The Rise and Fall of Pellagra in the American South

Karen Clay, Ethan Schmick, and Werner Troesken

We explore the rise and fall of pellagra (a disease caused by inadequate niacin consumption) in the American South. We first consider the hypothesis that the South's monoculture in cotton undermined nutrition by displacing local food production. Consistent with this hypothesis, a difference in differences estimation shows that after the arrival of the boll weevil, food production in affected counties rose while cotton production and pellagra rates fell. The results also suggest that after 1937 improved medical understanding and state fortification laws helped eliminate pellagra.

INTRODUCTION

The by-product of insufficient niacin consumption, pellagra is a nutrition-related disease characterized by dermatitis, aggression, diarrhea, dementia, and in extreme and untreated cases, death. During the early 1900s, pellagra deaths were recorded in every state in the Union, but the disease was much more pronounced in the South. At the disease's peak in 1928, there were around 230,000 cases of pellagra in the American South (the population of Atlanta at the time) and more than 7,000 deaths annually (Bollet 1992). In some Southern states, it was the ninth or tenth leading cause of death, and had a death rate comparable to malaria.[1] Early observers believed pellagra was contagious and unrelated to nutrition. It was only during the late 1930s that scientists established that the disease was caused by a niacin deficiency. Soon after this discovery, states throughout the country began passing laws mandating the enrichment of bread, flour, and corn products with niacin. Today the disease is largely unknown in the United States, except among homeless populations and others in extreme deprivation.[2]

[1] Data from the Metropolitan Life Insurance Company (Dublin 1919, pp. 255, 259) suggest the average annual mortality rate from pellagra in Southern districts was 4.3 deaths per 100,000, while the average annual morality from malaria over the same period was identical (4.3).

[2] The *Mortality Statistics of the United States* report 6,824 deaths from pellagra in the year 1928. Assuming a case fatality rate of 3 percent (Goldberger et al. 1928), this suggests there were approximately 230,000 cases of pellagra in the United States in 1928, which is equivalent to the population of Atlanta at the time. In places where pellagra was endemic, Goldberger et al. (1928) estimated that around 20 percent of all households had at least one person sick with the disease, though other sources (e.g., Love and Davenport 1920) suggest lower incidence rates. While pellagra was not as pervasive as hookworm (which infected around one-third of the Southern population) pellagra is an extreme indicator: one need not have developed a full-blown case of pellagra to have been poorly nourished, and according to some observers (e.g., Etheridge 1972, Youmans 1964), the high incidence of pellagra is suggestive of broader nutritional deficits.

In this paper, we ask: What drove the rise and fall of pellagra in the American South? We begin our analysis by exploring the long-standing claim that pellagra stemmed from the South's cotton monoculture. In particular, widespread cotton production is thought to have displaced local production of niacin-rich foods and driven poor Southern farmers and mill workers to consume milled Midwestern corn, which was relatively cheap but also devoid of the niacin necessary to prevent pellagra. Previous work has sought to document the connection between cotton production and pellagra by using simple time series and cross sectional comparisons. These correlational exercises show that when and where cotton production was high so too was the pellagra rate (Park et al. 2000, Goldberger et al. 1920, Rajakumar 2000). However, ascribing causality to the positive correlation between cotton production and pellagra is problematic. For example, it might conflate changes in income with changes in food availability: perhaps years of high cotton production were also years of low income, and it was the reduction in income, not the reduction in local food production, that drove the increase in pellagra.[3]

To test for a causal link between cotton production and pellagra, we follow previous research and treat the arrival of the boll weevil in the cotton belt during the early 1900s as an exogenous shock that disrupted cotton production. Using a difference-in-differences estimating strategy and county-level data from North Carolina and South Carolina, we regress pellagra mortality against an indicator variable for boll weevil penetration interacted with pre-boll weevil measures of cotton production or pellagra.

[3] Such concerns are only heightened by the contentious but long-standing claim that cotton over-production left farmers much poorer than they otherwise would have been (DeCanio 1973). See also the debate between Wright and Kunreuther (1975), McGuire and Higgs (1977), Wright and Kunreuther (1977), and McGuire (1980) on the riskiness of cotton production.

Our results show that counties with high levels of either cotton production or pellagra experienced relatively large reductions in pellagra mortality following the arrival of the boll weevil. These results are robust to potential confounding factors such as malaria, urbanization, interpolation of inter-Census population estimates, and changes in overall mortality. In addition, we run a series of placebo tests on death rates from other diseases and find no evidence that they fell in response to the boll weevil. These results suggest that the reductions in pellagra that followed the arrival of the boll weevil were not caused by improvements in the overall disease environment. Finally, we do not find evidence that the groups most likely afflicted with pellagra (e.g., women and children) migrated out of cotton producing counties (post-boll weevil) at higher rates than less vulnerable groups.

To further explain our results, we establish a mechanism linking the boll weevil and pellagra. In particular, we show that the arrival of the boll weevil in cotton producing counties prompted farmers to diversify their crop mix by planting niacin-rich foods. This, in turn, would have increased the availability of niacin to nearby populations.

Having explored cotton's role in the rise of pellagra, we then turn to an analysis of the forces that helped bring an end to the disease in the American South. Pellagra rates dropped sharply, and permanently, during the 1930s and 1940s. This drop happens shortly after the discovery that pellagra was caused by niacin deficiency in 1937 and continues after the passage of states laws in the 1940s mandating that breads and grains be enriched with niacin. Historical observers have long hypothesized a causal connection between these events and the concurrent reductions in pellagra. To test this claim we use county data from North Carolina and South Carolina and a standard difference-in-differences estimation approach. The results suggest that improved medical understanding and state fortification laws significantly reduced pellagra related mortality.

Taken together, our results contribute to four literatures. First, the observation that malnutrition can emerge in poor agricultural societies that rely heavily on cash crops is not unique to the American South; development economists and colonial historians offer similar arguments for other parts of the world (e.g., National Academy of Sciences 1978, p. 44; and Bhatia 1963). Second, the American South has long lagged behind the North in economic performance, and only after World War II did incomes begin to converge. Standard explanations for these patterns fall into one of three categories: institutional, technological, and disease-related.[4] The results here reinforce the idea that the South's disease environment – particularly as it relates to nutrition-related diseases – is important to understanding the long-term economic evolution of the region.

Third, the literature that explores nutritional shocks primarily achieves identification by focusing on shocks that adversely affect both nutrition and income (see Lumey et al. 2011 for a literature review). The results here complement and extend this literature. Of particular interest is our use of the boll weevil, which breaks the usual correlation between nutrition and income. Most shocks that reduce nutrition also reduce income, and it is difficult to disentangle the two effects as they are mutually reinforcing. The boll weevil, however, induced farmers to abandon a profitable crop (cotton) for less profitable crops (local food) and yet, because the shift to less

[4] Institutional explanations consider national labor standards (Wright 1987); Civil Rights legislation (Wright 2013, Collins 2003); and the decline of paternalism and other institutions hostile to black economic progress (Alston and Ferrie 1993, 1999). Technological explanations focus on air-conditioning (Biddle 2008, 2011), electrification (Downs 2014), and the mechanization of agriculture (Alston and Ferrie 1993, 1999). Disease-based explanations consider the eradication of hookworm and malaria (Bleakley 2007, 2010; Kitchens 2013).

profitable crops was often associated with expansions in local food supplies. The evidence presented here suggests that these shocks resulted in improved nutrition despite any reductions in income.

Finally, over the past decade, there has been revived interest in the role of the boll weevil in Southern economic history. Lange et al. (2009) show that in anticipation of the arrival of the boll weevil, cotton farmers in the South increased production but once the pest arrived shifted to the production of other crops. Bloome et al. (2017) explore how the boll weevil interacted with tenancy to shape marriage patterns. Their results indicate that with the arrival of the boll weevil, tenancy fell as did the frequency of marriages at early ages among African Americans. This reversed an early pattern of rising tenancy and marriage rates among young African Americans. Ager et al. (2017) also find evidence that the boll weevil reduced the number of tenant farms, wages in agriculture, and female labor force participation in cotton producing counties. On a more positive note, Baker (2015) shows how the arrival of the boll weevil promoted convergence in black and white school enrollment rates, as demand for child labor in cotton related tasks fell. Our results complement these findings.

HISTORICAL BACKGROUND

Pellagra is a disease caused by niacin deficiency that caused thousands of deaths in the South during the first half of the twentieth century. Pellagra is characterized by the four D's: dermatitis, diarrhea, dementia, and death. Conrad Elvehjem showed definitively that pellagra was caused by inadequate niacin consumption in 1937 (Elvehjem et al. 1937). Prior to that, physicians and public health workers had a range of theories, most of which focused on pellagra being a disease of unclear origin (Mooney et al. 2014, Siler et al. 1914, 1915).[5] The dermatitis and skin discoloration associated with severe cases of pellagra facilitated a proper diagnosis. For many, pellagra was a seasonal affliction, emerging in late spring and early summer, which is itself suggestive that access to local food supplies might matter in the propagation of the disease. In healthy populations, pellagra took about six months to develop.[6] In cases where diets were supplemented, pellagra tended to go away within a few months. The relationship between duration of pellagra and death is not clear. Because of the distinctive symptoms of the disease in severe cases, death rates for pellagra are probably well estimated.

Pellagra was much more prevalent in the South than in other parts of the United States. Figure 1 shows state pellagra death rates in 1920 and in 1935. Unfortunately, Southern states were not part of the United States death registration system until the mid-1910s, so the numbers of deaths during early twentieth century are not precisely known. What we do know is that by

---

[5] Joseph Goldberger, who worked for the United States Public Health Service in the late 1910s and early 1920s, argued that pellagra was a nutritional disease. He had difficulty convincing many doctors and local public health officials. (Goldberger et al. 1915, 1920, 1929). Consider, for example, the words of James A. Hayne, a doctor from South Carolina who headed a national commission on pellagra during the 1910s. Hayne argued: "That diet is the cause of pellagra I am yet unwilling to accept. I cannot conceive that such economic conditions can exist in my State as to make pellagra second in death rate only to tuberculosis. Knowing the economic conditions there, I cannot believe that 1,900 people died because they could not get the proper kind of food, or, they could get the proper kind of feed, because they would not eat it. South Carolina has only ¼ of 1% foreign-born population. Why, if the people [can] get the same kind of food they got twenty-five years ago have they suddenly determined to kill themselves by not eating it?" *Proceedings of the Conference of State and Provincial Boards of Health of North America* (1916), p. 29.

[6] See Goldberger et al. 1915 and Goldberger et al. 1923, which discuss the onset of pellagra in the Mississippi prison experiment and in an orphanage when diet supplementation ended for financial reasons.

1907 pellagra deaths were reported in *Journal of the American Medical Association* articles and by 1911 the Surgeon General of the U.S. Public Health Service expressed concerns regarding the growing prevalence of pellagra, particularly in the American South (Bollet 1992).[7]

Why was pellagra more prevalent in the South? The diet for poor whites and blacks in the South consisted primarily of salt pork, molasses, and corn – foods with very little niacin. Table 1 documents the importance of corn in Southern diets. This table is based on the Study of Consumer Purchases in the United States, 1935-1936, which collected data on food purchases from a large sample of households including Southern households in both urban and rural areas. The table demonstrates that compared to non-Southerners, Southerners were eating more corn meal, more salt pork, less bread, fewer potatoes, fewer eggs, and less meat, and they were drinking less milk. In comparison to corn, wheat and potatoes have about twice as much niacin per gram (Krehl et al. 1946). Salt pork was low in niacin, relative to other types of meat. Eggs and milk have tryptophan, which can be converted to niacin in the body.

In addition to varying regionally, the number of pellagra deaths varied over time. The time series variation is clear in Figure 2, which plots pellagra deaths and cotton production in North Carolina and South Carolina over time. These data suggest that pellagra was widespread in North Carolina and South Carolina in the mid-1910s. The boll weevil first arrived in a county in South Carolina in 1917, had reached 40 percent of counties in North Carolina and South Carolina by 1920, and reached the final counties in 1922. The growth in pellagra stops during the late 1910s at around the same time that the cotton economy stagnates with the penetration of the boll weevil.

One of the central themes of the extant literature on pellagra is that the disease stemmed

[7] Sutch (1975) suggests that pellagra was also rife among slaves in the American South.

directly from the South's cotton monoculture. Cotton production crowded out local food production, leading to the importation of less healthful food. In his study of South Carolina, Walter Edgar (1992) argues that a high debt burden forced many farmers to plant cotton, a cash crop with higher expected returns than other crops. Despite the population of South Carolina tripling from 1850 to 1935, the amount of food production remained about the same. As a result, South Carolina "had to import $70-$100 million worth of food annually. For poverty-stricken tenant farmers with little ready cash, this meant that there was less to eat. The consequent increased dependence on a diet of pork, cornbread, and molasses made poor Carolinians more susceptible to disease" (Edgar 1992, p. 47).

The importation of food into the South would have increased pellagra if the food being imported had lower levels of niacin. Indeed, historical observers have attributed the increase in pellagra to changes in the milling of Midwestern corn. Previous milling technology had removed less of the germ, retaining some niacin. The Beall degerminator, which was patented in 1900 and 1901, removed the germ. This led to a finer cornmeal with a longer shelf life, but much less niacin and other micronutrients. 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 addition, a survey conducted by the Thompson-McFadden Pellagra Commission of residents in six mill towns in South Carolina revealed that almost 60% of residents consumed shipped cornmeal on a daily basis and only 10% of residents never consumed shipped cornmeal. In contrast, 12% of residents consumed locally produced cornmeal on a daily basis, and 80% of residents never consumed locally produced cornmeal.[8]

Also relevant for our empirical analysis below, Lange et al. (2009) present evidence that the boll weevil reduced cotton production and increased local food production. The boll weevil, a beetle that feeds on cotton leaves, squares (flower buds), and bolls, appeared in Texas in 1892. It then progressed across north and east through the cotton belt. By 1922, the boll weevil had infected the entire cotton region. The arrival of the weevil had a large effect on agriculture. In their analysis of the boll weevil on the South, Lange et al. (2009) write (p. 710): "Overall, the corn results indicate a greater movement to alternative crops than suggested in the literature, which has downplayed the boll weevil's effects on diversification." In a footnote, they add (p. 710): "Based on the census data, we also find production of hay, Irish potatoes, peanuts, rice, and sweet potatoes; sugar cane, among other crops, showed statistically significant increases after the arrival of the weevil." We further examine the effect of the boll weevil on food production in North Carolina and South Carolina below.

Increased production of Southern corn and other crops following the arrival of the boll weevil was likely to increase niacin consumption. For corn, this could occur through increased consumption of fresh corn, the crowding out of Midwestern cornmeal, or both. Southerners tended to plant and harvest sweet corn, which contained relatively high levels of niacin, while the corn varieties grown in the Midwest contained 30 to 50 percent less niacin than sweet corn (Burkholder et al. 1944; Ayer 1895, p. 12-13). Southerners made "stone ground" corn meal, which was neither kiln dried nor degerminated, and so preserved the niacin. Locally sourced corn could also be used to make hominy grits. If prepared correctly (in a lime/alkali solution), hominy

[8] The complete results from the survey are shown in Siler et al. 1915, pp. 21, 34.

grits contained more niacin than ordinary corn, cornmeal, or corn bread. Peanuts and sweet potatoes are high in niacin, so increased production and consumption would also affect niacin intake.

Figure 2 shows that pellagra rebounds during the late 1920s, shortly after the effects of the boll weevil begin to recede and the cotton economy recovers. Pellagra plummets again during the late 1920s and early 1930s, with the onset of the Great Depression and a sharp decline in cotton-acres harvested. It is only after the discovery of niacin in 1937, marked by the dashed-vertical line in the graphs, and the passage of laws mandating the fortification of grains and breads with niacin, that the correlation between cotton production and pellagra seems to break down.

In 1936 and 1937 Conrad Elvehjem and his collaborators were conducting experiments with rats and dogs that would lead to the discovery that niacin cured black tongue in dogs. Black tongue in dogs had long been recognized as being related to pellagra in humans. He published their results in September 1937 in a letter to the editor of the Journal of the American Chemical Society. By the end of 1937, a number of other teams had replicated their results in dogs and the implications for treatment of pellagra in humans were clear. In 1938, some bakers began voluntarily fortifying their bread with high vitamin yeast. The direct effects of voluntary fortification on the South are unclear, because bread was not consumed in large quantities and was often made at home (Park et al. 2000, 2001).

Nineteen-thirty-seven was nonetheless a watershed year because the medical profession now knew that increased consumption of niacin rich foods could be used to address pellagra. Before this, doctors adopted ineffective treatment strategies. For example, a review of articles on PubMedCentral published between 1910 and 1937 suggests that during the 1910s, doctors in the

American South focused treatment on chemical interventions, particularly Salvarsan, which had been used to treat syphilis.

In 1939, the Council on Foods and Nutrition of the American Medical Association encouraged "with some qualification, fortification of certain staple foods with vitamins and minerals, specifically the restorative additions of thiamine, niacin, riboflavin, iron, and calcium to white flour and white bread" (Wilder 1956, pg. 1540). The committee had previously approved adding vitamin D to milk and iodine to salt. In 1941 the FDA established standards for the fortification of bread. In 1943 War Food Order No. 1 stated that all bread sold in interstate commerce had to meet FDA standards. Fortification of flour was not required and regulation was left to the states. The law was officially repealed in 1946.

Over the period 1942-1949, twenty-eight states passed some type of mandatory fortification law. For example, South Carolina passed a law in 1942 covering bread and flour and it was extended in 1943 to cover corn meal and corn grits. North Carolina passed a law in 1945 that covered bread, flour, corn meal and corn grits.[9] Spurred by this, major producers of cornmeal and grits in the Midwest began fortifying their products.[10]

Pellagra rates dropped sharply, and permanently, shortly after the discovery that pellagra was caused by niacin deficiency in 1937. The decline continued after the passage of states laws in the 1940s mandating that breads and grains be enriched with niacin. By the 1950s, the disease was largely eliminated from the United States.

---

[9] States that passed laws pertaining to cornmeal and hominy grits were: Alabama, Georgia, Mississippi, North Carolina, South Carolina, and Texas.

[10] A 1957 survey found that nearly all hominy grits sold were enriched, and that cornmeal was generally enriched, except in Florida and Virginia, where enrichment was less typical (Park et al. 2001, National Research Council 1958).

A SIMPLE ECONOMIC FRAMEWORK

In this section, we sketch out a simple economic framework that can explain how the South's reliance on cotton might have promoted higher pellagra rates in particular, and poor nutrition more generally construed. One of the central messages of this framework is that cash cropping does not necessarily result in poor nutrition; it only does so under certain conditions.

Consider a largely agricultural economy, where farmers are deciding how to allocate their land, labor, and capital: they can either plant, harvest, and sell a cash crop in an international market (in this case, cotton); or they can deploy their resources to produce food for the local market. In deciding how to allocate resources, farmers look toward expected prices.[11] To the extent expected cotton prices are relatively high, farmers would allocate their land and resources to planting and selling cotton and produce little food for the local market. This would decrease the supply of locally produced foods, driving up the relative price. Consumers in this economy would then substitute away from local foods and begin importing degerminated corn from the Midwest, which as noted above, was niacin deficient. As an empirical matter, we cannot observe the expected price of cotton or the price of locally produced foods. However, we can observe acres dedicated to cotton and food production, which is perhaps an even better indicator of farmers' beliefs about the expected relative profitability of food and cotton. In addition, we will also exploit a situation where expected prices did not drive planting decisions: the arrival of the boll weevil, which induced farmers to shift away from cotton and diversify crops.

[11] Risk might also enter such considerations, but in the case of the American South, cotton not only exhibited higher average profitability; it also had lower variance and was a relatively low risk crop. See McGuire and Higgs (1977) and McGuire (1980).

For the process above to have yielded high rates of pellagra, two conditions need to be satisfied. First, it must be the case that there are, in fact, nutritional differences between imported corn and locally-sourced foods. While we cannot directly test this proposition, there is anecdotal evidence to suggest this was the case. In the case of corn, as explained in the previous section, locally-produced Southern corn was not degerminated and so it is thought to have been healthier and richer in niacin. There is also evidence (discussed below) that aside from corn, Southern farmers would switch to growing peanuts and sweet potatoes when cotton prices were low or when cotton production was not feasible. Peanuts and sweet potatoes are both rich in niacin and other micronutrients. Second, it must be the case that the price effect dominates any income effect.[12] More precisely, if demand for nutrition grows with income and higher cotton prices, it is possible that consumers in the region might begin importing relatively expensive niacin-rich foods, rather than degerminated corn. Having said this, nutritionally rich foods in general, and foods that were high in niacin, in particular, were poorly understood during our study period. Put another way, if cash cropping generates sufficiently high wages and income, and nutrition is a normal good, cash cropping need not imply poor nutrition.

[12] This point is particularly relevant in relation to our boll weevil identification strategy. Specifically, the arrival of the boll weevil had two countervailing effects. First, it caused farmers to shift away from cotton toward food production, lowering the price of locally-sourced (high-niacin) foods. This would have helped lower pellagra rates. Second, the arrival of the boll weevil also reduced the income of Southern farmers. As Ager et al. (2017) and others explain, this reduction was partly reflected in the fact that Southern tenants moved down the agriculture ladder from fixed renters to share croppers. This second channel, would have worked against the price channel and undermined nutrition, putting upward pressure on pellagra rates. For the arrival of the boll weevil to have promoted better nutrition and reduced pellagra, the first channel must have dominated the second channel.

DATA

County-level crop production data are from the 1909, 1919, 1924, and 1929 Censuses of Agriculture. These data are compiled in Haines et al. (2015) *United States Agriculture Data, 1840-2010*. We use data on cotton, corn, peanut, sweet potato, and tobacco acreage and acreage per capita.

We use data on county and state population, the year the boll weevil arrived in a county, and the dates that states passed fortification laws. Population data are from the 1900 to 1950 Censuses of Population. We linearly interpolate county and state populations between decennial censuses. Data on the first year the boll weevil arrived in a county are taken from Lange et al. (2009), which originally came from USDA boll weevil maps.[13] The year of state fortification law passage was taken from Park et al. (2001).

We collected data on pellagra mortality at the county-level for North Carolina from 1915-1949 and for South Carolina for 1916-1949. North Carolina and South Carolina are the only states, to our knowledge, that consistently reported pellagra deaths at the county level during this entire time period (1915-1949). Pellagra deaths for counties in North Carolina come from *The Annual Report of the Bureau of Vital Statistics of the North Carolina State Board of Health*.[14] The North Carolina State Board of Health did not issue a vital statistics report for the years 1918

[13] We reviewed the original USDA boll weevil map published in Hunter and Coad (1923) and found a few discrepancies between the map and the coding of the boll weevil arrival in Lange et al. (2009). The map shows that the boll weevil arrived in Cherokee County, South Carolina in 1920, but it is coded as 1921 in Lange et al. (2009). The map shows the boll weevil arriving in Iredell County and Wake County, North Carolina in 1921, but it is coded in Lange et al. (2009) as 1922. We changed the coding in these cases to align with the original map.

[14] In 1920 and 1921 these reports are found in *The Health Bulletin* published by the North Carolina State Board of Health.

and 1919; accordingly we do not have data on pellagra deaths for those years. Pellagra deaths for counties in South Carolina from 1916-1949 come from the *Annual Report of the State Board of Health of South Carolina*.

To supplement the analysis of pellagra in North Carolina from 1915 to 1925, we collected county-level deaths for the following diseases: malaria, measles, pneumonia, typhoid, and tuberculosis. Comparable data are not available for South Carolina.[15]

Table 2 presents summary statistics for three types of counties. We define high cotton counties as counties in the top 25% of the distribution of cotton acres per capita in North Carolina and South Carolina in 1909, which is prior to the arrival of the boll weevil. All of these counties received the boll weevil. Low cotton producing counties include all counties that received the boll weevil, but were not classified as high cotton producing counties. Finally, 22 counties did not receive the boll weevil. For ease of exposition unless there is a risk of confusion, we will refer to these counties as high cotton, low cotton, and no cotton counties. When compared to low cotton or no cotton counties, high cotton counties had higher cotton acres in 1909, higher numbers of pellagra deaths in 1916, larger populations in 1910, higher cotton per capita in 1909, and higher pellagra death rates in 1916.

COTTON, THE BOLL WEEVIL, AND PELLAGRA

Lange et al. (2009), Baker (2015), Bloome et al. (2017), and Ager et al. (2017) all use the boll weevil as an exogenous change to examine a range of outcomes. These authors argue that it is reasonable to treat the timing of the boll weevil as exogenous because there was little farmers

[15] Ideally, we would have collected these data for South Carolina, but the death rates for these diseases are missing for much of our study period. Typhoid fever deaths are not consistently reported in South Carolina until 1919; pneumonia and measles deaths are not consistently reported until 1934.

and local officials could do to prevent the boll weevil from invading their county.[16] Following the lead of these previous studies, we use the arrival of the boll weevil to test the long-standing hypothesis that pellagra stemmed, in part, from the South's monoculture in cotton.

Our empirical work on the boll weevil proceeds in three steps. We first focus on how disease rates responded to the arrival of the boll weevil, and show that the boll weevil was associated with reductions in pellagra. We then implement a series of econometric tests to see if our findings are robust to the following exercises: more aggressive controls for changes in overall mortality; dropping the years of the Great Influenza Pandemic; dropping counties with border changes; an explicit control for population; and placebo tests involving diseases other than pellagra. In an appendix, we further explore the robustness of our results, giving particular attention to the possibility of selective migration, our measure of cotton intensity, and interpolation. The third and final part of our empirical analysis here of focuses on the mechanisms linking pellagra and the boll weevil. We do this by analyzing how the boll weevil altered planting choices and prompted farmers to harvest food crops instead of cotton.

Figure 3 motivates the first part of our empirical analysis. Panel A (B) plots pellagra deaths (death rates) against cotton production for counties in South Carolina and North Carolina from 1915 to 1925. The vertical lines indicate key dates regarding the arrival of the boll weevil. From both panels, it is clear that following the arrival of the boll weevil, pellagra deaths and pellagra death rates are everywhere declining over time, but fall more in cotton producing counties than in non-cotton counties (that were not invaded by the boll weevil).

To formally study the relationship between the boll weevil shock and pellagra, we

[16] Famers tried burning crops and applying calcium arsenate to deter boll weevil penetration, but these were not widely adopted. See Lange et al. (2009) for a full discussion of mitigation techniques.

estimate the following equation:

$$ln[pellagra]_{ct} = \alpha + \theta_1 * [boll\,weevil]_{ct} + \theta_2 * [boll\,weevil]_{ct} \times [intensity]_c + \theta_c + \theta_t + \varepsilon_{ct} \quad (1)$$

In equation (1), $ln[pellagra]_{ct}$ is the log of pellagra deaths or the log of the pellagra death rate in county *c* in year *t*. $[boll\,weevil]_{ct}$ is an indicator variable that takes a value of one after the boll weevil has arrived in a county. We interact the boll weevil indicator with a measure of intensity of treatment $[intensity]_c$. We adopt two measures of intensity. First, $[high\,cotton]_{c,1909}$ is an indicator variable if county c was in the top 25% of the distribution of cotton acres per capita in North Carolina and South Carolina in 1909. Second $[high\,pellagra]_{c,1915}$ is an indicator if a county was in the top 25% of the distribution of pellagra death rates in North Carolina and South Carolina in 1915 and 1916. 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 that are common across the sample.

In some specifications, we control for the malaria death rate in 1915 and the urbanization rate in 1910. According to Bleakley (2010) the malaria intervention in the American South occurs almost concurrently with the arrival of the boll weevil in North Carolina and South Carolina. Accordingly, we control for the county-level malaria death rate in 1915, just prior to the arrival of the boll weevil, interacted with year fixed effects. We also control for the percent of the county population living in an urban area during the 1910 census interacted with year. This controls for any urban-rural differences in access to food.

For the analysis of pellagra deaths and death rates, we again use the sample period 1915-1925, restricting the sample to counties that existed in 1910. This provides us with pellagra death data for 98 counties in North Carolina and 43 counties in South Carolina over this time period, giving us a sample of 141 counties and 1,353 observations.[17]

Our analysis presents results for both pellagra deaths and the pellagra death rate. We present results for both deaths and the death rate for the following reason. The pellagra death rate calculation is based on population numbers that are linearly interpolated between Census years. As a result, the calculated death rate will be based on population estimates that are too low prior to the boll weevil and too high following the boll weevil in counties where the boll weevil causes a decrease in population. In counties that see an increase in population after the arrival of the boll weevil, the interpolated population will too high prior to the boll weevil and too low following its arrival. Although neither deaths nor the death rate is a perfect measure, using both measures can help us assess the robustness of our results to concerns about interpolation.

Table 3 shows the effect of the boll weevil on pellagra deaths and pellagra death rates in North Carolina and South Carolina. In columns 1-3, pellagra deaths fell statistically significantly following the arrival of the boll weevil and fell statistically significantly more post-boll weevil in counties with high pre-boll weevil death pellagra rates (column 2) and in high cotton counties

---

[17] Because we do not have data on pellagra deaths in North Carolina for 1918 and 1919, we have only 882 observations for North Carolina (98 counties in 9 years). Additionally, we are missing data for Calhoun County and Laurens County South Carolina in the year 1915 meaning that we have 471 observations for South Carolina (43 counties in 11 years). We do not include the following counties in our analysis because they were founded after 1910: Avery County, North Carolina (founded in 1911); Hoke County, North Carolina (founded in 1911); Allendale County, South Carolina (founded in 1919); Jasper County, South Carolina (founded in 1912); McCormick County, South Carolina (founded in 1916).

(column 3). Pellagra fell 33% more in counties with high pre-boll weevil pellagra death rates than in counties with low pre-boll weevil pellagra death rates. Pellagra fell 21% more in high cotton counties than in low cotton counties. Column 4 adds controls for malaria and urbanization, each interacted with year fixed effects. Pellagra fell 27% more in counties with high cotton counties than in low cotton counties. The patterns in columns 5-8 for pellagra death rates are similar in sign and significance, although the magnitudes of the interaction terms are smaller. This is because the rates adjust for the declines in population, which the counts do not.

Table 4 examines the robustness of the results in Table 3 to three sets of concerns: the influenza pandemic (1918-19); changing county borders; and the aforementioned interpolation concern. For comparison, column 1 re-reports the results for pellagra deaths from Table 3 column 4. Column 2 drops 1918 and 1919 for South Carolina, since we do not observe data in North Carolina in those years. Column 3 drops counties that change borders. Column 4 uses a different method of adjusting for population for counties that receive the boll weevil during that decade. Instead of interpolating population, the population is assumed to be constant from the census year up to the year of the boll weevil, and then to drop or increase to its value in the next census year. Columns 5-8 repeat the analysis for pellagra death rates.

In an Appendix (Table A.3), we further explore the robustness of our baseline model. In particular, we obtain similar (though weaker) results if we use cotton acres as a share of total acres as our intensity of treatment measure. We also consider different controls and measure of mortality, showing that we obtain the same results if we control for the overall death or use the ratio of pellagra deaths to total deaths as our dependent variable. Finally, we interpolate pellagra deaths for 1918 and 1919 for North Carolina and show that our central results remain.

In Table 5 we use data from North Carolina to examine the effect of the boll weevil on diseases that are not caused by nutritional deficiencies.[18] All columns control for the county-level malaria death rate in 1915 interacted with year fixed effects and the percent of the county population living in an urban area during the 1910 census interacted with year fixed effects. Column (1) displays the baseline effect of the boll weevil on pellagra in North Carolina. The arrival of the boll weevil is associated with a 25% decrease in pellagra deaths. Columns (2)-(6) examine the effect of the arrival of the boll weevil on typhoid fever, tuberculosis, measles, pneumonia, and overall deaths (minus pellagra deaths), respectively. The boll weevil is associated with a small but statistically significant increase in overall deaths (minus pellagra deaths) of 5%. Columns (7)-(12) examine the effect of the arrival of the boll weevil on death rates of different disease. The boll weevil is not associated with significant decreases in the death rate of any of the non-nutrition related diseases or the overall death rate.

One concern surrounding our analysis is the possibility that the groups most affected by pellagra migrated out of high cotton producing counties at a higher rate than the rest of the population. To address this issue, we looked for evidence of differential migration among affected groups. We used the 1910, 1920, and 1930 complete count census data to count the population of groups most affected by pellagra; children age 2-10 and females age 22-44. We then generated two population counts for each county-year cell in North Carolina and South Carolina; the count for the affected group and the count of the rest of the population. We regressed these counts on year fixed effects, county fixed effects, and a post boll weevil indicator

[18] It is possible that improved nutrition might improve immunity leading to long-run gains in overall health. However, we believe that the short-run effects of improved nutrition would be most evident in nutritional diseases, like pellagra, not non-nutritional diseases.

interacted with cotton (or pellagra) intensity and interacted with an indicator if the count was for the affected group.

The results of these "triple difference" regressions are displayed in Appendix table A4, columns (2)-(5). The coefficient on the triple interaction is never significant and is close to zero in all specifications. Therefore, there is no evidence that children age 2-10 or females age 22-44 are migrating out of high cotton producing counties at a higher rate than the rest of the population after the arrival of the boll weevil.

Appendix table A4, column (1) also provides what might be a more direct test of whether groups most affected by pellagra migrate at a higher rate after the arrival of the boll weevil. In this specification we regress the population of a county in NC or SC on year fixed effects, county fixed effects, and a post boll weevil indicator interacted with cotton intensity and pellagra intensity. Again, the coefficient on the triple interaction term is not significant meaning that counties with high cotton production and high pellagra are not experiencing differentially high outmigration after the arrival of the boll weevil. These patterns suggest the groups most vulnerable to pellagra did not migrate out of high cotton/high pellagra counties at elevated rates.

THE BOLL WEEVIL AND LOCAL FOOD PRODUCTION

We next turn to the effect of the boll weevil on crop acreage and crop acreage per capita in North Carolina and South Carolina. We adopt a specification similar to Lange et al. (2009):

$$\begin{aligned} ln[crop\ outcome]_{ct} &= \alpha + \theta_1 * [boll\ weevil]_{ct} + \theta_2 \\ &* [boll\ weevil]_{ct} \times [cotton\ acres\ pc]_{c,1909} + \theta_3 * tS_c + \theta_4 \\ &* t^2 S_c + \theta_c + \theta_t + \varepsilon_{ct} \end{aligned} \tag{2}$$

This specification is similar to equation (1), but the outcome is the log of acres dedicated to cotton, corn, peanuts, sweet potatoes, or tobacco or the acres per capita dedicated to these crops. In addition, we include a quadratic time trend, t and t^2, interacted with the share of cotton in total acres harvested in 1909, S_c. We restrict the sample to counties that existed in 1909. This restriction leaves us with 141 counties. Standard errors are clustered at the county level.

Table 6 displays the estimates from equation (2) for the agricultural censuses between 1909 and 1929. Cotton yields and cotton acres per capita fell more in high cotton counties after the boll weevil arrived. In addition, corn acres per capita, peanut acres, and sweet potato acres per capita, all saw significant increases in high cotton counties after the boll weevil. Notably, corn acres per capita increased 7.5% in high cotton counties relative to low cotton counties. Our results for North Carolina and South Carolina show evidence that acres and acres per capita devoted to food production increased after the boll weevil and are similar to the Lange et al. (2009) results for the South more broadly. These results suggest a mechanism (i.e., increased availability of nutritionally-rich, locally-sourced foods) through which the arrival of the boll weevil might have promoted better nutrition, particularly in relation to niacin and pellagra.

NIACIN AND THE FALL OF PELLAGRA

To motivate our analysis of the decline of pellagra, Figure 4 plots pellagra deaths and death rates in South Carolina and North Carolina. The figure compares cotton producing counties and non-cotton producing counties from 1934 to 1949. Following the discovery of niacin as a cure of pellagra in 1937 (marked by the dashed lines in Figure 4), pellagra deaths and pellagra death rates fall overall and fall more in cotton producing counties.

To analyze the effect that the discovery of niacin had on pellagra we estimate a variant of equation (1) where $[boll\,weevil]_{ct}$ is replaced with a dummy variable that takes a value of one starting in 1937. We run this regression on county-level pellagra data for North Carolina and South Carolina.[19] We again use two intensity of treatment variables. The first is an indicator variable that takes a value of one if county c was in the top 25% of the distribution of pellagra death rates in 1928, prior to the discovery of niacin. The second intensity of treatment variable is an indicator variable if county c was in the top 25% of the distribution of cotton acres per capita in North Carolina and South Carolina in 1909.

Table 7 uses three different time periods to explore the effects of the discovery of niacin and the passages of mandatory fortification laws. Columns (1) and (2) use the time period 1934-1941 and study the effects of the discovery of niacin on pellagra death rates. Pellagra deaths fell more after the discovery of niacin in high-pellagra counties and in high cotton counties. Columns (3)-(5) use the time period 1938-1949 and study the effects mandatory fortification laws on pellagra death rates. The passage and implementation of a mandatory fortification law is associated with a decrease in the pellagra death rate, with larger decreases occurring in high-pellagra and high-cotton counties. Finally, columns (6)-(7) use the entire time period 1934-1949 and study the effects of both the discovery of niacin and the passage of a mandatory fortification law. When estimating the effects simultaneously, we still find that the pellagra death rate decreased more in high-pellagra and high-cotton counties after the discovery of niacin and after the passage of a mandatory fortification law. High-pellagra counties saw about a 15% decrease in the pellagra death rate after the discovery of niacin and high-cotton counties saw about a 7%

[19] Results for state-level pellagra data for Southern states are presented in the appendix. Pellagra deaths by county for all states were only reported in the Vital Statistics of the United States for the years 1946-1948.

decrease. Both high-pellagra and high-cotton counties saw around a 10% decrease in the pellagra death rate after the passage of a fortification law.

Overall, the results in Table 7 indicate that counties with high-level of cotton acreage per capita and poor baseline nutrition gained the most from the discovery of niacin and mandatory fortification laws. In the Appendix table A.5, we also use state (rather than county) level data to show that the passage of mandatory fortification laws was associated with decreases in the pellagra death rate, and these decreases were larger for states with poor baseline nutrition and high cotton acreage per capita.

CONCLUSION

In this paper we have explored the rise and fall of pellagra in the United States. Prior researchers suggest that pellagra emerged in part because of increased cotton production in the American South and the substitution of locally grown corn for corn that was milled in the Midwest. The Midwestern milled corn was degerminated, which stripped the corn of much of its nutritional value. To establish the causal relationship between cotton acreage and pellagra we exploit an exogenous shock in cotton production that occurred from the arrival of the boll weevil. We show that, following the arrival of the boll weevil, the death rate from pellagra fell in counties with high initial pellagra or high initial cotton production. We also establish a plausible dietary mechanism to explain this result: the production of locally grown food increased as the boll weevil prompted farmers to shift away from cotton production.

These results are robust to confounding factors related to malaria, urbanization, the Great Influenza Epidemic, changing county borders, and inter-Census population estimates based on interpolation. We also provide evidence that the arrival of the boll weevil was not associated with overall improvements in health. The death rates for typhoid, tuberculosis, measles, and pneumonia experienced no significant changes after the arrival of the boll weevil. This implies that one of the main impacts the boll weevil had on short-run health was improved nutrition. Furthermore, while the boll weevil induced outmigration in counties with high cotton production, our estimates suggest the groups most vulnerable to pellagra were not out-migrating at significantly higher rates.

In the last part of the paper, we explore the forces that permanently reduced pellagra in the South. We focus on two sets of events: the discovery that niacin worked as an anti-pellagrant, which occurred in 1937; and the passage of state-level mandatory fortification laws from 1942 to 1949. Our results indicate that both sets of events mattered and contributed to the (near) elimination of pellagra in the South.

REFERENCES

Aaronson, Daniel, and Bhashkar Mazumder. "The impact of Rosenwald schools on black achievement." *Journal of Political Economy* 119.5 (2011): 821-888.

Ager, Philipp, Markus Brueckner, and Benedikt Herz (2017). "The boll weevil plague and its effect on the southern agricultural sector, 1889–1929." *Explorations in Economic History* 65:94-105.

Alston, Lee J and Joseph P Ferrie (1993). "Paternalism in Agricultural Labor Contracts in the Us South: Implications for the Growth of the Welfare State." *The American Economic Review*: 852-876.

Alston, Lee J and Joseph P Ferrie (1999). *Southern Paternalism and the American Welfare State: Economics, Politics, and Institutions in the South, 1865-1965*. Cambridge: Cambridge University Press.

The Annual Report of the Bureau of Vital Statistics of the North Carolina State Board of Health. North Carolina State Board of Health (1914-1917; 1922-1950). Raleigh, NC: Edwards & Broughton Printing Company.

The Annual Report of the State Board of Health of South Carolina. South Carolina State Board of Health (1916-1949). Columbia, SC.

Ayer, Hartwell M. (1895). *Resources and Manufacturing Industries of the State of South Carolina*. Charleston: Lucas & Richardson Company.

Baker, Richard B. (2015) "From the Field to the Classroom: The Boll Weevil's Impact on Education in Rural Georgia." *The Journal of Economic History* 75.4: 1128-1160.

Bhatia, B (1963). *Famines in India: A Study in Some Aspects of the Economic History of India with Special Reference to Food Problems*. Bombay: Asia Publishing House.

Biddle, Jeff (2008). "Explaining the Spread of Residential Air Conditioning, 1955–1980." *Explorations in Economic History* **45**(4): 402-423.

Biddle, Jeff (2011). "Making Consumers Comfortable: The Early Decades of Air Conditioning in the United States." *The Journal of Economic History* **71**(4): 1078-1094.

Bleakley, Hoyt (2007). "Disease and Development: Evidence from Hookworm Eradication in the American South." *The Quarterly Journal of Economics* **122**(1): 73-117.

Bleakley, Hoyt (2010). "Malaria Eradication in the Americas: A Retrospective Analysis of Childhood Exposure." *American Economic Journal: Applied Economics* **2**(2): 1-45.

Bloome, Deirdre, James Feigenbaum, and Christopher Muller. "Tenancy, Marriage, and the Boll Weevil Infestation, 1892–1930." *Demography* 54.3 (2017): 1029-1049.

Bollet, Alfred J (1992). "Politics and Pellagra: The Epidemic of Pellagra in the Us in the Early Twentieth Century." *The Yale Journal of Biology and Medicine* **65**(3): 211.

Burkholder, Paul R, Ilda Mc Veigh and Dorothy Moyer (1944). "Niacin in Maize." *The Yale Journal of Biology and Medicine* **16**(6): 659.

Cereal Enrichment in Perspective, 1958. National Research Council Food and Nutrition Board (1958). Prepared by the Committee on Cereals. Washington, D.C.: National Academy of Sciences.

Collins, William J (2003). "The Labor Market Impact of State-Level Anti-Discrimination Laws, 1940–1960." *International Labor Relations Review* **56**(2): 244-272.

DeCanio, Stephen (1973). "Cotton “Overproduction” in Late Nineteenth-Century Southern Agriculture." *The Journal of Economic History* **33**(3): 608-633.

Downs, Matthew L (2014). *Transforming the South: Federal Development in the Tennessee Valley, 1915-1960*: LSU Press.

Edgar, Walter (1992). *South Carolina in the Modern Age*. Columbia: University of South Carolina Press.

Elvehjem, Co A, Rj Madden, Fm Strong and Dw Wooley (1937). "Relation of Nicotinic Acid and Nicotinic Acid Amide to Canine Black Tongue." *Journal of the American Chemical Society* **59**: 1767-1768.

Etheridge, Elizabeth W (1972). *The Butterfly Caste. A Social History of Pellagra in the South*.

Goldberger, Joseph, C. H. Waring, and William F. Tanner (1923). "Pellagra prevention by diet among institutional inmates." *Public Health Reports (1896-1970)*: 2361-2368.

Goldberger, Joseph, C. H. Waring and David G Willets (1915). "The Prevention of Pellagra: A Test of Diet among Institutional Inmates." *Public Health Reports (1896-1970)*: 3117-3131.

Goldberger, Joseph, George Alexander Wheeler, Edgar Sydenstricker and Wilford I King (1928). "A Study of Endemic Pellagra in Some Cotton-Mill Villages of South Carolina: An Abstract." *Public Health Reports (1896-1970)*: 2645-2647.

Goldberger, Joseph, George Alexander Wheeler and Edgar Sydenstricker (1920). "A Study of the Relation of Diet to Pellagra Incidence in Seven Textile-Mill Communities of South Carolina in 1916." *Public Health Reports (1896-1970)*: 648-713.

Goldberger, Joseph, George Alexander Wheeler, Edgar Sydenstricker and Willford Isbell King (1929). "A Study of Endemic Pellagra in Some Cotton Mill Villages of South Carolina." *Hygienic Laboratory Bulletin No. 153*.

Haines, Michael, Price Fishback and Paul Rhode (2015). "United States Agriculture Data, 1840–2010. Icpsr35206-V2." *Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor]*: 08-05.

The Health Bulletin. North Carolina State Board of Health (1920).

The Health Bulletin. North Carolina State Board of Health (1921).

Hunter, Walter David and Bert Raymond Coad (1923). *The Boll-Weevil Problem*. Washington, D.C.: US Dept. of Agriculture.

Kitchens, Carl (2013). "The Effects of the Works Progress Administration's Anti-Malaria Programs in Georgia 1932–1947." *Explorations in Economic History* **50**(4): 567-581.

Krehl, W. D., De La Huerga, J., Elvehjem, C. A., & Hart, E. B. (1946). The distribution of niacin amide and niacin in natural materials. *Journal of Biological Chemistry*, *166*, 53-57.

Lange, Fabian, Alan L Olmstead and Paul W Rhode (2009). "The Impact of the Boll Weevil, 1892–1932." *The Journal of Economic History* **69**(03): 685-718.

Love, Albert Gallatin and Charles Benedict Davenport (1920). *Defects Found in Drafted Men*. Washington, D.C.: US Government Printing Office.

Lumey, Lambert H, Aryeh D Stein and Ezra Susser (2011). "Prenatal Famine and Adult Health." *Annual Review of Public Health* **32**: 237-262.

McGuire, Robert A (1980). "A Portfolio Analysis of Crop Diversification and Risk in the Cotton South." *Explorations in Economic History* **17**(4): 342-371.

McGuire, Robert and Robert Higgs (1977). "Cotton, Corn, and Risk in the Nineteenth Century: Another View." *Explorations in Economic History* **14**(2): 167-182.

Mooney, Stephen J, Justin Knox and Alfredo Morabia (2014). "The Thompson-Mcfadden Commission and Joseph Goldberger: Contrasting 2 Historical Investigations of Pellagra in Cotton Mill Villages in South Carolina." *American Journal of Epidemiology* **180**(3): 235-244.

Mortality Statistics. United States Department of Commerce: Bureau of the Census (1900-1936). Washington, D.C.: United States Government Printing Office.

Park, Youngmee K, Margaret A Mcdowell, Eric A Hanson and Elizabeth A Yetley (2001). "History of Cereal-Grain Product Fortification in the United States." *Nutrition Today* **36**(3): 124-137.

Park, Youngmee K, Christopher T Sempos, Curtis N Barton, John E Vanderveen and Elizabeth A Yetley (2000). "Effectiveness of Food Fortification in the United States: The Case of Pellagra." *American journal of public health* **90**(5): 727.

Rajakumar, Kumaravel (2000). "Pellagra in the United States: A Historical Perspective." *Southern Medical Journal* **93**(3): 272-277.

Proceedings of the Thirty-First Annual Meeting of the Conference of State and Provincial Boards of Health of North America Held at Washington, D.C., May 15, 1916.

Siler, Joseph Franklin, Pe Garrison and Wj Macneal (1914). *Pellagra: A Summary of the First Progress Report of the Thompson-Mcfadden Pellagra Commission*. Chicago: American Medical Association.

Siler, Joseph Franklin, Pe Garrison, Wj Macneal, Hd Singer, Pa Schule and Os Hillman (1915). *Pellagra Ii: Second Progress Report of the Thompson-Mcfadden Pellagra Commission of the New York Post-Graduate Medical School and Hospital*. Chicago: American Medical Association.

Spark, Arlene, Lauren M. Dinour, and Janel Obenchain. *Nutrition in public health: principles, policies, and practice.* Boca Raton: CRC Press, 2015.

Spies, Tom D. "Observations on the Treatment of Pellagra." *Journal of Clinical Investigation* 13.5 (1934): 807–816.

Strengthening U.S. Programs to Improve Health in Developing Countries. National Academy of Sciences, Institute of Medicine (1978). Washington, D.C.: National Academy of Sciences.

Study of Consumer Purchases in the United States, 1935-1936. United States Department of Labor. Bureau of Labor Statistics. Cost of Living Division, United States Department of Agriculture. Bureau of Home Economics. Economics Division, United States National Resources Committee. Consumption Research Staff. Industrial Section, United States Central Statistical Board, and United States Works Progress Administration. ICPSR08908-v3. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2009-06-29.

Sutch, Richard. 1975. "The Treatment Received by American Slaves: A Critical Review of the Evidence Presented in Time on the Cross." *Explorations in Economic History*, 12:335-438.

Vital Statistics of the United States. United States Department of Commerce: Bureau of the Census (1937-1950). Washington, D.C.: United States Government Printing Office.

Wilder, Russell M (1956). "A Brief History of the Enrichment of Flour and Bread." *Journal of the American Medical Association* **162**(17): 1539-1541.

Wright, Gavin (1987). "The Economic Revolution in the American South." *The Journal of Economic Perspectives* **1**(1): 161-178.

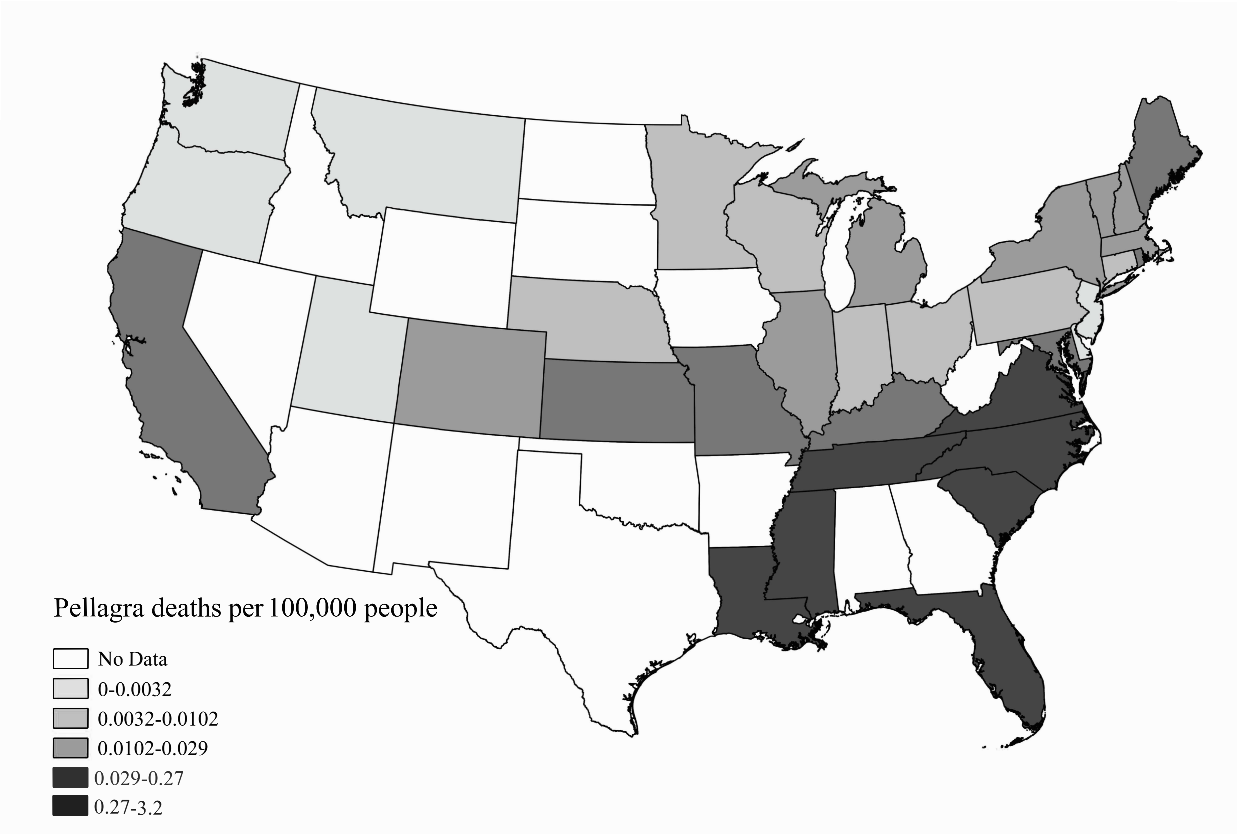
Wright, Gavin (2013). *Sharing the Prize*. Cambrdige, MA: Harvard University Press.

Wright, Gavin and Howard Kunreuther (1975). "Cotton, Corn and Risk in the Nineteenth Century." *The Journal of Economic History* **35**(3): 526-551.

Wright, Gavin and Howard Kunreuther (1977). "Cotton, Corn, and Risk in the Nineteenth Century: A Reply." *Explorations in Economic History* **14**(2): 183-195.

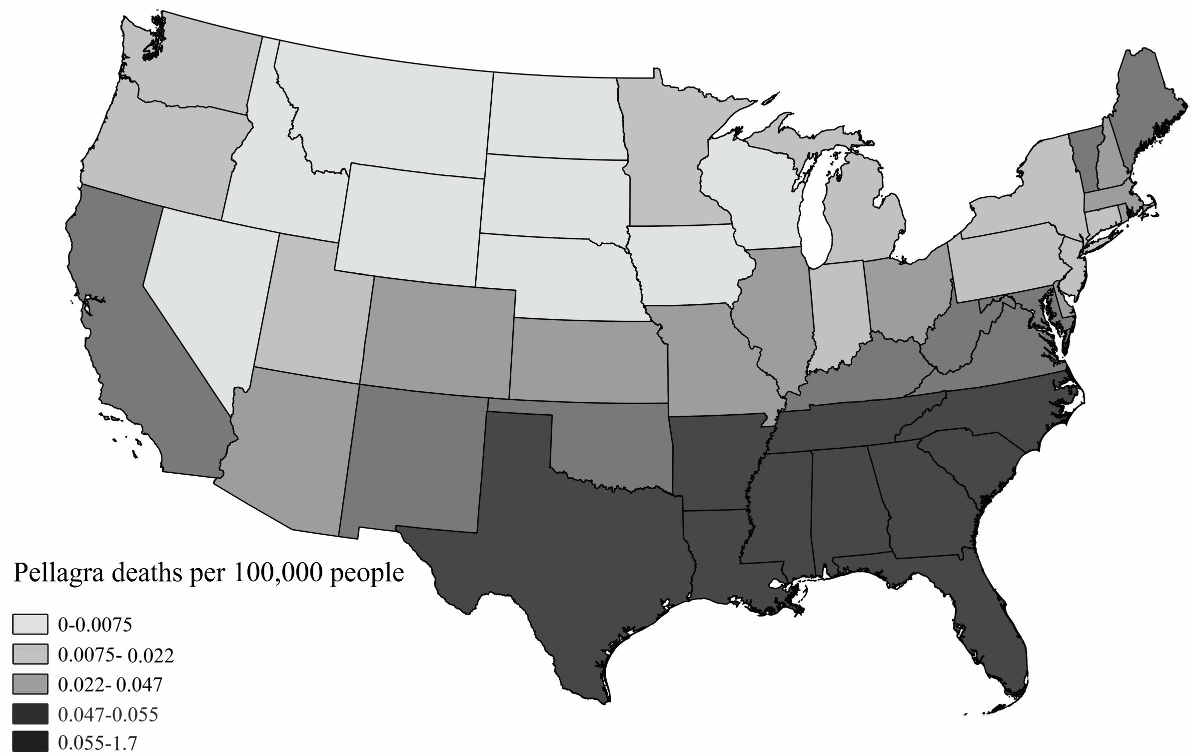
Youmans, John B (1964). "The Changing Face of Nutritional Disease in America." *Journal of American Medical Association* **189**(9): 672-676.

Figure 1
Panel A: Pellagra death rates in 1920



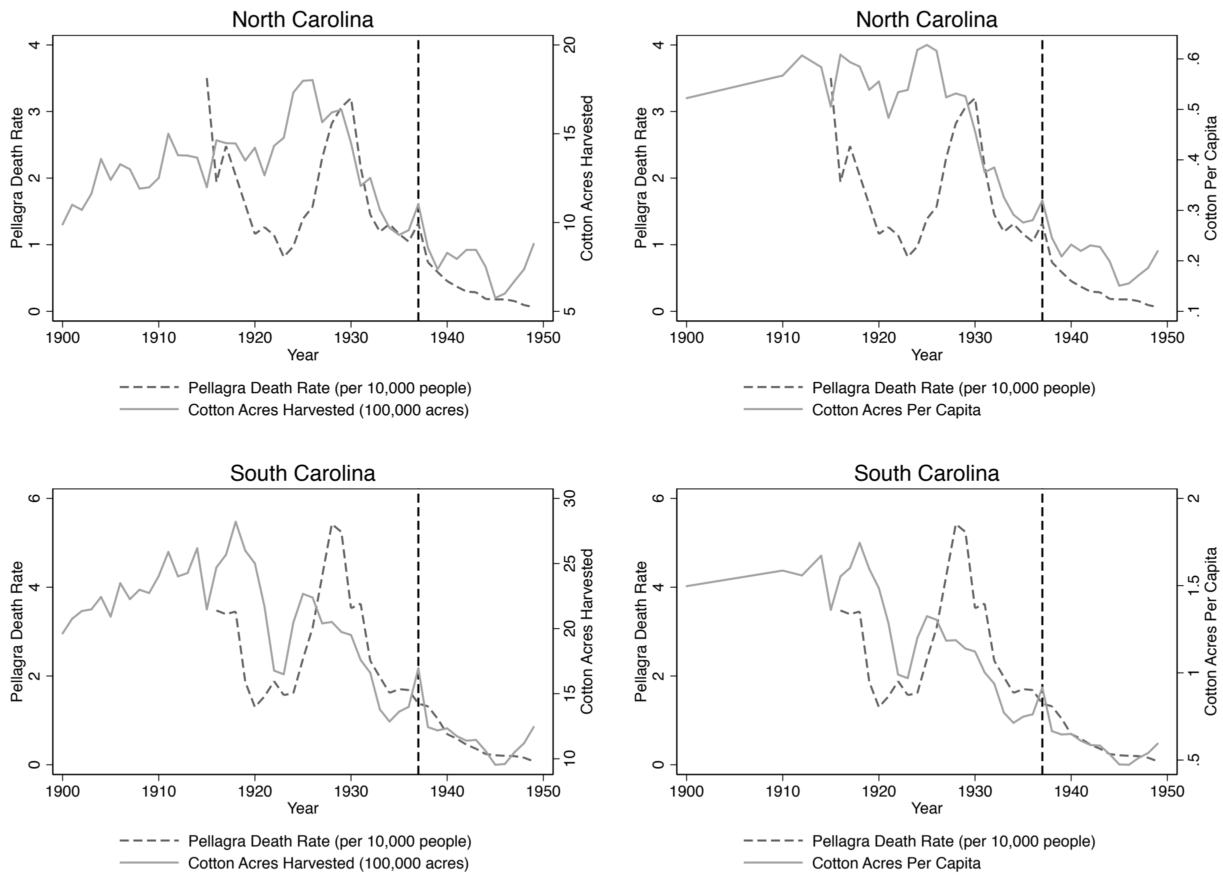
Source: Pellagra deaths at the state-level for the year 1920 come from the *Mortality Statistics of the United States, 1920*.

Panel B: Pellagra death rates in 1935



Source: Pellagra deaths at the state-level for the year 1935 come from the *Mortality Statistics of the United States, 1935*.

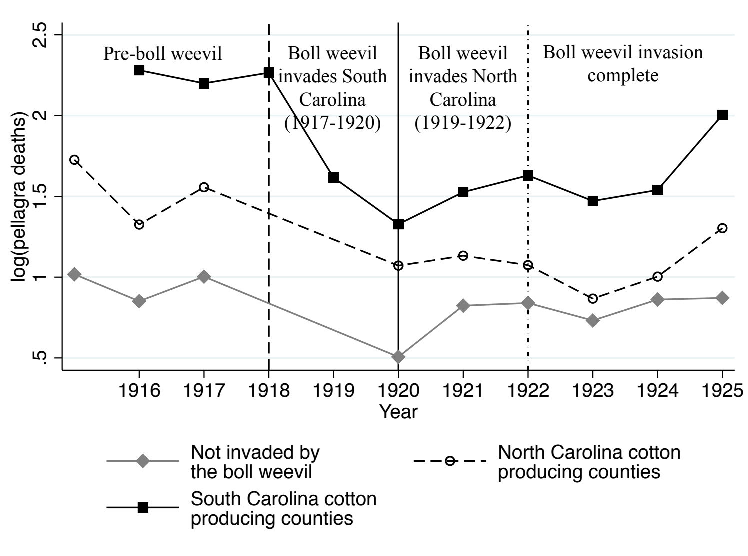
Figure 2: Pellagra and cotton acreage in North Carolina and South Carolina



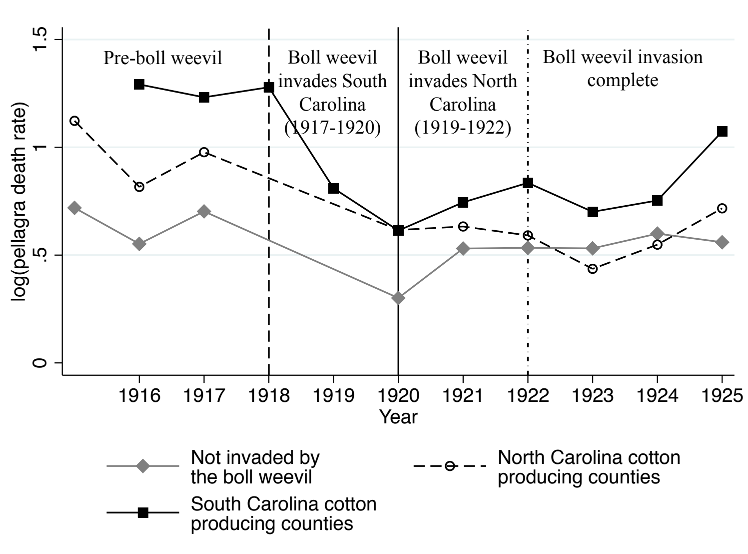
Notes: Pellagra deaths for North Carolina come from *The Annual Report of the Bureau of Vital Statistics of the North Carolina State Board of Health*. Pellagra deaths for South Carolina come from the *Annual Report of the State Board of Health of South Carolina*. Cotton acres harvested were taken from the United States Department of Agriculture's National Agricultural Statistics Service Database (Quick Stats 2.0).

Figure 3: Pellagra and the boll weevil

Panel A: Pellagra deaths



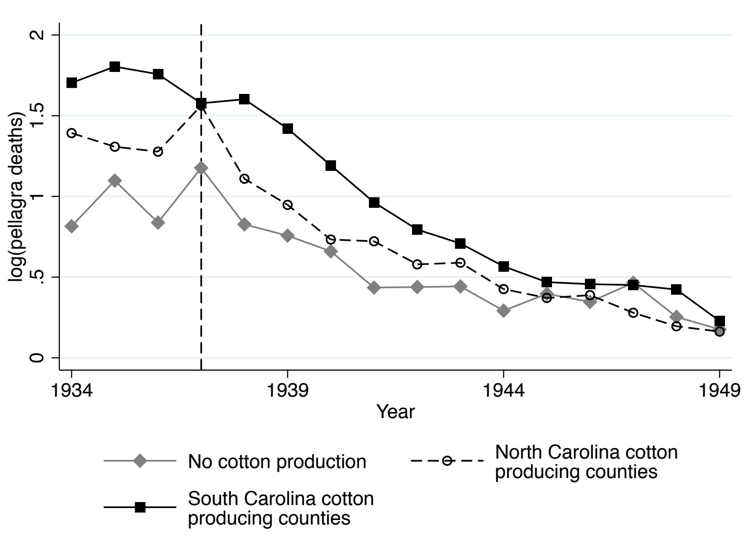
Panel B: Pellagra death rate per 100,000 people



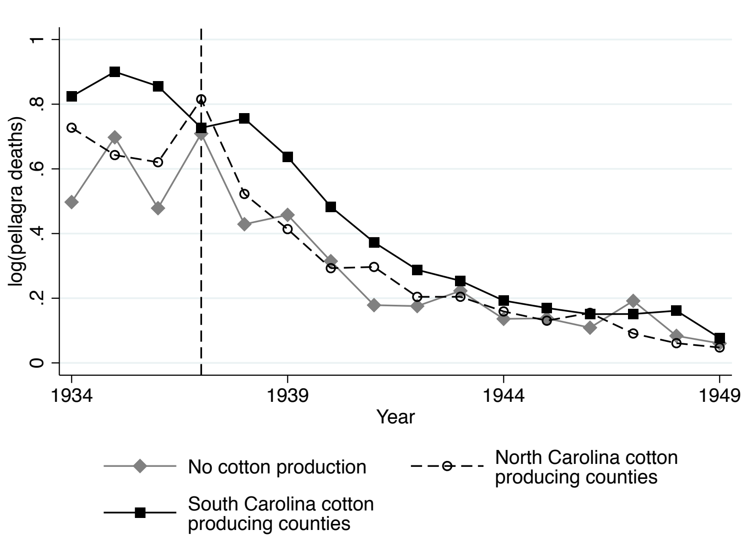
Notes: This figure graphs pellagra deaths and pellagra death rates for three sets of counties in North Carolina and South Carolina: those that were not invaded by the boll weevil (all in North Carolina), those that were invaded by the boll weevil in North Carolina, and those that were invaded by the boll weevil in South Carolina. North Carolina did not report pellagra deaths in 1918 and 1919.

Figure 4: Pellagra and the discovery of niacin

Panel A: Pellagra deaths



Panel B: Pellagra death rate per 100,000 people



Notes: This figure graphs pellagra deaths and pellagra death rates for three sets of counties in North Carolina and South Carolina: those that did not produce any cotton in 1909 (all in North Carolina), those that produced cotton in North Carolina, and those that produced cotton in South Carolina.

Table 1: Southern diets 1935 - 1936

	Non-Southern households	All Southern households	Southern urban households	Southern rural households
	(1)	(2)	(3)	(4)
Pounds of corn meal per family member used in past week	0.016	0.922***	0.425***	1.29***
Pounds of hominy grits per family member used in past week	0.002	0.126***	0.187***	0.081***
Pounds of corn meal and hominy grits per family member used in past week	0.018	1.05***	0.612***	1.37***
Loaves of white bread per family member used in past week	1.22	0.718***	1.26	0.322***
Pounds of white potatoes per family member used in past week	2.21	1.11***	1.18***	1.05***
Dozens of eggs per family member used in past week	0.43	0.367***	0.456	0.302***
Ounces of bottled milk per family member used in past week	55.92	26.56***	46.88***	11.72***
Pounds of salt pork per family member used in past week	0.012	0.289***	0.223***	0.337***
Total pounds of meat per family member used in past week	2.07	1.94**	2.33***	1.66***
Observations	2,672	1,040	439	601

Source: Study of *Study of Consumer Purchases in the United States, 1935-1936* accessed on ICPSR. Significant differences in column means relative to column (1) are reported.
* p<0.1, ** p<0.05, *** p<0.01

Table 2: Summary statistics

	High cotton producing counties	Low cotton producing counties	Did not receive boll weevil
Cotton acres (1909)	69,177	18,593	4.36
	(25,071)	(18,679)	(10.66)
Pellagra deaths pre-boll weevil (1916)	10.19	7.30	2.59
	(7.92)	(12.55)	(3.69)
Population pre-boll weevil (1910)	32,663	26,244	17,872
	(11,661)	(16,155)	(10,847)
Cotton acres per capita (1909)	2.15	0.67	0.00
	(0.40)	(0.44)	(0.00)
Pellagra death rate pre-boll weevil (1916)	2.85	1.89	1.08
	(1.62)	(1.90)	(1.31)
Percent of population urban (1910)	7.97	11.87	4.43
	(7.97)	(17.64)	(9.31)
Malaria death rate pre-boll weevil (1915)	1.70	2.39	0.12
	(1.74)	(3.54)	(0.31)
Counties	32	87	22

Notes: This table includes summary statistics for our sample of 141 counties in North Carolina and South Carolina. High cotton producing counties are defined as counties that were in the top 25% of the distribution of cotton acres per capita in 1909. All of these counties received the boll weevil. Low cotton producing counties include all counties that received the boll weevil, but were not classified as high cotton producing counties. Finally, 22 counties did not receive the boll weevil. Most of these counties did not have any cotton production, however, according to Haines et al. (2015), *United States Agriculture Data, 1840-2010*, a few of these counties did have very low level of cotton production. This is reflected in the fact that the average number of cotton acres in these counties is 4.36.

Sources: Cotton acres come from Haines et al. (2015) *United States Agriculture Data, 1840-2010*. Pellagra and malaria deaths come from the state health reports of North Carolina and South Carolina. County populations and urban populations come from decennial censuses.

Table 3: The boll weevil and pellagra

Dependent variable:	log pellagra deaths			
Geographic level:	Counties in NC (1915-1925) and SC (1916-1925)			
	(1)	(2)	(3)	(4)
Post boll weevil	-0.283***	-0.197***	-0.237***	-0.202***
	(0.0627)	(0.0687)	(0.0687)	(0.0664)
Post boll weevil * high county pre-boll weevil pellagra death rate (1915-1916 average)		-0.334***		
		(0.0943)		
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)			-0.205**	-0.267***
			(0.0911)	(0.0907)
Dependent variable:	log pellagra death rate			
	(5)	(6)	(7)	(8)
Post boll weevil	-0.235***	-0.161***	-0.212***	-0.185***
	(0.0490)	(0.0525)	(0.0528)	(0.0501)
Post boll weevil * high county pre-boll weevil pellagra death rate (1915-1916 average)		-0.291***		
		(0.0709)		
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)			-0.102	-0.150**
			(0.0660)	(0.0655)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Malaria and urbanization controls	No	No	No	Yes
Observations	1312	1312	1312	1312
Counties	141	141	141	141

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation is a county-year cell. Standard errors, reported in parentheses, are clustered at the county-level. The variable "high county pre-boll weevil pellagra death rate" is an indicator if a county was in the top 25% of the distribution of pellagra death rates in North Carolina and South Carolina in 1915 and 1916. The variable "high county pre-boll weevil cotton acres per capita" is an indicator if a county was in the top 25% of the distribution of cotton acres per capita in 1909. Malaria and urbanization controls include the malaria death rate in 1915 and the percentage of the county population that lived in an urban designated area in 1910 both interacted with a full set of year dummies.
Sources: The dependent variables come from the state health reports of North Carolina and South Carolina. The year that the boll weevil first arrived in a county comes from Lange et al. (2009). The high cotton acres indicator comes from Haines et al. (2015) *United States Agriculture Data, 1840-2010.*
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table 4: Robustness checks

	Baseline result from Table 3	Drop 1918 and 1919	Drop counties that changed borders	Control for interpolated population/ Adjust for population migration
Dependent variable:	log pellagra deaths			
Geographic level:	Counties in NC (1915-1925) and SC (1916-1925)			
	(1)	(2)	(3)	(4)
Post boll weevil	-0.202***	-0.244***	-0.256***	-0.196***
	(0.0664)	(0.0713)	(0.0689)	(0.0660)
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)	-0.267***	-0.343***	-0.241**	-0.280***
	(0.0907)	(0.0983)	(0.105)	(0.0934)
Log(interpolated population)				-0.221
				(0.596)
Dependent variable:	log pellagra death rate			
	(5)	(6)	(7)	(8)
Post boll weevil	-0.185***	-0.217***	-0.230***	-0.185***
	(0.0501)	(0.0539)	(0.0535)	(0.0502)
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)	-0.150**	-0.200***	-0.137*	-0.154**
	(0.0655)	(0.0708)	(0.0754)	(0.0638)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Malaria and urbanization controls	Yes	Yes	Yes	Yes
Observations	1312	1226	1006	1312
Counties	141	141	109	141

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation is a county-year cell. Standard errors, reported in parentheses, are clustered at the county-level. The variable "high county pre-boll weevil cotton acres per capita" is an indicator if a county was in the top 25% of the distribution of cotton acres per capita in 1909. Malaria and urbanization controls include the malaria death rate in 1915 and the percentage of the county population that lived in an urban designated area in 1910 both interacted with a full set of year dummies.

Sources: The dependent variables come from the state health reports of North Carolina and South Carolina. The year that the boll weevil first arrived in a county comes from Lange et al. (2009). The high cotton acres indicator comes from Haines et al. (2015) *United States Agriculture Data, 1840-2010*.

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

Table 5: The boll weevil and other diseases

Geographic level:	Counties in NC (1915-1925)					
	(1)	(2)	(3)	(4)	(5)	(6)
	log pellagra deaths	log typhoid deaths	log tuberculosis deaths	log measles deaths	log pneumonia deaths	log overall deaths minus pellagra deaths
Post boll weevil	-0.200**	0.0200	0.0278	-0.0130	0.0627	0.0544**
	(0.0791)	(0.0878)	(0.0478)	(0.0780)	(0.0450)	(0.0248)
	log pellagra death rate	log typhoid death rate	log tuberculosis death rate	log measles death rate	log pneumonia death rate	log overall death rate minus pellagra deaths
	(7)	(8)	(9)	(10)	(11)	(12)
Post boll weevil	-0.195***	0.0366	0.0278	-0.00323	0.0472	0.0363
	(0.0622)	(0.0700)	(0.0478)	(0.0570)	(0.0427)	(0.0244)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Malaria and urbanization controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	882	882	882	882	882	882
Counties	98	98	98	98	98	98

Notes: This table reports OLS estimates from equation (3) in the text, but uses diseases other than pellagra as the dependent variables in columns (2)-(6) and (8)-(12). The unit of observation is a county-year cell. Standard errors, reported in parentheses, are clustered at the county-level. Malaria and urbanization controls include the malaria death rate in 1915 and the percentage of the county population that lived in an urban designated area in 1910 both interacted with a full set of year dummies.
Sources: The dependent variables come from the state health reports of North Carolina and South Carolina. The year that the boll weevil first arrived in a county comes from Lange et al. (2009).
* p<0.1, ** p<0.05, *** p<0.01

Table 6: The boll weevil and crops

	Log cotton yield	Log cotton acres	Log cotton acres per capita	Log tobacco acres	Log tobacco acres per capita	
Geographic level:	Counties in North Carolina and South Carolina (1909, 1919, 1924, 1929)					
	(1)	(2)	(3)	(4)	(5)	
Post boll weevil	-0.0240	0.436***	0.115***	0.679***	0.0245***	
	(0.0184)	(0.161)	(0.0161)	(0.224)	(0.00879)	
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)	-0.0178	0.0356	-0.0821**	-0.431	-0.0277	
	(0.0294)	(0.166)	(0.0409)	(0.453)	(0.0213)	
	Log corn acres	Log corn acres per capita	Log peanut acres	Log peanut acres per capita	Log sweet potato acres	Log sweet potato acres per capita
Geographic level:	Counties in North Carolina and South Carolina (1909, 1919, 1924, 1929)					
	(6)	(7)	(8)	(9)	(10)	(11)
	0.00824	-0.00830	-0.164	0.0103	-0.112	-0.00642**
Post boll weevil	(0.0259)	(0.0126)	(0.193)	(0.00687)	(0.0752)	(0.00260)
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)	0.0157	0.0749***	0.666*	0.0111	0.184	0.0116***
	(0.0547)	(0.0232)	(0.356)	(0.0118)	(0.123)	(0.00340)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Quadratic time trend interacted with	Yes	Yes	Yes	Yes	Yes	Yes

share of cotton in total acres harvested in 1909						
Observations	564	564	564	564	564	564
Counties	141	141	141	141	141	141

Notes: This table reports OLS estimates from equation (2) in the text. The unit of observation is a county-year cell. Standard errors, reported in parentheses, are clustered at the county-level. The variable "high county pre-boll weevil cotton acres per capita" is an indicator if a county was in the top 25% of the distribution of cotton acres per capita in 1909.

Sources: The dependent variables come from Haines et al. (2015) *United States Agriculture Data, 1840-2010*. The year that the boll weevil first arrived in a county comes from Lange et al. (2009). See the text for more details.

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

Table 7: Discovery of niacin and fortification laws – North Carolina and South Carolina

	log pellagra death rate						
Time period:	(1934-1941)		(1938-1949)			(1934-1949)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post niacin discovery * high pre-niacin pellagra death rate (1928)	-0.147**					-0.154**	
	(0.0688)					(0.0638)	
Post niacin disocvery * high pre-niacin cotton acres per capita (1909)		-0.0706					-0.0668
		(0.0520)					(0.0504)
Post fortification law			-0.0479*	-0.0131	0.00371	-0.0163	-0.00274
			(0.0254)	(0.0303)	(0.0276)	(0.0295)	(0.0270)
Post fortification law * high pre-niacin pellagra death rate (1928)				-0.114***		-0.101***	
				(0.0319)		(0.0337)	
Post fortification law * high pre-niacin cotton acres per capita (1909)					-0.132***		-0.0925***
					(0.0314)		(0.0315)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Malaria and urbanization controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1128	1128	1692	1692	1692	2256	2256
Counties	141	141	141	141	141	141	141

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation is a county-year cell. Standard errors, reported in parentheses, are clustered at the county-level. "Post niacin discovery" is an indicator variable that takes a value of one beginning in 1937 with the discovery of niacin. "Post fortification law" is an indicator variable that takes a value of one beginning in the year that a state past a mandatory fortification law. North Carolina passed a mandatory fortification law in 1945 and South Carolina passed a mandatory fortification law in 1942. The variable "high pre-niacin pellagra death rate (1928)" is an indicator if a county was in the top 25% of the distribution of pellagra death rates in North Carolina and South Carolina in 1928. The variable "high pre-niacin cotton acres per capita (1909)" is an indicator if a county was in the top 25% of the distribution of cotton acres per capita in 1909. Malaria and urbanization controls include the malaria death rate in 1915 and the percentage of the county population that lived in an urban designated area in 1910 both interacted with a full set of year dummies.
Sources: The dependent variables come from the state health reports of North Carolina and South Carolina. The high cotton acres indicator comes from Haines et al. (2015) *United States Agriculture Data, 1840-2010*.
* p<0.1, ** p<0.05, *** p<0.01

APPENDIX

In this appendix, we present more historical background and further robustness checks. Table A.1 provides details on the bread enrichments standards proposed by the FDA in 1941.

Table A.2 provides more details on the arrival of the boll weevil. In particular, it shows the cumulative percentage of counties in our sample to have been impacted by the boll weevil by year. Most of the invasion occurs between 1917 and 1922 and 22 counties are not treated by the boll weevil.

Table A.3 shows the following. Column (1) uses the log of the pellagra death rate as the dependent variable and uses a different measure of cotton intensity (cotton acres as a percent of all fam acres) than in our baseline regressions. Although the not quite statistically significant (p-value = 0.27), the same sign is obtained as when cotton acres per capita is used. Column (2) uses the log of the pellagra death rate as the dependent variable, but controls the overall death rate (minus pellagra deaths). Our main result remains unchanged. Finally, column (3) uses the ratio of pellagra deaths to overall deaths as the dependent variable and column (4) interpolates pellagra deaths in 1918 and 1919 for NC and uses the log of interpolated pellagra death rate. In columns (3) and (4), the dependent variable decreases after the arrival of the boll weevil and decreases more in high cotton counties.

Table A.4 is requires a more extensive motivation and that is provided in the following section.

Table A.5 uses state level data and presents additional evidence that pellagra declines after a state passes a mandatory fortification law.

IS THERE EVIDENCE OF SELECTIVE MIGRATION?

One key concern with our results centers on migration. While we adopt several remedial strategies in to address concerns about migration and population change, in this section we adopt a series of more direct tests. Our goal here is to explore the possibility that boll-weevil induced out-migration might bias our estimates. Three observations motivate our concerns about migration. First, Lange et al. (2009) show that the boll weevil caused laborers to migrate out of afflicted counties. Second, Ager et al. (2015) show that women in high cotton counties were the most likely to leave the labor force in response to the arrival of the boll weevil. Third, Spark et al. (2015, p.77) show that the most affected groups from pellagra were children age 2-10 and females 22-44. These findings suggest that the two groups most likely to have suffered from pellagra also might have been the most likely to have migrated out of affected counties after the boll weevil arrived. In the face of such selective migration, it is possible that some, or all, of the reductions in pellagra we observe stem not from improved nutrition, but from the elevated rates of outmigration among the groups most likely to have suffered from the disease. Hence, in this section, we run a series of regressions in search of evidence that counties with relatively large numbers of individuals vulnerable to pellagra exhibit elevated rates of outmigration. To measure the extent of such selective out-migration, we again use the data from North Carolina and South Carolina and adopt two separate triple difference strategies similar those employed by Aaronson and Mazmder (2011).

In our first triple difference strategy, we ask if counties with high initial cotton and high initial pellagra rates exhibit elevated rates of outmigration. More precisely, our regression equation is:

$$
\begin{aligned}
&ln[population]_{ct} \qquad (3)\\
&= \alpha + \gamma * [high\,pellagra]_{c,1915} + \beta_0 * [boll\,weevil]_{ct} + \gamma\\
&* [high\,cotton]_{c,1909} + \beta_1 * [boll\,weevil]_{ct} \times [high\,cotton]_c + \beta_2\\
&* [boll\,weevil]_{ct} \times [high\,pellagra]_{c,1915} + \beta_3\\
&* [boll\,weevil]_{ct} \times [high\,cotton]_{c,1909} \times [high\,pellagra]_{c,1915}\\
&+ \theta_c + \theta_t + \varepsilon_{ct}
\end{aligned}
$$

All variables are defined as above.

The main variable of interest for this regression is the triple interaction between boll weevil, high cotton, and high pellagra. If counties with both high initial pellagra and high initial cotton exhibit elevated rates of outmigration, the coefficient on this interaction (β_3) would be negative and statistically significant. The coefficients on the boll weevil-high cotton interaction (β_1) and the boll weevil-high pellagra interaction (β_2) are also of some interest. In particular, the coefficient on the boll weevil-high cotton interaction serves as a sort of replication/verification exercise and asks if the patterns we observe in North Carolina and South Carolina comport with Lange et al. (2009) whose work suggests a negative and significant coefficient (i.e., the boll weevil induced outmigration from high cotton counties). The second interaction on the boll weevil and high pellagra indicators tells us whether places with high pellagra rates (independent of their status in terms of cotton production) are generally observing more outmigration.

In our second triple difference strategy we focus on women (age 22 to 44) and children (age 2 to 10) and ask if those groups exhibit elevated rates of outmigration in counties with high intensity treatment. Specifically, the regression is as follows:

$$
\begin{aligned}
ln[group\_pop]_{gct} \qquad (4) \\
= \alpha + [group]_c + \beta_0 * [boll\,weevil]_{ct} + \gamma * [intensity]_c + \beta_1 \\
* [boll\,weevil]_{ct} \times [intensity]_c + \beta_2 * [boll\,weevil]_{ct} \times [group]_c \\
+ \beta_3 * [boll\,weevil]_{ct} \times [intensity]_c \times [group]_c + \theta_c + \theta_t + \varepsilon_{ct}
\end{aligned}
$$

In equation (4), $ln[group\_pop]_{cgt}$ is the population for group g in county c in census year t. $[boll\,weevil]_{ct}$ and $[intensity]_c$ have the same definitions as in equation (1), and as above we include county and year fixed effects. Groups are defined by their vulnerability. In one set of regressions, the vulnerable group will be children, age 2 to 10, and in another set of regressions the vulnerable group will be females, age 22 to 44. The non-vulnerable group consists of everyone not contained in the vulnerable group. Hence, the variable $[group]_c$ is an indicator that equals 1 if the population group g is vulnerable, and 0 otherwise.

The main variable of interest here is the triple interaction between boll weevil, intensity, and group. If women and children (the groups most vulnerable to pellagra) exhibit elevated rates of outmigration the coefficient on this interaction (β_3) would be negative and statistically significant.

The results are reported in Table A.4. The results from column (1) are consistent with Lange et al (2009) (high cotton counties exhibit higher rates of outmigration post boll weevil), and show that high pellagra is not associated with elevated rates of migration in either the double or triple difference. The results from columns (2) and (3) indicate that females (age 22 to 44) do not exhibit significantly higher rates of outmigration post-boll weevil than other (less vulnerable) groups. Similarly, the results from columns (4) and (5) indicated that children (age 2 to 10) do not exhibit significantly higher rates of outmigration post-boll weevil than other (less vulnerable) groups. Overall the patterns observed here provide little support for the hypothesis that the groups most vulnerable to pellagra are migrating out of high cotton counties in response to the boll weevil at higher rates than other groups.

Table A1: Bread enrichment standards proposed by FDA (1941)

	Minimum (mg)	Maximum (mg)
Thiamine	1.1	1.8
Riboflavin	0.7	1.6
Niacin	10	15
Iron	8	12.5
Optional Ingredients:		
Vitamin D	150	750
Calcium	300	800

Source: Food and Bread Enrichment 1949 - 1950; National Research Council Committee on Cereals.

Table A2: Arrival of the boll weevil

	Number of counties	Cumulative percent of sample
Year of boll weevil arrival:		
1917	1	0.71
1918	7	5.67
1919	36	31.21
1920	13	40.43
1921	29	60.99
1922	33	84.40
Does not arrive	22	100

Source: The year that the boll weevil first arrived in a county comes from Lange et al. (2009).

Table A3: Additional robustness checks

	Different measure of cotton intensity	Control for overall death rate (minus pellagra deaths)	Dependent variable: Pellagra deaths to overall deaths ratio	Dependent variable: Interpolated log pellagra death rate
	(1)	(2)	(3)	(4)
Post boll weevil	-0.202***	-0.184***	-0.00414***	-0.179***
	(0.0501)	(0.0505)	(0.00119)	(0.0495)
Post boll weevil * high county pre-boll weevil cotton acres as percent of farm acres (1909)	-0.0777			
	(0.0702)			
Post boll weevil * high county pre-boll weevil cotton acres per capita (1909)		-0.161**	-0.00600***	-0.151**
		(0.0653)	(0.00187)	(0.0653)
Log(overall death rate minus pellagra deaths)		0.111		
		(0.110)		
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Malaria and urbanization controls	Yes	Yes	Yes	Yes
Observations	1312	1312	1312	1508
Counties	141	141	141	141

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation is a county-year cell. Standard errors, reported in parentheses, are clustered at the county-level. The variable "high county pre-boll weevil cotton acres as percent of farm acres (1909)" is an indicator if a county was in the top 25% of the distribution of cotton acres as a percent of total farm acres 1909. The variable "high county pre-boll weevil cotton acres per capita" is an indicator if a county was in the top 25% of the distribution of cotton acres per capita in 1909. Malaria and urbanization controls include the malaria death rate in 1915 and the percentage of the county population that lived in an urban designated area in 1910 both interacted with a full set of year dummies.

Sources: The dependent variables come from the state health reports of North Carolina and South Carolina. The year that the boll weevil first arrived in a county comes from Lange et al. (2009). The high cotton acres indicator comes from Haines et al. (2015) *United States*

Agriculture Data, 1840-2010.
* p<0.1, ** p<0.05, *** p<0.01

Table A4: The boll weevil and migration

	(1)	(2)	(3)	(4)	(5)
Census years:	1910, 1920, 1930				
Dependent variable:	log(population)	log(female age 22-44 population) or log(population – female age 22-44 population)		log(children age 2-10 population) or log(population – children age 22-44 population)	
Population:	Entire	Female age 22-44	Female age 22-44	Children age 2-10	Children age 2-10
Intensity1:	High cotton	High cotton	High pellagra	High cotton	High pellagra
Intensity2:	High pellagra	None	None	None	None
	Coefficients				
β_0 = Post BW	0.0616**	0.0541**	0.0130	0.0988***	0.0364
	(0.0268)	(0.0217)	(0.0204)	(0.0249)	(0.0223)
β_1 = Post BW*Intensity1	-0.194***	-0.165***	0.0128	-0.187***	-0.00646
	(0.0616)	(0.0428)	(0.0477)	(0.0425)	(0.0446)
β_2 = Post BW*Population/Intensity	0.0429	0.0393***	0.0203**	-0.0577***	-0.0288***
	(0.0665)	(0.0119)	(0.00799)	(0.0122)	(0.00938)
β_3 = Post BW * Intensity1*Population/Int	0.0195	-0.0190	-0.00879	0.0183	0.00516
	(0.0997)	(0.0133)	(0.0138)	(0.0170)	(0.0184)
	Differences (Pre BW - post BW)				
β_0	0.0616**	0.0541**	0.0130	0.0988***	0.0364
	(0.0268)	(0.0217)	(0.0204)	(0.0249)	(0.0223)
$\beta_0 + \beta_1$	-0.133**	-0.111***	0.0259	-0.0884**	0.0299
	(0.0551)	(0.0360)	(0.0412)	(0.0345)	(0.0378)
$\beta_0 + \beta_2$	0.105*	0.0934***	0.0333	0.0411*	0.00760
	(0.0622)	(0.0268)	(0.0238)	(0.0228)	(0.0209)
$\beta_0 + \beta_1 + \beta_2 + \beta_3$	-0.0702	-0.0911***	0.0373	-0.128***	0.00630
	(0.0539)	(0.0353)	(0.0403)	(0.0394)	(0.0448)

	Difference in Difference				
β_1	-0.194***	-0.165***	0.0128	-0.187***	-0.00646
	(0.0616)	(0.0428)	(0.0477)	(0.0425)	(0.0446)
$\beta_1 + \beta_3$	-0.175**	-0.184***	0.00404	-0.169***	-0.00130
	(0.0813)	(0.0445)	(0.0477)	(0.0475)	(0.0515)
β_2	0.0429	0.0393***	0.0203**	-0.0577***	-0.0288***
	(0.0665)	(0.0119)	(0.00799)	(0.0122)	(0.00938)
$\beta_2 + \beta_3$	0.0624	0.0203***	0.0115	-0.0394***	-0.0236
	(0.0744)	(0.00598)	(0.0112)	(0.0119)	(0.0159)
	Triple difference				
β_3	0.0195	-0.0190	-0.00879	0.0183	0.00516
	(0.0997)	(0.0133)	(0.0138)	(0.0170)	(0.0184)
County FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	423	846	846	846	846
Counties	141	141	141	141	141

Notes: This table reports OLS estimates. The unit of observation in column (1) is a county-year cell. The unit of observation in columns (2)-(5) is a county-year-population group cell. Standard errors, reported in parentheses, are clustered at the county-level. Column (1) reports the coefficients from a triple-difference estimation where an indicator for Post BW is interacted with a high pellagra and high cotton indicator. A county is considered a high pellagra county if it was in the top 25% of the distribution of pellagra death rates in North Carolina and South Carolina in 1915 and 1916. A county is considered a high pellagra cotton if it was in the top 25% of the distribution of cotton acres per capita in 1909. In columns (2)-(5) each county has two observations per year. The first observation is the population of a group that was especially susceptible to pellagra; women 22-44 years of age or children 2-10 years of age. The second observation is the population of the rest of the county that is not a part of the susceptible group. The coefficients in columns (2)-(5) are from a triple-difference estimation where an indicator for Post BW is interacted with a high pellagra or high cotton indicator and an indicator if the observation is for the susceptible population.

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

Table A5: Discovery of niacin and fortification laws - state

	log pellagra death rate						
	(1934-1941)		(1938-1949)			(1934-1949)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post niacin discovery * high pre-niacin pellagra death rate (1928)	-0.00269					-0.00900	
	(0.0149)					(0.0148)	
Post niacin disocvery * high pre-niacin cotton acres per capita (1909)		0.0180					0.0168
		(0.0121)					(0.0128)
Post fortification law			-0.00868**	-0.000822	-0.00295	0.000899	-0.00477
			(0.00343)	(0.00549)	(0.00497)	(0.00659)	(0.00469)
Post fortification law * high pre-niacin pellagra death rate (1928)				-0.0126		-0.0169*	
				(0.00797)		(0.00858)	
Post fortification law * high pre-niacin cotton acres per capita (1909)					-0.00892		-0.0126*
					(0.00793)		(0.00692)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	96	96	144	144	144	192	192
States	12	12	12	12	12	12	12

Notes: This table reports OLS estimates from equation (3) in the text. The unit of observation is a state-year cell. Standard errors, reported in parentheses, are clustered at the state-level. States includes in the analysis are: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Virginia. "Post niacin discovery" is an indicator variable that takes a value of one beginning in 1937 with the discovery of niacin. "Post fortification law" is an indicator variable that takes a value of one beginning in the year that a state past a mandatory fortification law. Alabama passed a law in 1943, Arkansas in 1945, Georgia in 1945, Louisiana in 1942, Mississippi in 1945, North Carolina in 1945, Oklahoma in 1947, and South Carolina in 1942. The variable "high pre-niacin pellagra death rate (1928)" is an indicator if a state was in the top 50% of the distribution of pellagra death rates in 1928. The variable "high pre-niacin cotton acres per capita (1909)" is an indicator if a state was in the top 50% of the distribution of cotton acres per capita in 1909. Malaria and urbanization controls include the state malaria death rate in 1928 and the percentage of the state's population that lived in an urban designated area in 1910 both interacted with a full set of year dummies.

Sources: The dependent variable comes from the *Mortality Statistics of the United States, 1915-1936* and the *Vital Statistics of the United States, 1937-1949*. Cotton acres harvested were taken from the United States Department of Agriculture's National Agricultural Statistics Service Database (Quick Stats 2.0).

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