Swat That Mosquito: Estimating the Decline of Malaria in Georgia 1937-1947

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July 10, 2012

Abstract

Between 1930 and 1950, malaria rates in the southeast United States went from infecting over thirty percent of the population to nearly zero. Several factors have been put forward as causes for the decline in malaria mortality and morbidity rates: increased public works targeting malaria, newly developed insecticides, and out migration of the rural poor to non endemic areas. This paper focuses on two of the primary explanations: (i) public works constructed by the Works Progress Administration throughout the 1930's and (ii) the introduction of DDT following the conclusion of World War II. To estimate the effect of both the WPA programs and DDT spraying, I construct a panel of county specific malaria rates from Georgia between 1932 and 1947. I find that the WPA malaria campaigns are responsible for two thirds of the decline in malaria during the 1930'ss and that the introduction of DDT after 1945 completely eliminated malaria in Georgia by the 1950.

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1 Introduction

By the mid 20th century, the southeastern United States witnessed a marked decline in malaria mortality and morbidity rates. Figure 1 shows this decline in both malaria mortality (denoted on the left axis) and malaria morbidity (denoted on the right axis) in Georgia between 1932 and 1945. Rates peaked in 1936 during a particularly wet year and steadily declined to zero following the introduction of DDT in 1945. By 1950, malaria was no longer a serious problem in the United States. Historically a variety of reasons have been put forth to explain the decline: changes in migration patterns to healthier geographic locations, the arrival of effective insecticides such as DDT, large scale public works such as the Tennessee Valley Authority (TVA), and more targeted local health measures, such as ditching and swamping performed by the various New Deal agencies. This paper attempts to quantify the control efforts by the Works Progress Administration (WPA) during the 1930's and the introduction of DDT in the mid 1940's.

The role of migration on malaria rates has been examined by Barreca, Fishback, and Kantor (2011) who find that out migration during the Great Depression from highly malarious regions led to a very slight reduction in malaria mortality rates. Kitchens (2011) examines the effect of TVA reservoirs on malaria rates and finds that having a TVA reservoir located in a county increases malaria rates, although only in a relatively small geographic area. These studies combined suggest that other factors played a key role in the elimination of malaria throughout the 1st half of the 20th century.

While public works constructed by the TVA did not lead to declines, there were several other New Deal agencies providing labor and materials to help control the malaria problem. In Georgia, it was reported that as soon as Franklin Roosevelt came into office in 1933, malaria project labor was provided by the Federal Emergency Relief Administration (FERA) which was eventually transitioned in the the Works

Project Administration (WPA) during the second wave of New Deal programs in 1936. These projects were carried out until 1940, when the military formed the Malaria Control in War Areas (MCWA) division to protect military establishments from malaria during World War II. The MCWA, in conjunction with the United States Public Health Service (USPHS), eventually became the arm of the government responsible for dispersing DDT following its release to the states in 1945.

While initially limited in its availability, DDT production increased and was made available to state health agencies in order to control the malaria problem. It was quickly adopted and by 1950, its heavy use appears to have eliminated the malaria problem. Successful eradication campaigns occurred in the United States, Puerto Rico, Italy, Israel, India, among many others. Even though it had been widely used in eradication efforts, it was banned in the 1970's following public outcry in response to the book Silent Spring, which emphasized the negative environmental impacts of DDT. As the prevalence of malaria has increased in tropical regions over the last two decades, prevention experts have looked for new methods and technologies to combat malaria, however, DDT still seems to be at the top of several lobbying groups lists for use in these regions. While DDT has begun to be used in some of these areas, it may be several years before the total impact of DDT residual spray is known.

Even though malaria is no longer prevalent in the United States, it is instructive to examine its eradication experience to better understand how to combat a growing threat in the developing world. In tropical and subtropical regions between 100 and 300 million people are infected annually, leading to approximately one to three million deaths (Sachs 2003). Children under five bear the brunt of exposure, contracting malaria at such a young age can have long term life cycle affects, such as lower human capital accumulation, decreased physical stature and health, as well as reduced income and reduced physical wealth (Bleakley 2007, Cutler et al 2010, Hong 2007, Hong 2010).

In order to identify which factors led to the decline in malaria rates in the United States, I have constructed a panel of annual county level malaria morbidity and mortality rates in Georgia as well as data pertaining to when, where, and the scope of WPA projects, and DDT spraying from 1936-1947. I estimate the effect that WPA malaria-specific spending has on malaria rates. I find that the WPA was able to reduce the malaria rate in some instances, however these declines came at high cost. I then estimate the decline in malaria rates associated with the introduction of DDT following World War II. The results show that DDT was responsible for overcoming the remaining pockets of malaria that existed in rural areas of the Southeast, and that this was done at a very low cost.

2 A Simple Model of Malaria Transmission

Because malaria requires both the human host and the mosquito to propagate, it is important to consider both the human population currently carrying the parasite and the mosquito population and proportion of that population that is carrying. Suppose that there is an exogenous distribution of malaria in the human population, α proportion of the population is infected and $(1-\alpha)$ is uninfected. At the same time, there is an independent probability that a mosquito has malaria, β and $(1-\beta)$ probability that the mosquito is uninfected. This probability is a function of the number of mosquitoes, M in the system, where M is a function of the control efforts taken by local officials. As vector control efforts increase, the number of mosquitoes in the population is reduced. If an uninfected mosquito comes in contact with an infected human host, the disease is transmitted, similarly, if an infected mosquito comes into contact with an uninfected human, the disease propagates. Note however, that if an uninfected human and uninfected mosquito come into contact, there is no transmission, and if an infected human and infected mosquito come into contact, there is no increase in the malaria rate. Formally, the probability of any new individual contracting malaria becomes $Pr(Malaria) = (\alpha(1-\beta(M(c))) + \beta(M(c))(1-\alpha)$. As control efforts, such as ditching and spraying occur, the expected change in the malaria rate is negative as long as $\alpha < .5$.

$$\frac{\partial Pr(Malaria)}{\partial c} = (1-2\alpha)\frac{\partial \beta}{\partial M} \cdot \frac{\partial M}{\partial c} < 0$$

Mosquito vector control efforts reduce the number of mosquitoes, the probability of a human coming into contact with a mosquito falls, reducing the probability of contracting malaria. Since all of the activities carried out by the WPA or the state health agencies are considered to be mosquito reducing, it should be expected that draining ponds and swamps, constructing ditches, and spraying DDT should lead to reductions in malaria morbidity and mortality.

3 The WPA

This section focuses on the efforts performed by the WPA in Georgia and the Southeastern states more generally throughout the 1930's. The first subsection will discuss the history of the WPA, and prior malaria control efforts occurring in the South prior to the WPA efforts. I then outline an empirical strategy to identify the effect of WPA malaria spending on malaria rates.

3.1 WPA Background

Starting in the mid teens of the 1900s, several states began addressing their public health needs. The first efforts undertaken in the South primarily focused on the eradication of hookworm. These efforts were funded in part by the United States Public Health Service (USPHS), as well as the Rockefeller Foundation. Hookworm eradication programs sprung up in several counties, leading to the establishment of county and local health centers. Following the control of hookworm in the 1920s these agencies turned their attention to other public health needs. Due to the prevalence of malaria in the region, several of the state agencies turned their attention to fighting malaria. Morbidity rates were extremely high in parts of Georgia during the sample period. Morbidity rates ranged from 0 to 5402 cases per 100,000 people. However, this represents an extreme lower bound of true morbidity rates. During WWII, the Malaria Control in War Areas (MCWA) reported that true morbidity rates may be two to four times greater than reported. Georgia health officials went a step further during the 1930's, indicating that they believed that the reported rate represented only five percent of the true prevalence.[1]

Initial efforts to control mosquito populations occurred in cities, where there was the largest demand for control of insects. Coincidentally, the control efforts occurred in areas where malaria was least prevalent. Urban areas were less prone to malaria because there was little sitting water relative to rural areas that contained ponds and other unaltered geographic features. However, it was cost effective to implement control efforts in cities because a large population could be protected at a relatively low cost when compared to the countryside.

In the mid to late 1920s efforts began to turn towards rural areas. In 1922, the state of Georgia received aid from the USPHS to provide education on the transmission of malaria. It also began promoting quinine treatment offered through local drugstores and experimented with spraying Paris Green, an oil based insecticide. In 1925, the Georgia Department of Public Health (GDPH) began to target rural areas by implementing regulation regarding the impoundment of large bodies of sitting water created from the construction of hydro electric dams operated by the Georgia Power Company.[2] By 1931 and 1932, over twenty Georgia counties had a full time

[1] Georgia State Board of Health Biennial Report 1933 p41

[2] GDPH Biennial Report 1925 p20

engineer devoted to malaria management and the control of impoundments.

Despite the excellent work taking place during the 1920s, the health agencies were always faced with the problem of how to implement vector control in a cost effective way. The budgets of each agency were anemic and many of the activities, such as ditching and spraying were relatively expensive. Prior to the Great Depression, the GDPH called upon labor provided by local inmates on chain gangs to work on projects. However, in light of the depression, relief agencies made a push to employ workers on a part-time basis to work on the projects. In 1931, Georgia employed the equivalent of 1000 full-time positions to work on malaria projects through its own relief agencies.[3] In 1933, New Deal agencies, such as the Federal Emergency Relief Agency (FERA) provided labor to the state health agencies.[4] In 1936, relief workers were provided by the WPA. The WPA relief workers were then assigned to local health agencies who put them to work. In Georgia during 1936 over three million man hours were spent on malaria projects, in 1937, over two million man hours used on various projects.[5] This labor was used to drain ponds and swamps, and to construct drainage ditches to eliminate sitting water. Between 1937 and 1940 when detailed county level data is available, the average county had 11 miles of drainage ditch constructed and over 100 acres of sitting pond water drained.[6] These reductions in sitting water should contribute to a reduction in malaria.

3.2 Identifying the WPA's Effect on Malaria 1937-1940

The WPA used a variety of techniques to reduce the burden of malaria: they dug drainage ditches, drained ponds, and either drained or filled swampy areas to reduce the amount of sitting water in the county. Rather than determine the effectiveness of each individual component, I estimate the overall effect of the WPA by using

[3] GDPH Biennial Report 1931-32 p29-30
[4] GDPH Biennial Report 1933 p36
[5] GDPH Annual Report 1937 p74-75
[6] GDPH Annual Report 1937-1940.

data before and after all of the WPA activities were completed. In the most basic specification, I estimate the average treatment effect of WPA activities on the malaria mortality and morbidity rate. I estimate the following reduced from model.

$$R_{it} = C_i + \alpha WPA_{i,t} + \beta_1 R_{i,t-1} + \beta_2 MalariaRank_{i,t-1} + \delta X_{it} + \eta_{it}$$

Where R_{it} is the mortality or morbidity rate in county i in year t. C_i is a vector of county fixed effects, to control for time invariant features such as topography which would lead to differential malaria rates. $WPA_{i,t}$ is an indicator equal to one if the county obtained WPA malaria projects between 1936 and 1940 and is zero otherwise. $R_{i,t-1}$is the malaria rate from the previous period in county i, and controls for the natural transmission of malaria, which depends on the prior levels of malaria and the interactions between humans and mosquitoes. $MalariaRank_{i,t-1}$ is the relative ranking of the malaria mortality rate within the state from the prior period, and controls for how funds are allocated within the state between counties. This is important to control for because the GDPH typically provided funding to areas which had the most severe malaria problem in the state. To the extent which this changes over time, it may explain why funds were allocated to various counties. X_{it} is a vector of time varying county level co-variates capturing shocks to the environment consisting of annual precipitation and average annual temperature, which contribute to the current period malaria rate.

The identifying assumption is that conditional on the prior malaria rate, the relative ranking in the state, current period shocks, and time invariant features, the allocation of WPA malaria funds are exogenous to the malaria rate in county i in year t. This assumption may be problematic if there are unobserved characteristics that affect the malaria rate both in the past and in the current period, or if unobservables dictate where WPA funds were allocated. The use of county fixed effects should eliminate time invariant unobservable features that are correlated with malaria.

An additional threat to the identification of α is that the allocation of WPA malaria control programs may be non random. The GDPH noted in their 1933-34 biennial report that there were some projects they would like to undertake in areas where malaria was most severe, but the local manpower was not available, and thus, projects were often directed to areas with large enough urban populations to provide manpower where malaria was problematic. This would suggest that if selection is not controlled for, the estimates of the effectiveness of the WPA would be underestimated.

To control for the relative severity of malaria within the state, I include the Malaria Mortality Rank variable. The county with the lowest malaria rate is assigned a 1, and the county with the highest rank is assigned 159 (the number of counties in Georgia). While the GDPH made this statement, the empirical evidence shows that counties with the most severe malaria problems were the most likely to receive WPA malaria projects. Predictions from a fixed effect logit regression show that the probability of receiving WPA malaria funding is increasing in the within state malaria rank index as seen in Figure 2.

In addition to estimating the average treatment effect of the WPA malaria programs, I also estimate the impact of spending by the WPA on malaria mortality and morbidity. In these specifications I include spending linearly and also include higher order polynomials of WPA spending to capture non linear effects of WPA malaria spending on malaria. As a further robustness check I also explore an instrumental variables strategy using variation in total WPA funds net of malaria specific funds. In that setting counties that received more WPA funding were also more likely to receive funding for WPA malaria projects.

3.3 WPA Malaria Data

The sample used to estimate the total effect of WPA programs is comprised of malaria mortality and morbidity data comes from the GDPH between for the years 1932, 1935, and 1940. Additional years of the GDPH annual report are used to determine where WPA spending occurs and how much spending there was during the years in which the WPA was active. Between 1937 and 1940, when the WPA spending data are reported, the average county received over $18,000, with over $1,000,00 being spent in one county. Maps show that there is a strong correlation between the allocation of funds and the malaria rate. Figure 3(a) shows the malaria mortality rate in 1932, Figure 3(b) shows the malaria mortality rate in 1935, both years were prior to the allocation of WPA funds, which is shown in Figure 3(c). There is a strong correlation between pre existing malaria and the allocation of WPA funds.

Weather data is derived from the U.S. Historic Climatology Network data. This data provides annual and monthly average, minimum, and maximum temperatures as well as precipitation measures for each existing weather station in the United States. To obtain annual county-level observations, a triangular interpolation method was implemented as described in Kitchens (2011WP) which weights weather station observations by the inverse of their distance. In 1937, a particularly wet year rainfall totaled up to 72 inches for the year in some counties, with an average of 54 inches. The average rainfall in other years was only 47 inches. The increase in precipitation would directly lead to increases in sitting water, leading to increases in the malaria rate.

Temperature also plays a critical role in the incidence of malaria. In order for mosquitoes to breed, the temperature must remain a specific threshold, approximately seventy degrees. If temperatures fall, mosquitoes are unable to breed, which would reduce the burden of malaria. Certain months may be particularly important. Experts at the TVA reported that the egg laying phase of the mosquito life cycle begins during the warmer days near the end of February and beginning of March.[7] If the weather remains cooler for an extended period of time during this part of the year, the stock of mosquitoes may be significantly reduced, leading to a lower probability of contracting the disease. Table 1 presents summary statistics for the annual malaria mortality and morbidity rates, as well as summary statistics for weather variables. The variation in weather conditions shown here will directly correlate with the observed malaria rate.

3.4 WPA Change in Malaria Rate Results

The estimation results are presented in Tables 2 and 3. Table 2 presents the results when treatment is considered binary. Columns 1 and 2 present the results for the effect of the WPA malaria programs on malaria mortality and Columns 3 and 4 present the results for malaria morbidity. Columns 1 and 3 present the results using the fixed effects regression specified above, while Columns 2 and 4 present the results from propensity score matching. The results suggest that the WPA malaria projects led to a large and significant reduction in malaria mortality and had no significant impact on malaria morbidity.

In counties that had WPA projects, the malaria rate was reduced by 8.9-10.1 deaths per 100,000 people. Prior to treatment, the average malaria mortality rate was 17.4 deaths per 100,000. Thus the WPA led to a 48.8 percent decrease in malaria mortality.[8] By 1940, the average malaria mortality rate in Georgia was 3.8 deaths per 100,000. This suggests that the efforts undertaken by the WPA were responsible for up to two thirds of the decline in malaria mortality in the second half of the 1930's.

While the WPA appears to be very successful in eliminating malaria mortality,

[7] Malaria and its Control in the Tennessee Valley 1942. p11

[8] These results are robust to the inclusion of a variety of control variables such as per capita retail sales and other New Deal program spending.

there is little evidence that the WPA was effective in reducing malaria morbidity. The estimated results show that the WPA did not lead to any significant reductions in malaria morbidity during the period in which they were active. Anecdotal evidence by Humphreys suggests that the drainage ditches constructed by the WPA were of poor quality and often became filled with debris, creating small pools of sitting water in which mosquitoes bred.

Table 3 presents the results when the total spending by the WPA between 1937 and 1940 is the variable of interest. Columns 1 and 3 present the results when WPA spending enters the regression linearly, and Columns 2 and 4 present the results when a 5th order polynomial in WPA spending is used. The results in Columns 1 and 3 are consistent with those presented above. The average county received $18,000 from the WPA, which suggest that in the linear specification, the WPA had a minimal effect. However, when WPA spending enters the model non linearly, the estimated effect of WPA spending is -0.499 per $1,000 in WPA spending. Therefore, the average county experienced a reduction in the malaria rate of 8.9 deaths per 100,000 people.

The primary results outlined in this section used a simple difference-in-differences specification. In order for these results to be meaningful, the counties that obtained WPA anti malaria projects must have been on similar trends prior to treatment. To examine this I look at the differences in malaria mortality rates year by year in the pre and post treatment periods. These results are summarized in Figure 4. The results show that with the exception 1936, a year of major malaria outbreak across the southeast, that conditional on county fixed effects and the other co-variates, that treated and non treated counties did not have any significant differences in malaria mortality prior to treatment.

3.5 Instrumental Variables Approach

While the selection of which counties has been addressed by the inclusion of the Mortality Rank variable, it is possible that there are still unobservables which are correlated with the WPA and malaria which are driving the large decline in malaria mortality. To address this issue, I adopt an instrumental variables strategy to identify the effect of WPA malaria programs on the malaria rate. To instrument for WPA malaria programs, I use the total WPA spending in a county between 1936 and 1940 net of the WPA malaria program spending. Counties that received a high level of WPA spending for all projects other than malaria would also be more likely to obtain at least some funding for their malaria projects.

The instrumental variables results are presented in Table 3. Column 1 reports the first stage result using the malaria mortality data. Column 2 reports the second stage results using the mortality data. Columns 3 and 4 present the corresponding results using the malaria morbidity data. In the mortality sample, the results from the first stage suggest that counties that received higher levels of WPA spending were more likely to have WPA malaria programs in their county. For counties that received some positive WPA spending, they were 1.8 percent more likely to obtain a WPA malaria project.

In the second stage, the results are similar to those find in the OLS regressions. While the point estimate is slightly smaller in absolute value, the OLS point estimate is within the confidence interval of the IV estimate. Thus, endogeneity arising from omitted variable bias does not appear to be a problem in the OLS regressions.

In Columns 3 and 4, the corresponding results are presented using the morbidity data. The first stage results show a strong correlation between areas receiving high levels of WPA funds and WPA malaria projects. In the second stage, the results suggest that the WPA malaria programs reduced the malaria morbidity rate by 66 cases per 100,000, which would be a 45 percent reduction in the malaria morbidity rate. However, this estimate is not statistically different than zero, which is consistent with the OLS results.

3.6 WPA Cost of Saving a Life

Given the estimates presented above, it is possible to determine how much money was spent to save a malaria life between 1937 and 1940. Given that every $1,000 dollars spent by the WPA led to a .499 point reduction in the malaria mortality rate, approximately $2,000 dollars would lead to a 1 point reduction in the malaria mortality rate. Given that the average population of a Georgia county was 18,000, it would take approximately $11,000 dollars to save a malaria life in 1935 dollars, worth approximately $150,000 in year 2010 dollars. This estimate is substantially lower than the spending required to save a life by other New Deal Projects as noted by Fishback, Haines, and Kantor, who report that to prevent a non-infant deaths, New Deal Agencies spent between $800,000 and $3 million. One main reason that the WPA projects were relatively good values, was that draining a pond or filling a swamp in one period could provide protection for several years to come.

4 Eradication in the 1940's

During the 1940's, there were two major shifts in Georgia regarding malaria control. The first shift is associated with a change from control efforts being financed by the WPA to the MCWA, which focused on protecting factories and army camps deemed crucial to the war effort. Unfortunately, neither the State of Georgia or the MCWA reports detail the activities in each county beyond an indication of the MCWA's presence. The second major shift in malaria control policy came at the end of World War II, when DDT was released from military control in 1945 and was provided on a limited basis to states through the USPHS.

4.1 DDT Residual Home Spraying

One major worry was that returning soldiers from war areas would pose a threat to the local malaria balance. Malaria rates had been on the decline since their peaks in 1936 and 1937. In urban areas, pre existing methods had been proven effective, such as draining, however these methods were never cost effective in rural areas. General residual spraying of DDT began in 1945 across the southeast. Residual spraying was believed to be one of the most effective ways to stop the spread of malaria by preventing the survival of mosquitoes that had just taken a blood meal. According to the 1944-45 MCWA Report

> ... for the first time, a method is available- the application of DDT residual spray to walls and ceilings of homes. DDT residual spray evaporates leaving a layer of crystals on the treated surface. For several months these crystals are toxic to mosquitoes upon contact. Anopheles quadrimaculatus commonly rests upon walls and ceilings after taking a blood meal. By killing these particular mosquitoes which have entered the houses and fed on human beings... the malaria chain is broken.[9]

The United States Public Health Service (USPHS) helped to implement and fund the DDT residual spraying. The USPHS created a variety of educational and training programs for the field officers and work crews that were responsible for the actual spraying. Standardized techniques were adopted by these work crews. A contact person would typically use prepared maps detailing the local malaria prevalence. Once the houses to receive spraying were determined, this point of contact would schedule the spraying with the household and provide instructions to make the spraying quicker. Once scheduled a spray crew would arrive at the home and spray the DDT emulsion on walls and ceilings. The average labor cost was just over one man hour

[9] Malaria Control in War Areas Report 1944-45 p15

for the typical five room home. In 1945, there were fourteen counties that received treatment with DDT, home spraying was carried out in 25,000 homes each receiving between one and three treatments.[10] In 1946, the Georgia DDT residual spray program sprayed almost 160,000 homes, one year later the number of homes being sprayed with DDT increased significantly to over 218,000 homes.[11] At its peak, spending on DDT residual spray programs totaled $171,000, or about 78 cents per home sprayed.

Initially, the USPHS dictated that DDT should be provided to the counties with the highest average mortality rates between 1938 and 1942. It declared that counties with an average death rate greater than 10 were of significant concern, creating a threshold where spraying should occur with certainty. Knowledge of a selection rule may be useful in estimating the causal effect of DDT residual spray, however, following 1945, states expanded their own spraying programs through special appropriations, which makes knowledge of a selection rule difficult to implement.

4.2 Identification of DDT's Causal Effect

To estimate the causal effect of DDT on malaria mortality and morbidity rates, I exploit the exogenous timing of DDT's release and variation in malaria rates within counties over time. DDT was discovered as a useful insecticide in 1939 and arrived in 1942 to the United States, however, due to the war effort, all of its production was diverted to the military until the end of WWII in 1945. In 1945, the USPHS released limited quantities of the insecticide to states for distribution, dictating that particular attention should be paid to counties experiencing average mortality rates above five deaths per 100,000 during the prewar period 1938-1942 inclusive. Without controlling for this type of selection effect, the estimated effect of DDT would likely be understated, capturing the correlation between high levels of malaria and treatment

[10] Georgia Department of Public Health Annual Report 1945 p81

[11] Georgia Department of Public Health Annual Report 1946 p83, 1947 p89

with DDT.

If counties with higher malaria rates have higher rates due to time invariant features in the county, such as geographic features: lakes, rivers, swamps, latitude, longitude, etc, the endogeneity bias will be removed with the inclusion of county fixed effects or by first differencing. Time varying shocks are captured by the inclusion of climate variables such as temperature and precipitation. I specify the following reduced form relationship:

$$R_{it} = \alpha_1 DDT_{it} + \beta Climate_{it} + \delta MCWA_{it} + \lambda TVA_{it} + C_i + \varepsilon_{it}$$

Where R_{it} is either the annual malaria morbidity rate or mortality rate in county i year t. DDT_{it} is an indicator variable that takes on the value 1 if a county received DDT residual spray during year t. $Climate_{it}$ is a vector of annual climate variables pertaining to the average temperature and precipitation. $TVA_{it}$is an indicator of whether or not the TVA constructed a new reservoir in county i in year t. Finally, C_i is a vector of unobserved county fixed effects.

The data used in the section are derived from the same state reports previously mentioned, but from the years 1941-1947. During this period, the Georgia Department of Public Health reported the presence of MCWA labor, newly constructed reservoirs,[12] and malaria morbidity and mortality rates.

4.3 DDT Results

The regression results presented in Tables 4 and 5 show that DDT had a large statistical and economic effect on malaria mortality and morbidity rates. In the baseline specification, DDT residual spray programs led to a 4.1 reduction in the malaria mortality rate. In the same specification, the morbidity rate fell by 18.4

[12]the TVA was the only agency to construct new dams during the sample period, the US Army Corps of Engineers did not complete and inundate their projects on the Altoona River until 1948

illnesses per 100,000 individuals. As expected, reductions in the mosquito population, caused by DDT residual home spraying led to a reduction in these rates.

The baseline specification with mortality as the dependent variable is presented in Column 3 of Table 4. These results show that mortality was reduced by 4.1 deaths per 100,000. This sizable effect was enough to offset the potential increases in malaria that would have resulted from high levels of rainfall in the late 1940's. In the absence on DDT, malaria rates would have likely been much higher; 1947 was a particularly wet year, the expected malaria rate for those years was approximately 4.2 deaths per 100,000. However, because DDT was being used, the expected increase in malaria prevalence did not occur.

The baseline result with morbidity as the dependent variable is shown in Column 3 of Table 5. The malaria morbidity rate declined sharply following the introduction of DDT. Counties that received DDT residual spray experienced a reduction in the malaria morbidity rate by 18 points. Between 1940 and 1945, the average morbidity rate for the state was 27 cases per 100,000.

In both sets of regressions, the MCWA vector control activities appear to have been ineffective at best. This may be due to the location of many of the military bases, which were not in areas typically impacted by malaria as well as its focus on constructing drainage ditches which are often though to be less effective that draining ponds and filling swamp land with dirt. This sort of activity has been shown to be ineffective, because it typically leads to more sitting water in ditches that were poorly constructed. This result has been shown anecdotally by Humphreys (2001). [13]

4.4 Assessing DDT

It has been shown that DDT had a large negative effect on both malaria mortality and morbidity rates following the end of WWII. While it led to large declines in the

[13] These results are robust to a variety of alternative specifications. Additional columns presented in Tables 4 and 5 control for correlation over time and space,these results are generally robust.

malaria rates, its cost effectiveness must also be explored. One way to do this is to examine the value of the lives saved and the illnesses prevented by spraying DDT. The estimates provided in Table 6 column 8 suggest that DDT led to a reduction of 4.1 deaths per 100,000 people, and the morbidity rate was reduced by 18 illnesses per 100,000. In the mid 1940's Georgia's population was approximately two million people. This would then imply that DDT residual spraying led to approximately 82 fewer deaths per year and 360 fewer illnesses a year.

To put a value on this life and illness savings external estimates provided by Costa and Kahn (2004) and Kitchens (2011 WP a) may be used. Costa and Kahn estimate that the value of a statistical life during the 1940's ranges in value from $1.1- $1.6 million dollars (Year 2009 Dollars) and Kitchens estimates the cost of malaria morbidity to range from $697-$1180 (year 2009 Dollars). Using the lower bounds of these estimates, the value of the saved lives is approximately $96 million dollars a year and the value of preventing illness is approximately $358,000 per year. During the peak of the spraying program in 1947, federal and state expenditures in Georgia were only $1.6 million dollars. Relative to other malaria fighting methods, DDT residual spraying was very successful. It is significantly lower cost than other methods of control introduced in the 1920's and carried out in the 1930's by the WPA.

5 Assessing Malaria Eradication

This paper examined two of the primary catalyst behind the eradication of malaria during the first half of the twentieth century in the United States, WPA drainage efforts and the introduction of DDT. To assess the impact of each vector control method, a panel of county level disease specific morbidity and mortality in Georgia 1932-1947 was compiled. Panel data methods were then used to determine the change in malaria rates resulting from WPA spending. The results showed that during the 1930's campaigns undertaken various New Deal agencies, such as FERA and the WPA led to significant declines in malaria morbidity rate, explaining between half and two thirds of the decline in malaria mortality during the 1930's.

While morbidity and mortality rates dropped sharply during the 1930's, the price paid for these efforts were large relative to the cost of DDT. When DDT was introduced following the conclusion of WWII malaria was eradicated at a very low cost. The DDT residual home spray program cost approximately $7.50 cents per home sprayed. At its peak the program cost less than the value of a single prevented death. In a given year, DDT prevented 82 deaths, making it a very profitable public health venture.

Given the relatively large declines in malaria rates and the cost effectiveness of both the WPA methods and DDT, the role of drainage and the application of insecticides should be considered in the effort to control malaria today. Malaria experts at the WHO have also come to this conclusion: in 2006, the WHO started to actively promote the use of DDT residual spray in the homes of those living in endemic areas. While the WHO is lending support to DDT residual spray, the legality of its use is subject to local laws in developing nations. If DDT residual spray recommendations fall on deaf ears, draining unnecessary water impoundments can also alleviate the malaria problem, albeit at a higher cost. Each of the methods outlined in this paper should be examined closely, as the burden of malaria is a growing problem in developing nations with potentially long lasting life cycle effects on human capital and wealth accumulation.

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Appendix A - Figures and Tables

Figure 1: Average Malaria Rate in Georgia 1932-1945

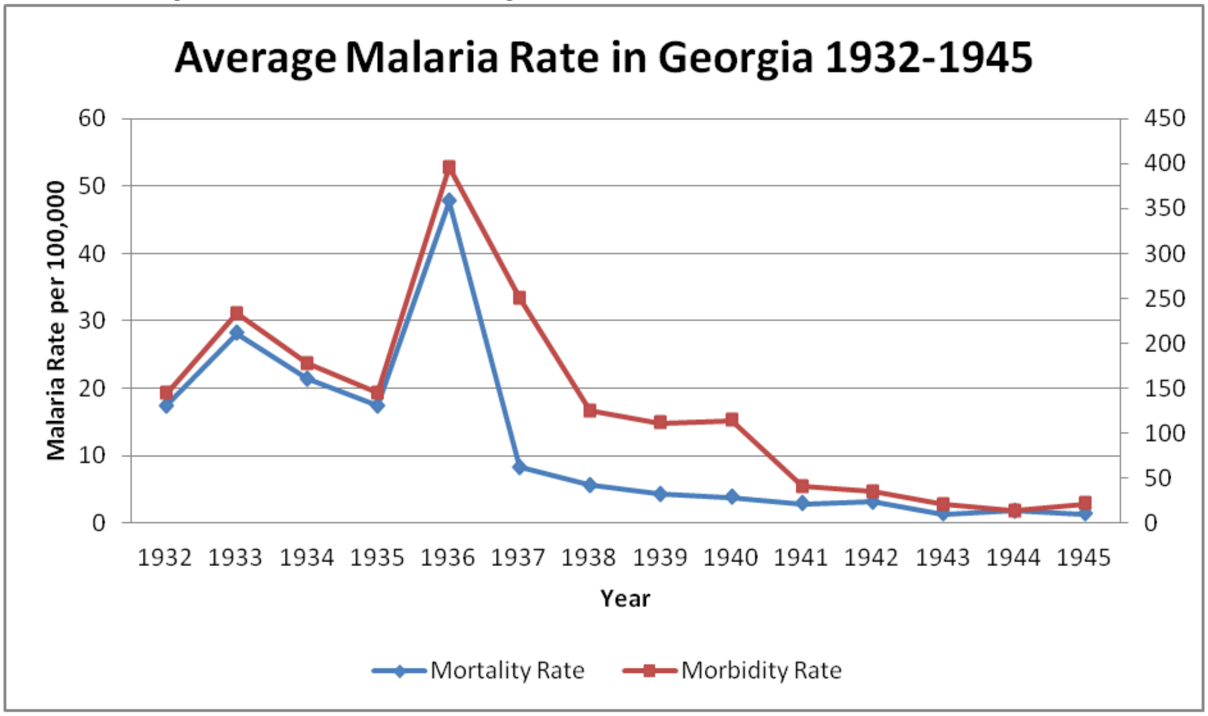


Figure 2: Probability of Receiving WPA Malaria Funds Based on Relative Ranking of Malaria Mortality Within Georgia

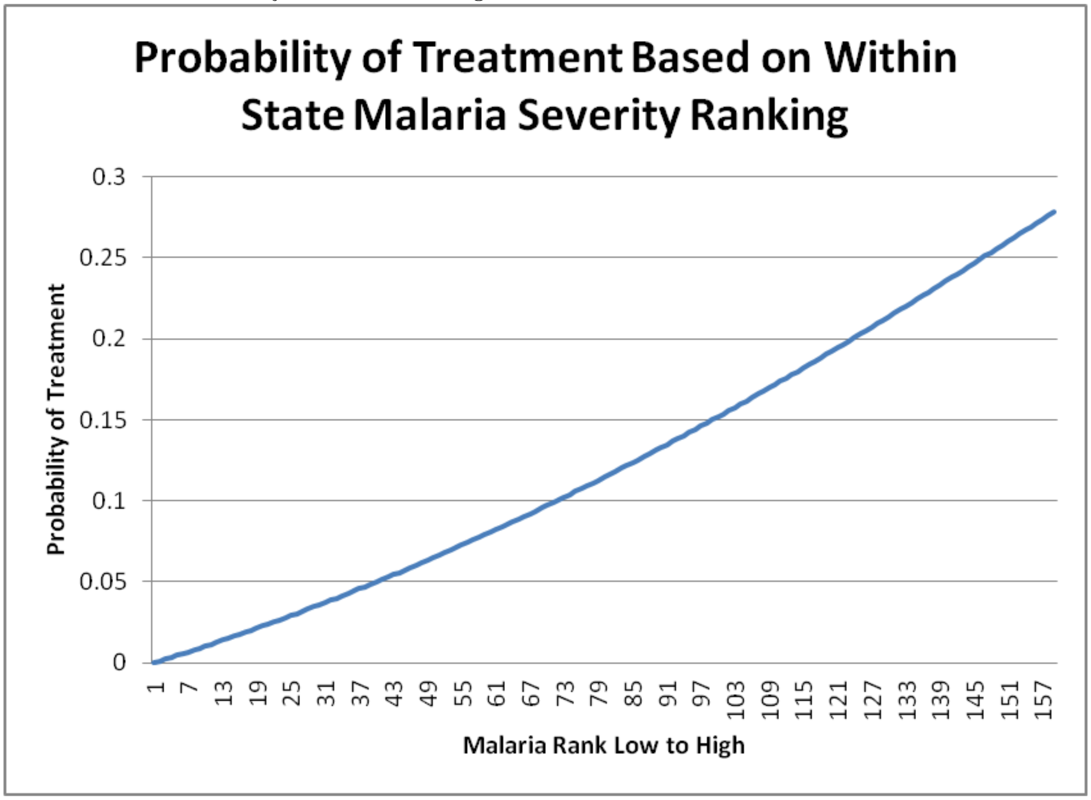
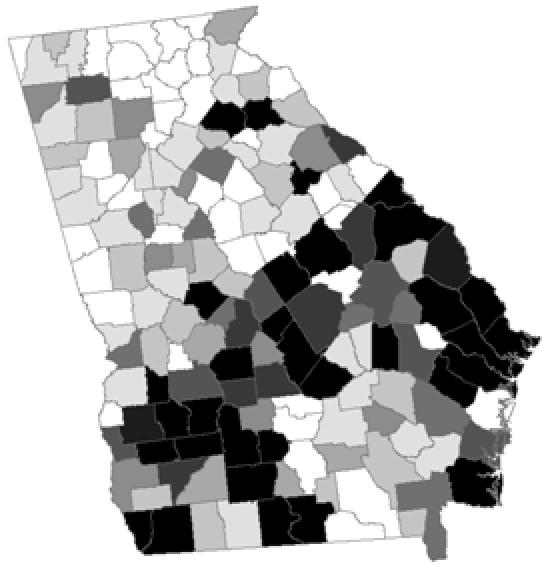
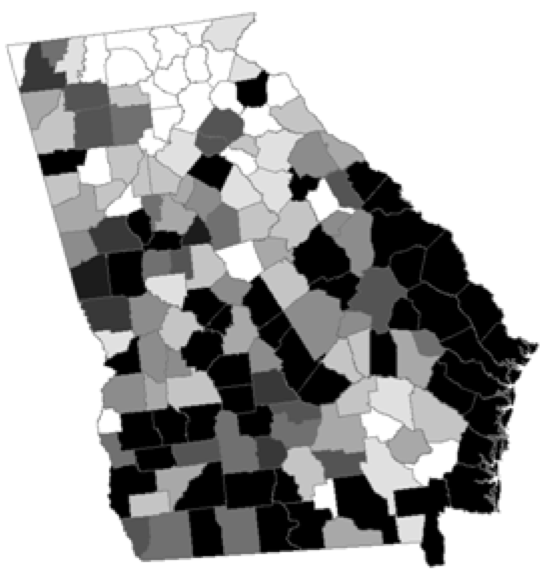


Figure 3(a): Georgia Malaria Mortality Rate 1932



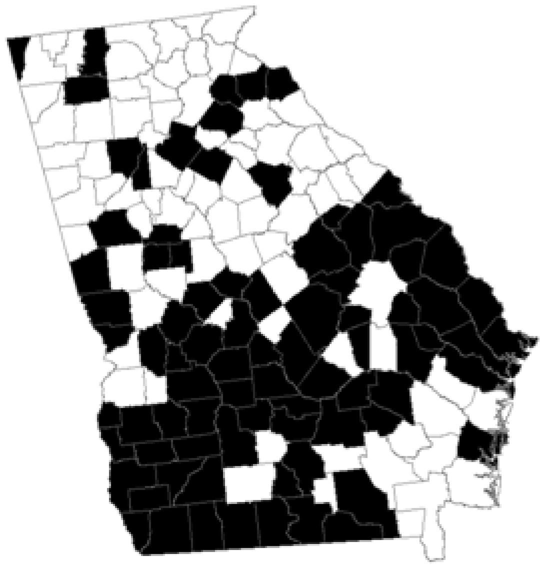
Note: Areas shaded in white had zero deaths per 100,000 while areas in black had over 16 deaths per 100,000

Figure 3(b): Georgia Malaria Mortality Rate 1935



Note: Areas shaded in white had zero deaths per 100,000 while areas in black had over 16 deaths per 100,000

Figure 3(c): Location of Georgia WPA Malaria Spending 1937-1940



Note: Areas shaded in white did not receive WPA funding, areas shaded in black received WPA malaria funds.

Figure 4: Pre and Post WPA Trends by Treated and Untreated Counties

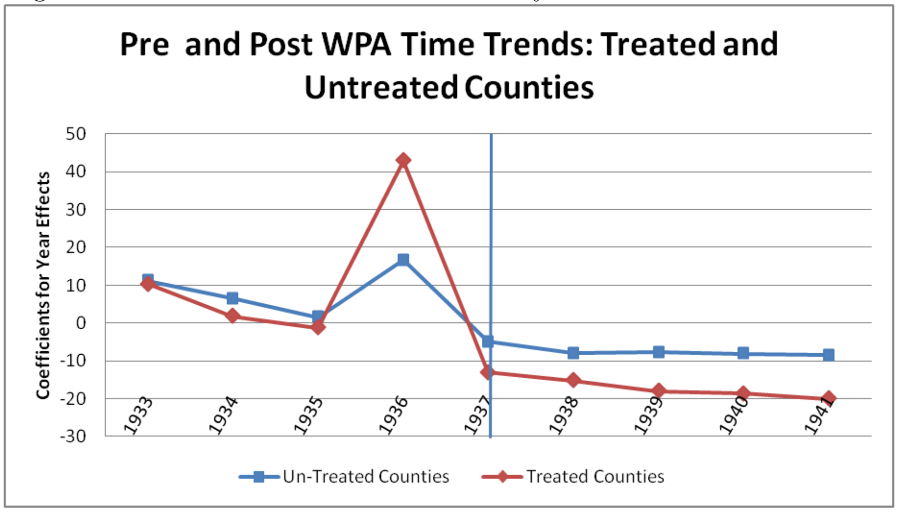


Table 1: WPA Malaria Program Average Treatment Effect Results

WPA = {0,1}	MORTALITY		MORBIDITY	
	1	2	3	4
WPA	-8.946 **	-10.100 ***	51.923	43.590
	(3.668)	(4.451)	(49.900)	(60.903)
Mortality Lagged	-0.094 ***		-	
	(0.034)		-	
Morbidity Lagged	-		-0.308 ***	
	-		(0.055)	
Within State Rank Lag	-0.185 ***		-1.663 ***	
	(0.047)		(0.643)	
Rain	0.390		-2.793	
	(0.274)		(3.728)	
Temp	3.933 ***		22.883	
	(1.226)		(16.680)	
N	318	318	318	318

* p<.1, ** p<.05, *** p<.01

Table 2: WPA Malaria Spending Results

	WPA = Spending in $1,000's							
	MORTALITY				MORBIDITY			
	1		2		3		4	
WPA	-0.021		-		-0.263		-	
	(0.020)		-		(0.269)		-	
WPA Total Effect	-		-0.499	*	-		1.912	
	-		(0.294)		-		(3.980)	
Mortality Lagged	-0.090	***	-0.090	***	-		-	
	(0.034)		(0.034)		-		-	
Morbidity Lagged	-				-0.313	***	-0.308	***
	-				(0.055)		(0.055)	
Within State Rank Lag	-0.197	***	-0.209	***	-1.694	***	-1.786	***
	(0.048)		(0.049)		(0.640)		(0.659)	
Rain	0.423		0.377		-2.791		-2.995	
	(0.277)		(0.282)		(3.724)		(3.820)	
Temp	5.866	***	5.083	***	8.812		13.187	
	(0.897)		(1.020)		(12.016)		(13.827)	
N	318		318		318		318	

* p<.1, ** p<.05, *** p<.01

Table 3: Instrumental Variables Results

	WPA = {0,1}			
	MORTALITY		MORBIDITY	
	1st Stage	2nd Stage	1st Stage	2nd Stage
WPA Spending Net Malaria	0.000046 ***		0.000046 ***	
	(0.000016)		(0.000016)	
WPA		-6.211		-66.800
		(5.145)		(48.664)
Mortality Lagged	-0.003	-0.018	0.000	
	(0.004)	(0.017)	(0.000)	
Morbidity Lagged				-0.027
				(0.026)
Within State Rank Lag	0.002	0.104 **	0.002 ***	1.347 ***
	(0.001)	(0.032)	(0.000)	(0.351)
Rain	0.006	-0.095	0.001	0.884
	(0.003)	(0.276)	(0.003)	(2.440)
Temp	-0.010	1.693	-0.010	19.140 ***
	(0.007)	(0.430)	(0.007)	(5.137)
F - Stat	8.300		8.390	
N	318	318	318	318

* p<.1, ** p<.05, *** p<.01

Table 4: MCWA and DDT Mortality Results

Table 6: MCWA and DDT Mortality Results

	1	2	3	4	5
MCWA	-0.60203 *	-0.37917	0.28859	0.05135	0.28859
	(0.33054)	(0.56015)	(0.69157)	(0.81410)	(0.92828)
DDT	-0.62779	-4.01134 ***	-4.09881 **	-4.08947 **	-4.09881 ***
	(0.64264)	(0.68057)	(0.79607)	(0.83281)	(0.94286)
Rainfall (Inches)	0.0718 **	0.07596 **	0.09141 **	0.09197 **	0.09141 ***
	(0.02949)	(0.03172)	(0.02947)	(0.03005)	(0.03355)
Temp (Degrees Farenheit)	0.52122 ***	0.02037	-0.44554	-0.62993	-0.44554
	(0.06696)	(0.32289)	(0.70739)	(0.84562)	(0.84106)
Linear Time Trend	-0.74167 ***	-0.48954 ***	-0.41652 **	0.07906	-0.41652 ***
	(0.09255)	(0.12264)	(0.12199)	(0.56893)	(0.13978)
County FE	N	Y	Y	Y	Y
Year FE	N	N	Y	Y	Y
AR(1) Error Structure	N	N	N	Y	N
Multi-Dimensional Clustering	N	N	N	N	Y
N	1099	1099	942	942	942

* p<.1, ** p<.05, *** p<.01

Table 5: MCWA and DDT Mortality Results

Table 7: MCWA and DDT Morbidity Results

	1	2	3	4	5
MCWA	-19.2063 ***	-17.57694	-7.29036	-8.22743	-7.29036
	(4.54115)	(13.92481)	(8.97876)	(10.46299)	(10.80872)
DDT	19.08452	-46.90408 ***	-18.43515	-20.96442 *	-18.43515 ***
	(15.10880)	(14.31755)	(11.77157)	(12.30669)	(6.78604)
Rainfall (Inches)	0.67082 *	-1.44808 **	-0.24103	-0.25559	-0.24103
	(0.38331)	(0.56432)	(0.23350)	(0.26553)	(0.27627)
Temp (Degrees Farenheit)	7.15457 ***	-23.27016 ***	-18.42206 *	-20.04437 *	-18.42206
	(1.12765)	(8.08347)	(9.51788)	(10.74056)	(12.29798)
Linear Time Trend	-14.9949 ***	-3.30258 ***	-7.84131 **	-31.42698 *	-7.84131 **
	(2.77149)	(1.06549)	(2.46457)	(18.77494)	(3.28071)
County FE	N	Y	Y	Y	Y
Year FE	N	N	Y	Y	Y
AR(1) Error Structure	N	N	N	Y	N
Multi-Dimensional Clustering	N	N	N	N	Y
N	1256	1256	1099	1099	1099

* p<.1, ** p<.05, *** p<.01

Appendix B - WPA Program Analysis Using Annual Data 1932-1940

In the main body of the paper, the total net effect of WPA anti malaria programs are examined by ignoring the timing variation of when WPA programs were initiated in each county. This is convenient because an instrument can easily be constructed to control for any potential endogeneity that is left unaccounted for by the inclusion of the fixed effects and the within state malaria rank variable in the OLS regressions. The results in the main body of the paper suggested that the panel regressions do a reasonable job of controlling for any endogeneity arising, as the OLS and IV estimates were statistically indistinguishable. Henceforth the analysis will focus on the results from additional OLS regression specifications.

In this appendix, I dig further into the data by using the timing of the introduction of WPA anti malaria projects. I respecify the panel used to estimate the regression equation outlined in Section 3.2 to include annual malaria mortality and morbidity data from 1932-1940. The coefficient of interest is still the one corresponding to the WPA variable, which is now defined as being equal to 1 when the county first receives WPA malaria funding and is zero otherwise.

The results from this regression are shown in Table B-1. Columns 1 and 2 show the results using mortality as the outcome of interest and Columns 3 and 4 show the results using morbidity as the outcome. As before, when the WPA initiates projects in a county, there is a sharp decrease in the malaria mortality rate. The estimated decrease in malaria mortality is 12 cases per 100,000, which explains approximately 68 percent of the decline in malaria mortality during the 1930's. As before, WPA projects have no statistically significant impact on malaria morbidity rates.

When using higher order polynomials of the total WPA spending rather than the binary treatment variable, the estimated coefficient is once again similar to the results presented in the main body of the paper. The estimated effect in this setting is -0.64 per $1,000 of WPA malaria spending. Given the $18,000 spent in the average county, the estimated reduction in malaria for the average county under this specification is 11.5 deaths per 100,000 or two thirds of the reduction in malaria during the 1930's. Regardless of how the panel is constructed, using either annual or lower frequency data, there is a sharp decline in the malaria mortality rate throughout the 1930's attributable to the WPA.

Table B-1

	MORTALITY		MORBIDITY	
	WPA = {0,1}	Spending 1,000's	WPA = {0,1}	Spending 1,000's
	1	2	3	4
WPA	-12.020 **	-0.641 *	52.154	-0.563
	(5.820)	(0.354)	(49.199)	(2.326)
Mortality Lagged	0.036	0.034	-	-
	(0.062)	(0.063)	-	-
Morbidity Lagged	-	-	0.066	0.068
	-	-	(0.059)	(0.061)
Within State Rank Lag	0.108 ***	0.104 ***	0.707	0.703 ***
	(0.027)	(0.026)	(0.252)	(0.247)
Rain	-1.028 ***	-1.040 ***	-6.243 **	-6.229 **
	(0.318)	(0.322)	(2.941)	(2.969)
Temp	-1.390	-0.034	46.695	41.490
	(8.709)	(8.377)	(73.648)	(71.206)
N	1272	1272	1272	1272

* p<.1, ** p<.05, *** p<.01