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

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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 annual county specific malaria rates from Georgia between 1937 and 1947. I find that spending by the WPA was effective in reducing malaria, yet at high cost relative to more modern control methods. The introduction of DDT led to further reductions in malaria, leading to its eradication at very low cost.

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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 using morbidity rates from counties in Georgia between 1932 and 1947. Rates peaked in 1936 during a particuarly 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.

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 sSouth 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 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 engineer devoted to malaria management and the control of impoundments.

Despite the excellent work taking place during the 1920s, the health agencies

[1]Georgia State Board of Health Biennial Report 1933 p41
[2]GDPH Biennial Report 1925 p20

were always faced with the problem of how to implement vector control in a cost effective way. The budgets of each agency were paltry and many of the activities, such as ditching and spraying were labor intensive. 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

While the WPA used a variety of techniques to reduce the burden of malaria in a county, such as draining ponds and constructing ditches, the choice of which control method to use is endogenous, making it difficult to estimate the impact of each control method. Rather than try to estimate the cost of each method separately, I assume that within each county, spending on each of the activities was chosen optimally given the conditions in the county. I then directly estimate the effect of

[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.

WPA spending and man hours on the malaria mortality and morbidity rates.

Spending and the use of labor are also both endogeneous decisions with respect to malaria, therefore, I estimate the following reduced from model with the inclusion of lagged levels of WPA spending.

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

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. Y_t is a vector of year fixed effects to control for shocks occurring in a given year that are common to all cross sectional units. $WPA_{i,t-1}$ is either the spending in county i in the previous period, or the man hours of labor used in the previous period fr the WPA malaria control projects. 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. The identifying assumption then is that the current period malaria rate can not effect the spending on malaria control in the past. This assumption may be problematic if there are unobserved characterisitcs that affect the malaria rate both in the past and in the current peiod, as prior spending may be correlated with prior period malaria rates. The use of county fixed effects should eliminate this persistent correlation between period by removing unobserved time invarient features of the county that will make it prone to higher rates of malaria, such as swamps, rivers, and flat topography.

The second source of endogeneity comes from omitted variables. Variables such as insecticide treatments or prior control efforts are not available at the county-level. If the spraying of insecticide is correlated with the vector control methods, the model will be incorrectly specified, biasing the coefficients. I argue that this type of endogeneity is unlikely. In 1936 in Georgia it was reported that only one county had

an operating mosquito larvacide unit, and additional spraying only occurred in two other urban areas.[7]

3.3 WPA Malaria Data

For the empirical analysis, malaria mortality and morbidity data comes from the GDPH between 1937 and 1940. In these years of the annual reports detailed county activities of the WPA projects were included for every county in Georgia. The data detail the number of ponds drained, as well as the acreage associated with the drained ponds, the data also details the length of ditches that were constructed in a county during the given year, more importantly, the data detail the county level spending on these projects and the number of man hours used to complete the work. In counties where the WPA operated, the spending averaged over $16,600, and was up to $281,000 and used an average of 37,600 man hours of labor to complete the work. These workers dug an average of just over two miles of drainage ditch in the county and drained just over 100 acres of sitting pond water.

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

[7] GDPH 1935-1936 p.98

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.[8] 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 2-5. Tables 2 and 3 present the results using WPA spending as the variable of interest for morbidity and mortality. Tables 4 and 5 present the results using WPA man hours as the variable of interest for mortality and morbidity. In each table, the results are reported for five separate regressions. Column 1 presents the results using the current period WPA efforts with the inclusion of county and year fixed effects. Column 2 reports the OLS results with the lagged WPA effort, Column 3 adds county fixed effects, Column 4 adds year effects, and Column 5 reestimates the model clustering the standard errors on the three dimensions of weather station used for the weather variable interpolation.

In Table 2, the baseline results in Column 1 suggests that increases in spending by the WPA would yield increases in the malaria rate. This result is consistent with a positive endogeneity bias, where spending by the WPA was directed to areas with more severe malaria problems. In Column 2, when lagged values of WPA

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

spending are used instead, the coefficient changes in sign. Increased expenditures in the previous period result in decreases in the current period malaria morbidity rate. These results hold with the inclusion of a variety of fixed effects. The preferred specification, reported in Column 4 include both county and year specific fixed effects. These results suggest that for every dollar spent by the WPA on its malaria control efforts led to a 0.0004 reduction in the malaria morbidity rate. Conditional on receiving funding, the average county had over $16,000 spent on WPA malaria control measures. In the average county, this led to a 4.4 percent reduction in the malaria morbidity rate.[9]

Table 3 presents the results using the WPA spending as the variable of interest, while using the malaria mortality rate as the outcome variable. The results presented here are quite similar to those reported for the malaria morbidity rate. In Column 1, when current period WPA expenditures are used, the coefficient on WPA expenditures is positive, suggesting a positive endogeneity bias. When lagged WPA spending is used, as in Columns 2-5, the coefficient is negative. In Column 4, the preferred specification, the results show that for each additional dollar spent by the WPA, the malaria mortality rate fell by 0.00001 cases per 100,000 people. In the average county that received WPA spending, this leads to a 0.16 reduction in the malaria mortality rate, or approximately a 3 percent decline in the malaria mortality rate for each year.

The results presented in Table 4 and 5 replicate the results using lagged WPA man hours as the variable of interest. These results also show that the efforts undertaken by the WPA lead to modest declines in the malaria morbidity and mortality rates between 1937 and 1940.[10]

[9]Note that the malaria rates in counties receiving funding was typically double the average, thus, relative to counties with high malaria rates the WPA expenditures represent a 2 percent decrease.

[10]In a seperate set of regressions, it is shown that of the methods adopted by the WPA, drainage ditches actually led to increases in malaria, while draining ponds and filling in swamp lands led to declines. The coroborates anecdotal evidence given by Humphreys (2001) that the poor mantainence of ditches led to increases in sitting water.

3.5 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, and determine the amount of money spent to prevent illness. Provided that one dollar of WPA malaria control effort led to a 0.00001 decline in the malaria mortality rate, a 1 point reduction in the malaria rate would cost $100,000, or approximately $1.5 million in year 2010 dollars. This estimate closely corresponds to previous estimates of expenditures by New Deal agencies to prevent death. Fishback, Haines, and Kantor (2007) report that to prevent a non-infant deaths, New Deal Agencies spent between $800,000 and $3 million, placing the WPA malaria control program well within this range.

These estimates also imply that the WPA spent approximately $2500 in 1937-1940 dollars for a 1 point reduction of the morbidity rate, in year 2010 dollars, this is approximately $38,000 dollars. This far exceeds the value placed on estimates from the time period with regards to the cost of malaria. Contemporary estimates of the cost of a case of malaria range from $45-$75, [11] which suggests that the WPA investments broke even in 10-20 years by just examining the change in morbidity. This suggests that the initial investment by the WPA in malaria reduction efforts would not yield a payback for about 50 years. These investments may have looked attractive at the time they were made, but breakthroughs in malaria technology during WWII would ultimately make these investment look relatively costly.

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

[11] Atlanta Journal Constitution, Kitchens (2011)

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.[12]

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

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

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 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.[13] 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.[14] 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

[13]Georgia Department of Public Health Annual Report 1945 p81
[14]Georgia Department of Public Health Annual Report 1946 p83, 1947 p89

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 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,[15] and malaria morbidity and mortality rates.

[15]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

4.3 DDT Results

The regression results presented in Tables 6 and 7 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 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 6. 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 7. 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 result is not a complete surprise, the MCWA primarily concerned itself with traditional control activities initiated by the WPA, such as ditching. 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) and there is a growing literature showing that ditching wass ineffective throughout the 1930's and 1940's by Kitchens

(2011WP). Newly constructed reservoirs by the TVA led to increases in the malaria morbidity and mortality rate, which further confirms the idea that even when precautions are taken, the large increase in water surface area more than offsets any control efforts prior to DDT.[16]

These results are robust to a variety of alternative specifications. Additional columns presented in Tables 6 and 7 control for correlation over time and space,these results are generally robust

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 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

[16]The TVA reservoirs in Georgia were not dusted with DDT following 1945

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, an annual panel of county level disease specific morbidity and mortality in Georgia 1937-1947 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 modest declines in malaria morbidity rate.

While morbidity and mortality rates dropped sharply during the 1930's, the price paid for these efforts were large, taking between 10 and 20 years to pay back the initial investment in malaria control activities. It was not until the end of WWII and the introduction of DDT that cost effective prevention efforts could be undertaken in rural areas. 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 DDT, its use in modern eradication should be reconsidered. 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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AppendixA - Figures and Tables

Figure 1

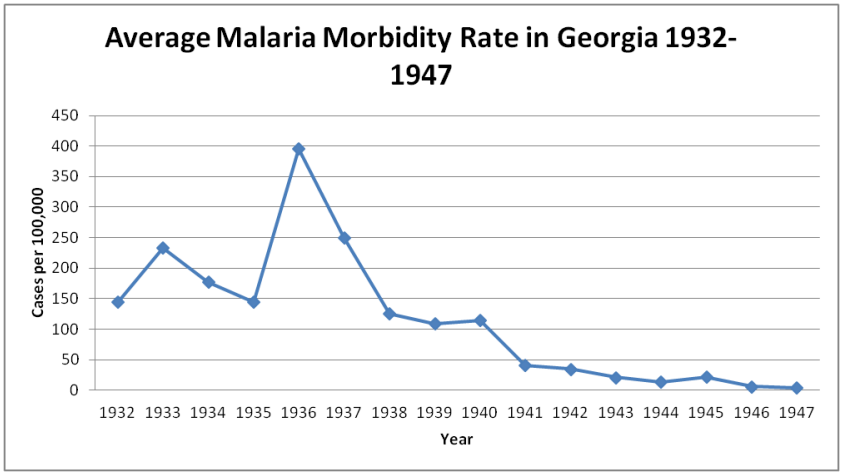


Table 1: Summary Stats of Malaria 1937-1940

Year	Mortality	Morbidity	Rain	Temp
1937	8.26	250.21	53.84	63.4
1938	5.6	124.8	40.93	64.47
1939	4.34	111.71	49.53	64.41
1940	3.85	114.09	46.91	61.68

Table 2: WPA Spending on Malaria Morbidity

	1	2	3	4	5
WPA Spending	0.00077				
	(0.00057)				
WPA Spending$_{t-1}$		-0.00026	-0.00099 ***	-0.0004 *	-0.0004 *
		(0.00018)	(0.00029)	(0.00021)	(0.00022)
Rainfall	7.28395 **	7.98965 **	8.28115 ***	7.33398 **	7.33398 *
	(2.84871)	(3.09802)	(2.17942)	(2.85177)	(3.76991)
Avg Temp.	86.95639	40.20435 ***	8.17373	85.53224	85.53224
	(56.68719)	(7.06848)	(7.18067)	(57.08097)	(79.40923)
County FE	Y	N	Y	Y	Y
Year FE	Y	N	N	Y	Y
CGM Cluster	N	N	N	N	Y
N	636	636	636	636	636

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

Table 3: WPA Spending on Malaria Mortality

	1	2	3	4	5
WPA Spending	0.00001				
	(0.00001)				
WPA Spending$_{t-1}$		-0.00002 ***	-0.00003 ***	-0.00001	-0.00001
		(0.00001)	(0.00001)	(0.00001)	(0.00001)
Rainfall	0.06107	0.09722	0.14656 **	0.06207	0.06207
	(0.10261)	(0.06604)	(0.07038)	(0.10255)	(0.11526)
Avg Temp.	0.46899	1.23225 ***	0.47122 **	0.44027	0.44027
	(1.55861)	(0.14278)	(0.19058)	(1.55797)	(1.85257)
County FE	Y	N	Y	Y	Y
Year FE	Y	N	N	Y	Y
CGM Cluster	N	N	N	N	Y
N	636	636	636	636	636

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

Table 4: WPA Man Hours on Malaria Morbidity

	1	2	3	4	5
WPA Man Hours	0.00028				
	(0.00034)				
WPA Man Hours$_{t-1}$		0.00011	-0.00021	-0.00022	-0.00022
		(0.00012)	(0.00014)	(0.00014)	(0.00018)
Rainfall	7.06761 **	8.16188 ***	8.18921 ***	7.29017 **	7.29017 *
	(2.80937)	(3.12100)	(2.19140)	(2.85744)	(3.82499)
Avg Temp.	87.26147	40.25513 ***	6.95642	87.0936	87.0936
	(56.76885)	(7.06770)	(7.26410)	(57.02026)	(80.13177)
County FE	Y	N	Y	Y	Y
Year FE	Y	N	N	Y	Y
CGM Cluster	N	N	N	N	Y
N	636	636	636	636	636

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

Table 5: WPA Man Hours on Malaria Morbidity

	1	2	3	4	5
WPA Man Hours	0				
	(0.00000)				
WPA Man Hours$_{t-1}$		0	-0.00001	0	0
		(0.000003)	(0.000004)	(0.000004)	(0.000005)
Rainfall	0.05772	0.09745	0.14446 **	0.0611	0.0611
	(0.10350)	(0.06662)	(0.07122)	(0.10269)	(0.11537)
Avg Temp.	0.47221	1.22734 ***	0.43875 **	0.47457	0.47457
	(1.55873)	(0.14286)	(0.19254)	(1.55904)	(1.85568)
County FE	Y	N	Y	Y	Y
Year FE	Y	N	N	Y	Y
CGM Cluster	N	N	N	N	Y
N	636	636	636	636	636

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

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 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