Pellagra and Southern Welfare: Evidence from the Arrival of the Boll Weevil, and State-Level Fortification Laws

Karen Clay
Ethan Schmick
Werner Troesken

Abstract

This paper examines the effects pellagra, a disease caused by insufficient niacin consumption, on a variety of health-related outcomes in the American South during the first half of the twentieth century. The analysis draws on detailed county level data spanning 1915-1950 and an intensity of treatment approach. We have three main findings. The first two findings build off an historical literature that says the arrival of the boll weevil improved Southern diets, particularly in high cotton producing. First, in North Carolina counties, the arrival of the boll weevil between 1919 and 1922 caused pellagra mortality, infant mortality and all age mortality to fall. The effects were larger for counties with higher pre-boll weevil pellagra mortality rates and higher pre-boll weevil shares of land in cotton production. Second, over the period 1915-1921, the heights of white, southern born men who were drafted into the Army during World War II, rose after the boll weevil arrived in counties and rose more in boll weevil counties with higher shares of land in cotton production. Third, in Southern states the passage of mandatory fortification laws during the 1940s caused pellagra mortality, infant mortality, and all age mortality to fall. Fortification saved 2,030 infants per year. These results suggest that nutritional interventions played an important role in short and longer run improvements in Southern health.

1 Contact: Karen Clay, Associate Professor of Economics and Public Policy, Carnegie Mellon University, Heinz College, 5000 Forbes Avenue, Pittsburgh, PA 15213. Email: kclay@andrew.cmu.edu
2 Contact: Ethan Schmick, University of Pittsburgh, Department of Economics, 4901 Wesley W. Posvar Hall, 230 South Bouquet, Pittsburgh, PA 15260. Email: ejs83@pitt.edu
3 Contact: Werner Troesken, Professor of Economics and History, University of Pittsburgh, Department of Economics, 4901 Wesley W. Posvar Hall, 230 South Bouquet, Pittsburgh, PA 15260. Email: troesken@pitt.edu
1. Introduction

Nutrition is important for individual and population health. In the first half of the twentieth century, the American South had significant nutrition-related issues. Infant mortality was high, life spans were short, and substantial numbers of individuals had nutrition related diseases including pellagra, beriberi, rickets, and scurvy. The experience of the American South during this period bears similarities to some developing countries today (Niemesh 2015). The World Health Organization continues to work to disseminate guidelines and strategies for improving micronutrient consumption in vulnerable populations (WHO 2015).

Nutrition related interventions rarely take the form of a natural experiment, which makes it difficult to evaluate their effects. If natural experiments do occur, they are often associated with wars. Wars pose a problem, because declines in nutrition are accompanied by many other significant changes in life circumstance. The American South experienced two non-war related natural experiments: one that spanned 1892-1922 and one in the 1940s. The first occurred because of the arrival and spread of the boll weevil, which impaired cotton production. The arrival of the boll weevil in a county led to the diversification of agriculture, which had implications for diet. The other

---

4 For discussion of nutrition and nutrition in the Postbellum South, see Fogel (1986), Fogel and Costa (1997), Ethridge (1972), and Coclanis and Komlos (1995).
occurred in the 1940s when a substantial number of states mandated fortification of wheat and corn products with B vitamins and iron.

This paper uses an intensity of treatment approach and detailed county level data spanning 1915-1950 to examine the effects of these natural experiments on mortality and selected other health-related outcomes. Historical evidence from the period suggests that the boll weevil changed diets by changing the availability of local corn, animal products, vegetables, and fruits. If nutritional status increased, we should observe declines in pellagra, in infant mortality, and possibly in all age mortality. Pellagra, which is caused by niacin deficiency, is a marker for broader nutritional deficiencies. The effects should be larger in counties that had higher pellagra rates or were more dependent on cotton, prior to the arrival of the weevil. Using height data from the World War II enlistment records, we examine the effect of the boll weevil on the height of white draftees. If the arrival of fortification in the 1940s increased nutritional status, we should observe declines in pellagra, in infant mortality, and possibly in all age mortality and larger declines in locations that had higher pellagra rates.

Nutritional deficiencies were not the only factors affecting southern health up to 1950. Southerners were subject to hookworm, the Spanish influenza pandemic, malaria, goiter, rickets, and beriberi, among other nutritional and environmental insults. The Rockefeller Sanitary Commission hookworm interventions ended in 1914 (Ettling 2000). Spanish influenza pandemic of 1918-1919 killed 675,00-850,000 people in the U.S. including many in the South (Crosby 1989). There is some evidence that the pandemic was more severe in places with worse baseline health. Malaria campaigns took place in
the first half of the 1920s, and malaria mortality fell during that period (Bleakley 2010). A goiter intervention occurred with the national iodization of salt in 1924 (Feyrer et al 2013). Some southern dairies began to add vitamin D to milk in the late 1930s and some grain fortification included vitamin D (Schwab 2010). Grain fortification included thiamin, probably reducing the incidence of beriberi, and iron, which reduced anemia (Niemesh 2015). We plan to explore the effects of these interventions in some specifications.

Our analysis suggests three main findings. First, in North Carolina counties, the arrival of the boll weevil in counties between 1919 and 1922 caused pellagra mortality, infant mortality and all age mortality to fall. The effects were larger for counties with higher pre-boll weevil pellagra mortality rates and higher pre-boll weevil shares of land in cotton production. Second, over the period 1915-1921, the heights of white, southern born men who were drafted into the Army during World War II, rose after the boll weevil arrived in counties and rose more in boll weevil counties with higher shares of land in cotton production. Consistent with changes in production in cotton and other crops, the positive effect on heights was increasing in the first four years after the boll weevil arrived. Third, in Southern states the passage of mandatory fortification laws caused pellagra mortality, infant mortality, and all age mortality to fall. Fortification saved 2,030 infants per year.

This paper contributes to the literature on the short and long run effects of in utero conditions by examining the causal effects of two nutritional shocks on infant and all age mortality and selected later life outcomes. This paper contributes to the literature
on exogenous nutritional shocks. In our context the shock associated with the boll weevil was positive and primarily affected those with poor diets, who usually also had low incomes. In contrast, much of the literature on nutritional shocks involves events with large negative effects that adversely affected large segments of the population. A recent review paper by Lumey et al. (2011) examined “nineteenth-century crop failures in Sweden and Finland, the Siege of Leningrad of 1941–1944, the Dutch Hunger Winter of 1944–1945, seasonal famines in the Gambia between 1949 and 1994, the Chinese Great Leap Forward famine of 1959–1961, and recent seasonal famines in Bangladesh.” This paper presents new evidence on the effect on infant and all age mortality and heights of a positive exogenous shock that disproportionately affected the poor.

This paper also contributes to the literature on fortification. A large medical and public health literature examines fortification and mortality in contemporary settings in developed and developing countries. Mortality, particularly infant mortality, is considered a good indicator of current environmental conditions. When countries begin to develop, mortality is often one of the first things to be systematically measured. Fortification in the United States in the first half of the twentieth century has received much less attention from any scholars and little attention from economists. To the extent that there has been research by economists, the focus has been on later life outcomes. For example, Feyrer et al. (2013), Adhvaryu et al. (2015), and Niemesh (2015) explore long run outcomes related to iodine and iron fortification including increases in

---

5 Park et al (2000, 2001) discuss the effects of fortification on pellagra mortality, but the analysis is largely descriptive. There is also a historical literature that describes Goldberger’s efforts to combat pellagra. See Marks (2003).
This paper presents new evidence on the effects of infant and all age mortality.

2. Background

This section begins by discussing nutrition and pellagra. It then describes the boll weevil and fortification. Finally, it discusses a variety of other factors that may have influenced Southern health during this period.

a. Nutrition and Pellagra

During the first half of the twentieth century, much of the Southern population was experiencing nutritional deficiencies (Youmans 1964). Pellagra, rickets, scurvy, and beriberi were caused by deficiencies in niacin, vitamin D, vitamin C, and thiamin. There may have been other diet related deficiencies including anemia and goiter, which were caused by deficiencies in iron and iodine.

Pellagra deaths may have been a marker for the broader set of nutrition related diseases (Bollet 1992, Etheridge 1973, Humphreys 2009). Pellagra’s symptoms were extremely distinctive. Public health officials monitored pellagra rates and studied causes and treatments. Bollet (1992) estimates that “the epidemic of pellagra, which lasted from about 1906 to 1940, resulted in roughly 3 million cases, with 100,000 deaths in the reporting states.” Because pellagra was a reportable disease, we have evidence on where deficiencies were severe. Figure 1 shows that there was considerable cross sectional variation in pellagra in the American South during the period 1939-1941. Later we show that there was substantial time series variation as well.
Pellagra emerged around 1906 because of changes in milling of Midwestern corn. Previous milling technology had removed less of the germ, retaining some niacin.

Newer technology removed the germ more completely, leading to a finer corn meal with a longer shelf life. Expansion of large-scale milling and movements of goods by railroad meant that this corn reached the South in increasing quantities. Bollet (1992, p. 219) notes that “in the textile mill towns, surrounded by cotton fields, food was shipped in by railroad, and the cornmeal that could be purchased in the company stores was processed in the Midwest, where it had been degerminated.” In the Midwest, corn consumption was relatively small, milk consumption was high, and diets were more varied, so pellagra was rare. In the South, however, much of the population was consuming nutritionally marginal diets. The change tipped the balance.

At the time, the cause of pellagra was unclear. Some researchers believed it was an infectious disease, caused by spoiled corn or flies. Others believed pellagra was related to diet. In 1914, the Public Health Service sent a physician, Joseph Goldberger, to investigate.

Goldberger quickly surmised that the issue was diet. “Struck by the limited, monotonous diet served at those institutions, Goldberger immediately focused on it as a likely cause of the disease. He had difficulty explaining the absence of the disease in staff members, since they usually ate the same meals in the same dining rooms. He noticed, however, that the staff ate first, taking the leanest portions of the meat and whatever variety was available, and, of course, they could also supplement their diet with food obtained outside the institution. At the Georgia State Sanitarium, milk was occasionally...
served to patients, but attendants, who never got pellagra, drank it twice a day. Inmates were left with cornmeal mush, cane syrup or molasses, gravy, and biscuits—the ubiquitous diet of the poor southerner. This diet was called the "Three M's," meaning meat, meal, and molasses; the meat was mostly very fatty pork, such as "fatback," and the meal was cornmeal." He did experiments in orphanages and prisons to confirm his hypothesis.

In a study in 1916 of seven cotton mill villages in South Carolina, Goldberger, Wheeler, and Sydenstricker (1920) collected detailed data on diet. Low income households ate less of a wide variety of foods including dairy, meat, fruits and vegetables than households with high incomes. Pellagrous households – households with at least two cases of pellagra – ate extremely limited amounts of meat, peas and beans, cheese, butter, and milk.

Unfortunately, Goldberger died in 1929 before discovering that it was specifically a niacin deficiency. The work continued and in 1937, Conrad Elvehjem of the University of Wisconsin discovered that niacin was the cause of pellagra.

b. The Boll Weevil

The Boll weevil appeared in Texas in 1892. Figure 2 shows its progression through the cotton belt. By 1922, the boll weevil had infected the entire cotton region. Lange et al. (2009) show that the arrival of the boll weevil dramatically reduced county cotton production and yields and reduced land values. Income from cotton fell less than

production, because of increases in cotton prices. Population fell in cotton intensive counties, as farm laborers and other marginal workers left.

The boll weevil caused a change in the crop mix. Farmers diversified, increasing production of corn, hay, Irish potatoes, peanuts, rice, and sweet potatoes. This arguably affected health through consumption of a more varied diet. With the arrival of the boll weevil, corn production increased, but corn may have been ground at home or milled locally. And even if corn remained extremely low in niacin, increases in consumption of other foods may have addressed niacin deficiency.

c. Fortification

After 1937, when niacin was identified as the cause of pellagra, voluntary and then mandatory fortification began (Park et al. 2000, 2001). In 1941 the FDA established standards for the fortification of flour. Table 1 shows the standards. Up to January 1943, fortification was increasingly common, but remained voluntary. Further, it was primarily restricted to bread and flour. Fortification was briefly required and then federal war powers ended and regulation devolved to the states. Corn products, a staple of southern diets, began to be fortified as well in the early 1940s. Figure 3 shows the states and years in which fortification became effective. As a result, major producers of corn meal and corn grits in the Midwest began fortifying their products. Local producers in states where fortification was not required, sometimes voluntarily fortified. A 1957 survey found that nearly all corn grits sold were enriched, and that cornmeal was
generally enriched, except in Florida and Virginia, where enrichment was less typical (Park 2001, NRC 1958).

Southern diets can help us understand the importance of fortification of different food items. The Study of Consumer Purchases in the United States, 1935-1936 collected data on food purchases from a large sample of households including Southern residents, Southern rural residents, and non-Southern residents. Table 2 shows that southern rural residents consumed far more corn meal and hominy grits than non-Southern residents. Moreover, they consumed far less white bread. For example, Southern rural residents consumed 4.25 pounds of corn meal and hominy and 1.13 pounds of white bread per week. Non-Southern residents consumed 0.09 pounds of corn meal and hominy and 4.33 pounds of white bread per week.

d. Hookworm, Spanish Influenza, Malaria, and Later Interventions

A number of other health related interventions potentially had effects on health outcomes. Spanish influenza, although it affected the entire United States, may also have affected health by selectively killing certain groups of individuals. Hookworm and pellagra may have interacted, if hookworm worsened the niacin deficiency or having pellagra increased the severity of the hookworm infection. There is some evidence that individuals with pellagra sometimes also had hookworm. Malaria and pellagra may also have interacted, pellagra made it more difficult for the body to fight malaria or malaria made pellagra more acute. Spanish influenza is relevant, because there is some evidence that it disproportionately killed individuals with certain diseases (Noymer 2010). One
question is whether it disproportionately killed off individuals with nutritional
deficiencies such as pellagra. Fortification of salt with iodine beginning in 1924 and of
flour and bread with six vitamins and minerals beginning in the early 1940s may have
affected Southern health as well. In the empirical section, we examine the interaction
effects. Here we provide some background on the interventions.

At the turn of the century, hookworm was widespread and often severe public
health issue in the South. The Rockefeller Sanitary Commission was established in 1909.
Its purpose was “… to bring about a co-operative movement of the medical profession,
public health officials, boards of trade, churches, schools, the press and other agencies
for the cure and prevention of hookworm disease.” Hookworm severity varied with
temperature, soil type, the number of infected individuals, and the prevailing sanitary
practices. The commission sought to identify and treat as many individuals as possible,
inform the public about ways to avoid reinfection, and improve sanitary practices by
improving privies. Although the commission ended at the end of 1914, the work of
hookworm eradication continued under newly formed state boards of health.
Hookworm continued to be a problem, but resurveys between 1920 and 1923 did find
that infection rates had fallen significantly (Jacocks 1924).

The influenza pandemic in 1918-1919 had large effects on infant and all age
that pollution, proximity to World War I bases, and baseline city health conditions can
account of 76 percent of cross-city variation in infant mortality and 46 percent of
variation in all age mortality. Almond (2006) finds that cohorts exposed to the pandemic in utero had lower income and higher disability rates than surrounding cohorts.

According to Bleakley (2010), “the federal government’s large-scale efforts against malaria in the South began with World War I (WWI). In previous wars, a significant portion of the troops were made unfit for service because of disease contracted on or around encampments. The PHS, working now with both a strong knowledge base on malaria control and greatly increased funding, undertook drainage and larviciding operations in Southern military camps as well as in surrounding areas. … By the mid-1920s, the boards of health of each state, following the IHB/PHS model, had taken up the mantle of malaria control in all but the most peripheral areas of the region.” (See also Stapleton 2004 and Bradley 1966.) Malaria mortality fell substantially over the first half of the 1920s.

Iodization of salt occurred between 1924 and 1927. Iodization began, when David Cowie at the University of Michigan convinced Michigan salt producers to begin iodizing salt to reduce goiter (Markel 1987). The salt went for sale in May of 1924 and by the fall, Morton’s salt was distributing iodized salt nationally. While iodization had significant effects on a variety of outcomes, the effects were generally larger in Michigan and selected western states (Adhvaryu et al. 2015, Feyrer et al. 2013). Southern states had some goiter, but the rates were generally low. For example, World War I draftees from the top six states had rates of simple goiter of 15 per 1,000 men. Virginia’s rate was 3.38 per 1,000. The remaining Southern states were below 2 per 1,000.
Fortification of bread, flour, cornmeal, corn grits, macaroni, farina, and related products involved addition of thiamin, riboflavin, niacin, iron, calcium, and vitamin D. While we focus on pellagra and its reduction, the nutritional benefits of fortification appear to have been broader. Niemesh (2015) finds that iron fortification had short term benefits as measured by changes in school attendance and income between 1940 and 1950 and long term benefits as measured by 1970 income. While there was some fortification of milk in the South in the late 1930s, fortification of cereal products beginning in 1943 may have increased vitamin D consumption. Schwab (2010) finds that fortification of milk increased school attendance of African American children.

3. Data

   a. Boll Weevil Data

   We begin our study of the effect of the boll weevil on Southern nutrition by studying mortality in the state of North Carolina. Data on the year the boll weevil first arrived in a county are taken from Lange et al. (2009), which originally came from USDA boll weevil maps. In North Carolina the boll weevil arrives between 1919 and 1922.

   Data on pellagra deaths, infant deaths, all-age deaths, and births per county were transcribed from the Annual Report of the Bureau of Vital Statistics of the North Carolina State Board of Health (1915-1924). Infant deaths per county are also taken from the Vital Statistics of the United States (1921-1924). The North Carolina State Board of Health did not issue a Vital Statistics report for the years 1918 and 1919. Accordingly, we

---

7 We would like to thank Price Fishback for providing this data
do not have measures of pellagra deaths at the county level for these years. However, we are able to obtain measures of the infant mortality rate and all-age mortality rate from the 1922 report, which reports these measures for the years 1918-1922. Only North Carolina is used to analyze the effect of the boll weevil on mortality since they are the only state, to our knowledge, that is consistently reporting deaths by cause at the county level during the boll weevil invasion of the South. Trends in pellagra, infant, and overall mortality for North Carolina over our sample time period (1915-1924) are displayed in Figure 4.

To further explore the effects of the boll weevil on nutrition we use World War II enlistment records, which allows us to expand our study beyond North Carolina. These micro-level data provide height and AGCT scores, which are highly correlated with IQ (see Ferrie et al. 2013 for evidence on this point), for approximately 9.2 million World War II soldiers. We make several sample restrictions to obtain a sample that is likely to be representative for each cohort. We restrict to white men who were drafted, born in the South, born between 1915 and 1924, report a valid height (between 5 feet and 6.5 feet), and report a valid weight (between 100 pounds and 400 pounds). Since we do not observe county of birth, we further restrict to soldiers that were living in the same state they were born in when they enlisted. This reduces the sample to 342,705 observations. After making these sample restrictions we assume that, at the time of enlistment, soldiers are living in the same county they were born in.

Finally, in both the mortality and the height analysis, we use data on the percent of a county’s farmland used in cotton production from the 1909 Census of Agriculture.
b. State Fortification Laws Data

In the second part of our analysis we turn to the effect of mandatory state fortification laws passed during the 1940s on Southern mortality. The year of fortification law passage as well as the types of cereal-grains the law pertained to (bread, flour, corn meal, or corn grits) were taken from Park et al. (2001). Southern infant mortality and all-age mortality at the county level are from the Vital Statistics of the United States (1935 – 1950). Finally, to study the effect of the fortification laws on pellagra mortality we transcribed pellagra deaths for all states in the United States from the Vital Statistics of the United States. We restrict to only Southern states in this analysis since these are the states that have the most to gain from mandatory fortification because they lagged behind the rest of the nation in the voluntary enrichment of bread and because they had highest pellagra rates. Figure 5 shows the trends in Southern pellagra, infant, and overall mortality from 1935 to 1950.

4. Estimation Strategy

We estimate the effect of the boll weevil and mandatory fortification laws on a variety of outcomes including: pellagra mortality rates, infant mortality rates, overall mortality rates, and height. We are interested in comparing these outcome variables after the treatment to the counterfactual scenario in which the same county did not

---

8 We define Southern states to be: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.
receive the treatment (either the boll weevil or the fortification law). Since, we never observe the true counterfactual, we estimate it using a difference-in-differences model. The difference-in-differences model also eliminates one of the primary concerns in our analysis: counties and states that received treatment are systematically different from counties and states that did not receive treatment. For example, perhaps states that pass fortification laws are low income, which is correlated with poor nutrition, pellagra and infant mortality. The difference-in-differences strategy allows us to control for unobserved, time-invariant characteristics of states that might be correlated with both the decision to pass a fortification law and the pellagra and infant mortality rates. Our baseline difference-in-differences model is given by:

\[
\text{outcome}_{ct} = \beta \text{treatment}_{ct} + \gamma_c + \delta_t + \epsilon_{ct}
\] (1)

In equation (1), \([outcome]_{ct}\) is the pellagra, infant, or overall mortality rate in county \(c\) for year \(t\). When using height as the outcome variable the variable is recorded at the individual level not at the county level. When analyzing the boll weevil nutritional shock, \([treatment]_{ct}\) is an indicator variable that takes a value of one after the boll weevil has arrived in a county. When analyzing the mandatory fortification laws, \([treatment]_{ct}\) takes a value of one after the state that contains county \(c\) passed a mandatory fortification law. Finally, we include county fixed effects to control for unobserved time invariant county characteristics and year fixed effects to control for any unobserved shocks in a particular year.
To further test our causal mechanism we introduce an intensity of treatment measure into our difference-in-differences framework. Our difference-in-differences intensity of treatment model is given by:

\[ \text{outcome}_{ct} = \beta \text{[treatment]}_{ct} \times \text{[intensity]}_{c} + \gamma_c + \delta_t + \epsilon_{ct} \]  

(2)

All variables in equation (2) are identical to equation (1), but now we interact \([treatment]_{ct}\) with a county level measure of the intensity of the treatment: \([intensity]_{c}\). During the boll weevil invasion we use two independent measures for \([intensity]_{c}\). The first measure is the percent of county farmland (in acres) that was used in cotton production in 1909, before our samples begin in 1915. Since the boll weevil feeds on cotton, we suspect that counties with a larger percent of farmland dedicated to the production of cotton should be more affected by the boll weevil. The second measure is the average pellagra death rate during the years 1916 and 1917, which is before the boll weevil arrives in North Carolina in 1919. Places with a higher pellagra death rate prior to the arrival of the boll weevil likely have worse nutrition and, therefore, might experience the largest nutritional gains after the boll weevil invades. These two measures are constructed independently of each other and have a low correlation of 0.12.

When analyzing the effect of mandatory fortification laws on mortality the intensity of treatment measure is the average state-level pellagra death rate for the five years prior to the passage of a fortification law. State-level pellagra death rates are used since county level pellagra death rates for the entire South are not available for this time period. Again, places with higher pellagra death rates prior to fortification likely have poor nutrition and, therefore, might experience the largest nutritional gains due to
fortification. All intensity of treatment variables have been standardized so they have a mean of zero and a standard deviation of one.

5. Results

a. Boll Weevil Analysis

Table 3 presents the results for the impact of the boll weevil on mortality in North Carolina. We first look at pellagra mortality, which is presented in columns (1)-(3). Column (1) indicates that the arrival of the boll weevil is associated with a significant decrease in the pellagra death rate of about one death per 10,000 people. Column (2) interacts the post boll weevil indicator with our first intensity of treatment measure: the average pellagra death rate in the county for the years 1916 and 1917. The coefficient on the post boll weevil indicator shows that counties with the average pellagra death rate prior to the boll weevil experience a decrease in the pellagra death rate of about half a death per 10,000 people. Every one standard deviation increase in the pellagra death rate prior to boll weevil arrival is associated with an additional decrease in the pellagra death rate of about 1.3 deaths per 10,000 people. Finally, column (3) interacts the post boll weevil indicator with our second intensity of treatment measure: the percent of a county’s farmland that was used for cotton production in 1909. The coefficient on the post boll weevil indicator, again, shows that counties with the average amount of farmland used for cotton production see a decrease in the pellagra death rate of about one death per 10,000 people. Every one standard deviation increase in the percent of farmland used in cotton production
reduced the pellagra death rate by an additional half a death per 10,000 people. The effect of the boll weevil on the pellagra death rate appears to be very strong. We interpret these results, especially the fact that the coefficients on both intensity of treatment interactions are negative, as affirmation that the boll weevil improved niacin intake after its arrival. The only way to reduce the pellagra death rate in a population is to have that population consume more niacin. As such, the arrival of the boll weevil appears to have led to a diet that is higher in niacin for the people of North Carolina.

We next turn to the effect of the boll weevil on infant mortality in North Carolina in columns (4)-(6) of table 3. In column (4) the arrival of the boll weevil is associated with a decrease in the infant mortality rate of approximately 3 infant deaths per 1,000 births. The interaction with the average pellagra death rate is not significant, but the interaction with our measure of cotton production is significant (column (5) and (6)). Every one standard deviation increase in the percent of farmland that used in cotton production decreases the infant mortality rate by an additional 3 infant deaths per 1,000 births. We use the coefficient in column (4) to provide a sense of the magnitude of these results. The average decrease in the infant mortality rate after the boll weevil invaded these counties was 2.839 deaths per 1,000 births. There were 77 counties in North Carolina that were invaded by the boll weevil. Finally, the average number of births in the counties invaded by the boll weevil in 1923, after the boll weevil had proliferated through North Carolina, was 906. Therefore, we estimate that approximately 198 infant lives per year were saved in the state of North Carolina as a result of the boll weevil. Of
course, this number would be much larger if the boll weevil affected the entire Southern United States in the same manner that it affected North Carolina.

In columns (7)-(9) of table 3 we turn to the effect of the boll weevil on overall mortality in North Carolina. Column (7) indicates that the arrival of the boll weevil is associated with a decrease in the all-age mortality rate of about 3 deaths per 10,000 people. A one standard deviation increase in the pellagra death rate prior to the boll weevil invasion reduced the overall mortality rate by an additional 3 deaths per 10,000 people and a one standard deviation increase in the percent of farmland used in cotton production decreased the overall mortality rate by an additional 5 deaths per 10,000 people (columns (8) and (9)). We can, again, provide some idea of the magnitude of these results. The average population in 1923 in the 77 North Carolina counties invaded by the boll weevil was 29,505. Using the coefficient estimate in column (7) of a decrease in the overall mortality rate of approximately 3.319 deaths per 10,000 people we estimate that approximately 753 all-age lives per year were saved in North Carolina as a result of the boll weevil invasion.

Finally, we turn to the effect of the boll weevil on height. If the arrival of the boll weevil is improving nutrition, as suggested in table 3, we might also expect that individuals should be taller after the arrival of the boll weevil. To study the effect of the boll weevil on height we turn to the individual level data contained in the World War II enlistment records. Since the World War II enlistment records are available for the entire Southern United States, we no longer restrict to just the state of North Carolina. However, by using the entire South we lose one of our two intensity of treatment
measures: we do not have county level pellagra mortality rates prior to the boll weevils’ arrival for the entire South. Table 4 displays the main height results. Column (1) shows that the arrival of the boll weevil is, on average, associated with an increase in height of 0.07 inches. In column (2), the arrival of the boll weevil is associated with about a 0.07 inch increase in height for counties with the average percent of farmland used in cotton production. However, every one standard deviation increase in the percent of farmland used in cotton production increases height by an additional 0.02 inches. Therefore, the boll weevil invasion is associated with about a tenth of an inch increase in height in counties that are one standard deviation above the average percent of farmland used in cotton production.

Based on the analysis of Lange et al. (2009) there is reason so believe that nutrition improved gradually over the first five years the boll weevil was in a county. Figure 6 reprints a figure from Lange et al. (2009), which shows that cotton production decreased each year for the first five years after the boll weevil arrived in a county.

We explore the fact that nutrition might be improving and height might be increasing over time in figure 7. In this figure we plot the coefficient and confidence interval from a regression of soldier height on an indicator if the soldier was born the year the boll weevil arrived in his county of enlistment, an indicator if the soldier was born one year after the boll weevil arrived in his county of enlistment, an indicator if the soldier was born two years after the boll weevil arrived in his county of enlistment, etc. The final indicator takes a value of one if the soldier was born six or more years after the boll weevil arrived in his county of enlistment. Thus, the omitted category is soldiers
who were born before the boll weevil arrived in their county of enlistment. Figure 7 demonstrates a similar pattern to figure 6 from Lange et al (2009). Individuals born two years after boll weevil arrival are approximately 0.063 inches taller than individuals born before the boll weevil arrived. Height reaches a maximum for the cohort born four years after the boll weevil arrived, when individuals are approximately 0.13 inches taller than individuals born before the boll weevil arrived.

Taken together, tables 3 and 4 and figure 7 provide strong evidence that the arrival of the boll weevil was associated with a nutritional improvement in the American South.

b. Mandatory Fortification Laws Analysis

We next explore the effects of mandatory fortification laws on Southern mortality in table 5. We begin with pellagra mortality, which is presented in columns (1) and (2) of table 5. Column (1) indicates that the passage of a mandatory fortification law decreases the pellagra death rate by 0.2 deaths per 10,000 people. Column (2) interacts the fortification indicator with the average pellagra death rate in the state for the five years prior to the passage of the law. The coefficient on the interaction in column (2) shows that mandatory fortification laws are associated with a decrease in the pellagra death rate of 0.15 deaths per 10,000 people for every one standard deviation increase in the pellagra death rate prior to fortification. This entire analysis is done at the state level, since county level pellagra mortality rates are not recorded during this time period.
In columns (3) and (4) we explore the effects of mandatory fortification on county level infant mortality rates. Column (3) shows that the passage of a mandatory fortification law is associated with a decrease in the infant mortality rate by about 2.4 infant deaths per 1,000 births. Column (4) shows that for every one standard deviation increase in the intensity measure the passage of a fortification law is associated with a decrease in the infant mortality rate of about 2 infant deaths per 1,000 births. We use the coefficient in column (1) to provide an estimate of the magnitude of this result. The average number of births in counties in Southern states that passed a mandatory fortification law was 821 in the year 1948, after the last Southern state passed a fortification law (Oklahoma). Furthermore, there were 1044 counties affected by the fortification laws, so we estimate that 2,030 Southern infant lives were saved by the passage of the mandatory fortification laws.

Finally, in columns (5) and (6) of table 5 we turn to the effects of mandatory fortification on overall mortality. Column (5) shows that the passage of a mandatory fortification law is associated with a decrease in the overall mortality rate of about 2 deaths per 10,000 people. In column (2), for every one standard deviation increase in the intensity measure the passage of a mandatory fortification law is associated with a decrease in the overall mortality rate of 3 deaths per 10,000 people. Once again, we provide an estimate of the magnitude of this result using the coefficient estimate in column (5). The average population of the 1044 Southern counties that were affected by the mandatory fortification laws was 30,442 in 1948. We, therefore, estimate that mandatory fortification laws saved approximately 5,760 all-age lives. Our estimate that
2,030 infant lives were saved by implies that approximately 3730 non-infant lives were saved by the passage of mandatory fortification laws. We interpret table 5 as evidence that mandatory fortification laws significantly improved Southern nutrition.

6. Conclusion

Our results provide evidence that the invasion of the boll weevil and state-level mandatory cereal-grain fortification laws improved Southern nutrition and decreased pellagra, infant, and overall mortality. The invasion of the boll weevil also led to a significant increase in heights amongst World War II enlistees.

We believe that these results might have implications for Southern economic development. Several studies demonstrate a link between nutrition (caloric intake, protein intake, etc.) and productivity (see Jha et al. 2009 and Strauss and Thomas 1998). One of the reasons the South might have lagged behind the North’s economic development for so long could have been poor nutrition. The two shocks to Southern nutrition considered in this paper might have contributed to the narrowing of the productivity gap between the North and South and will be pursued in future research.
References


Humphreys, Margaret (2009). “How four once common diseases were eliminated from the American South.” *Health Affairs* 28(6): 1734-1744.


Young, Genevieve S., Elaine L. Jacobson, and James B. Kirkland (2007). "Water maze performance in young male Long-Evans rats is inversely affected by dietary intakes of niacin and may be linked to levels of the NAD+ metabolite cADPR." *The Journal of Nutrition* 137(4): 1050-1057.

Figures

Figure 1
Average Pellagra Death Rate in the American South (1939 - 1941)

Figure 2
Source: Hunter and Coad (1922) *The Boll weevil Problem*

Figure 3

State Fortification Laws in the American South (1940 - 1950)
Figure 5
Table 1: Enrichment Standards proposed by FDA (1941)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Minimum (mg)</th>
<th>Maximum (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiamine</td>
<td>1.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>0.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Niacin</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Iron</td>
<td>8</td>
<td>12.5</td>
</tr>
<tr>
<td>Optional Ingredients:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin D</td>
<td>150</td>
<td>750</td>
</tr>
<tr>
<td>Calcium</td>
<td>300</td>
<td>800</td>
</tr>
</tbody>
</table>

**Source:** Food and Bread Enrichment 1949 - 1950; National Research Council Committee on Cereals
Table 2: Southern Diets 1935 - 1936

<table>
<thead>
<tr>
<th></th>
<th>All Southern residents (1)</th>
<th>Southern rural residents (2)</th>
<th>Non-Southern residents (3)</th>
<th>Difference between columns (2) and (3) (4)</th>
<th>p-value of difference (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pounds of corn meal used in past week</td>
<td>2.81</td>
<td>3.67</td>
<td>0.07</td>
<td>3.6</td>
<td>0.00***</td>
</tr>
<tr>
<td>Pounds of hominy grits used in past week</td>
<td>0.62</td>
<td>0.59</td>
<td>0.02</td>
<td>0.57</td>
<td>0.00***</td>
</tr>
<tr>
<td>Pounds of corn meal and hominy grits used in past week</td>
<td>3.43</td>
<td>4.25</td>
<td>0.09</td>
<td>4.15</td>
<td>0.00***</td>
</tr>
<tr>
<td>Pounds of white bread used in past week</td>
<td>2.31</td>
<td>1.13</td>
<td>4.33</td>
<td>-3.2</td>
<td>0.00***</td>
</tr>
<tr>
<td>Observations</td>
<td>1473</td>
<td>909</td>
<td>2740</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Data comes from the Study of Consumer Purchases in the United States, 1935-1936 accessed on ICPSR
Table 3: Boll Weevil and Mortality in North Carolina (1915 - 1924; Population Weighted)

<table>
<thead>
<tr>
<th>Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pellagra Death Rate (per 10,000 people)</td>
<td>Infant Mortality Rate (per 1,000 births)</td>
<td>All-age Mortality Rate (per 10,000 people)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post BW Indicator</td>
<td>-0.868**</td>
<td>-0.462*</td>
<td>-0.939**</td>
<td>-2.839</td>
<td>-2.890</td>
<td>-3.180</td>
<td>-3.319</td>
<td>-2.301</td>
<td>-3.804</td>
</tr>
<tr>
<td></td>
<td>(0.339)</td>
<td>(0.247)</td>
<td>(0.387)</td>
<td>(2.563)</td>
<td>(2.602)</td>
<td>(2.563)</td>
<td>(2.794)</td>
<td>(2.726)</td>
<td>(2.809)</td>
</tr>
<tr>
<td>Post BW Indicator # Average Pellagra Death</td>
<td>-1.33***</td>
<td>0.156</td>
<td>-3.105**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate Pre BW</td>
<td>(0.210)</td>
<td>(0.970)</td>
<td>(1.310)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post BW Indicator # % Cotton Acres 1909</td>
<td>-0.529</td>
<td>-3.301*</td>
<td>-4.703*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.567)</td>
<td>(1.867)</td>
<td>(2.426)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>776</td>
<td>776</td>
<td>776</td>
<td>961</td>
<td>961</td>
<td>961</td>
<td>961</td>
<td>961</td>
<td>961</td>
</tr>
</tbody>
</table>

Robust standard errors clustered at the county level reported in parentheses

*** p<0.01, ** p<0.05, * p<0.1
### Table 4: Boll Weevil and Height

<table>
<thead>
<tr>
<th>Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post BW Indicator</td>
<td>0.0651***</td>
<td>0.0647***</td>
<td>0.0688***</td>
<td>0.0616**</td>
</tr>
<tr>
<td></td>
<td>(0.0222)</td>
<td>(0.0222)</td>
<td>(0.0267)</td>
<td>(0.0269)</td>
</tr>
<tr>
<td>Post BW Indicator # % Cotton Acres 1909</td>
<td>0.0213</td>
<td>0.045*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0219)</td>
<td>(0.0265)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>342,705</td>
<td>342,705</td>
<td>256,342</td>
<td>256,342</td>
</tr>
</tbody>
</table>

**Notes:** To be included in the regressions individuals must have met the following criteria: white, living in a Southern state, living in the same state they were born in, and they must have been drafted. Robust standard errors clustered at the county level reported in parentheses

*** p<0.01, ** p<0.05, * p<0.1
<table>
<thead>
<tr>
<th>Variable</th>
<th>(1) Pellagra Mortality Rate (per 10,000 people)</th>
<th>(2) Infant Mortality Rate (per 1,000 births)</th>
<th>(3) All-age Mortality Rate (per 10,000 people)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Fortification Indicator</td>
<td>-0.201** (0.0911)</td>
<td>0.0541 (0.0983)</td>
<td>-2.369** (1.059)</td>
</tr>
<tr>
<td>Post Fortification # Average State Pellagra Death Rate Pre Fortification</td>
<td>-0.153*** (0.0337)</td>
<td>-2.137* (1.125)</td>
<td>-2.997*** (0.863)</td>
</tr>
<tr>
<td>State FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>224</td>
<td>224</td>
<td>22,686</td>
</tr>
</tbody>
</table>

Robust standard errors clustered at the state level reported in parentheses

*** p<0.01, ** p<0.05, * p<0.1