The "Golden Age" of Pesticides? Trade-offs of DDT and Health in the US*

Eyal G. Frank†

Charles A. Taylor‡

Abstract

New technologies that deliver large improvements see widespread adoption, even if little is known at the time regarding potential adverse side effects. An example is the rapid and widespread adoption of DDT for civilian use after World War II, which ushered an era of high synthetic pesticide use. In the years after its introduction in the US, evidence linking DDT with harmful impacts on wildlife and cancer incidence in humans led to a ban in the US in 1972. Currently, DDT is still used in 24 countries, and there are periodic calls to cancel its ban. In this paper, we use several natural experiments that created variation in DDT use to test its historical impact on health. We find strong evidence that in the US South, where DDT was used extensively in cotton production, infant mortality rates (IMR) increased by 11% relative to the baseline in 1945. Looking at DDT use for the control of forest insects, we find suggestive evidence of increased IMR in some regions but not others. In a public health setting, we find inconclusive results in relation to CDC-led DDT spraying programs for malaria and typhus control. These results highlight DDT's overall negative effect on health, but shows that the impacts vary depending on the setting and application intensity.

JEL Codes: I10, K32, Q10, Q18, Q51, Q53, Q57
Keywords: Technology adoption, environmental regulation, externalities, pesticides, pollution, health, DDT, forest pests, residual spraying.

---

*We wish to thank Alessandra Guerrero and Mina Solujic for providing excellent research assistance. We gratefully acknowledge the support from the Becker-Friedman Institute at the University of Chicago.

†Harris School of Public Policy and the Energy Institute Policy (EPIC) at the University of Chicago. Office 2057, 1307 E. 60th Street, Chicago, IL 60637, USA. Email: eyalfrank@uchicago.edu

‡School of International and Public Affairs, Columbia University. 420 W 118th Street, New York, NY 10027, USA. Email: cat2180@columbia.edu

1 Introduction

In the presence of harmful externalities, introductions of new technologies can lead to benefits that come at the expense of other outcomes (Greenwald and Stiglitz 1986; Acemoglu et al. 2016). The period after World War II (WWII) is characterized with the adoption of new technologies ranging from water purification to radar (Lindsten 1984; Sethi 2013). One key technology that was converted from wartime use to civilian use was DDT, a highly effective synthetic insecticide.

DDT was extensively used in agriculture and forestry for pest control, and public health for mosquito eradication (Schmitt 2016). Even though DDT was regarded as a miracle chemical, it was banned in 1972 due to growing evidence of its adverse effects on wildlife populations and increased cancer incidence in humans over the long term (Davis 2014). Most countries have since banned DDT, yet at least 24 countries still use DDT today (see Figure 1), and there have been calls to re-introduce DDT in the fight against new insect pests and vector-borne diseases (Kapp 2000; Mandavilli 2006). Further, a recent epidemiological paper reviews known associations in the literature between DDT exposure and negative human health outcomes, highlighting the potential health risk that DDT poses (Eskenazi et al. 2009). Nearly fifty years after its ban in the US, the short-term causal health impacts of DDT remain an open question.

We study the impacts of the widespread adoption of DDT in the post-war period starting in 1945 up until its ban in 1972, with a specific focus on infant health. We exploit several settings spanning the US that led to high DDT use in some areas relative to otherwise similar areas. Specifically, we use baseline differences in the following settings: first, the cultivation intensity of crops that greatly benefited from DDT; second, DDT spraying initiatives to control forest pest outbreaks; and third, public health programs that targeted vector-borne diseases with DDT. Our results provide evidence that DDT use resulted in increased infant mortality, even during a time period when infant health was greatly improving year-on-year.

The agricultural sector was by far the biggest user of DDT in the US, the majority of which was used for cotton. Cotton production at the time was concentrated in the US south. We use data from USDA Agricultural Censuses prior to the adoption of DDT to classify counties in the South as high or low cotton intensity. Prior to 1945, infant mortality rates (IMR) between the two groups essentially overlapped until DDT was introduced, at which point the rates sharply diverged. Using a difference-in-differences strategy, we find that the IMR gap increased by 5 deaths per-1,000 live births in cotton-intensive counties relative to the control group, with a peak in 1951. While IMR was in decline during this time, it was still high in southern agricultural counties where it reached 40-50 deaths per-1,000 live births. We find that the impact of cotton intensity on IMR persisted after 1952 in a weakened state through the 1950s, 1960s, and 1970s. The relationship disappears by 1980, eight years following the federal ban.

This relationship between cotton intensity and IMR only shows up when we compare cotton intense to non-intense counties, but not when comparing crop-intensive to non-intensive counties. This helps rule out alternative explanations regarding other patterns of agricultural intensification that could drive the observed increase in IMR.

We use the introduction of an agricultural pest for further identification. During our sample period, cotton cultivation migrated west from the US Southeast, in part due to the invasion of a cotton pest, the pink bollworm (Saffell 2000). We show that cotton acres declined following the pest's arrival, especially after it developed resistance to DDT. When we focus on the high cotton intensity counties that were not yet affected by the resistance to DDT, we recover more precise, yet similar in magnitude, estimates of the impact of cotton intensity on IMR.

Another important use of DDT was mitigating the spread of malaria and typhus, transmitted through mosquitoes and lice, respectively. The Center for Disease Control (CDC) partnered with 13 states in the South to coordinate spraying programs designed to leave residual traces of DDT in homes and buildings, as well as drying out of standing water in order to reduce the population of the vectors of transmission. We find that while the counties that participated in the residual spraying program throughout its entire duration, 1947-1951, saw large declines in IMR, infant deaths were already downward trending prior to the launch of the program. For counties that entered and exited the program, we find no evidence of an impact of these programs on IMR. To account for the potential joint effect of these treatments in the South, we incorporate both the cotton intensity measure and the residual spraying program using a triple-differences strategy. Our results still find higher IMR in high cotton intensity counties, but do not find differential impacts due to the residual spraying program.

DDT was also used in the forests of the Northeast and Northwest to control against gypsy moth and spruce budworm. We compare the counties exposed to DDT as a result of US Forest Service (USFS) control efforts, and compare them to counties that were not sprayed. We find suggestive evidence of an increase in IMR following the USFS spraying programs in the Northeast, but not in the Northwest. A partial explanation to the lack of observed effect in the Northwest could be the lower population densities in the affected areas, relative to the other treatment groups.

These results build on previous work regarding the history of DDT and its impacts in the US. During WWII, DDT was used by Allied Forces to reduce typhus-related deaths in Europe. The insecticide was celebrated as a new tool for reducing the risk of disease transmission (Davis 2014; Schmitt 2016; Conis 2017). After receiving approval for civilian use in late 1945, DDT was widely adopted throughout the US until concerns were raised regarding its impact on ecosystems and human health (Bevenue 1976; Hellou et al. 2013). In 1962, *Silent Spring* (Carson 1962) placed a spotlight on the environmental costs of DDT and remains a seminal book in the histories of DDT and the environmental movement. In recent years, several epidemiological studies have associated DDT with negative infant health, suggesting higher rates of infant mortality and lower cognitive development as a result of exposure (Longnecker et al. 1997; Longnecker et al. 2001; Dörner and Plagemann 2002; Chen and Rogan 2003; Farhang et al. 2005; Eskenazi et al. 2006). However, these studies rely on small samples that do not approximate random assignment of DDT exposure. In this paper, we use multiple identification strategies to test for a negative effect of DDT on infant health.

Our work adds to our knowledge of negative externalities following the adoption of new technologies, in particular of chemical pollution and health effects (Currie and Walker 2011; Chen et al. 2013; Brainerd and Menon 2014; Ebenstein et al. 2017; Van Boeckel et al. 2017; Missirian 2020). Specifically, the results add to a growing body of work documenting causal negative impacts of pesticides on human health (Frank 2018; Dias et al. 2019; Maertens 2019; Taylor 2019). As more papers in epidemiology associate DDT with adverse infant health outcomes, these findings contribute to ongoing policy discussions regarding the continued removal of DDT use across other countries, as well as debates whether DDT should be re-introduced under certain conditions. Finally, this paper examines an important period in the chemical intensification of agriculture and vector-borne disease control that has remained understudied.

Many papers that study new technologies focus on the potential for sub-optimal rates of adoption due to network externalities, and positive spillovers that are not internalized by the agents in the market (Jaffe et al. 2003; Foster and Rosenzweig 2010; Katz and Shapiro 1986). A recent example of negative impacts from the adoption of an agricultural technology is Missirian (2020), who finds that a certain herbicide-resistant soybean variety generates an externality on farmers in the wind corridor due to pesticide drift, which kills the crops in neighboring fields. To mitigate these damages, farmers are forced to switch to the new herbicide and soybean variety, with no observed increase in yield. Other examples in environmental economics study technology and pollution. Following the provision of cheap coal for heating north of the Huai river in China, life expectancy declined due to the increased air pollution (Ebenstein et al. 2017; Chen et al. 2013). Similarly, Ebenstein (2012) finds that industrialization in China led to higher cancer rates. On the other hand, Currie and Walker (2011) find that after adopting an automatic toll system in the US, E-ZPass, infant mortality declined because of the lower congestion-induced pollution.

In agricultural settings, the availability of new technologies such as electricity and water pumps can increase productivity, but also lead to depletion of water resources, resulting in large negative externalities from the new technology (Blakeslee et al. 2020). With respect to agrichemicals, whose use has been increasing globally since WWII, Brainerd and Menon (2014) find that fertilizer use in India leads to lower health outcomes, especially for children in rural communities. Several studies are also examining the link between antibiotics in livestock farming and the rise of antimicrobial resistant bacteria (Van Boeckel et al. 2017). This serves as yet another example of how rapid and large-scale adoption of new emergent technologies can result in substantial negative externalities.

While papers in epidemiology associate pesticide exposure with negative health outcomes, these papers do not include quasi-experimental variation, and as such cannot be interpreted as causal effects (Schwartz et al. 1986; Petit et al. 2009; Garry 2004; Vincent F Garry et al. 2002; V F Garry et al. 1996; Rauh et al. 2012). Recent work exploits settings that shift the use of agricultural inputs, namely pesticides. Maertens (2019) studies the Renewable Fuel Standard policy for ethanol generation, which increased the profitability of growing corn, and finds deteriorating fetal health in the areas that expanded their corn acres. Dias et al. (2019) examine downstream spillovers of the herbicide glyphosate and find an increase in infant mortality in municipalities in Brazil. Using ecological shifters of insecticide use in the US, Taylor (2019) uses the cycle of cicada emergence and finds an increase in IMR and lower test scores following spikes in insecticide use, while Frank (2018) exploits the arrival of a disease-causing-fungus that is deadly to an important predator of insects, bats, and finds increases in insecticide use resulting in higher IMR, following the spread of the disease.

Improving our understanding regarding the impacts of pesticide exposure in general, and specifically DDT is important given the numerous calls for its legalization in places it has been banned. As New York City was experiencing the first signs of the West Nile virus in 2000, an article in the Wall Street Journal called for the re-introduction of DDT in order to control mosquito populations (Avery and Avery 2000). A New York Times article from 2004, titled "What the World Needs Now Is DDT," argues that spraying DDT inside homes in malaria stricken countries is vital as malaria kills around two million people a year (Rosenberg 2004). This was echoed by the World Health Organization in 2006 when it announced it supports the use of DDT in controlling malaria in low and middle income countries (Mandavilli 2006). More recently, in 2016, with the emergence of the Zika virus, there were multiple op-eds and articles discussing whether DDT should be brought back to face the Zika-emergency.[1]

2 DDT: From "Magic Bullet" to 1972 Ban

In this section, we summarize DDT's history and rise to fame after spending nearly a century in anonymity. We proceed to describe how it fell from grace following the discovery of the impacts it had on wildlife, and association with cancer in humans. After reviewing the main DDT events of the 20th century, we examine the main uses of DDT in the US and their role as plausible exogenous variation in exposure to DDT. We elaborate on each one of the uses in the Appendix.

2.1 Early History of DDT & Events Leading to its Ban

The invention of DDT is credited to a graduate student who in 1874 only recorded that he managed to create the substance, but did not study its properties.[2] In the 1930s, as part of research conducted at a Swiss chemical firm on how to protect clothes from moths, Dr. Paul Mueller discovered that DDT is incredibly effective at killing different insects (Davis

[1] See "Zika outbreak revives calls for spraying with banned pesticide DDT." Source: https://www.statnews.com/2016/02/02/zika-revives-calls-for-ddt/, "Zika Virus Shows It's Time to Bring Back DDT." Source https://fee.org/articles/zika-virus-shows-its-time-to-bring-back-ddt/, "To Combat Zika, Bring Back DDT." Source: https://thefederalist.com/2016/02/09/to-combat-zika-bring-back-ddt/, and "Why Bringing Back DDT to Fight Zika Mosquitoes Could Backfire." https://time.com/4205214/zika-virus-ddt-mosquitoes/. Accessed: 06/18/2020.

[2] DDT is the abbreviation of Dichlorodiphenyltrichloroethane.

2014; Roberts et al. 2016).[3] In 1942, as WWII waged on, the Swiss shared the formula and data with both the Axis and Allies, as they realized that DDT could be used to control typhus-spreading lice. Typhus was a major cause of death during times of war, inflicting heavy losses on soldiers and civilians alike (Raoult et al. 2004). The Allies saw the potential, independently tested DDT, and by late 1943 were producing large quantities that were used on the battle fields of WWII, which some attribute as an important explanation for the Allies winning the war (Davis 2014; Roberts et al. 2016).

There are two key attributes that made DDT so effective during WWII and after, toxicity and persistence. DDT is extremely toxic to almost all insects, and its application could result in 95% reduction of the target insect (Lindquist et al. 1944). While the effect was not instantaneous such as other insecticides at the time, there appeared to be no acute toxic effect on humans. This meant that there were application levels that were considered safe for humans, but deadly for insects. In addition to its toxicity targeting insects and not people, areas treated with DDT remained deadly to insects even months after DDT was applied (Turusov et al. 2002; Vieira et al. 2001; Hitch and Day 1992). This meant that once applied, a house or a set of clothes would be almost insect and lice free for several months. In fact, the half-time of DDT is on the magnitude of 10-15 years in soils and up to 150 years in water, while that of modern insecticides is on the scale of only a few months (NPIC 2000).[4] Combined with its relative low cost of production and little to no observed side effects, many considered DDT to be a "magic bullet" (Davis 2014; Roberts et al. 2016). This led to quick civilian adoption in post-WWII for agricultural and public health purposes (Conis 2010; 2017; Humphreys 1996; Hill et al. 1951).[5]

However, as the years passed by scientists started to observe detrimental impacts on mammals, fish, and birds. The evidence was compiled in Rachel Carson's 1962 book *Silent*

[3] For his work on DDT and the improvements in public health associated with it, Dr. Mueller received the Nobel Prize for Physiology or Medicine in 1948.

[4] See the following for a collection of half lives of modern pesticides: https://extension.usu.edu/waterquality/files-ou/Agriculture-and-Water-Quality/Pest/FactSheet151.pdf. Accessed: 06/18/2020.

[5] See Figure C1 for examples that advocated the use of DDT for civilian purposes.

Spring which played a key role in changing public perceptions regarding DDT (Carson 1962). Following the release of *Silent Spring*, environmental organizations campaigned to have the use of DDT either heavily restricted or prohibited altogether. The growing concerns around DDT's use involved its potential role in causing cancer in people, as well as its numerous adverse impacts on wildlife. One of the key arguments regarding DDT's toxicity to humans involved its accumulation of fat-tissues. Calculations suggest it takes the body 10-15 years to be DDT-free after exposure ends, but that a by-product of DDT, DDE, might remain in the body for its entire lifespan (Turusov et al. 2002). While DDT did not appear to have acute health impacts on people, there was a concern regarding chronic exposure as DDT residue built up in the body's fat-tissues, namely in women's breasts, leading to DDT residue in breast milk (Smith 1999; Musial et al. 1974). After several rounds of reviewing findings, the newly established Environmental Protection Agency decided to heavily restrict the use of DDT, effectively banning its use, in 1972 (USDA 1975).

2.2 Major Uses of DDT in the United States

DDT was declared an "insect killing war hero," and was lauded as a the new and best weapon the US has in its fight against bugs (Schmitt 2016). Following the end of WWII, in late 1945, the US government removed the restrictions on domestic DDT sales, which was reserved for wartime uses until then. The US quickly adopted and adapted DDT in large quantities in agriculture, public health, and forest management. We consider these three sources of variation as different natural experiments we exploit in our empirical strategy. Here, we summarize each prominent use of DDT, and include more detailed information in the Appendix.

The first source of variation we use is the fact that relative to other crops, DDT was heavily used in cotton (Saffell 2000; Lange et al. 2009).[6] This means that counties that

[6] In its summary document on the restriction on DDT, the USDA notes that "Historically more insecticides have been used for cotton than for any other domestic agricultural crop." (USDA 1975) Writing on the successful experiments with DDT and cotton pests, Ware (1974) notes that "The results of experi-

were cultivating large areas of cotton fields before the introduction of DDT in 1945, were more likely to become DDT adopters, relative to counties that were either non-agricultural or were growing different crops.

The use of DDT, and insecticides in general, in cotton production is linked with the different crop pests that cotton farmers had to deal with across time. By the end of the 19th century, cotton producing states in the south were already plagued by the boll wevil, which caused large damages to cotton crops (Lange et al. 2009). In 1917, a new invasive crop pest emerged, the pink bollworm, considered to have been even more devastating than the boll wevil (Henneberry and Naranjo 1998; Lowry and Tsao 1961; Lowry et al. 1965). The 1917 infestation was swiftly dealt with and was considered over by 1919. Additional pink bollworm outbreaks occurred during 1936 and 1950, but were largely contained in the southern part of Texas. Starting in the 1950s, the pink bollworm expanded its range, and infestations were detected in other states as well (Henneberry and Naranjo 1998). As part of the control and damage mitigation actions, large quantities of DDT were used until it developed resistance to DDT (Lowry and Berger 1965).[7]

The second source of variation we use comes from the use of DDT in the prevention of vector-borne diseases. During the 1940s and 1950s, malaria rates were already very low relative to its historic presence in the south. However, due to a combination of imprecise measurements, concerns about cyclical dynamics of the disease, and the prevalence it had on the battle fronts during WWII, malaria remained a key public health issue. This led to large investments in anti-malaria programs (Humphreys 1996). While malaria was already declining at the time, typhus was a growing public health concern during the mid-1940s. Cases in the south more than doubled from 1940 to 1944, and studies at the time estimated that due to underreporting the incidence rate was three times higher (Hill et al. 1951). As

ments in 1944 and 1945 using DDT on cotton were so outstanding in controlling most cotton pests and increasing yields that it was generally used by the growers in 1946."

[7] Since 2018, the pink bollworm is considered eradicated from the US after successful joint implementation of several pest-control strategies. For more details, see: https://www.usda.gov/media/press-releases/2018/10/19/usda-announces-pink-bollworm-eradication-significantly-saving. Accessed: 01/02/2020.

part of a broad residual spraying campaign, the Center for Disease Control (CDC) assisted local states and counties in designing and executing control operations that ran between 1946 and 1952.[8] These included aerial spraying of DDT, dusting and larviciding, as well as indoor residential spraying meant to leave behind residual DDT.[9]

While DDT was predominately used in the south, it was also used in the Northeast and Northwest in control efforts against forest pests. Spraying programs across forested areas used DDT to control outbreaks of gypsy moths in the Northeast, and spruce budworm in the Northwest (Carolin and Coulter 1971; Cope 1961; Tomlin and Forgash 1972; Huddleston et al. 1960). Between 1945 and 1974, the US Forest Service (USFS) sprayed over 26 million acres with DDT, most of it in the Northeast and Northwest, as part of control programs for forest pests like the gypsy moths and spruce budworm. Spruce budworm control operations were more sporadic, as certain areas were only sprayed in specific years. Gypsy moth control efforts focused along a barrier line, and the use of DDT greatly intensified during 1950-1958 when more funding became available.

3 Data

We compile data at a county-year level on infant mortality rates, and include data on cotton production, cotton pest infestations, public health operations that utilized DDT, and forest health programs that used DDT in pest control efforts. Our main sample spans 1942-1972, while an extended sample spans 1933-1980. Throughout the analysis, we balance the panel for each outcome, unless we explicitly mention otherwise.

Infant Mortality Rates (IMR): We obtain annual data on IMR at the county-level

[8] At the time, the CDC was founded in 1946 as the "Communicable Disease Center," and was renamed in 1970.

[9] These residual spraying programs were based on similar interventions carried out during WWII. Environmental historian, Elena Conis, describes the experience of Irma Materi, the wife of a US colonel in Korea near the end of WWII. They were visited by an army's DDT detail, on which Materi commented: "We stood on the slippery floors and watched the kerosene dripping from the light fixtures. 'It would be a good idea not to let the baby touch anything with DDT on it,' suggested the Lieutenant." Source: https://www.sciencehistory.org/distillations/beyond-silent-spring-an-alternate-history-of-ddt. Accessed: 06/12/2020.

from 1915-2007 from the Inter-University Consortium for Political and Social Research (Bailey et al. 2018). Throughout most of the analysis, we use data from 1942-1972. Starting in 1942, the IMR data were systematically reported based on the residence county of the mother instead the county of birth occurrence. We truncate the sample at 1972 as we are not estimating long-term effects of DDT exposure, and estimating the impacts of the 1972 ban is complicated by reductions in DDT use that preceded the ban.

Cotton Acres: Data come from the U.S. Department of Agriculture's National Agricultural Statistics Service online tool. County-level cotton production data begins in 1919. We focus on upland cotton, by far the most common cotton variety, and have data for production, yield, acres planted, and acres harvested.[10] We also use historical U.S. Censuses of Agriculture available online through the Inter-university Consortium for Political and Social Research ((Haines et al. 2014)). We divide the cotton acres by the county's area to obtain the land share under cotton cultivation. We use the data for the 1934, 1939, 1944 census years to construct a baseline of cotton growing intensity, specifically, we take the mean land share under cotton cultivation.[11] We define three groups: (i) counties with zero cotton land share during the baseline period, (ii) counties at the bottom 50% of cotton land share, and (iii) counties at the top 50% of cotton land share.

Presence of Pink Bollworm: The pink bollworm (*Pectinophora gossypiella*) was the primary cotton pest during our study period, costing farmers and the government billions of dollars (Henneberry and Naranjo 1998). Data on the geographic extent of pink bollworm come from Cooperative Economic Insect Reports, published by the U.S. Department of Agriculture, National Agricultural Library. In some of the volumes, there are county-level maps showing insect extent and the quarantine range. Scanned copies of the reports from 1954 to 1975 are available from the Biodiversity Heritage Library (USDA 1956).[12] We digitize

[10] Data values of '(D)', which USDA codes as confidential, were coded as 'not available' and county-year values of '(Z)', which USDA codes as being too small to estimate, were coded as zero.

[11] We do not include data post-1945 when creating the measure of cotton intensity as the emergence of DDT might have made cotton cultivation more profitable. This would make cotton acres endogenous to the availability of DDT, and could bias our results if used to determine treatment and control groups.

[12] See: www.biodiversitylibrary.org/bibliography/45971#/summary. Accessed: 03/13/2019

the data at the county-year level. For years for which no maps are available, bollworm presence was assumed to be the same as the previous year(s). We use state-level estimates on the year of the first appearance of DDT-resistant pink bollworm, provided by Sparks (1981).

Residual Spraying Programs: The Center for Disease Control (CDC) summarized the actions taken as part of control operations against malaria and typhus in yearly reports and bulletins published throughout the duration of the program, 1947-1951. We digitize tables and maps with information on the counties that received these treatments, and their mean intensities (see the Appendix for more information). Using the data, we define counties as either: (i) ever participating in the program, (ii) always participating in the program, or (iii) as never participating in the program.

Forest Pest Control Programs: The U.S. Forest Service (USFS) produced reports with data on the areas sprayed, and the amounts of DDT used, in its effort to control the gypsy moth and spruce budworm. We digitize the maps and tables that detail the spraying area in each region (see the Appendix for more information). Data are not available for every year in which control programs were taking place, however, we use the data to classify counties as either ever or never exposed to DDT as a result of USFS control programs, and when available, use the first known year in which DDT spraying started.

In Figure 2, we plot the mean levels of IMR for the three different cotton intensity groups of counties defined above. Three stylized facts emerge from the data. First, mean infant mortality rates declined from 40 to 50 infant deaths per-1,000 live births in 1940 to about 15 in 1980. Second, there was a difference in IMR of almost 15 infant deaths between cotton growing areas and non-cotton growing areas in 1945. Third, IMR overlapped between the top 50% and bottom 50% cotton growing counties (measured by baseline acres) until 1947, when they started to diverge, opening up to a gap of almost 5 deaths per-1,000 live births (about a 14% increase relative to the IMR of the bottom 50% counties). By the 1980s, there were still observable differences between the three groups of counties yet they were much smaller than before, and all were on a declining trend.

To show the spatial variation in cotton cultivation, and the dispersion of the CDC's residual spraying program, we classify and plot the counties in Figure 3a. This bivariate choropleth map shows each county, and assigns a different color based on its baseline cotton group category, and whether it participated in the residual spraying program. The map shows that both cotton and CDC programs to control malaria and typhus were heavily concentrated in the Southeastern U.S. While there is a clear geographic concentration of these two sources of DDT exposure, there is variation between the cotton intensity, and residual program status, within each state. In Figures 3b and 3c, we plot the counties in the Northwest and Northeast and their classification as control or treatment counties.

4 Empirical Strategy

The adoption and DDT and its ban in 1972 create two events of interest. If DDT had detrimental effects on health we should expect to observe them post-1945, when it became available and widely adopted for civilian purposes. If the use of DDT was persistent throughout 1945-1972, then following the ban in 1972, we should expect to see the health impacts of DDT attenuating. In the US, DDT consumption was already declining even before the ban (see Figure 2), making the ban a less compelling event of interest. In addition, the ban itself might have led farmers to substitute from DDT to more harmful pesticides, worsening health impacts. Without granular data, it is difficult to disentangle the joint impact of the DDT ban and potential substitution to other pesticides. For this reason, we focus our attention on the first event of interest, the wide scale adoption of DDT following 1945.

4.1 Approximating Random Assignment of DDT Use

A simple comparison of outcomes before and after 1945 could be confounded by several factors. Prior to 1945, the US was still recovering from the Great Depression and undergoing a structural transformation following the aftermath of World War II. Any effect on health could easily be attributable to these large scale disruptions. Another important confounder is that the US was experiencing year-by-year improvements in infant health, represented in a decline in mean infant mortality rate (IMR) from 40 to 15 deaths per-1,000 live births between 1942 and 1980 (see Figure B1).

To estimate the causal effect of DDT applications on infant health requires us to approximate an ideal experiment where counties are assigned at random as DDT adopters. In order to approximate the ideal experiment, we use variation in different regions of the US that led to different use rates of DDT. These shifters in DDT use are plausibly as-good-as-random with respect to the outcome of interest, IMR.

Using a difference-in-differences (DD) strategy, we compare counties we classify as having experienced higher exposure to DDT relative to those who experienced a lower one. Counties with low exposure to DDT might have also experienced an effect in terms of infant health, and considering them as controls might attenuate our estimates, resulting in a lower bound of the true effect. Specifically, we either compare (i) counties with high cotton production to counties with low cotton production, (ii) counties that took part in the CDC's residual spraying program for malaria or typhus to those that did not, or (iii) counties that were exposed to DDT as part forest pest-control efforts to those that were further away from treated areas.

4.2 Exploiting Variation in DDT Exposure

Our analysis uses proxies for DDT exposure level following its introduction by the end of 1945. For each of our sources of variation, we define $Treated_{cs}$ as equal to one for county c, in state s, when we classify that county as a high DDT exposure county. Throughout most of the analysis, we consider 1945 as the baseline year, and measure impacts relative to it. For our main outcome of interest, IMR_{csy}, the infant mortality rate per-1,000 live births for county c, in state s, in year y, we run the following flexible DD specification:

$$IMR_{csy} = \sum_{\substack{\tau \in \{\underline{T}, \ldots, \overline{T}\} \\ \tau \neq 1945}} \beta_\tau \mathbb{1}\{Treated_{cs} = 1\} \times \mathbb{1}\{y = \tau\} + \lambda_c + \delta_{sy} + \varepsilon_{csy} \tag{1}$$

The DD regression compares high-exposure to low-exposure counties, pre- and post-exposure onset, for a time window between $\underline{T}$ and $\overline{T}$.[13] We control for county time-invariant properties with county fixed effects, λ_c. We allow for flexible and pooled time trends at the level of the state by including state-year fixed effects, δ_{sy}. Any other unobserved heterogeneity is captured by the error term, ε_{csy}. We cluster the standard errors at the county-level.

Our identifying assumption is that counties would have developed along similar trends with respect to infant health in the absence of exposure to DDT. While we cannot test directly for parallel trends on the counterfactuals, we use the coefficients from the pre-treatment years to inform the validity of this assumption. This assumption could be violated if the counterfactual outcomes were different in a way that is systematically correlated with treatment assignment. To further rule this out, we also exploit the invasion of the pink bollworm as a shifter of cotton cultivation, and as a result of DDT use, as well as devise treatment assignment rules that should not lead to an increased use of DDT as a falsification exercise. These are reviewed and discussed after the main results.

5 Results on Infant Mortality: Comparing High to Low Cotton Intensity Counties

We use the specification in Equation (1) and estimate the effect that DDT use had in agricultural counties. We use the classification of high and low cotton intensity counties, defined being in the top or bottom 50% of cotton land share during the baseline period of 1934, 1939, and 1944, omitting the counties that were not producing cotton during that

[13] We start the analysis in 1942 as the measurement of natality records shifted to being based on mother's residence instead of occurrence (see Figure B1). We end the analysis in 1972, when DDT was banned. As mentioned previously, the ban itself was not as strong of a DDT use shifter as consumption already declined prior to the ban. In the Appendix, we report results using data that spans 1933-1980.

period. In Figure 4, we plot the results from the DD regression for counties in cotton producing states.[14] Starting in 1947, IMR increases, and continues to increases until 1951, when we estimate it is higher by 5 deaths per-1,000 live births relative to the 1945 baseline. This reflects an increase of 11% relative to the mean value of IMR in the sample in 1945. Furthermore, for 1951 we can reject increases in IMR below 3 deaths per-1,000 live births, at the 5% significance level.

Following 1951, the difference in IMR between high and low cotton intensity counties declines to about 3 death per-1,000 births, and while results remain significant at the 5% level, they are much more imprecise than in the first few years after the introduction of DDT for civilian uses. From 1968 onward, precision declines yet the point estimates remain roughly stable up to the 1972 ban. Although we only have three pre-periods, we cannot reject a zero difference between the groups prior to 1945, and the point estimates suggest that high intensity cotton counties were on a downward trend in IMR relative to the low intensity cotton counties. However, this downward trend reverses after 1945, resulting in a substantial and precise increase in IMR. In Figure A1, we perform different sensitivity analysis to the definition of the sample, and results remain equivalent.

5.1 Accounting for the Spread of Pink Bollworm

The spread of the pink bollworm throughout states in the south meant farms increased their use of DDT (Henneberry and Naranjo 1998). Unfortunately for the farmers, like many other insects, pink bollworm started developing resistance to DDT (Lowry and Berger 1965; Metcalf 1973; Davies et al. 2008). There are two plausible responses by farmers to growing resistance of insects to DDT. If resistance simply raises the threshold of DDT required to observe a meaningful decline in crop pests, farmers can decide to increase DDT inputs.

[14] We use the 1934, 1939, and 1944 Agricultural Censuses to define the sample of cotton producing states as: Alabama, Arizona, Arkansas, California, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

However, if insects become virtually immune to DDT then farmers might either substitute DDT with a different insecticide, switch to a different crop, or absorb the damages to yields.

Ideally, we would like to directly test the impact of pink bollworm invasions on DDT use. Unfortunately, our data from the National Agricultural Library on pink bollworm presence starts in 1951. Meaning we do not have detailed geographic information on prior invasions and infestations. The other limiting factor is that we do not have county-year data on DDT use. Instead, we test for the impact on cotton acres as a proxy for DDT use. Our assumption is that if farmers chose to either substitute DDT or absorb damages, we should not observe large declines in DDT acres in affected counties. However, if farmers exited cotton production, that will likely be correlated with a reduction in DDT applications as cotton and DDT were so strongly linked at the time.

We use data from the USDA Agricultural Census on cotton acres for the years 1944, 1949, 1954, 1959, 1964, and 1969 to run a regression of cotton acres on different measures of pink bollworm intensity. We use either the first year of pink bollworm presence, measured at the county-level, or the first year of DDT resistance, measured at the state-level (USDA 1956; Sparks 1981). We also interact each variable with the baseline classification of cotton intensity. The results in Table 1 show large reductions in cotton acres, measured in log-points. The presence of pink bollworm lowers, on average, cotton acres by 48.8% (column 1), while DDT resistant pink bollworm results in a decline of 39.3%.[15] Interacting these effects with the baseline cotton intensity dummies shows the effects are mostly driven by reductions in the lower intensity counties, group 2, but are also present in group 3, while group 1 potentially sees an increase in cotton acres (columns 4 and 5).

Repeating this analysis in levels, reported in Table A1, results in a similar pattern for presence and DDT resistance (columns 1 and 2). However, the amount of cotton acres lost are mostly concentrated in the high intensity cotton counties, group 3 (columns 4 and 5). Counties classified as high cotton intensity at baseline saw a reduction of 12,000 (column 5)

[15] Using $e^{\beta} - 1$ to convert from log points to percent change for a coefficient on a dummy variable.

to 17,000 (column 4) acres, relative to a mean of about 16,500 acres. The levels analysis also highlights that zero intensity counties at baseline, group 1, saw an increase of about 3,000 to 4,000 acres (columns 5 and 4, respectively). The evidence on the decline in cotton cultivation is consistent with historic accounts on the shift of cotton to the west in order to avoid the emergence of cotton pests in the southeast (Saffell 2000).

A reduction in cotton acres, with a subsequent reduction in DDT use, should result in a lower IMR. In the results on high versus low cotton intensity in Figure 4, we do not account for pink bollworm developing resistance. The evidence in Table 1 suggests that cotton intensity, and plausibly DDT intensity, went down in counties and states negatively affected by DDT resistant pink bollworm. We incorporate this into the analysis by including interaction terms for DDT resistance with the high intensity cotton group-year dummies. These interactions absorb the effect of reducing cotton intensity on IMR.

We focus our attention on the set of coefficients we originally report in Figure 4, that are now estimating the mean IMR in a high versus low cotton intensity counties that are not yet residing in a state with DDT resistant pink bollworm. We include both the original set of coefficients and the new ones we obtain after including the DDT resistance interactions in Figure 5. The coefficients from both regressions are almost identical until 1959, the first year in our data with DDT resistance. Following 1959, the high cotton intensity counties are still seeing higher IMR relative to the low intensity counties. These results suggest that some of the decline in the magnitude and precision of the effects in the 1960-1972 period, seen in the hollow circles in Figure 5, are capturing a decline in cotton intensity due to the spread of the pink bollworm.

5.2 Falsification Test Using Overall Crop Production

One important concern with the interpretation of the results of IMR and cotton intensity is that we might be capturing overall agricultural intensification of inputs, and not DDT specifically. If post-1945, there were many other newly available agricultural inputs then the impact on IMR could be driven by a mix of those inputs, and not DDT specifically. If so, we should observe a similar impact on IMR when we repeat the analysis using a classification based on total cropland. Similarly to the baseline cotton classification, we classify each county into terciles of cropland share.[16] We then run the analysis in Equation (1) for the full sample of the Contiguous US for both classifications. Results in Figure 6 show that IMR increases following 1945 in high intensity cotton counties, but that does not happen in high intensity cropland counties. This helps to validate the interpretation that the observed impact on IMR is directly connected to the use of DDT, and not to other changes in agricultural inputs that were systematically changing at the time.

6 Results on Infant Mortality: Impacts of the CDC Residual Spraying Programs

We use the data from the CDC activity reports and bulletins to classify counties as ever participating, or always participating in a CDC residual spraying program.[17] Because some counties started participating when the program first started in 1947, and continued to participate, while others entered and exited from the program, we run the analysis using both calendar years and event time. We report the res ults for the treatment groups, always and ever participated, using either sample years or years relative to the first year of participation in Figure 7.

IMR rates in both treatment group counties were on a declining pre-trend with respect to IMR even prior to 1945. Following 1945, the counties that always participated in the program saw a decline in IMR of 6 deaths per-1,000 live births by 1950. However, the counties that entered and exited from the program saw much smaller effects. Following

[16] We use terciles instead of separating the zero cropland share group from the top and bottom 50% as we do for the baseline cotton groups because there are only 85 counties with zero cropland acres (in the Agricultural Census years of 1934, 1939, and 1944). We compare the third to second tercile of cropland share as it captures increasing agricultural intensity.

[17] There are 421 counties that participate at least once in a residual spraying program, but only 37 that participate every year between 1947-1951.

the end of the program in 1952, we cannot reject the null of no effect for either group. Because of the existing pre-trends, it is hard to interpret these results as evidence that the residual spraying program lowered IMR due to reductions in vector-borne diseases. It is also important to note that the residual spraying program might have lowered deaths due to specific causes, yet we lack the data to formally test those impacts. If DDT had both a positive and negative impact on IMR, then the counties that received residual spraying, might on net exhibit small changes in IMR, but that could be masking effects operating in opposite directions. Ultimately, the resolution of health data from that period limits our ability to fully evaluate the residual spraying programs.

The combination of DDT use in cotton agriculture and in vector-borne disease control efforts means that the south was experiencing two DDT-related treatments. In order to estimate the separate and joint impacts that these treatments had, we extend the analysis to a triple-differences (DDD) strategy. Our treatment of interest is the interaction between a high cotton intensity county and participating in the residual spraying program. We compare those counties relative to low intensity cotton counties that did not participate in residual spraying following 1945. We make sure to also account for the double interactions of high intensity cotton or residual spraying, following 1945. Specifically, we run the following regression specification:

$$\begin{aligned} IMR_{csy} = & \sum_{\substack{\tau \in \{\underline{T},\ldots,\overline{T}\} \\ \tau \neq 1945}} \beta_\tau \mathbb{1}\{\text{High Cotton Intensity}_{cs} = 1\} \times \mathbb{1}\{\text{Residual Spraying}_{cs} = 1\} \times \mathbb{1}\{y = \tau\} + \\ & \sum_{\substack{\tau \in \{\underline{T},\ldots,\overline{T}\} \\ \tau \neq 1945}} \gamma_\tau \mathbb{1}\{\text{High Cotton Intensity}_{cs} = 1\} \times \mathbb{1}\{y = \tau\} + \\ & \sum_{\substack{\tau \in \{\underline{T},\ldots,\overline{T}\} \\ \tau \neq 1945}} \pi_\tau \mathbb{1}\{\text{Residual Spraying}_{cs} = 1\} \times \mathbb{1}\{y = \tau\} + \\ & \lambda_c + \delta_{sy} + \varepsilon_{csy} \end{aligned} \tag{2}$$

Where High Cotton Intensity$_{cs}$ and Residual Spraying$_{cs}$ represent the classifications of the county as either a high cotton intensity, or a county that ever participated in a residual spraying program. The specification estimates the triple interaction of cotton intensity, residual spraying, and year dummies, relative to an omitted category of 1945. We include the double interactions of cotton intensity or residual spraying with year dummies, while the single effects are nested by the fixed effects. All other variables are the same as in Equation (1).

Results in Figure 8 include point estimates for the triple and double interactions from Equation (2).[18] The point estimates for the triple interaction are mostly centered around zero, but have extremely wide 95% confidence intervals. Double interactions for the residual spraying program are negative but imprecise. Double interactions for the high intensity cotton counties are positive throughout all of the sample period, and remain precise until 1963.

We interpret these results as suggestive evidence that residual spraying might have contributed to reductions in IMR. However, the increase in IMR we document in high cotton intensity counties does not cancel out due to participation in a residual spraying program. A Partial explanations for these effects is that cotton cultivation and the use of DDT occurred annually, while residual spraying only happened in some years, and very few counties participated persistently.

[18] We estimate the specification for the sample of states that had at least one county that participated in the residual spraying program: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, Tennessee, Texas

7 Results on Infant Mortality: The Effects of DDT Use in Forest Pest Control

7.1 Results Using Gypsy Moth Spraying Programs in the Northeast

We use the maps and summary of activity reports produced by the US Forest Service (USFS) to classify the exposure of counties to DDT. First, we define the control group as the set of counties for which we never have an indication of USFS spraying DDT as part of its gypsy moth control efforts.[19] Then we construct two treatment groups. The first is a set of barrier counties based on the map in Perry (1955). These counties received both labor interventions meant to destroy gypsy moth egg concentrations, and were also the target of DDT spraying. See Figure C5b which highlights the counties designated as the barrier counties. The second set of counties are defined using the map in a US Department of Agriculture report on gypsy and brown-tail moths (USDA 1952). Figure C5d shows the geographic extent of quarantine counties considered at the time as infested with the moths, and as such, an area of focus for DDT spraying campaigns. We further refine these treatment groups to only include counties for which we have positive indications that they were treated with DDT by the USFS.[20]

Using the DD specification in Equation (1), we compare the counties in either the barrier or quarantine groups to the counties in the never sprayed group. Even though large-scale use of DDT in the Northeast only started in the 1950s, we keep the baseline year as 1945, for easier comparison with previous results. The results in Figures 9a and 9b show an imprecise increase in IMR in the 1950s. While the point estimates show that counties that were designated as either part of the gypsy moth barrier counties, or experienced infestations of gypsy moths, had 2 deaths per-1,000 live births more than their surrounding counties, relative to 1945, the confidence intervals are wide, and we obtain a noisy zero result for these

[19] Resulting in 154 counties in Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont

[20] Resulting in 19 counties in the barrier group, and 21 counties in the quarantine group.

counties.

7.2 Results Using Spruce Budworm Spraying Programs in the Northwest

In the case of the spruce budworm DDT spraying, we are able to digitize information on each county and the year it was sprayed (Dolph 1980). This provides us with a set of DDT events that turn on and off, as some counties are sprayed multiple times, but not in consecutive years.[21] Because of the high persistence of DDT, we consider a county treated after its first spraying campaign takes place. When analyzing the impact of the spruce budworm spraying on IMR, we modify Equation (1) such that instead of calendar year dummies, we include leads and lags dummies from the year in which the first spraying event took place.

Results in Figure 9c show no effect of being included in the USFS spraying campaigns against the spruce budworm on IMR. One potential explanation for the lack of any observed effect of DDT spraying on IMR in the Northwest is that the population densities are much lower relative to the other settings. In Figure A2, we plot kernel densities for the population density by treatment group, using data from the 1950 Census. The mean population density is 5.9 people per-squared km in the spruce budworm treatment sample, whereas it is four times higher in the Southern states, and an order of magnitude higher in the Northeast. A smaller population density might mean there are fewer people exposed, and fewer live births affected, making it harder to detect a signal in what is a relatively rare event of infant death.

8 Conclusions

We revisit the "Golden Age" of pesticides that started with the post-WWII adoption of DDT in agriculture, forestry, and public health. Using identification strategies that result in high and low exposure areas, for each one of the DDT use domains, we find evidence

[21] There are 25 counties that are sprayed at least once in Oregon and Washington, 50 counties that are never sprayed, and 58 county-year spray events.

for an adverse effect on infant health. This effect is mostly driven by the use of DDT in cotton agriculture in the south. Our results highlight potential negative outcomes when new technologies, on which little is known regarding their side effects, are adopted at large-scales.

In ongoing work, we are extending the analysis to cover the impacts on agricultural yields, and forest health, in order to produce a welfare analysis that considers both the social benefits and costs from the widespread adoption of DDT.

References

Acemoglu, Daron, Ufuk Akcigit, Douglas Hanley, and William Kerr. 2016. "Transition to Clean Technology." *Journal of Political Economy* 124 (1): 52–104.

Avery, Alex, and Dennis Avery. 2000. *Bring Back DDT, and Save Lives.* `https://www.wsj.com/articles/SB964734570707088800`. Accessed: 2020-6-18.

Bailey, Martha, Karen Clay, Price Fishback, Michael R Haines, Shawn Kantor, Edson Severnini, and Anna Wentz. 2018. *Inter-university Consortium for Political and Social Research: U.S. County-Level Natality and Mortality Data, 1915-2007.*

Berg, Henk van den, Gamini Manuweera, and Flemming Konradsen. 2017. "Global trends in the production and use of DDT for control of malaria and other vector-borne diseases." *Malaria journal* 16 (1): 401.

Bevenue, Arthur. 1976. "The "bioconcentration" aspects of DDT in the environment." In *Residue Reviews,* 37–112. Springer New York.

Blakeslee, David, Ram Fishman, and Veena Srinivasan. 2020. "Way Down in the Hole: Adaptation to Long-Term Water Loss in Rural India." *American Economic Review* 110 (1): 200–224.

Bottrell, D G, and P L Adkisson. 1977. "Cotton Insect Pest Management." *Annual review of entomology* 22 (1): 451–481.

Brainerd, Elizabeth, and Nidhiya Menon. 2014. "Seasonal effects of water quality: The hidden costs of the Green Revolution to infant and child health in India." *Journal of development economics* 107 (0): 49–64.

Carolin, V M, and W K Coulter. 1971. "Trends of Western Spruce Budworm and Associated Insects in Pacific Northwest Forests Sprayed with DDT." *Journal of economic entomology* 64 (1): 291–297.

Carson, Rachel. 1962. *Silent spring.* Houghton Mifflin.

Chen, Aimin, and Walter J Rogan. 2003. "Nonmalarial infant deaths and DDT use for malaria control." *Emerging infectious diseases* 9 (8): 960–964.

Chen, Yuyu, Avraham Ebenstein, Michael Greenstone, and Hongbin Li. 2013. "Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy." *Proceedings of the National Academy of Sciences of the United States of America* 110 (32): 12936–12941.

Conis, Elena. 2010. "Debating the health effects of DDT: Thomas Jukes, Charles Wurster, and the fate of an environmental pollutant." *Public health reports* 125 (2): 337–342.

———. 2017. "Polio, DDT, and Disease Risk in the United States after World War II." *Environmental history* 22 (4): 696–721.

Cope, Oliver B. 1961. "Effects of DDT Spraying for Spruce Budworm on Fish in the Yellowstone River System." *Transactions of the American Fisheries Society* 90 (3): 239–251.

Corliss, John M. 1952. *The Gypsy Moth.* Technical report. Yearbook of Agriculture.

Currie, Janet, and Reed Walker. 2011. "Traffic Congestion and Infant Health: Evidence from E-ZPass." *American economic journal. Applied economics* 3 (1): 65–90.

Davies, Tg Emyr, Andrias O O'Reilly, Linda M Field, Ba Wallace, and Martin S Williamson. 2008. "Knockdown resistance to DDT and pyrethroids: from target-site mutations to molecular modelling." *Pest management science* 64 (11): 1126–1130.

Davis, Frederick Rowe. 2014. *Banned: A History of Pesticides and the Science of Toxicology.* Yale University Press.

Dias, Mateus, Rudi Rocha, and Rodrigo R Soares. 2019. "Glyphosate Use in Agriculture and Birth Outcomes of Surrounding Populations." *Working Paper.*

Dolph, R E, Jr. 1980. *BUDWORM ACTIVITY IN OREGON AND WASHINGTON, 1947-1979.* Technical report. USFS.

Dörner, Günter, and Andreas Plagemann. 2002. "DDT in human milk and mental capacities in children at school age: an additional view on PISA 2000." *Neuro endocrinology letters* 23 (5-6): 427–431.

Ebenstein, Avraham. 2012. "The Consequences of Industrialization: Evidence from Water Pollution and Digestive Cancers in China." *The review of economics and statistics* 94 (1): 186–201.

Ebenstein, Avraham, Maoyong Fan, Michael Greenstone, Guojun He, and Maigeng Zhou. 2017. "New evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River Policy." *Proceedings of the National Academy of Sciences* 114 (39): 10384–10389.

Eskenazi, Brenda, Jonathan Chevrier, Lisa Goldman Rosas, Henry A Anderson, Maria S Bornman, Henk Bouwman, Aimin Chen, et al. 2009. "The Pine River statement: human health consequences of DDT use." *Environmental health perspectives* 117 (9): 1359–1367.

Eskenazi, Brenda, Amy R Marks, Asa Bradman, Laura Fenster, Caroline Johnson, Dana B Barr, and Nicholas P Jewell. 2006. "In utero exposure to dichlorodiphenyltrichloroethane (DDT) and dichlorodiphenyldichloroethylene (DDE) and neurodevelopment among young Mexican American children." *Pediatrics* 118 (1): 233–241.

Farhang, Lili, June M Weintraub, Myrto Petreas, Brenda Eskenazi, and Rajiv Bhatia. 2005. "Association of DDT and DDE with birth weight and length of gestation in the Child Health and Development Studies, 1959-1967." *American journal of epidemiology* 162 (8): 717–725.

Foster, Andrew D, and Mark R Rosenzweig. 2010. "Microeconomics of Technology Adoption." *Annual Review of Economics* 2.

Frank, Eyal. 2018. "The Effects of Bat Population Losses on Infant Mortality through Pesticide Use in the U.S." *Working Paper.*

Garry, V F, D Schreinemachers, M E Harkins, and J Griffith. 1996. "Pesticide appliers, biocides, and birth defects in rural Minnesota." *Environmental health perspectives* 104 (4): 394–399.

Garry, Vincent F. 2004. "Pesticides and children." *Toxicology and applied pharmacology* 198 (2): 152–163.

Garry, Vincent F, Mary E Harkins, Leanna L Erickson, Leslie K Long-Simpson, Seth E Holland, and Barbara L Burroughs. 2002. "Birth defects, season of conception, and sex of children born to pesticide applicators living in the Red River Valley of Minnesota, USA." *Environmental health perspectives* 110 Suppl 3:441–449.

Greenwald, Bruce C, and Joseph E Stiglitz. 1986. "Externalities in Economies with Imperfect Information and Incomplete Markets." *The quarterly journal of economics* 101 (2): 229–264.

Haines, Michael, Price Fishback, and Paul Rhode. 2014. *United States Agriculture Data, 1840 - 2012: Version 4.* `https://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/35206/versions/V4`.

———. 2018. *United States Agriculture Data, 1840 - 2012. Inter-university Consortium for Political and Social Research [distributor].*

Hellou, Jocelyne, Michel Lebeuf, and Marilynn Rudi. 2013. "Review on DDT and metabolites in birds and mammals of aquatic ecosystems." *Environmental Review* 21 (1): 53–69.

Henneberry, Thomas J, and Steven E Naranjo. 1998. "Integrated management approaches for pink bollworm in the southwestern United States." *Integrated Pest Management Reviews* 3 (1): 31–52.

Hill, Elmer L, Harvey B Morlan, Bernice C Utterback, and Joseph H Schubert. 1951. "Evaluation of County-Wide DDT Dusting Operations in Murine Typhus Control (1946 through 1949)." *American journal of public health and the nation's health* 41 (4): 396–401.

Hitch, R K, and H R Day. 1992. "Unusual persistence of DDT in some Western USA soils." *Bulletin of environmental contamination and toxicology* 48 (2): 259–264.

Huddleston, E W, George G Gyrisco, and D J Lisk. 1960. "DDT Residues on New York Dairy Farms Following the Gypsy Moth Eradication Program." *Journal of economic entomology* 53 (6): 1019–1021.

Humphreys, M. 1996. “Kicking a dying dog. DDT and the demise of malaria in the American South, 1942-1950.” *Isis; an international review devoted to the history of science and its cultural influences* 87 (1): 1–17.

Jaffe, Adam B, Richard G Newell, and Robert N Stavins. 2003. “Chapter 11 - Technological change and the Environment.” In *Handbook of Environmental Economics,* edited by Karl-Göran Mäler and Jeffrey R Vincent, 1:461–516. Elsevier.

Kapp, Clare. 2000. *WHO wins reprieve for DDT against malaria.*

Katz, Michael L, and Carl Shapiro. 1986. “Technology Adoption in the Presence of Network Externalities.” *Journal of Political Economy* 94 (4): 822–841.

Kenworthy, E W. 1972. “DDT BANNED IN U.S. ALMOST TOTALLY, EFFECTIVE DEC. 31.” *The New York Times.*

Lange, Fabian, Alan L Olmstead, and Paul W Rhode. 2009. “The Impact of the Boll Weevil, 1892–1932.” *The journal of economic history* 69 (3): 685–718.

Lindquist, Arthur W, A H Madden, H G Wilson, Howard A Jones, et al. 1944. “The Effectiveness of DDT as a residual Spray against Houseflies.” *Journal of economic entomology* 37 (1).

Lindsten, Don C. 1984. “Technology transfer: Water purification, U.S. Army to the civilian community.” *The Journal of technology transfer* 9 (1): 57–59.

Longnecker, M P, M A Klebanoff, H Zhou, and J W Brock. 2001. “Association between maternal serum concentration of the DDT metabolite DDE and preterm and small-for-gestational-age babies at birth.” *The Lancet* 358 (9276): 110–114.

Longnecker, M P, W J Rogan, and G Lucier. 1997. “The human health effects of DDT (dichlorodiphenyl-trichloroethane) and PCBS (polychlorinated biphenyls) and an overview of organochlorines in public health.” *Annual review of public health* 18:211–244.

Lowry, W L, M T Ouye, and R S Berger. 1965. “Rate of Increase in Resistance to DDT in Pink Bollworm Adults.” *Journal of economic entomology* 58 (4): 781–782.

Lowry, William L, and Robert S Berger. 1965. “Investigations of Pink Bollworm Resistance to DDT in Mexico and the United States.” *Journal of economic entomology* 58 (3): 590–591.

Lowry, William L, and Ching H Tsao. 1961. “Incidence of Pink Bollworm Resistance to DDT.” *Journal of economic entomology* 54 (6): 1209–1211.

Maertens, Ricardo. 2019. “Biofueling Poor Fetal Health?” *Working Paper.*

Maguire, Steve, and Cynthia Hardy. 2009. “Discourse and Deinstitutionalization: the Decline of DDT.” *Academy of Management Journal* 52 (1): 148–178.

Mandavilli, Apoorva. 2006. “Health agency backs use of DDT against malaria.” *Nature* 443 (7109): 250–251.

Metcalf, R L. 1973. “A century of DDT.” *Journal of agricultural and food chemistry* 21 (4): 511–519.

Missirian, Anouch. 2020. “Yes, in your backyard: Forced technological adoption and spatial externalities.” *Job Market Paper.*

Musial, C J, O Hutzinger, V Zitko, and J Crocker. 1974. “Presence of PCB, DDE and DDT in human milk in the provinces of New Brunswick and NOVA Scotia, Canada.” *Bulletin of environmental contamination and toxicology* 12 (3): 258–267.

NPIC. 2000. *DDT (Technical Fact Sheet).* Technical report. National Pesticide Information Center.

PAN. 2009. *DDT and the Stockholm Convention: States on the edge of non-compliance.* Technical report.

Perry, C C. 1955. *Gypsy Moth Appraisal Program and Proposed Plan to Prevent Spread of the Moths.* Technical report Technical Bulletin No. 1124. United State Department of Agriculture.

Petit, Claire, Marta Blangiardo, Sylvia Richardson, Cécile Chevrier, and Sylvaine Cordier. 2009. “The Effect of Environmental Exposure to Pesticides on Birth-Weight.” *Epidemiology* 20:S43.

Raoult, Didier, Theodore Woodward, and J Stephen Dumler. 2004. “The history of epidemic typhus.” *Infectious disease clinics of North America* 18 (1): 127–140.

Rauh, Virginia A, Frederica P Perera, Megan K Horton, Robin M Whyatt, Ravi Bansal, Xuejun Hao, Jun Liu, Dana Boyd Barr, Theodore A Slotkin, and Bradley S Peterson. 2012. “Brain anomalies in children exposed prenatally to a common organophosphate pesticide.” *Proceedings of the National Academy of Sciences of the United States of America* 109 (20): 7871–7876.

Roberts, Donald, Richard Tren, Roger Bate, and Jennifer Zambone. 2016. *The Excellent Powder: DDT's Political and Scientific History.* Dog Ear Publishing.

Rosenberg, Tina. 2004. “What the World Needs Now Is DDT.” *The New York Times.*

Saffell, Cameron L. 2000. “When Did King Cotton Move His Throne (And Has It Moved Back)?” *Agricultural History* 74 (2): 293–308.

Schmitt, James Erwin. 2016. “From the Frontlines to Silent Spring: DDT and America's War on Insects, 1941-1962.” *CONCEPT* 39.

Schwartz, D A, L A Newsum, and R M Heifetz. 1986. “Parental occupation and birth outcome in an agricultural community.” *Scandinavian journal of work, environment & health* 12 (1): 51–54.

Sethi, Anand Kumar. 2013. “World War II: Radar, Sonar, Cryptography, and Beyond.” In *The Business of Electronics: A Concise History,* edited by Anand Kumar Sethi, 49–60. New York: Palgrave Macmillan US.

SHELGA. 2006. *Nepal Country Situation Report on Persistent Organic Pollutants (POPs).* Technical report.

Smith, D. 1999. “Worldwide trends in DDT levels in human breast milk.” *International journal of epidemiology* 28 (2): 179–188.

Sparks, Thomas C. 1981. “Development of Insecticide Resistance in Heliothis zea and Heliothis virescens in North America.” *Bulletin of the Entomological Society of America* 27 (3): 186–192. ISSN: 0013-8754, accessed April 28, 2019. doi:10.1093/besa/27.3.186. https://academic.oup.com/ae/article/27/3/186/220747.

Taylor, Charles A. 2019. “The Cicada Song: the Impact of Insecticides on Infant Health and Long-term Outcomes.” *CEEP Working Paper.*

Tomlin, Alan D, and Andrew J Forgash. 1972. “Toxicity of Insecticides to Gypsy Moth Larvae.” *Journal of economic entomology* 65 (4): 953–954.

Turusov, Vladimir, Valery Rakitsky, and Lorenzo Tomatis. 2002. “Dichlorodiphenyltrichloroethane (DDT): ubiquity, persistence, and risks.” *Environmental health perspectives* 110 (2): 125–128.

USDA. 1952. *GYPSY and BROWN-TAIL MOTH INSPECTION and CERTIFICATION.* Technical report.

———. 1956. *Cooperative Economic Insect Report.* Technical report.

———. 1975. *DDT: A Review of Scientific and Economic Aspects of the Decision to Ban Its Use as a Pesticide.*

Van Boeckel, Thomas P, Emma E Glennon, Dora Chen, Marius Gilbert, Timothy P Robinson, Bryan T Grenfell, Simon A Levin, Sebastian Bonhoeffer, and Ramanan Laxminarayan. 2017. “Reducing antimicrobial use in food animals.” *Science* 357 (6358): 1350–1352.

Vieira, E D, J P Torres, and O Malm. 2001. “DDT environmental persistence from its use in a vector control program: a case study.” *Environmental research* 86 (2): 174–182.

Ware, George W. 1974. “Ecological History of DDT in Arizona.” *Journal of the Arizona-Nevada Academy of Science* 9 (2): 61–65.

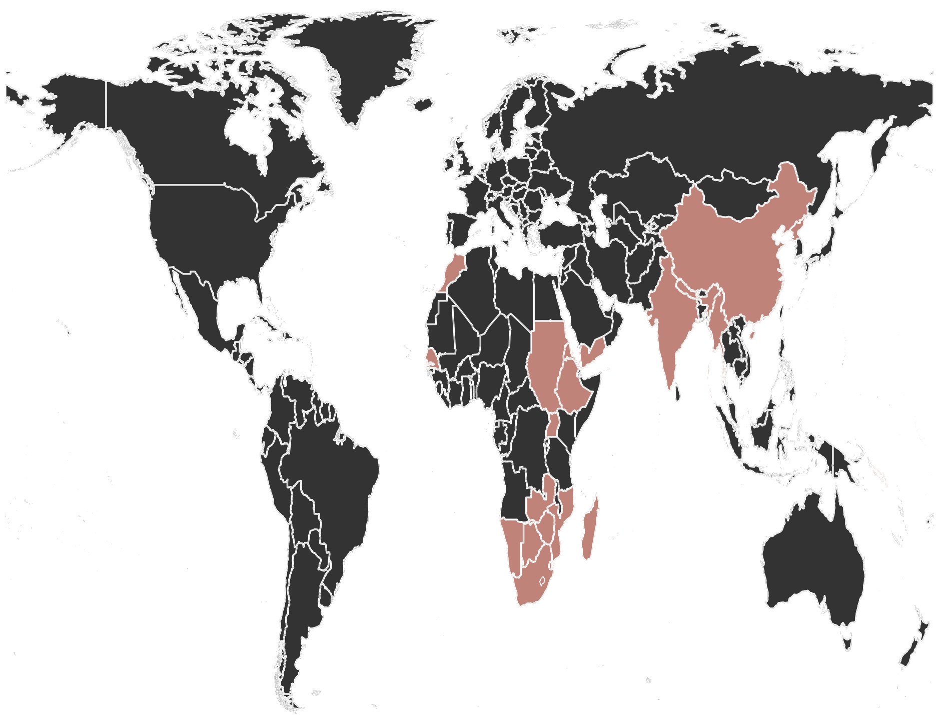


Figure 1: Known or Suspected Countries With Current DDT Use

Notes: Classification of countries as still actively using DDT relies on sources that mention their use of DDT for either agricultural or public health reasons (PAN 2009), public health measures (Berg et al. 2017), or illicit smuggling(SHELGA 2006).

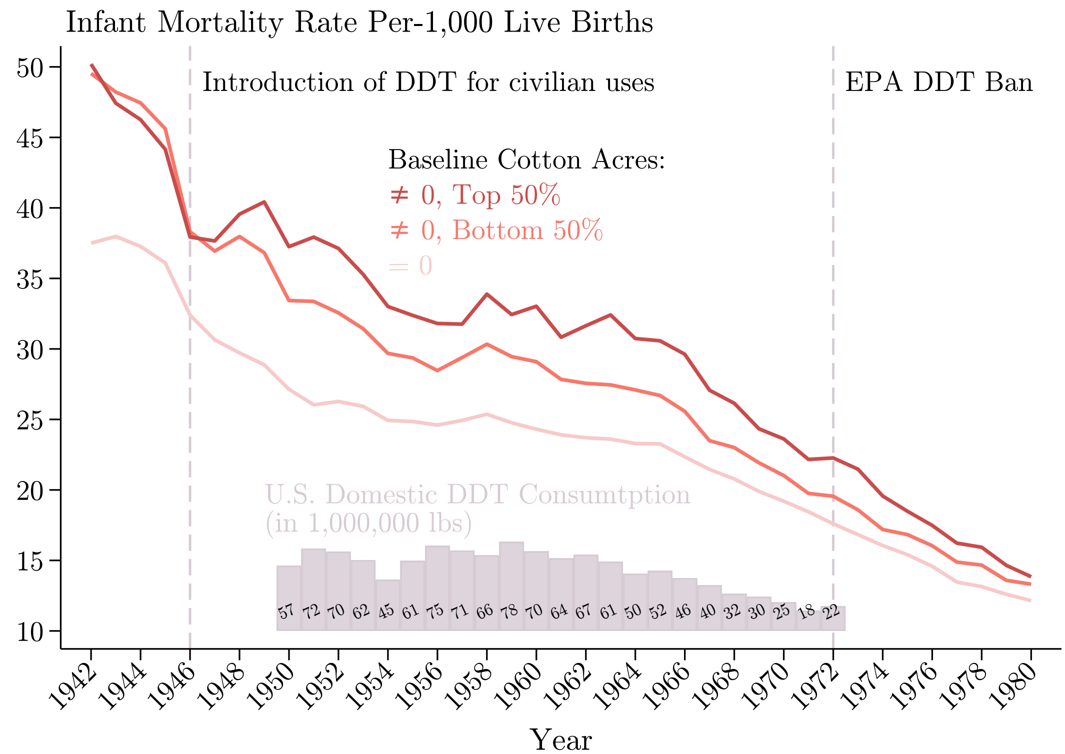
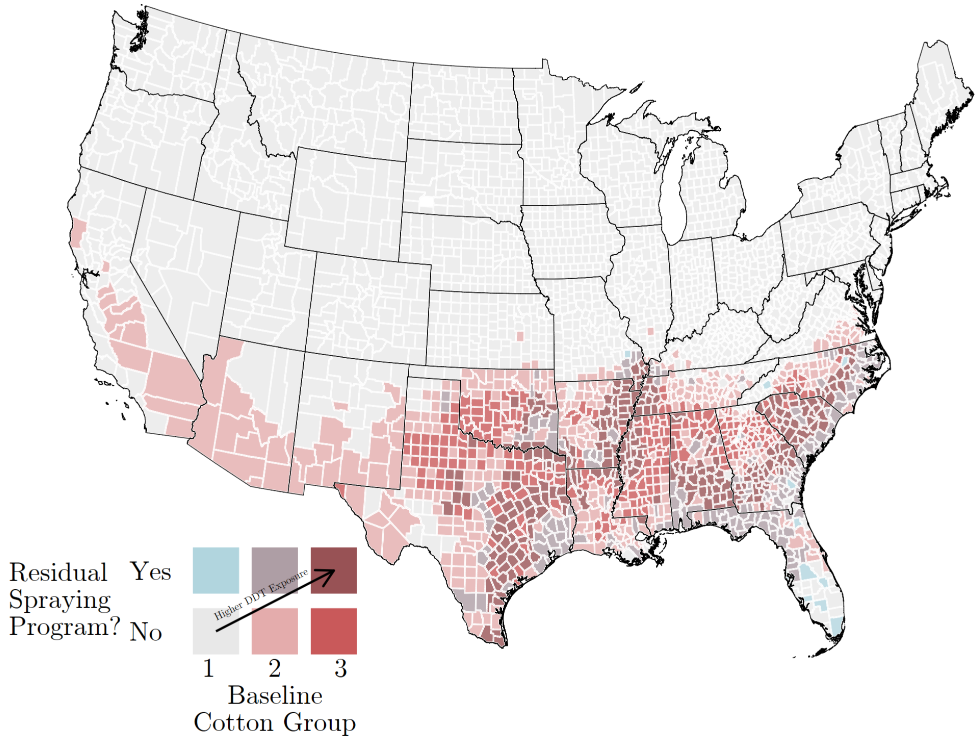


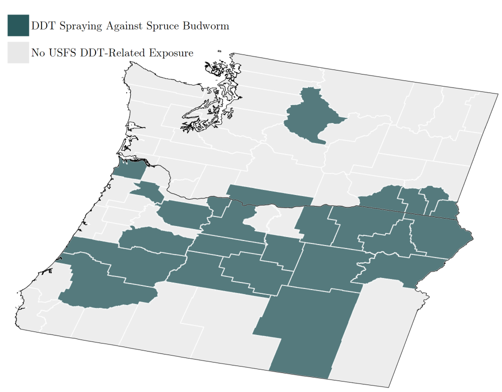
Figure 2: Mean Infant Mortality Rates Across Cotton Production Intensities

Notes: Solid lines show mean infant mortality rates based on mother's county of residence, weighted by the number of live births in the county in the year. Each lines corresponds to the number of cotton acres during the baseline period of 1934, 1939, and 1944.

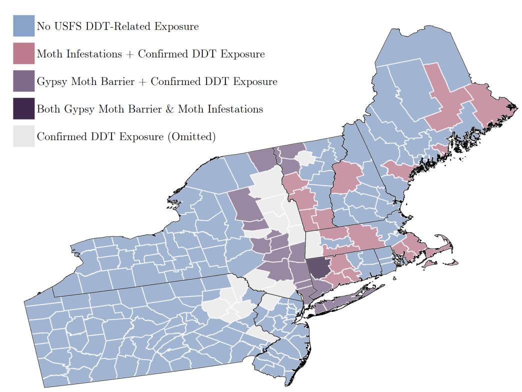
Source: IMR data from (Haines et al. 2014), cotton acres data from (2018), and DDT consumption data from (USDA 1975).



(a) Baseline Cotton Groups & Residual Spraying Program Counties



(b) Northwest Sample of USFS Forest Spraying Program



(c) Northeast Sample of USFS Forest Spraying Program

Figure 3: Counties in the Sample & Their Treatment Status

Notes: A map showing the counties classified by their baseline land share under cotton cultivation, and whether they ever participated in a CDC residual spraying program. Black solid lines delineate state borders.

Source: Cotton acres data from (Haines et al. 2018), CDC residual spraying data from the center's activity reports for fiscal years 1946-1953, data on USFS spraying from (USDA 1952; Perry 1955; Dolph 1980), as well as USFS Fiscal Reports and Gypsy Moth Annual Reports for years 1945-1956.

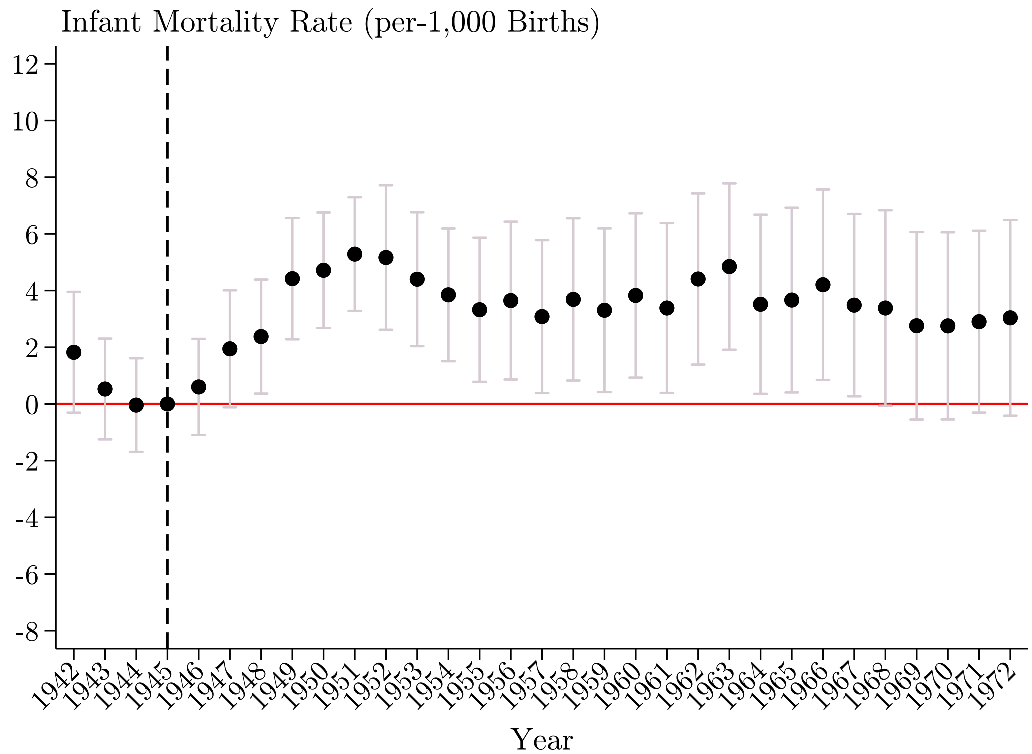


Figure 4: IMR in High VS. Low Cotton Intensity Counties

Notes: Results from Equation (1) for IMR. Capped gray lines show the 95% CIs. Observations are weighted by live births, and standard errors are clustered at the county level.
Source: IMR data from (Haines et al. 2014), and cotton acres data from (2018).

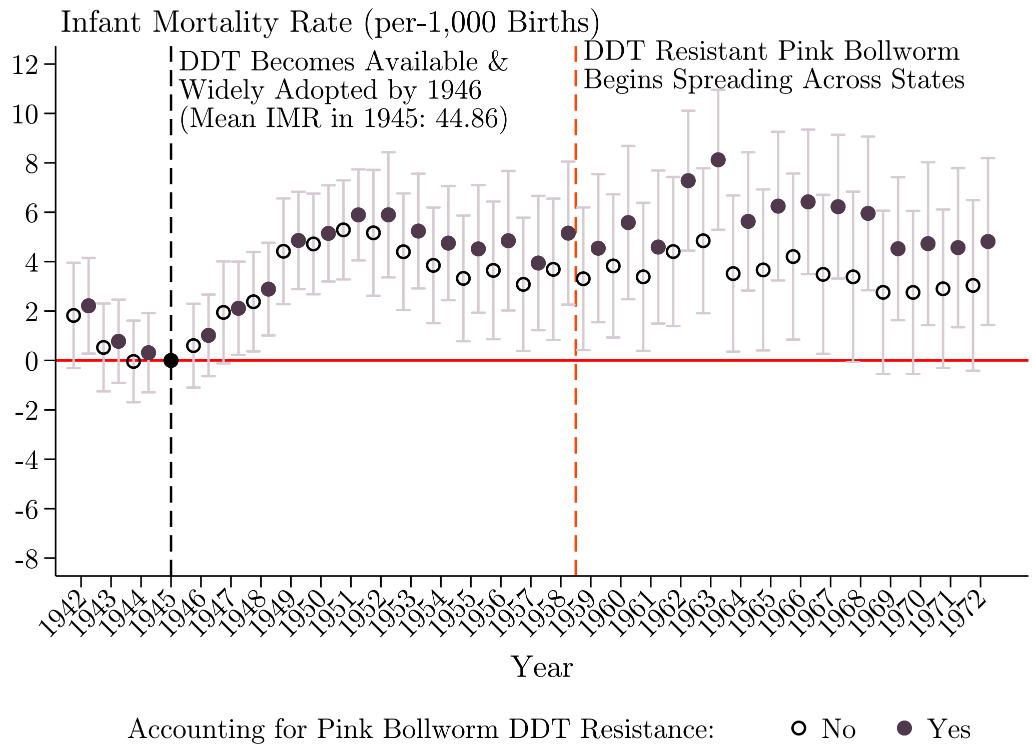
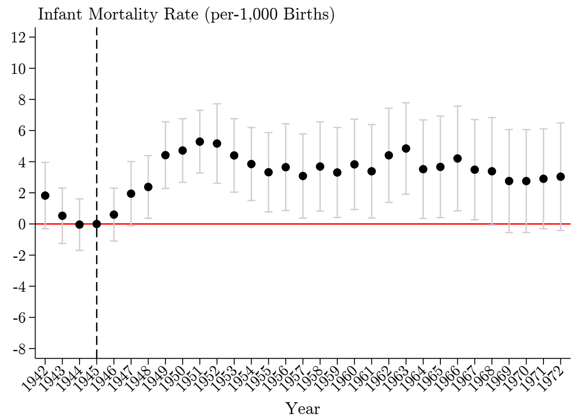
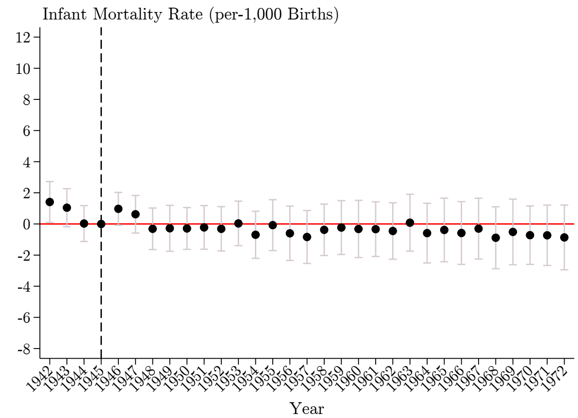


Figure 5: Accounting for Pink Bollworm Resistance to DDT

Notes: Estimation results of Equation (1), replicated from Figure 4 (hollow circles), and results from running:
$IMR_{csy} = \sum_{\substack{\tau \in \{\underline{T},\ldots,\overline{T}\} \\ \tau \neq 1945}} \beta_\tau \times \mu_\tau + \sum_{\substack{\tau \in \{\underline{T},\ldots,\overline{T}\} \\ \tau \neq 1945}} \alpha_\tau \times \mu_\tau \times \mathbb{1}\{\text{DDT Resistant}_s = 1\} + \lambda_c + \delta_{cy} + \varepsilon_{csy}$,
where $\mu_\tau = \mathbb{1}\{Treated_{cs} = 1\} \times \mathbb{1}\{y = \tau\}$ (full circles, showing β_τ). Capped gray lines show the 95% CIs. Observations are weighted by live births, and standard errors are clustered at the county level.
Source: IMR data from (2014), cotton acres data from (2018), and pink bollworm DDT resistance data from (USDA 1956; Sparks 1981).



(a) Using Baseline Cotton Groups



(b) Using Overall Cropland Terciles

Figure 6: Impact of Agricultural Intensity on IMR

Notes: Results from Equation (1) using either (a) baseline cotton groups, comparing the high intensity to the low intensity, or (b) the terciles of cropland share, comparing the third to the second tercile. Capped gray lines show the 95% CIs. All observations are weighted by the number of live births, and standard errors are clustered at the county-level.
Source: IMR data from (Haines et al. 2014), and cotton and cropland acres data from (2018).

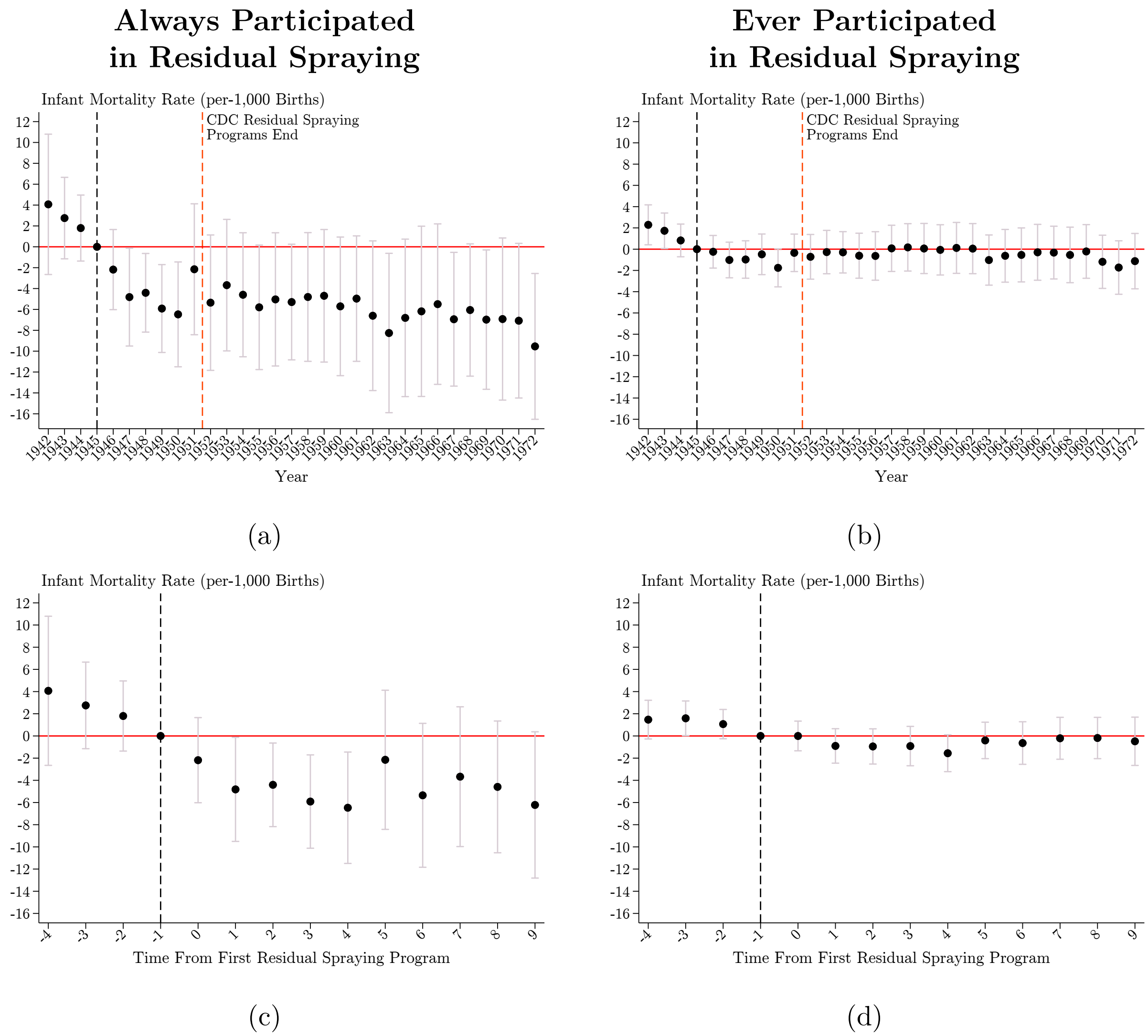


Figure 7: Impact of CDC Residual Spraying Programs on IMR

Notes: Estimation results using Equation (1) for (a) and (b), and a modified version for (c) and (d) that uses leads and lags from the first year of residual spraying taking place in the county. Capped gray lines show the 95% CIs. All observations are weighted by the number live births, and standard errors are clustered at the county level.
Source: IMR data from (2014), and residual spraying program data from yearly CDC reports and bulletins published throughout the duration of the program, 1947-1951.

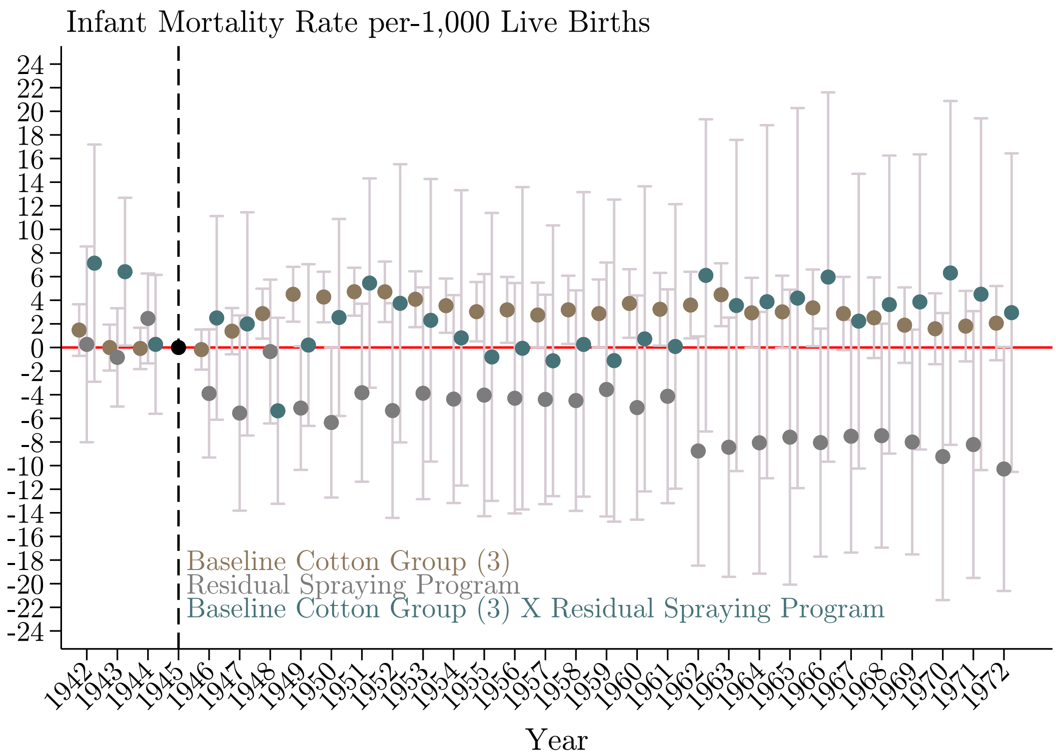
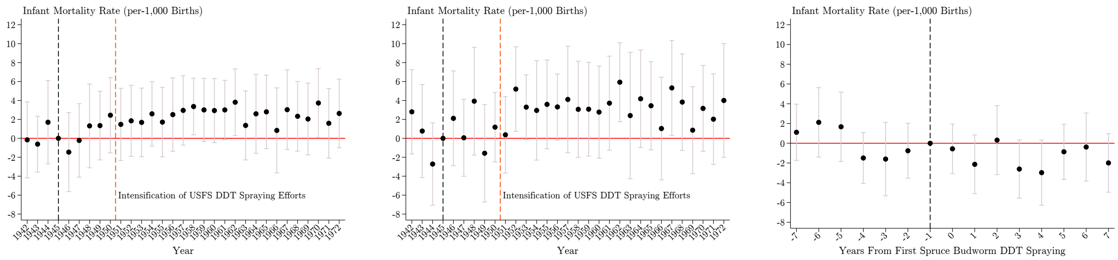


Figure 8: Impacts of Cotton Agriculture & Vector-Borne Disease Control on IMR

Notes: Estimation results for the specification in Equation (2). Showing both the triple and double interactions. Capped gray lines show the 95% CIs. All observations are weighted by the number live births, and standard errors are clustered at the county level. Source: IMR data from (2014), cotton acres data from (2018), and residual spraying program data from yearly CDC reports and bulletins published throughout the duration of the program, 1947-1951.



(a) Gypsy Moth Barrier (b) Gypsy Moth Infestations (c) Spruce Budworm

Figure 9: IMR in Counties Exposed to DDT Through USFS Spraying Campaigns

Notes: Estimation results using Equation (1) for (a) and (b), and a modified version for (c) that uses leads and lags from the first year of spraying. Capped gray lines show the 95% CIs. All observations are weighted by the number live births, and standard errors are clustered at the county level.

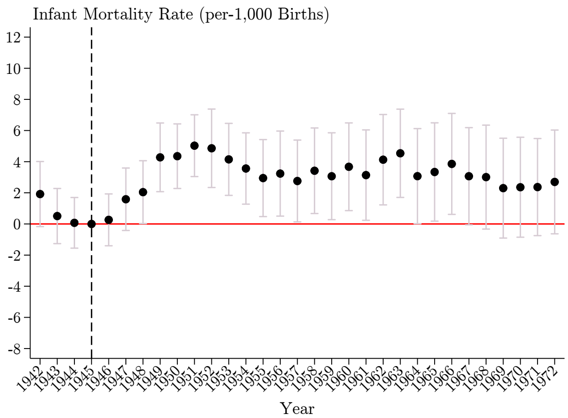
Table 1
Cotton Acres (in Log Points) & Pink Bollworm Regression Estimates

	(1)	(2)	(3)	(4)	(5)
PB Present	-0.67				
	(0.29)				
PB DDT Resistant		-0.50			
		(0.23)			
PB Present			-0.63		
			(0.32)		
PB DDT Resistant			-0.45		
			(0.28)		
PB Present & DDT Resistant			0.20		
			(0.28)		
PB Present × B.Cotton (1)				0.44	
				(0.31)	
PB Present × B.Cotton (2)				-0.83	
				(0.34)	
PB Present × B.Cotton (3)				-0.60	
				(0.29)	
DDT Resistant × B.Cotton (1)					0.04
					(0.55)
DDT Resistant × B.Cotton (2)					-0.91
					(0.25)
DDT Resistant × B.Cotton (3)					-0.38
					(0.21)
Dep. Var. Mean	6.2	6.3	6.3	6.2	6.3
R^2	0.931	0.930	0.931	0.932	0.931
N	8,951	8,945	8,945	8,951	8,945
Clusters	1,492	1,491	1,491	1,492	1,491
County FE	X	X	X	X	X
Year FE	X	X	X	X	X

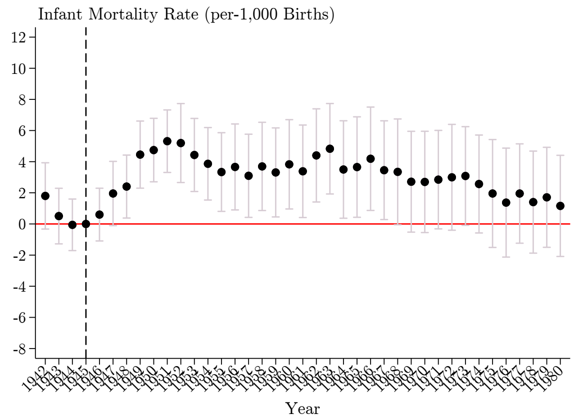
Notes: Estimation results from running cotton acres, reported during census years, on dummies for presence of pink bollworm, its resistance to DDT, and interactions with baseline cotton groups. Standard errors are clustered at the county level.

Appendix

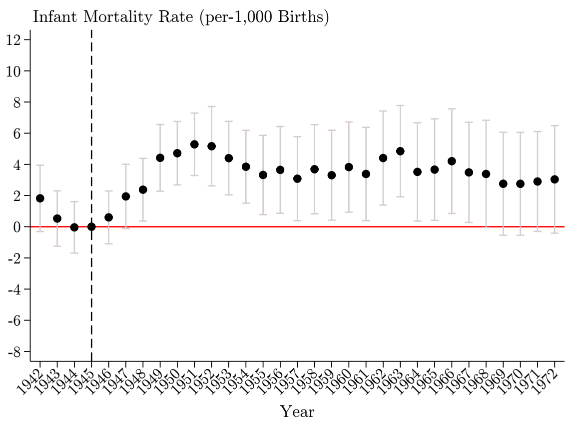
A Additional Results



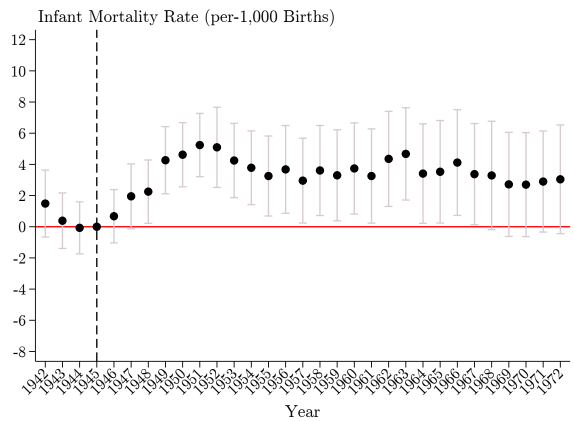
(a) Including Zero Cotton Acres Counties



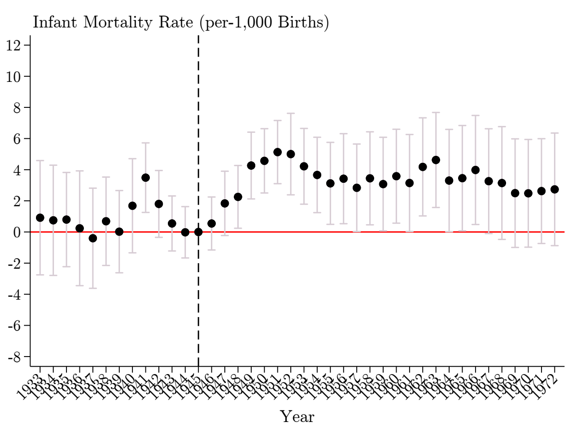
(b) Extending to 1980



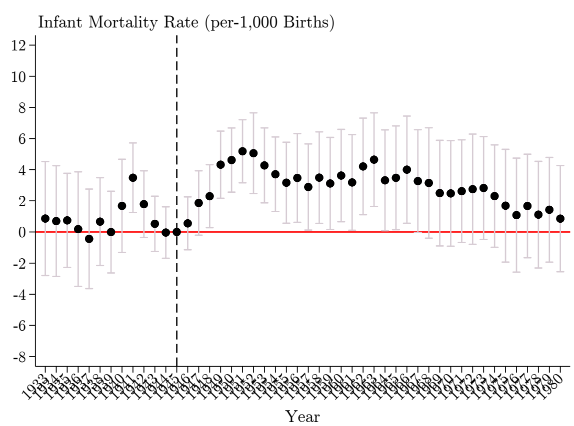
(c) Sample of Old Cotton Belt States



(d) Sample of all Southern States



(e) Extending from 1933



(f) Extending from 1933 to 1980

Figure A1: Sensitivity Checks for High VS. Low Cotton Intensity Counties: IMR

Notes: Repeating the analysis in Figure 4 with the following changes: (a) Comparing high cotton intensity to low intensity and zero intensity counties based on the baseline period; (b) Extending the sample until 1980; (c) Changing the sample to include only states considered to be part of the old cotton belt pre-DDT availability; (d) Changing the sample to include all southern states; (e) Adding years of data, for all states, from 1933-1941 when IMR was recorded at the county of occurrence; (f) Extending the sample to include 1933-1980, for all states.

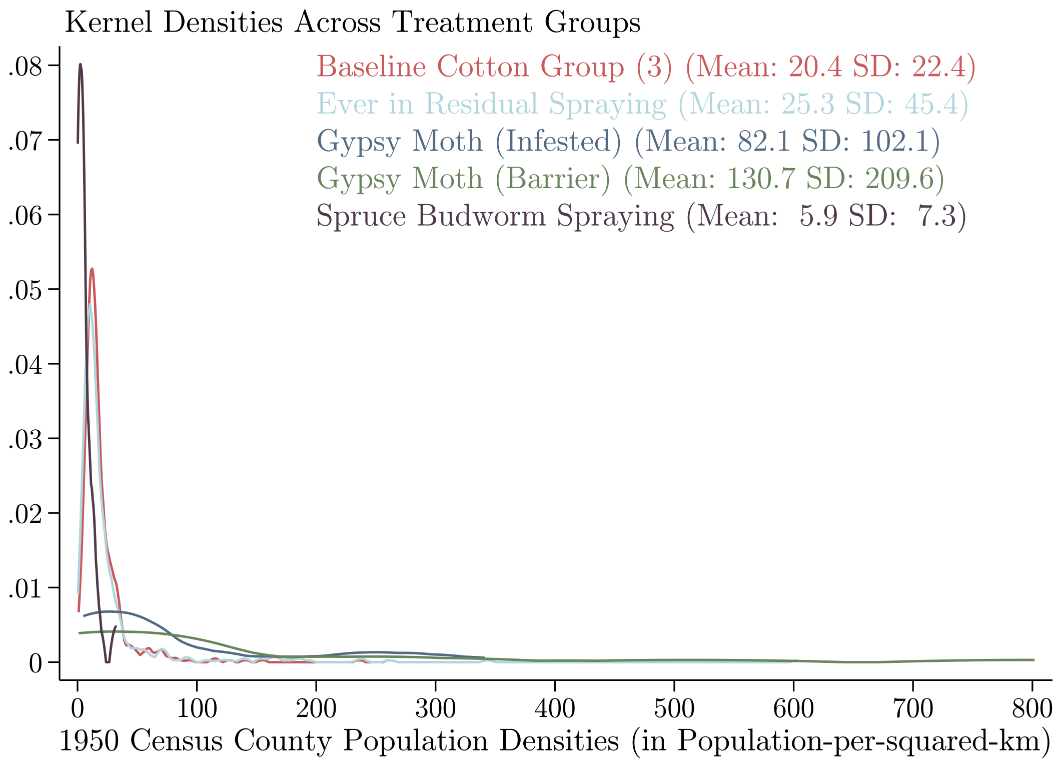


Figure A2: Population Densities (1950-Census) Across Treatment Counties

Notes: Kernel densities fitted for the population densities (people per-squared-km) across the different treatment groups used in the analysis.

Table A1
Cotton Acres (in 1,000s) & Pink Bollworm Regression Estimates

	(1)	(2)	(3)	(4)	(5)
PB Present	-7.02				
	(1.69)				
PB DDT Resistant		-4.01			
		(0.80)			
PB Present			-4.28		
			(1.56)		
PB DDT Resistant			-0.96		
			(0.64)		
PB Present & DDT Resistant			-4.82		
			(1.73)		
PB Present × B.Cotton (1)				4.12	
				(0.71)	
PB Present × B.Cotton (2)				2.93	
				(1.19)	
PB Present × B.Cotton (3)				-17.27	
				(1.98)	
DDT Resistant × B.Cotton (1)					3.42
					(0.51)
DDT Resistant × B.Cotton (2)					0.82
					(0.77)
DDT Resistant × B.Cotton (3)					-12.16
					(1.39)
Dep. Var. Mean	16.5	16.7	16.7	16.5	16.7
R^2	0.921	0.920	0.921	0.925	0.924
N	8,951	8,945	8,945	8,951	8,945
Clusters	1,492	1,491	1,491	1,492	1,491
County FE	X	X	X	X	X
Year FE	X	X	X	X	X

Notes: Estimation results from running cotton acres, reported during census years, on dummies for presence of pink bollworm, its resistance to DDT, and interactions with baseline cotton groups. Standard errors are clustered at the county level.

B Data Appendix

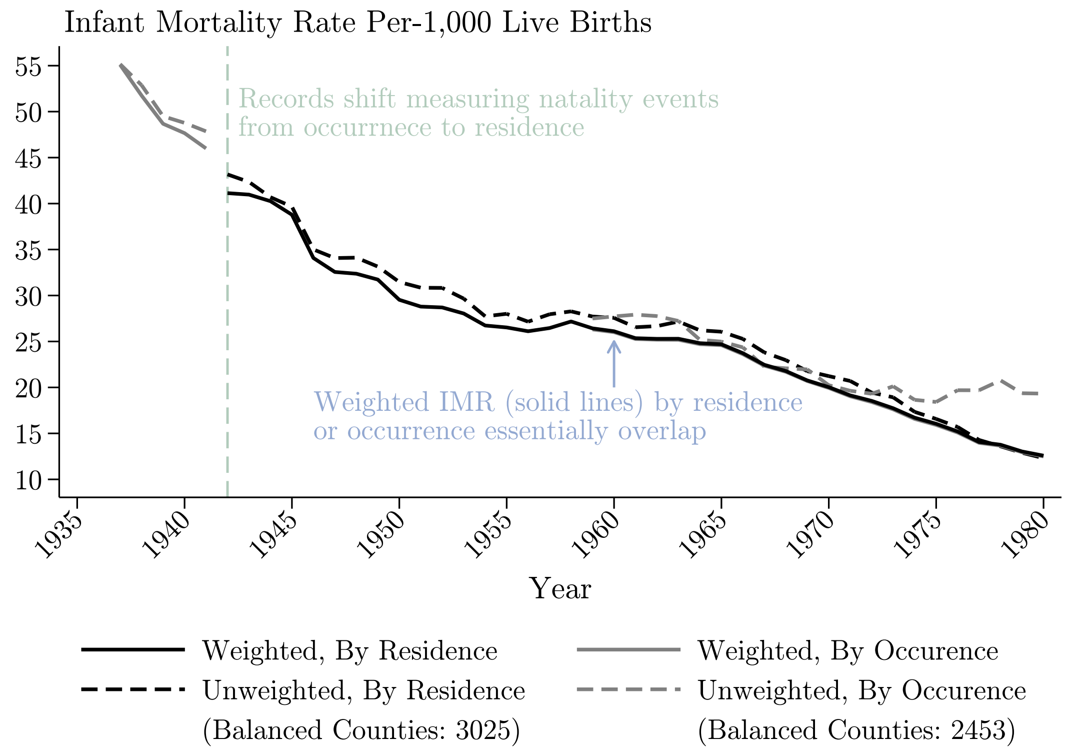


Figure B1: Mean IMR in the United States: 1937-1980

Notes: IMR data by either the residence county of the mother, or the occurrence county, weighted by live births or unweigted, for a set of balanced counties.

C DDT Spraying Appendix

C.1 Adoption of DDT for Civilian Purposes

C.2 Use as an Insecticide for Crop Pests

Growers in the US used DDT on a variety of food and other agricultural crops, including beans, cotton, soybeans, sweet potatoes, peanuts, cabbage, tomatoes, cauliflower, brussels sprouts, corn, and other crops. Heavy dependence on DDT in cotton was related to the control of the boll weevil, pink bollworms, and the tobacco budworms (Bottrell and Adkisson 1977). In itself, cotton was one of the most intensive users of insecticides, such that half of all insecticides used on agricultural products were for cotton (as of 1971) (1977; NPIC 2000; USDA 1975).

Commenting on the successful early experiments with DDT and pest-control, Ware (1974) writes that "The results of experiments in 1944 and 1945 using DDT on cotton were so outstanding in controlling most cotton pests and increasing yields that it was generally used by the growers in 1946." Application intensities on cotton were high, as Bottrell and Adkisson (1977) note that "entomologists recommended that the farmers spray or dust regularly, usually once a week, from the time the cotton started squaring until all of its green bolls had hardened."

Although the exact percentage breakdown of DDT use per-crop differ, the EPA reports that of the amount of DDT used in 1970 to 1972, more than 80% was for cotton, with the remaining 20% used predominantly on peanuts and soybeans, even if by that time DDT usage had dropped from a high of 80 million pounds in 1959 to 12 million pounds (NPIC 2000). As reported by the New York Times in December 1972, roughly 86% of DDT usage was on cotton, while 9% for peanuts, and 5% on soybeans (negligible amounts used on other agricultural crops) (Kenworthy 1972). By all accounts, the vast majority (67-90%) of the total US usage of DDT was on cotton to control the pink bollworm. The remainder was primarily used for peanuts and soybeans at a much lower volume. The use of DDT in cotton persisted up until the ban, as Maguire and Hardy (2009) note that the "ban forced cotton growers, the single remaining large market for DDT, to switch to substitutes."

C.3 CDC Residual Spraying Programs

As part of ongoing efforts to reduce vector-borne diseases in the south, the CDC collaborated with 13 states in an effort to coordinate control and spraying actions. The residual spraying program launched in July- 1947, and ended by 1952. The CDC functioned to assist state and county health departments upon request of local state department. These programs offered: (i) operational field investigations and demonstrations (training) where the required facilities were beyond the resources of the department; (ii) field training in public health and in the production of instructional aids for technical and professional training in communicable diseases; and (iii) supplying evaluation and consultation services concerning techniques and practices in public health diagnostic laboratories.

The diseases that were the main objects of interest for CDC activities were: malaria, amoebiasis, schistosomiasis, ancylostomiasis, filariasis, yellow fever, dengue fever, sandly fever, poliomyelitis, encephalitis, typhus, and dysentery. Those that were heavily targeted with DDT use were malaria and typhus, with DDT additionally used in general mosquito control in Southern states. The Engineering Division of the CDC directed and conducted the various insect control operations of the CDC. It secured the cooperation of state and local health departments, assigned professional personnel to state CDC programs, made available the necessary equipment, and maintained the equipment in use. As such, the CDC programs pertaining to the use of DDT to control the diseases mentioned above were conducted by the Engineering Division.

The two major activities of the Engineering Division during the duration of widespread DDT use in insect and disease control were the malaria control program (conducted in 13 Southern states) and the typhus control program (conducted in 9 Southern states), with occasional additional programs in outstanding cases (such as the 1952 encephalitis outbreak in Northern California). For example, the Engineering Division (ED), with the cooperation of the Mississippi River Commission, carried airplane DDT larviciding projects at the Sardis and Arkabutla reservoirs in Mississippi for malaria control. Afterward, emergency plane larviciding with DDT were initiated in flooded areas of Arkansas (Forrest City, Helena, West Memphis, and Marianna).

During the first two quarters of the 1947 fiscal year DDT malaria control operations (carried out by the Mosquito Control Branch) were pre-approved in 188 counties with malaria death rates of 10 or more per 100,000 population (expansion of the program then called for a death rate of 5 or more per 100,000 population, increasing the counties in the program). By June 1947, operations had taken place in 297 counties. The residual spraying program was limited to rural homes and small communities, and larviciding and minor drainage was used to provide control for larger communities (populations of 2,500 or more). A total of 35 areas received malaria control by larviciding and minor drainage during the fiscal year. However, larger cities with populations of more than 2,500 contributed independently for residual house spraying, which was completed entirely using local funds.

Residual spraying programs were intensive in terms of the amounts sprayed. For example, Tennessee began "premise" spraying in 1947, wherein all buildings occupied by humans and animals after nightfall were given a residual DDT treatment per season. In the 1947 fiscal year, 1,278,000 DDT residual house spray applications were made, in 297 counties of the 13 operating states. Approximately 1,046,000 lbs. of DDT were used (an average of 0.82 lbs. per house). We use reports compiled by the CDC and digitize tables and maps that summarize the amounts of DDT used, and the counties that had operation areas. See Figure C2 for examples of summary tables and treatment area maps.

The Typhus Control Branch directs the operation of the typhus control program, consisting of ratproofing, DDT dusting, rat poisoning, and sanitation activities in cooperation with state health departments in areas where there is sufficiently high endemicity of the disease.

Operations were approved in counties officially reporting 10 or more cases of typhus a year. Following the 1946 season, there were 188 counties pre-approved for typhus control. DDT dusting was carried out in 123 reporting counties by the end of of the fiscal year. During the year, the number of premise application of DDT totalled 584, 067.

C.4 Spraying Against Forest Pests in the Northeast & Northwest

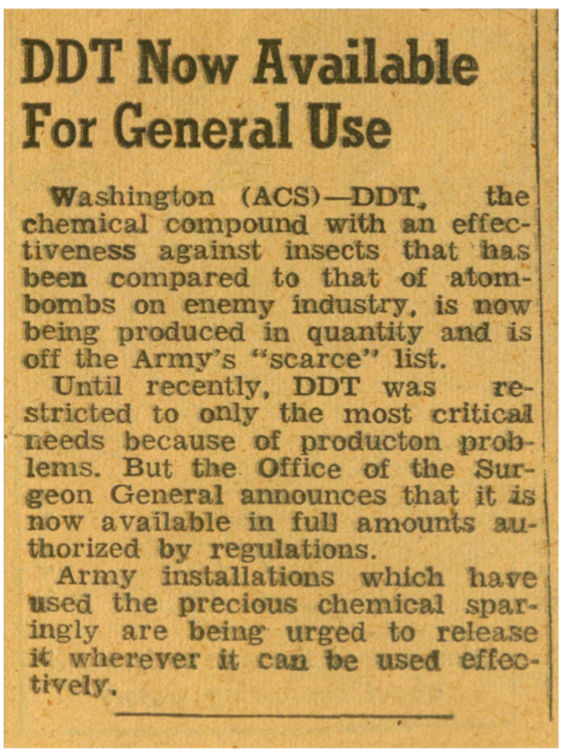
Before the late 1950s, the US Forest Service (USFS) used DDT in pesticide spraying programs against the gypsy moth and the spruce/western budworm, particularly in the forests of the Pacific Northwest, the Northeast, and the Atlantic Seaboard. In 1957, the USFS and the US Department of Agriculture (USDA) prohibited the spraying of DDT around aquatic areas in its jurisdiction and began phasing out DDT formally in 1958. In 1973 and 1974 under Section 18 exemptions for potential economic emergencies, the EPA granted requests by the states of Washington and Idaho, as well as the USFS, to combat the pea leaf weevil and the Douglas-fir tussock moth. The following tables by the USFS show forest areas sprayed with insecticides between 1945 and 1974 by year and target species, and the type of insecticides used by year. The western budworm and gypsy moth were the ones most widely targeted by aerial spraying, as summarized in tables extracts shown in Figure C3.

Between 1945 and 1965, about 1.8 million hectares (ha) of forests in Oregon were treated with DDT to combat the spruce/western budworm, and the height of DDT use in Oregon forests was between 1949 and 1958. In 1974, the USFS and USDA requested special Section 18 exemption to the DDT ban for potential economic emergencies due to the damage caused by budworm infestations, and was granted its exemption by the EPA. Figure C4 shows the aerial DDT spray projects in Oregon, the table details the application of DDT in Oregon, as well as the map of treated areas for both Oregon and Washington.

For gypsy moth populations in the Northeast, the USFS relied heavily on DDT use to fight against infestation from 1945 to 1957 and phased out use after 1958. Various âĂIJSlow the SpreadâĂİ programs resulted in DDT spraying projects in the region as administered by the USFS. Over 600,000 acres infestated with gypsy moths were sprayed with DDT. (Corliss 1952). In 1956 and 1957, DDT was used for the eradication of the gypsy moth in the states affected by the barrier zones of 1952. 9 The eradication zone compromised a total of 14,230 km2 between 1956 and 1957 spraying projects. This constituted the height of DDT use in the fight against the gypsy moth. In 1945, a series of plots in New York, Massachusetts, and Pennsylvania that were infested with gypsy moths were subject to a series of experimental pesticide spraying containing DDT. In addition to gypsy moth pesticide sprayings, spruce budworm infestations in Maine (and Quebec) were subject to DDT suppression program sprays between 1954 and 1967, with a total of 1,222,262 acres treated solely with DDT. In Figure C5, we highlight a few of the maps and tables we use to construct the treatment data for the gypsy moth spraying campaigns.

(a)

(b)



DDT Now Available For General Use

Washington (ACS)—DDT, the chemical compound with an effectiveness against insects that has been compared to that of atom-bombs on enemy industry, is now being produced in quantity and is off the Army's "scarce" list.

Until recently, DDT was restricted to only the most critical needs because of producton problems. But the Office of the Surgeon General announces that it is now available in full amounts authorized by regulations.

Army installations which have used the precious chemical sparingly are being urged to release it wherever it can be used effectively.

(c)

(d)

Figure C1: Ads & News Clips Promoting DDT for Civilian Uses

SUMMARY OF
CDC RESIDUAL HOUSE SPRAYING ACTIVITIES
FISCAL YEAR 1947

STATE	MAX. NO. COUNTIES OPERATING	NO. HOUSE SPRAY APPLICATIONS	POUNDS DDT PER SPRAY APPLICATION*	MAN-HOURS PER SPRAY APPLICATION*	UNIT COST	PERCENT LOCAL CONTRIBUTION*
Alabama	22	135,856	0.80	1.23	$3.12	20
Arkansas	38	179,332	0.88	2.02	3.43	22
Florida	27	60,010	0.90	1.49	4.80	19
Georgia	51	189,486	0.77	1.27	2.69	34
Kentucky	9	18,171	0.89	2.87	5.77	33
Louisiana	12	74,950	0.88	1.78	3.35	15
Mississippi	18	186,098	0.69	1.36	2.78	15
Missouri	7	71,040	0.62	1.17	3.10	14
North Carolina	34	58,829	0.68	1.30	3.87	36
Oklahoma	11	35,279	0.98	2.47	5.44	32
South Carolina	31	127,273	0.93	1.62	3.32	39
Tennessee	12	40,315	1.20	1.77	5.05	36
Texas	35	101,350	0.90	2.40	4.63	29
TOTAL	297	1,277,989				
(average)			0.82	1.62	$3.48	26%

* Second half of fiscal year only. (Man-hours include CDC and local; supervision and miscellaneous time included for second half of fiscal year only.)

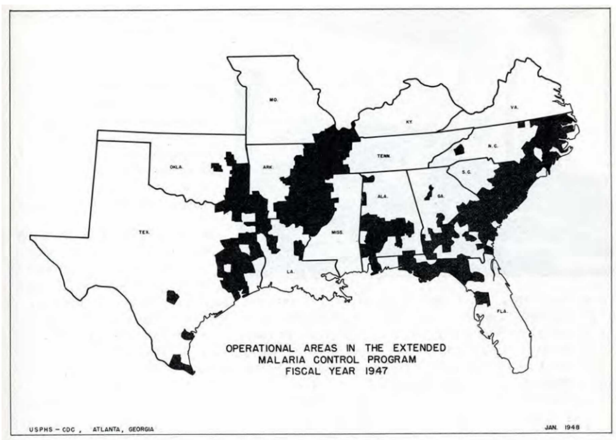
(a) State Summary for Malaria (1946)

SUMMARY OF
TYPHUS CONTROL OPERATIONS
FISCAL YEAR 1947

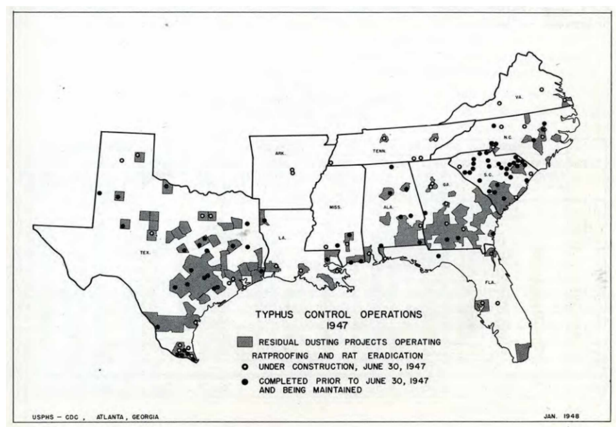
STATE	RESIDUAL DUSTING				RATPROOFING			MAN HOUR SUMMARY		
	COUNTIES REPORTING	PREMISE DUSTINGS	POUNDS 10% DDT DUST PER PREMISE	MAN HRS. L. & LF* PER PREMISE	PROJECTS REPORTING	ESTABLISHMENTS TREATED	MAN HRS. L. & LF* PER ESTAB.	USPHS MAN HRS. WORKED	OTHER MAN HRS. WORKED	TOTAL MAN HRS. WORKED
Ala.	10	58,071	3.67	0.56	3	20	21.00	45,144	46,637	91,781
Ark.	—	—	—	—	2	605	27.96	5,802	26,616	32,418
Fla.	5	49,658	2.57	0.68	4	446	35.80	27,385	47,426	74,811
Ga.	32	241,670	2.54	0.37	7	623	50.57	76,828	112,446	189,274
La.	6	41,190	2.83	0.37	5	694	46.26	31,472	47,328	78,800
Miss.	3	32,116	1.27	0.41	4	214	17.62	19,382	5,111	24,493
N. C.	5	69,072	1.25	0.26	5	1,847	18.58	14,843	51,479	66,322
S. C.	10	8,605	2.91	1.89	6	359	55.20	26,295	34,448	60,743
Tenn.	2	24,910	1.65	0.31	4	253	48.68	15,997	9,198	25,195
Tex.	49	53,391	2.75	1.22	17	2,340	51.19	99,797	213,880	313,677
Va.	1	5,384	3.71	0.83	—	—	—	5,248	4,722	9,970
TOTAL	123	584,067	2.45	0.51	57	7,401	38.77	368,193	599,291	967,484

* Labor and Labor Foremen

(b) State Summary for Typhus (1947)



(c) Areas Treated for Malaria (1947)



(d) Areas Treated for Typhus (1947)

Figure C2: Examples of Tables & Maps from CDC Reports

Notes: Tables and maps from CDC reports for 1946-1947.

FOREST AREA (1,000 ACRES) AERIALLY SPRAYED WITH INSECTICIDES IN THE UNITED STATES, 1945-1974, BY YEAR AND TARGET SPECIES

Year	WB	GM	SB	DFTM	PB	PPL	FC	JPBW	WHL	SS	GBTC	PTM	ES	BHPS	WBHBH	RHPS	SP
1945	-	5	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-
1946	-	61	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
1947	-	107	-	414	-	-	-	-	-	3	-	-	-	-	-	9	-
1948	4	211	-	-	-	-	-	-	-	1	-	-	-	-	-	2	-
1949	267	390	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
1950	938	583	-	-	-	-	-	-	-	11	16	-	-	-	-	-	-
1951	916	178	-	-	-	-	-	4	-	5	-	-	-	-	-	-	-
1952	669	202	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
1953	508	180	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-
1954	75	1,372	20	-	255	-	-	-	-	8	3	-	-	-	-	-	-
1955	2,333	1,083	-	-	-	226	-	-	-	9	2	-	-	-	-	-	-
1956	1,367	926	-	10	-	-	-	-	-	3	-	-	-	-	-	-	-
1957	1,445	3,395	-	-	-	-	-	40	-	6	4	-	-	-	6	-	-
1958	936	516	314	-	-	-	-	-	-	4	3	-	-	-	-	-	-
1959	127	115	7	29	-	-	-	1	-	2	-	-	1	18	-	-	-
1960	119	65	242	13	-	-	-	1	-	3	-	-	1	-	-	2	-
1961	-	142	66	1	-	-	1	40	-	2	-	-	2	-	-	-	-
1962	1,027	427	57	-	-	-	2	37	33	4	-	26	9	-	-	-	-
1963	1,220	414	498	12	-	-	1	-	59	5	-	7	11	-	10	-	-
1964	684	135	58	-	-	-	-	-	-	-	3	8	-	-	-	-	-
1965	8	226	-	245	-	-	107	-	-	-	23	-	-	-	-	-	-
1966	148	275	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
1967	2	203	101	-	-	-	-	-	-	1	-	-	-	-	-	-	-
1968	6	231	10	-	-	-	8	-	1	3	-	-	-	-	-	-	-
1969	8	91	18	-	-	-	10	-	-	6	-	-	-	-	-	1	-
1970	-	223	212	-	-	-	2	-	-	5	-	-	-	-	-	-	14
1971	9	391	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1972	-	177	500	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1973	-	189	473	70	-	-	-	-	-	-	-	-	-	-	-	-	-
1974	-	171	434	466	-	-	-	-	-	-	-	-	-	-	-	-	-
	12,816	12,684	[illegible],020	1,260	255	239	132	123	104	102	54	41	24	18	16	14	14

(a) Forest Acres Sprayed by Pest

FOREST AREA (1,000 ACRES) AERIALLY SPRAYED WITH INSECTICIDES IN THE UNITED STATES, 1945-1974, BY YEAR AND MATERIAL USED[a]

Year	DDT	Carbaryl	Mexacarbamate	Malathion	Fenitrothion	Trichlorfon	DFTM Virus	Gardona	Lead Arsenate	Methoxychlor	Phosphamidon	Bacillus	Dimethoate	Propoxur	GBTC Virus	Total
1945	7	--	--	--	--	--	--	--	9	--	--	--	--	--	--	16
1946	64	--	--	--	--	--	--	--	--	--	--	--	--	--	--	64
1947	533	--	--	--	--	--	--	--	--	--	--	--	--	--	--	533
1948	218	--	--	--	--	--	--	--	--	--	--	--	--	--	--	218
1949	661	--	--	--	--	--	--	--	--	--	--	--	--	--	--	661
1950	1,548	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1,548
1951	1,105	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1,105
1952	880	--	--	--	--	--	--	--	--	--	--	--	--	--	--	880
1953	700	--	--	--	--	--	--	--	--	--	--	--	--	--	--	700
1954	1,733	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1,733
1955	3,653	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3,653
1956	2,306	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2,306
1957	4,898	--	--	4	--	--	--	--	--	--	--	--	--	--	--	4,902
1958	1,773	--	--	--	--	--	--	--	--	--	--	--	--	--	1	1,774
1959	216	86	--	3	--	--	--	--	--	--	--	--	--	--	--	305
1960	430	11	--	1	--	--	4	--	--	--	--	--	--	--	--	446
1961	218	29	--	5	--	--	--	--	--	7	--	--	--	--	--	259
1962	1,592	31	--	--	--	--	--	--	--	--	--	--	--	--	--	1,623
1963	2,074	130	--	20	--	--	12	--	--	--	7	--	1	--	--	2,243
1964	632	97	--	161	--	--	--	--	--	--	--	2	--	--	--	891
1965	363	234	--	11	--	--	--	--	--	--	--	1	--	--	--	610
1966	--	275	5	143	--	--	--	--	--	--	--	--	--	--	--	424
1967	100	203	3	1	--	--	--	--	--	--	--	--	1	--	--	307
1968	--	201	7	7	10	39	--	--	--	--	--	--	--	1	--	265
1969	--	95	16	6	--	6	--	10	--	--	--	--	--	--	--	134
1970	--	233	--	5	212	3	--	3	--	--	--	--	--	--	--	456
1971	--	390	19	--	--	--	--	1	--	--	--	--	--	--	--	410
1972	--	172	500	13	--	3	--	--	--	--	--	2	--	--	--	690
1973	--	61	543	--	--	125	--	--	--	--	--	3	--	--	--	732
1974	425	90	470	--	--	77	--	--	--	--	--	15	--	--	--	1,077
	26,138	2,338	1,563	380	222	253	16	14	9	7	7	23	2	1	1	30,974

[a] Compiled by Charles Sartwell, USFS, Corvallis, Oregon, and David Alligood, USFS, Washington, D.C.

(b) Forest Acres Sprayed by Insecticide

Figure C3: Forest Acres Sprayed 1945-1974

Notes: The number of forest acres sprayed for gypsy moth (GM) and western budworm (WB), as well as the acres sprayed by each insecticide.

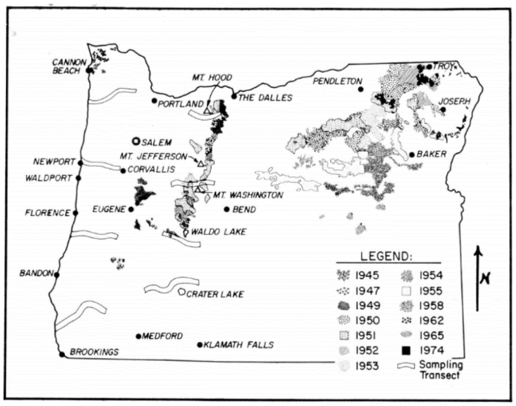
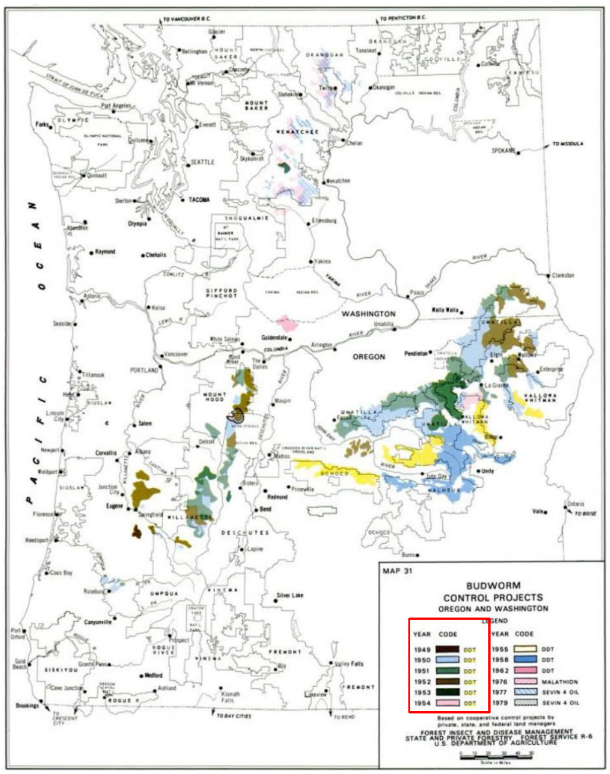


TABLE 1. *Application of DDT to forests in Oregon, 1945–74*

Year	Hectares	DDT Applied, kg: By Year	DDT Applied, kg: Cumulative
1945	931	1,043	1,043
1947	5,666	6,350	7,393
1948	1,700	1,905	9,298
1949	109,508	122,742	132,040
1950	367,213	411,590	543,630
1951	319,986	358,656	902,286
1952	211,206	236,730	1,139,016
1953	149,815	167,920	1,306,936
1954	27,397	30,708	1,337,644
1955	251,270	281,636	1,619,280
1958	331,034	371,038	1,990,318
1962	13,152	7,371	1,997,689
1965	26,710	22,453	2,020,142
1974	64,822	54,492	2,074,634
TOTALS	1,880,410	2,074,634	

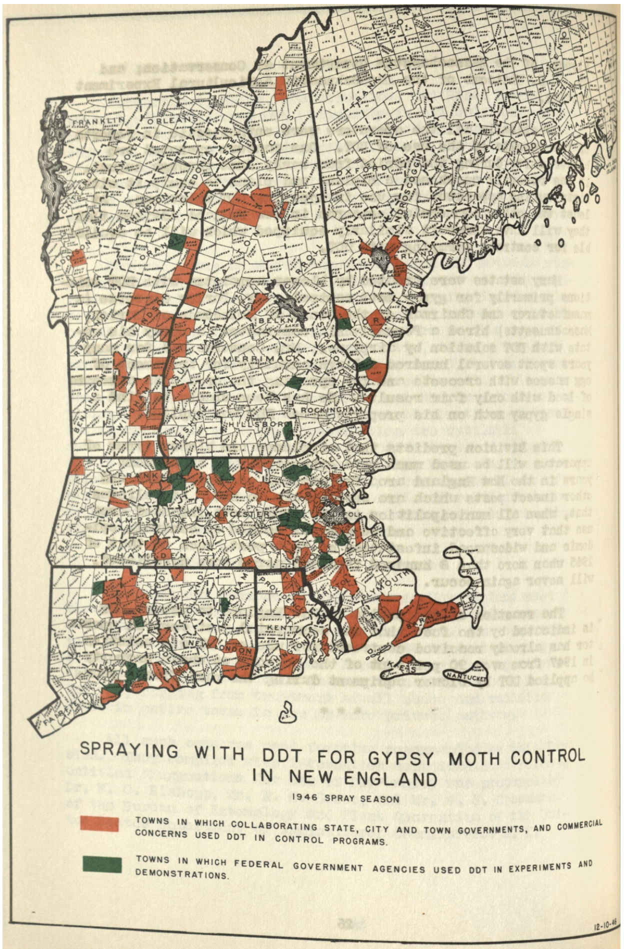
(a)



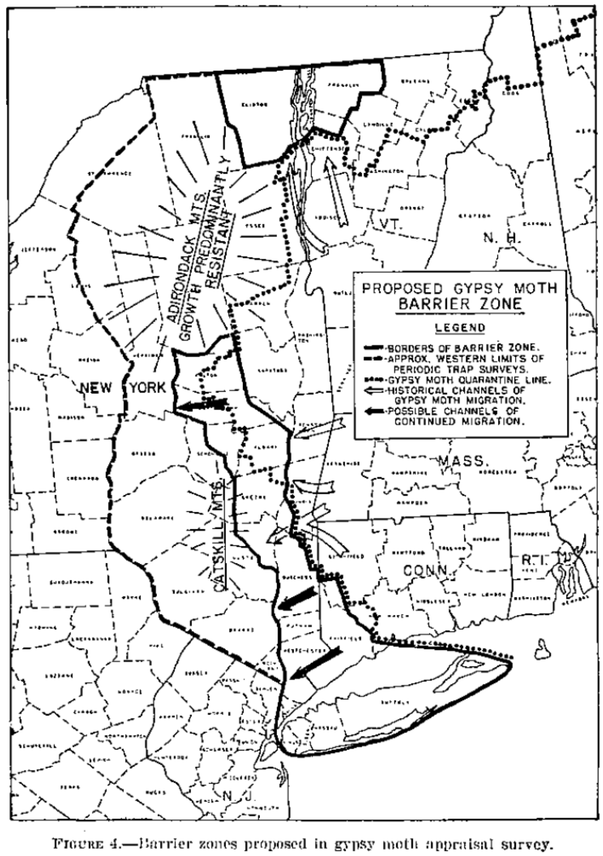
(b)

Figure C4: DDT Forest Applications in Oregon & Washington

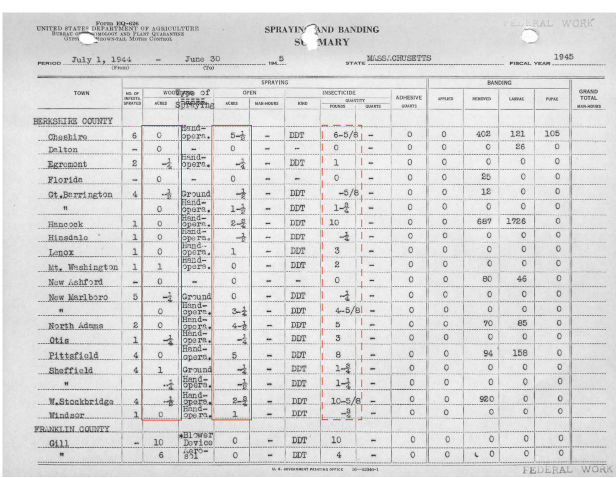
Notes: Maps of treated areas, as well as a summary of acres treated, and DDT amounts used.



(a) Gypsy Moth Sparying Map (1946)



(b) Gypsy Moth Barier Map



Form EQ-626
UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE
GYPSY AND BROWN-TAIL MOTHS CONTROL

SPRAYING AND BANDING SUMMARY

FEDERAL WORK

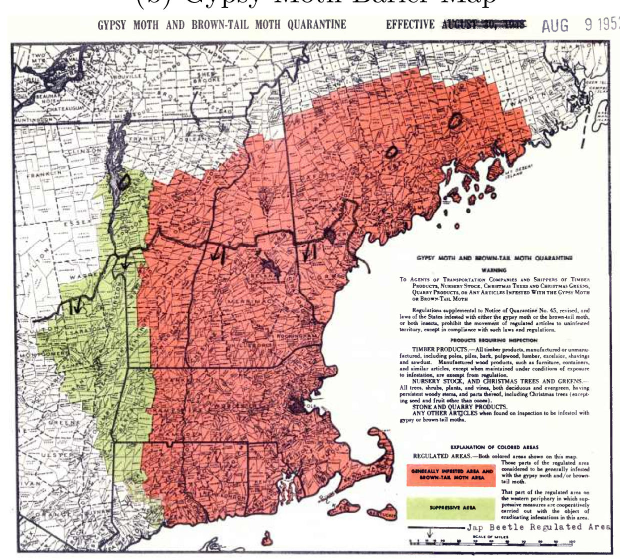
PERIOD July 1, 1944 (From) – June 30 (To) 1945 STATE MASSACHUSETTS FISCAL YEAR 1945

TOWN	SPRAYING: NO. OF INFESTS. SPRAYED	WOODS: ACRES	Type of Spraying	OPEN: ACRES	OPEN: MAN-HOURS	INSECTICIDE: KIND	QUANTITY: POUNDS	QUANTITY: QUARTS	ADHESIVE QUARTS	BANDING: APPLIED	REMOVED	LARVAE	PUPAE	GRAND TOTAL MAN-HOURS
BERKSHIRE COUNTY														
Cheshire	6	0	Hand-opera.	5-½	–	DDT	6-5/8	–	0	0	402	121	105	
Dalton	–	0	–	0	–	–	0	–	0	0	0	26	0	
Egremont	2	-¼	Hand-opera.	-¼	–	DDT	1	–	0	0	0	0	0	
Florida	–	0	–	0	–	–	0	–	0	0	25	0	0	
Gt.Barrington	4	-½	Ground	-½	–	DDT	-5/8	–	0	0	12	0	0	
"		0	Hand-opera.	1-½	–	DDT	1-¾	–	0	0	0	0	0	
Hancock	1	0	Hand-opera.	2-¾	–	DDT	10	–	0	0	687	1726	0	
Hinsdale	1	0	Hand-opera.	-½	–	DDT	-¼	–	0	0	0	0	0	
Lenox	1	0	Hand-opera.	1	–	DDT	3	–	0	0	0	0	0	
Mt. Washington	1	1	Hand-opera.	0	–	DDT	2	–	0	0	0	0	0	
New Ashford	–	0	–	0	–	–	0	–	0	0	80	46	0	
New Marlboro	5	-¼	Ground	0	–	DDT	-¼	–	0	0	0	0	0	
"		0	Hand-opera.	3-¼	–	DDT	4-5/8	–	0	0	0	0	0	
North Adams	2	0	Hand-opera.	4-½	–	DDT	5	–	0	0	70	85	0	
Otis	1	-¼	Hand-opera.	-¼	–	DDT	3	–	0	0	0	0	0	
Pittsfield	4	0	Hand-opera.	5	–	DDT	8	–	0	0	94	158	0	
Sheffield	4	1	Ground	-¼	–	DDT	1-¾	–	0	0	0	0	0	
"		-½	Hand-opera.	-½	–	DDT	1-¼	–	0	0	0	0	0	
W.Stockbridge	4	-½	Hand-opera.	2-¾	–	DDT	10-5/8	–	0	0	920	0	0	
Windsor	1	0	Hand-opera.	1	–	DDT	-¾	–	0	0	0	0	0	
FRANKLIN COUNTY														
Gill	–	10	*Blower Device	0	–	DDT	10	–	0	0	0	0	0	
"		6	Aero-sol	0	–	DDT	4	–	0	0	0	0	0	

U. S. GOVERNMENT PRINTING OFFICE 16—42046-1

FEDERAL WORK

(c) Gypsy Moth Spraying Worksheet (1945)



(d) Gypsy Moth Quarantine Map

Figure C5: Gypsy Moth DDT Control Operations

Notes: Maps of known gypsy moth infestation areas that received special attention and control efforts, as well as data on county-year level spraying information.