 and C.11 for more details. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

Table A10: The Effect of Public Health Units on Mortality Rates by Cause of Death (SEs Adjusted for Spatial Autocorrelation)

Dependent variable:	Death	TB	IMR	Stillbirth
	(1)	(2)	(3)	(4)
Year -4	0.01	-0.02		
	(0.02)	(0.06)		
Year -3	-0.01	-0.05	-0.03	-0.00
	(0.02)	(0.06)	(0.03)	(0.04)
Year -2	-0.00	-0.02	-0.01	-0.02
	(0.02)	(0.04)	(0.02)	(0.05)
Year 0	-0.04**	-0.03	-0.06***	-0.01
	(0.02)	(0.04)	(0.02)	(0.03)
Year 1	-0.03	-0.12**	-0.04	-0.04
	(0.02)	(0.05)	(0.03)	(0.04)
Year 2	-0.07***	-0.18***	-0.07**	-0.03
	(0.02)	(0.06)	(0.03)	(0.06)
Year 3	-0.10***	-0.19***	-0.08**	-0.08
	(0.02)	(0.05)	(0.03)	(0.08)
Year 4	-0.09***	-0.18***	-0.07	-0.08
	(0.03)	(0.06)	(0.04)	(0.09)
Year 5	-0.09***	-0.21***	-0.09**	-0.07
	(0.03)	(0.06)	(0.04)	(0.11)
Year 6	-0.09***	-0.21***	-0.09**	-0.11
	(0.03)	(0.07)	(0.05)	(0.12)
Year 7	-0.11***	-0.26***	-0.13**	-0.10
	(0.04)	(0.07)	(0.05)	(0.13)
Observations	1,725	1,725	1,650	1,650

Notes: The dependent variables are log mortality rates. The coefficients are weighted least-squares estimates. The year prior to the establishment of the PHU is omitted. Event-years outside of the designated window are captured by "before" and "after" dummies. Standard errors are adjusted for spatial autocorrelation following Colella et al. (2019) with a distance cutoff of 30 km. and a time lag covering the entire study period. See Appendix C.12 for more details. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.

Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin.* Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports.

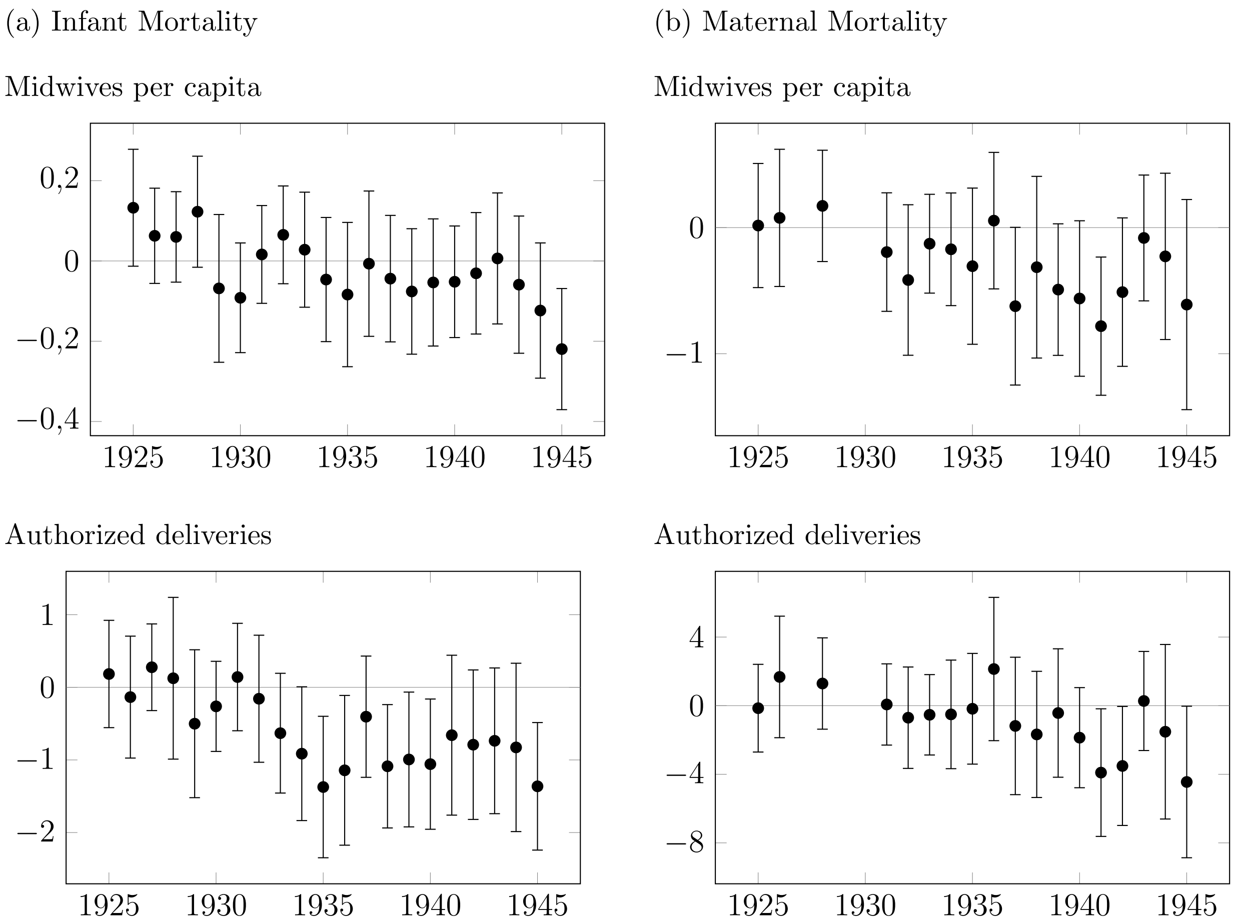
Table A11: The Effect of Public Health Units on Mortality Rates
(Difference-in-Differences Specifications)

Dependent variable:	Mortality	TB	IMR	Stillbirths	Malaria
	(1)	(2)	(3)	(4)	
Static DiD	-0.06***	-0.08*	-0.03	-0.03	-0.17*
	(0.02)	(0.04)	(0.03)	(0.04)	(0.10)
Baseline Specification	-0.08***	-0.17***	-0.08**	-0.06	-0.11
	(0.02)	(0.05)	(0.03)	(0.08)	(0.14)
Semi-dynamic specification	-0.08***	-0.11	-0.12***	-0.17	0.01
	(0.03)	(0.08)	(0.04)	(0.11)	(0.17)

Notes: The dependent variables are log mortality rates. The coefficients are weighted least-squares estimates. Standard errors are clustered by municipality. The coefficient shown is based on an indicator variable equal to 1 if a municipality is served by a PHU in that year. The coefficients from the baseline and semi-dynamic specifications are linear combinations of dynamic event study treatment effects from Year 0 to Year 7. Significance levels are denoted by * p <.10, ** p <.05, *** p <.01.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin.* Information on PHUs is drawn from Chaves (1942) and Commissioner of Health reports. Data on physicians per capita is found is Mountin et al. (1937), and data on population density and agricultural employment are derived from the 1920 and 1935 censuses, respectively.

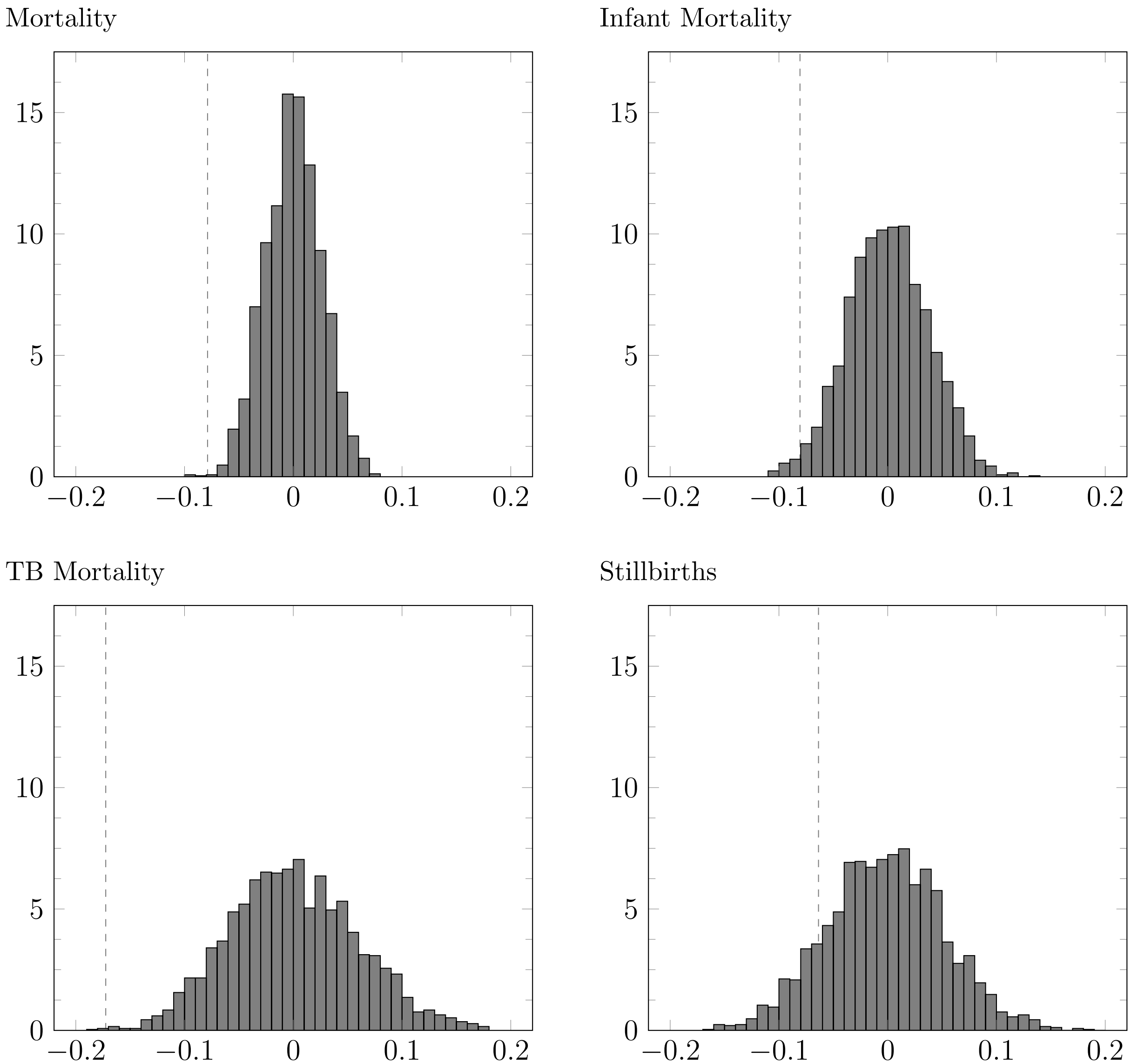
E Additional Figures

Figure A1: Treatment Heterogeneity by Midwives Per Capita
(Infant and Maternal Mortality)



Notes: The dependent variables are log mortality rates. Coefficients are weighted least-squares estimates based on a generalized difference-in-differences model that includes year and municipality fixed effects and a full set of year fixed effects interacted with the number of assistant midwives per capita in 1935 (top row) or the share of births attended by authorized persons (i.e. assistant midwives, nurse midwives, or physicians) in 1935-36 (bottom row), with the first year of data omitted. Errors bars are 95 percent confidence intervals and are based on standard errors clustered by municipality. Sample includes 75 municipalities and 1,650 municipality-year observations for infant mortality and 1,425 municipality-year observations for maternal mortality.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from annual reports of the Commissioner of Health and Chaves (1942).

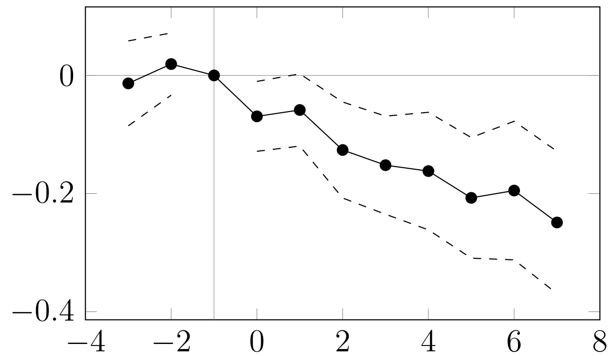
Figure A2: The Distributions of Coefficients From Random Placebo Tests



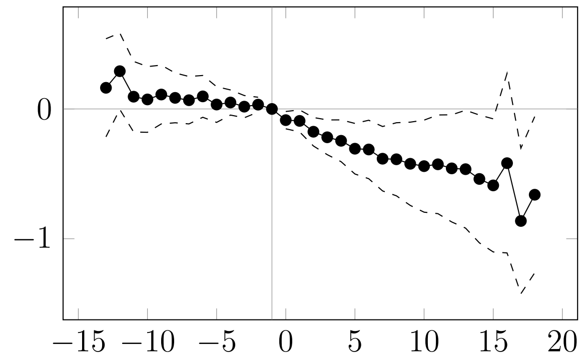
Notes: Each graph shows the distribution of estimated effects from a placebo intervention with a staggered rollout in which all municipalities are randomly assigned an inaugural year between 1927 and 1938. The distribution summarizes the results from 2,500 simulations. The estimated effect of public health units is represented by a dashed vertical line. Effects are estimated from Equation 1 and averaging across point estimates for event-years 0 to 7. The percent of placebo coefficients to the left of the dashed lines is 0.16% for mortality, 0.12% for TB mortality, 1.44% for infant mortality, and 12.88% for stillbirths.

Figure A3: The Effect of Public Health Units on the Ratio of Infant Deaths to Population

(a) Baseline Specification

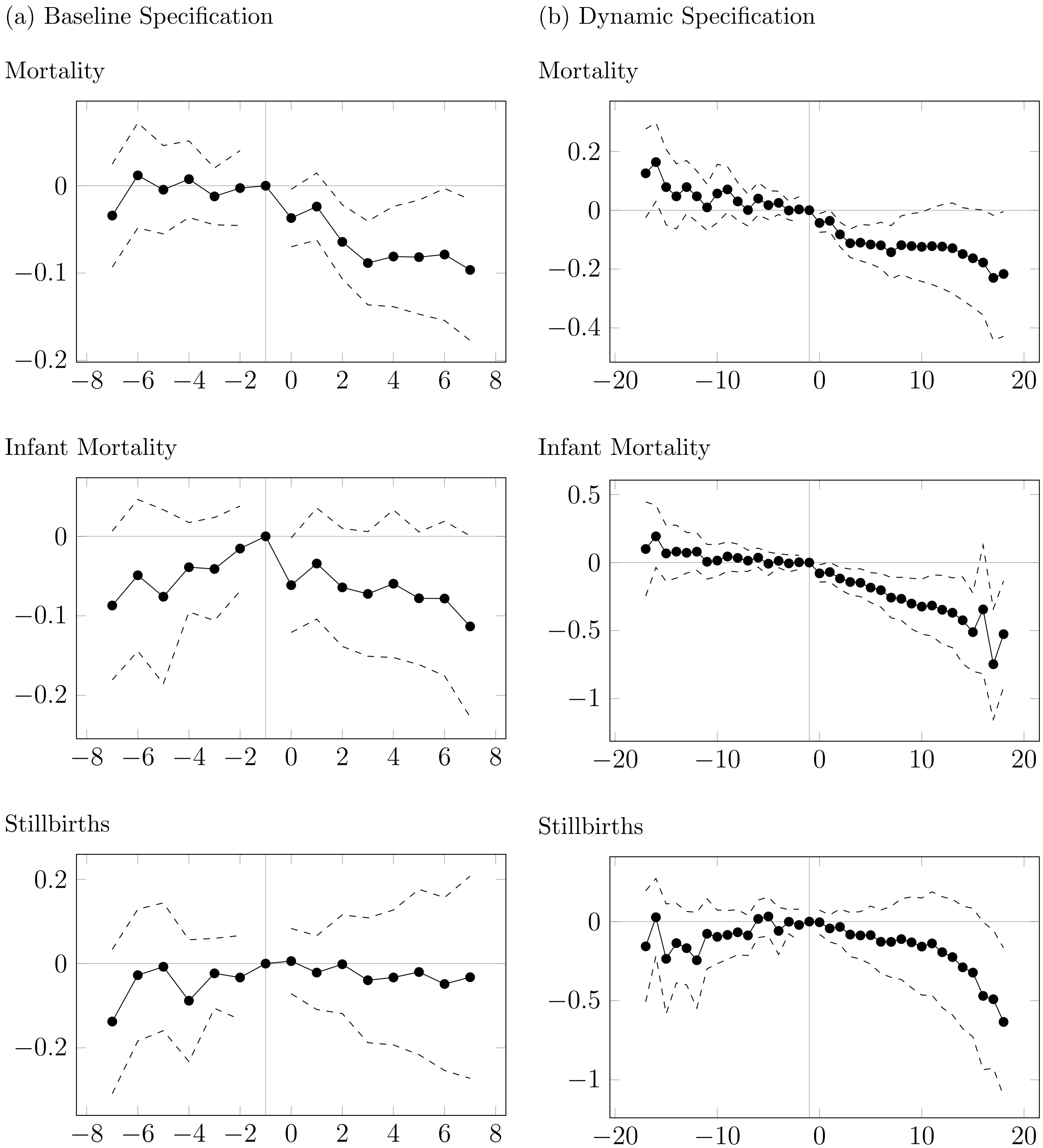


(b) Dynamic Specification



Notes: The dependent variables is the natural log of the ratio of deaths under 1 year old to population, computed by multiplying the infant mortality rate by the birth rate. Coefficients are weighted least-squares estimates. Dashed lines are 95 percent confidence intervals and are based on standard errors clustered by municipality. The year prior to the establishment of the PHU is omitted, as is the first event-year in the sample in Panel B. Sample includes 75 municipalities and 1,650 municipality-year observations. In Panel A, event-years outside of the designated window are captured by "before" and "after" dummies.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from annual reports of the Commissioner of Health and Chaves (1942).

Figure A4: The Effect of Public Health Units on Mortality Rates (Additional Years)

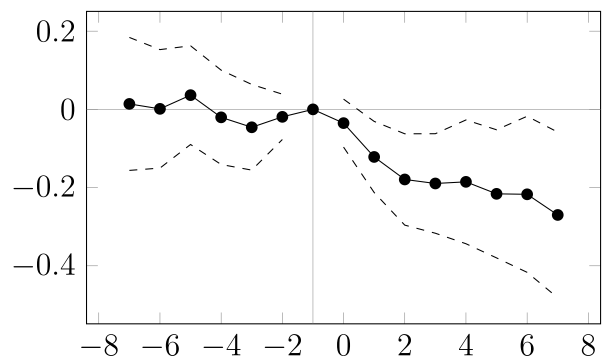


Notes: Dependent variables are log mortality rates. Coefficients are weighted least-squares estimates. Dashed lines are 95% confidence intervals and are based on standard errors clustered by municipality.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from annual reports of the Commissioner of Health and Chaves (1942).

Figure A5: The Effect of Public Health Units on Mortality Rates by Cause of Death (Additional Years)

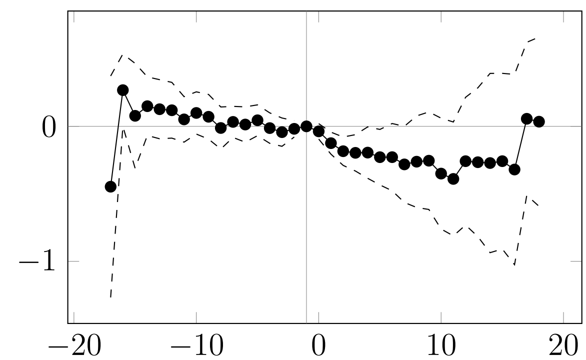
(a) Baseline Specification

Tuberculosis

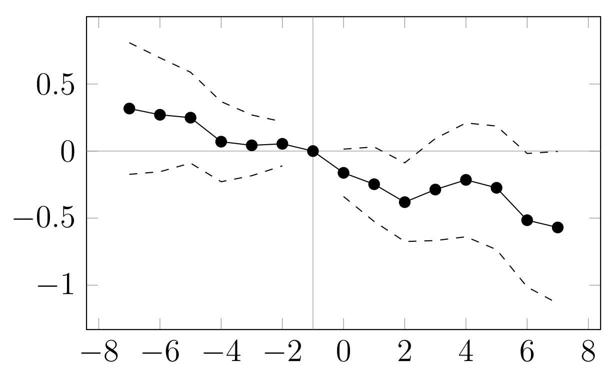


(b) Dynamic Specification

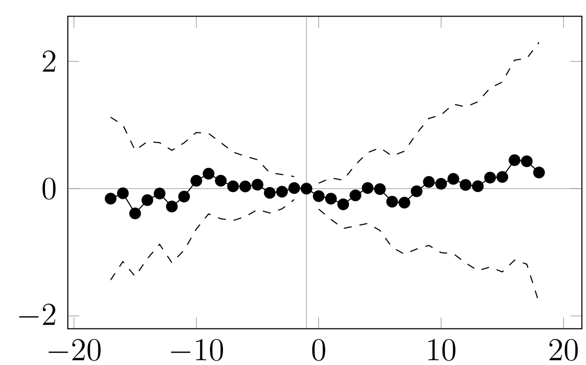
Tuberculosis



Malaria



Malaria



Notes: Dependent variables are log mortality rates. Coefficients are weighted least-squares estimates. Dashed lines are 95% confidence intervals and are based on standard errors clustered by municipality.
Sources: Mortality data come from annual Commissioner of Health reports and monthly data from the *Puerto Rico Review of Public Health and Tropical Medicine* and the *Puerto Rico Health Bulletin*. Information on PHUs is drawn from annual reports of the Commissioner of Health and Chaves (1942).