Private Benefits and Public Goods: Agricultural Drainage and Malaria in the United States 1850-1969*

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1 Introduction

A significant portion of the eastern United States has poorly drained soils that are not suitable for crop production absent artificial drainage. Drain tile, first used in the U.S. in upstate New York in 1835 and adopted across the upper Midwest in the following decades, made drainage "sufficiently cheap and efficient for general adoption (French, 1859)." In order for tile drainage to be successful, large open ditches were needed to serve as outlet drains, requiring improved engineering approaches and collective investment. It was the combination of innovations in local governance, engineering, and tile manufacture that allowed drainage to begin in earnest across the country (McCrory, 1928). Today, of 215 million acres of wetlands estimated to exist in the contiguous United States at colonization, 124 million have been drained, 80-87% for agricultural purposes (McCorvie and Lant, 1993; Tiner, 1984)

In 1880, it was estimated the drainage of unimproved wetlands increased sale value by a factor of five (Prince, 2008). Yet capturing these increased values required coordination among neighboring landowners that was initially absent. The U.S. government passed a series of Swamp Land Acts (1849, 1850, and 1860) which allowed 15 states to eventually claim nearly 65 million acres, provided the lands were reclaimed via drainage (Dahl and Allord, 1982). There was little or no initial improvement under the Acts because "piecemeal ditching" was ineffective absent open outlet channels and coordinated drainage works, which required the passage of "[d]itch laws or drainage laws authoriz[ing] the organization of drainage undertakings which required groups of farmers to participate (Prince, 2008)." Large investment in drainage works required institutional innovation, in the form of state legislation, for the creation of drainage management districts.

In addition to the local public good benefits of drainage cooperation, broad public goods were provided via the elimination of malarial infections contemporaneously linked to marshy areas and definitively linked to mosquitoes near the end of the century. Throughout the 1800s malaria affected most of the populated regions of the United States, was one of the country's leading causes of death (in 1850 45.7 of every 1,000 deaths were caused by malarial fevers), and had long-term health impacts including stunting and chronic conditions in later life (Hong, 2007). In the northern United States malarial decreases occurred prior to any conscious effort on the part of public health agencies (Barber, 1929). In the South, a slew of factors including impoverished soils made it "financially impossible to install scientific drainage," and malarial eradication required significant public investment, including via the successful eradication campaign of the Works Progress Administration (Faust, 1951; Kitchens, 2013b).

An economic framework based on local collective governance explains how drainage districts, technological change, and private costs and benefits affect the level of investment in agricultural drainage. In general, a standard theory of public goods would suggest that drainage investment would be under-supplied via voluntary contributions. However, a group of farmers seeking to to drain lands could act cooperatively, provided they solve the collective action problem (Olson, 1989). Ostrom (1990) offers insight into when such cooperation is likely to occur. I argue that drainage district laws provided sufficient legal authority for local collective investment in drainage, through contributions of time and labor a la Bergstrom et al. (1986) as well as through local taxing and eminent domain authority. Such local public good investment simultaneously addressed the larger public good of malaria control, making general public investment unnecessary.

In this paper, I provide evidence that this framework explains investment in drainage. While successful drainage organizations were established by statute in the upper Midwest, their adoption in the South lagged, as did tile-drainage and the eradication of malaria. Because county-level drainage measures do not exist prior to 1920, I show the passage of the first drainage district laws in each state coincided with a "catch-up" of improved acres and land value in counties with poorly drained soils relative to others. I estimate artificial drainage increased the value of agricultural land in the worst-drained counties by $13-29B (2020 dollars) in the eastern United states.

Drainage laws were not assigned to states exogenously, and multiple factors appear to jointly determine whether local collective action was sufficient to provide agricultural drainage. Because climatic and economic conditions outside the South were more conducive to the control of malarial infection, I provide a descriptive analysis of the linkages between drainage and malaria. Consistent with the economic framework, Southern states lagged in the passage of drainage district laws by around 50 years. The lack of local drainage investment in the South in the 1930s, after most drainage was complete elsewhere in the country, meant malarial eradication programs were required using additional public investment.

2 Empirical Setting

2.1 The Economics of Drainage Investment

In wet and poorly drained soils, excess water in the root zone of cultivated crops can create water-logging, preventing the absorption of oxygen and drastically reducing yields or killing the plants entirely. Water is held in the soil via surrounding soil pore pressure, and the water tables can be artificially lowered via within-soil flow if nearby drainage provides a lower pressure pathway. The construction of open ditches to remove excess standing water and lower water tables was utilized throughout the United States from its founding for this purpose. However, these ditches proved impractical for agricultural production in many cases. The ditches themselves were labor-intensive and typically three to five feet deep. To adequately drain agricultural soils, these ditches bisected fields at regular intervals, utilizing a significant amount of the land surface area and making planting and harvesting difficult. The ability to cover these ditches while maintaining drainage via *underdrainage* was required for practical use.

Stone and pole drainage was utilized throughout the 19th Century, but was uneconomical for general agricultural adoption. It was the advent and diffusion of clay drain tile, first used in the United States in Seneca County, NY in 1835, that changed agriculture in the United States (McCrory, 1928). In 1859 Henry D. French wrote in his book *Farm Drainage*: "[n]o system of drainage can be made sufficiently cheap and efficient for general adoption, with other materials than drain tiles (French, 1859)." Drain tiles were initially horseshoe shaped and then laid on flat tile, with this method replaced by cylindrical tile starting around 1858 (McCrory, 1928). The first tile machine was imported in 1848, with local production necessary due to the weight of tiles. Production quickly spread with 66 tile factories established from 1850-59, 234 from 1860-69, and 840 from 1870-79 (McCrory, 1928).

The natural wetlands of the United States were viewed by Federal Government policy as "unproductive and an economic waste" from formation until at least 1956 (Palmer, 1915). To encourage their development via drainage, Congress passed a series Swamp Land Acts (1849, 1850, and 1860) for reclamation. At the time, the *Congressional Globe* summarized the justification as follows:

The passage of this bill and the donation of these scraps of land, injurious as they exist, to the

States, and utterly valueless to this Government, is but the beginning of the work of reclamation; the State Legislatures must follow, appropriate money, and redeem them from the water—and the sooner the better for the health of the people and the prosperity of the country...These formations of swamps and periodically overflowed lands are common to almost all Territories of sufficient area to constitute a State. They are evils common to all countries, rendering, in their original condition, portions of the earth not only desolate and unsusceptible of cultivation, but fruitful promoters of disease and death. They can only be removed, or their evils gated by means of labor and money, which, when properly employed must redeem portions of the land from sterility, and make it valuable and useful, instead of the generator of disease.

-Rives et al. (1861) from (McCorvie and Lant, 1993)

Table 1: Swamp Land Acts

Year	State	Acres
1849	Louisiana	9,493,456
1850	Alabama	441,289
1850	Arkansas	7,686,575
1850	California	2,192,875
1850	Florida	20,325,013
1850	Illinois	1,460,184
1850	Indiana	1,259,231
1850	Iowa	1,196,392
1850	Michigan	5,680,310
1850	Mississippi	3,347,860
1850	Missouri	3,432,481
1850	Ohio	26,372
1850	Wisconsin	3,360,786
1860	Minnesota	4,706,503
1860	Oregon	286,108
TOTAL		84,895,415

Source: (Fretwell, 1996)

The lands made available to the states under the Acts are shown in table 1. As alluded to in the the *Congressional Globe*, the Acts were a first step, and the lands still required investment for reclamation. The initial belief that the government would simply use land sale funds to finance drainage proved incorrect because the funds raised were insufficient and state governments were incapable of funding these types of public works. Responsibility for the investment in reclamation passed from the states to counties, who subsequently divested the lands in the hopes that private investors would drain them (Prince, 2008). Some large landowners did engage in drainage projects, but generally the Swamp Land Acts led to large amounts of land in the hands of speculators lacking the ability to reclaim it individually.

The issue facing the owners of wetlands was one of coordination to invest in the local public goods required for reclamation. Common Law prohibitions prevented individual drainage that led water outflows onto neighboring parcels. While laying tiles constituted a private investment in individual agricultural production, a system of integrated outlet channels and was a prerequisite to farm-level drainage in most cases. Such drainage projects affect the lands of many landowners, often spanning multiple counties, and require new channels, levees, and embankments on private lands (Wright, 1907; Prince, 2008). A 1907 report to the U.S. Senate on the status of *Swamp and Overflowed Lands in the United States* by Wright (1907) described the problem faced in reclaiming these lands:

> *In order to secure the necessary cooperation for efficient work in all cases and to set out the detail of procedure so as to insure uniform practice, some legal method of compulsion has been found necessary, and drainage statutes have been enacted by many of the States. All the persons interested may not agree as to the necessity for the improvement, and even if they do, when it comes to deciding what lands shall be embraced in the project, where the ditches shall be located, how the work shall be done, and particularly, what each individual landowner shall pay, differences of opinion are sure to arise. To overcome this diversified sentiment and enable the owners of swamp and overflowed lands to reclaim the same in an efficient and equitable manner, drainage laws have been found necessary.*

Optimal investment by landowners in drainage infrastructure is described by the so-called Samuelson Condition: the sum of farmers' marginal rate of substitution between private goods and the public good is equal to the marginal rate of technological transformation (Samuelson, 1954). Thus, the farmers invest in producing the public good until the sum total of their marginal benefits is equal to the marginal cost of doing so.

Absent some mechanism for securing investment in the public good, there is reason to believe the public good will be under-supplied (Bergstrom et al., 1986). The result of private provision is that each sets their marginal benefit of the public good equal to the marginal cost of providing it, the Nash Equilibrium outcome. This outcome means too little public good is provided, but no farmer is willing to unilaterally invest in additional drainage infrastructure because individually their marginal benefits are equal to their marginal costs.

Olson (1989) provides a useful framework for the difficulties of solving this investment problem, which is a problem of collective action. Each farmer is better of with drainage investment, yet each also has an incentive to free-ride on the investment of others. Collective action in drainage requires some mechanism by which farmers agree to move beyond the Nash outcome via cooperation.

Ostrom (1990) provides guidance to the settings where local groups can successfully cooperate in managing natural resource problems. Relevant to this work is her finding that local groups are often successful at such management, even when central governments fail. In describing her *design principles* of successful organizations, Ostrom suggested that the right to organize locally be recognized by the central or local government, with decisions nested in local organizations. This was the key ingredient the drainage district provided.

In describing the emergence of irrigation districts in the western United States, Bretsen and Hill (2006) discuss the limitations of irrigation prior to the formation of irrigation districts, in many ways modeled after drainage districts. Large irrigation enterprises required substantial investment and rights-of-way, problems that were not solved without some governmental authority. Edwards (2016) discusses the formation of local groundwater management districts in Kansas as a result of state governmental laws. Groundwater management districts and irrigation districts are similar to drainage districts in the use of state government legislation to solve a local resource problem via local governance.

Table 2 shows the year of passage for drainage district laws for the 24 states that eventually adopt them in the eastern United States from McCorvie and Lant (1993). Although they varied somewhat in specifics, drainage districts were generally legislated to be formed via a petition from landowners in an area and typically required some combination of signatures and a vote by the majority of land area and land owners (McCorvie and Lant, 1993). Drainage districts received powers of eminent domain and taxation with decisions made by locally elected boards and provided the investments met some definition of benefiting the public at large, which courts often interpreted a requiring public health benefits (Prince, 2008). Another key feature of the dis-

Table 2: Year of Drainage District Legislation

State	Year	State	Year
Michigan	1857	Kentucky	1912
Ohio	1859	Arkansas	1921
Iowa	1873	Louisiana	1921
Illinois	1878	Oklahoma	1921
Kansas	1879	Virginia	1924
Nebraska	1881	Georgia	1926
Minnesota	1887	Florida	1927
Indiana	1889	Missouri	1929
Wisconsin	1891	South Dakota	1929
Texas	1904	Mississippi	1930
North Dakota	1905	North Carolina	1930
South Carolina	1911	Tennessee	1932

Source: Table is adapted from McCorvie and Lant (1993) based on data from Austin (1931)

tricts was financial, with districts able to issue low-interest bonds to secure cash for investment (McCrory, 1928).

In addition to facilitating public investment, drainage districts solved the problem of the anti-commons, where landowners under the common law were protected from changes in drainage that led to runoff onto their land, essentially giving farmers veto power over neighbors' projects. Bogue (1951) describes "violent opposition" from neighboring landowners to drainage projects in Illinois, but under drainage district law these types of issues were resolved in the courts and generally in favor of the public good, i.e. draining land.

The passage of drainage laws was viewed contemporaneously as a key determinant of drainage investment. When Wright (1907) wrote to the U.S. Senate about drainage, the Midwest had largely established drainage laws while the south had not (refer to table 2 for the dates):

> *Throughout the United States the progress that has been made by the several States in land drainage has depended more upon the character of the drainage laws than on the geographical location of the State or the fertility of its soils. The swamps of the Yazoo Delta, Mississippi, and those of the eastern part of North Carolina are more fertile and are susceptible of producing a field crop worth much more per acre than the lands in Indiana or Illinois, yet practically all the swamps in the latter States have been drained under the provisions of wise and beneficent State drainage laws, while little or nothing has been done to drain the lands of North Carolina and*

Mississippi.

Ultimately, it was the emerging understanding of the value of drained land, drainage technology, and drainage district legislation that facilitated the development of the lands from the Swamp Land Acts. Up to the year 1908 claims for 65,582,503 acres had been approved, and over 63,000,000 acres actually patented to the states (Palmer, 1915; Bogue, 1951).

While Mississippi, Florida, and Louisiana in the South received significant grants, Alabama's grant was less than half a million acres and Virginia, North and South Carolina, Georgia, and Tennessee were not included (see table 1). It appears that without the incentive to facilitate drainage to allow their states to claim land under the Swamp Land Act, these states (with the notable exception of South Carolina) were late in passing drainage district legislation (see table 2).

A number of institutional and state-specific geographic factors (e.g. the original colonies did not have government-owned surplus swamp lands) affected the passage of drainage district legislation and the formation of districts. But where drainage occurred was also affected by endogenous county and state characteristics. The framework of investment in a public good via local cooperation facilitated by state law provided in this section aids in understanding the factors that contributed to the success of farm drainage:

1. Investment in drainage is increasing in private agricultural benefits: Quality of the soil; suitability to high-value crops; and the effectiveness of drainage.

2. Investment in drainage is decreasing in the technical costs of drainage. Technical costs included: distance to tile factories; the availability of tile technology; and the dissemination of area-specific drainage practices.

3. Investment in drainage is decreasing in the costs of organizing and collective action. Such costs are related to the number of landowners; local institutional capacity; and the presence of drainage laws to facilitate cooperation.

While this framework is not entirely tested in the present paper, it provides some insight into the jointly determined decisions of investing in drainage and the passage of drainage district laws. Laws facilitated drainage, but the need for drainage laws was often a bottom-up phenomenon.

As such, areas where drainage was expected to be most valuable, where landowners were most familiar with its potential or where local institutional capacity was highest, moved first.

2.2 Malaria

Malaria is caused by the parasite Plasmodium and transmitted to humans via the Anopheles mosquito. By 1850 malaria had established itself throughout most of the United States (except northern New England and certain mountainous regions in the East and West) and the period ending in 1899 represented the climax of the disease in the country (Faust, 1951). In 1850, 45.7 of every 1,000 deaths were caused by malarial fevers and severe long-term health impacts of non-fatal cases included stunting and other chronic conditions (Hong, 2007). The importance of drainage for the eradication of malaria was well-understood, even prior to the understanding of disease pathology.

In the northern United States, malaria had decreased without any conscious effort on the part of public health agencies (Barber, 1929). By 1900 the disease had retreated into the South, primarily due to agricultural drainage beginning in the 1870s, but the burden of malaria persisted throughout the South until the 1910s, when eradication campaigns began, and much later in some areas (Hong, 2011).

An account of malaria in Virginia described by Barber (1929) suggested that the increase in malaria in the low lying coastal plain of Virginia subsequent to 1870, and well after a post-Civil War increase in malaria generally, was primarily attributable to the "abandonment of the land, and especially of the bottom land, leading to poor drainage," as a result of shifting agricultural production of corn in the Midwest making unprofitable lowland corn farming in Virginia. Similarly in North Carolina, the decrease in malaria rates from 1896 to 1913 was attributable to agricultural drainage management: "they cleaned up and drained more land and kept it freer from standing water (Barber, 1929).'

Wright (1907)'s report to the U.S. Senate attributed the reductions in malaria in northern regions to drainage:

> *The effect of draining swamp and overflowed lands upon the public health is shown by a decrease of malarial diseases and of mortality due to them . Such diseases prevailed to an alarming extent in the greater portions of Indiana , Illinois , and Iowa , prior to the construction of extended*

drainage systems in those States. The census of 1870 gives the number of deaths from malaria for the preceding year as 52.5 per thousand of the total, while the census of 1890 gives the deaths due to malaria at 8.6 for one thousand . During that time large areas of land in those States were drained, with the result that lands which were formerly swamp and unfit for cultivation were converted into productive farms. It is safe to conclude that these changes in malarial conditions were due to draining.

Wright later discusses the lack of progress on drainage and its relationship to the lack of malarial reductions in the South. While outside the southern malaria belt counties appear to have handled the malaria problem directly through "scientifically planned drainage," and despite some anecdotal accounts of progress against malaria in drained regions of the South (Barber, 1929; Wright, 1907), a number of factors, including impoverished soils, made it "financially impossible to install scientific drainage" in many areas. (Faust, 1951).

Ultimately, it was public health investments in the South that were successful in malaria reductions, although not all projects worked as planned: Tennessee Valley Authority anti-malaria programs did not fully offset the enhanced breeding areas created by the dams themselves and Works Progress Administration projects were often make-work projects that did little to improve drainage (Kitchens, 2013a; Humphreys, 1998). Two factors ultimately explain the reduction of malaria in the South, out-migration as a result of farm programs and general depopulation (Barreca et al., 2012; Humphreys, 1998) and New Deal investments in malaria eradication and the use of insecticides (Sledge and Mohler, 2013; Kitchens, 2013b).

Better mosquito habitat, lower standards of living and more exposure to infection, more limited medical treatment availability, and a lack of agricultural drainage led the South to lag in malaria eradication relative to the Midwest. Farm drainage in the Midwest provided a valuable private good. Drainage district laws allowed state governments, which were generally unable to develop swamp lands themselves, to harness the value of the private good to facilitate local investment in public works. The diffusion of tile drainage technology from Upstate New York facilitated adoption along the swampy areas south of the Great Lakes. The Great Lakes states were the first to pass drainage laws and decreases malaria deaths followed.

In contrast, in the South it has been suggested that different soil and wetland types made the adoption of tile drainage from the Midwest less straightforward. The legacy of monoculture and soil depletion further limited the benefits of drainage investment. The lack of local institutional capacity and cooperation following the Civil War, and generally as a result of the social structures of the South, delayed drainage district legislation. The benefits relative to the costs of private investment in farm drainage do not appear to have been large enough by the 1930s to have allowed sufficient private provision of local drainage to affect the public health problem of malaria. Given states' general inability to reclaim lands absent local districts, federal malaria reduction programs, where public good production was financed externally, were necessary to eradicate the disease.

3 Data & Empirical Strategy

3.1 Data

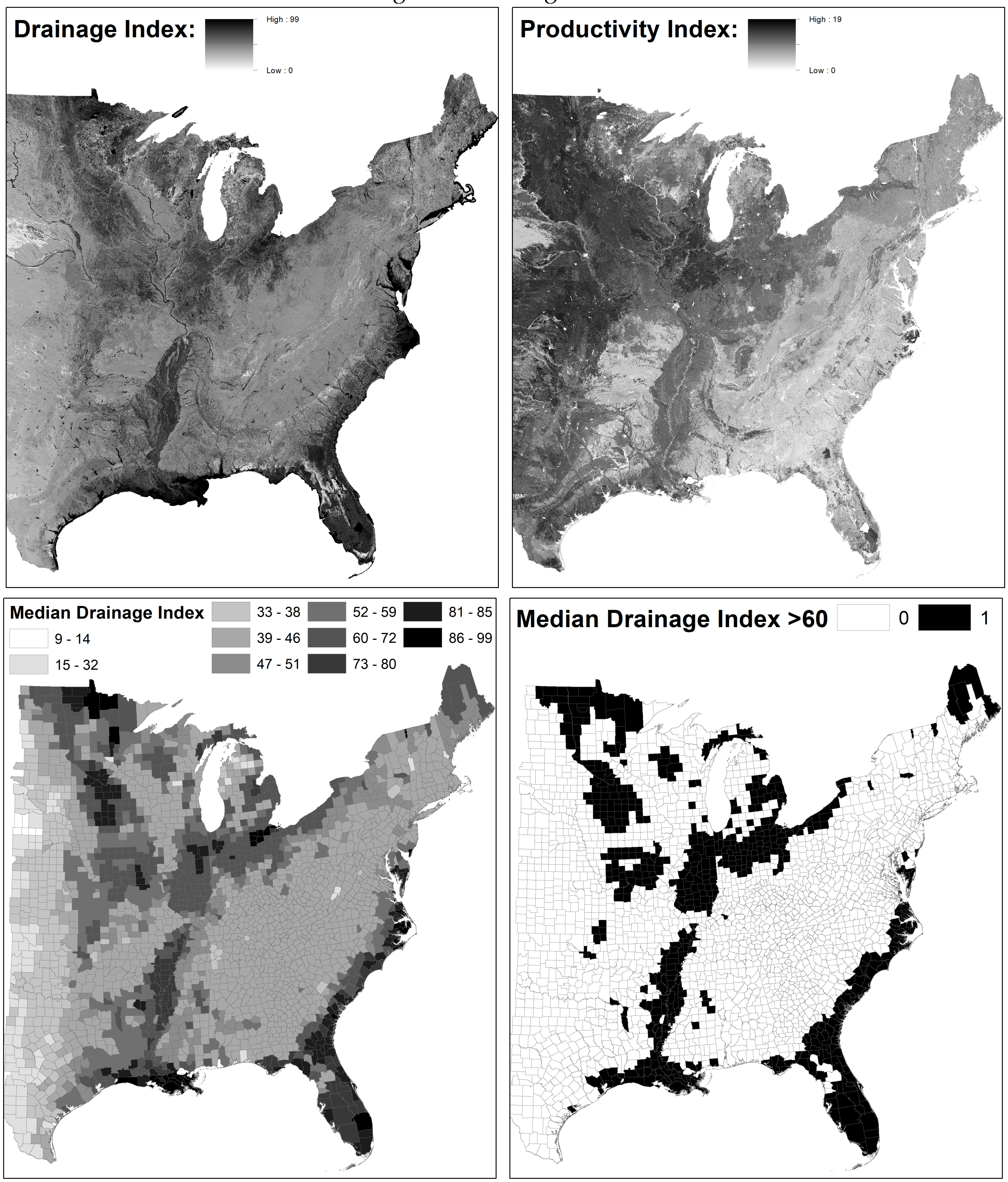
I construct a 109-year panel from 1850-1969 on *Improved Acres* and *Total Farm Value* from United States Censuses of Agriculture collected once per decade and digitized by Haines et al. (2019). We focus on counties east of the 100th Meridian, generally the dividing point between the humid and semiarid portions of the United States. Areas east of this line can be farmed without irrigation and were generally settled or being settled during the entire panel. [1] The USDA also conducted drainage censuses in 1920, 1930, and 1969 which recorded the number of *Drained Acres* in a county. I construct measures of *Percent of County Improved* and *Percent of County Drained* by dividing by total county area.

I use a Soil Drainage Index (DI) to represent the natural wetness of soil in a given county (Schaetzl et al., 2009). The DI is an ordinal measure of long-term soil wetness ranging from 0 to 99. Soils with a DI of around 60 are generally termed "somewhat poorly drained," while higher DI values represent more poorly drained up to 99, open water. Using a 240 meter cell resolution raster I extract the median DI value for each county. I then construct two variables to represent high DI (poor natural drainage). The first and primary measure is for counties with a median DI greater than 60, *DI High*. Figure 2 shows the relationship between median DI and the observed percent of a county drained in each of 1920, 1930, and 1969. The DI=60 cutoff represents a natural

[1] This analysis is preliminary and currently uses 1920 county shapes. Additional work is needed to scale county data based on changing county boundaries. Generally this issue is more problematic for earlier time periods.

break in the data. Counties with *DI High* have higher likelihood of having more area drained.

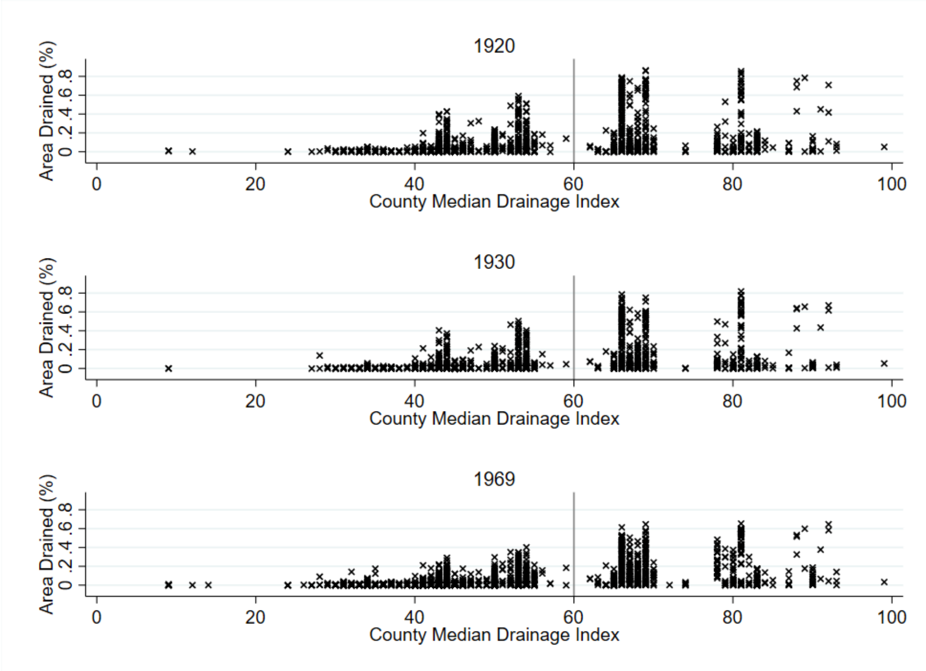
Figure 1: Drainage Index



Notes: The top panels show the Drainage Index and Productivity Index rasters used to create county-level measures. The bottom panels show the median drainage index for each county east of the 100th Meridian and the constructed variable *High Drainage* which is counties with median drainage index greater than 60.

To control for soil quality in cross-sectional regressions, I use the Soil Productivity Index (PI)

Figure 2: Drainage Index and Drainage



Notes: This figure depicts, for each county in our sample, the relationship between the median drainage index extracted from each county shape and the percent of county area drained for each of 1920, 1930, and 1969.

developed by Schaetzl et al. (2012). The PI is an ordinal measure of how advantageous the soil is to crop production based on soil taxonomy. The index ranges from 0 to 19, with 19 being the most productive.

Malaria data during the early time period is limited and comes from two sources, the 1850, 1860, and 1870 Census of Mortality digitized by Fogel et al. (2000) and a report by Maxcy (1923) digitized by the author. To my knowledge these sources represent the available data at the county level during this time period (Bleakley, 2010).

The data from the Censuses of Mortality is provided as a total number of deaths by ICD-9 code, which is the official system of assigning codes to diagnoses and procedures associated with hospital utilization in the United States. The records consist of around 370,000 deaths in 1,036 counties across 39 states. [2] Assigning cause of death to malaria directly is somewhat difficult in the historical context. Symptoms of malaria include fever and flu-like symptoms and were widely prevalent in the humid regions of the country, especially during the summer. Prior to a full understanding of the disease and diagnosis via microscopic identification of the malaria

[2]The data are missing all Ohio counties A-G and around 48,000 entries are missing cause of death.

parasite, cause of death would have been somewhat arbitrarily applied. For the purposes of this dataset I use code 28 in the dataset from Fogel et al. (2000), which includes two recorded causes of death: "Swamp Fever/Jungle Fever" and "Miasmia." The latter, based on the long-held belief that a noxious form of bad air caused disease, was generally associated during this time with the idea that bad swamp air caused the symptoms related to malarial fever.

The Maxcy (1923) data provides county death rates by malarial fever per 10,000 people for those counties with rates greater than 1. The data is provided as cumulative three-year death rates 1919-21 for some counties, and the 1921 death rate for a smaller set of counties. I record these rates directly from the original text and match them with the county names in the main data set. To create more comparable measures of malaria death rates over time, I divide 1870 malaria deaths by the total county population provided by the agricultural census and multiply by 10,000 to get the malaria death rate.

To deal with the data truncation issue in the 1920 data, as well as to create some measure of malaria prevalence over time, I code a dummy variable equal to one if a county shows up as having a malaria death for each year 1850, 1860, 1870, and 1920.

3.2 Empirical Strategy

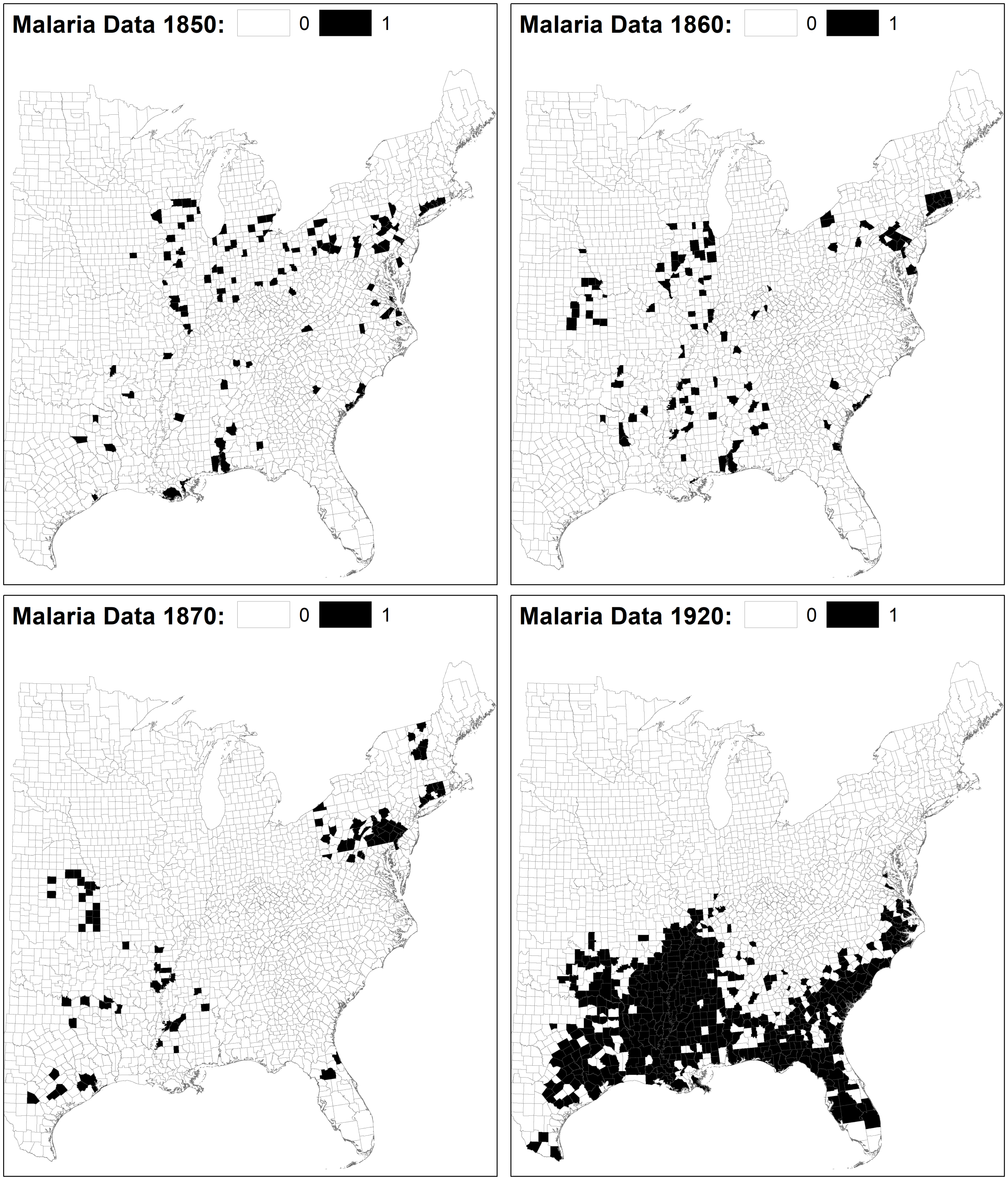
I use a difference-in-difference approach to estimate county-level improved acres and total agricultural value after state implementation of drainage districts. Within each state, outcomes of counties with a high DI index are compared to others before and after drainage law implementation. The typical approach for recovering difference-in-difference estimates of average treatment effects (ATT) would be to use a two-way fixed effects estimator (TWFE) of the form:

$$Y_{ist} = \beta_{TWFE} PostLaw_{st} \times HighDI_i + \lambda_i + \tau_t + \varepsilon_{ist} \tag{1}$$

where Y_{ist} is the outcome for county i in state s in year t, λ_i is a vector of county fixed effects, τ_t is a vector of year fixed effects, and $PostLaw$ and $HighDI$ are dummies indicating a state as passed a drainage law and a county is designated as having a high DI, respectively.

The coefficient on $PostLaw_{st} \times HighDI_i$ would traditionally be interpreted as the difference-in-difference coefficient, but recent work suggests problems with this interpretation. Namely,

Figure 3: Malaria Data



Notes: Maps showing counties reporting malaria deaths (1850, 1860, 1870 from Fogel et al. (2000)) and malaria death rates > 1 per 10,000 (1920 from Maxcy (1923)) using 1920 county boundaries.

β_{TWFE} potentially provides biased estimates of the ATT when different states are treated at different times and there is substantial heterogeneity in the treatment effects over time or between states (de Chaisemartin and d'Haultfoeuille, 2020; Callaway and Sant'Anna, 2020; Goodman-Bacon, 2021; Wooldridge, 2021). This bias arises because β_{TWFE} is a weighted average of all comparisons of "switchers" to "non-switchers" that appear in the data, which includes: i) comparisons of switchers to never-treated counties, ii) comparisons of early switchers to non-yet-treated counties, and iii) comparisons of late switchers to already-treated counties (Goodman-Bacon, 2021). The third comparison, where already-treated counties act as a control group for late-treated counties, can lead to negative weights in the weighted average represented by β_{TWFE}, resulting in a downward bias or even a negative coefficient when all underlying ATTs are in fact positive (de Chaisemartin and d'Haultfoeuille, 2020).[3]

de Chaisemartin and d'Haultfoeuille (2020) and Callaway and Sant'Anna (2020) both propose alternative DiD estimators that are robust to heterogeneous treatment effects across time and/or cohorts. I use both estimators as well as the traditional TWFE approach.

Identification of the ATT associated with post-drainage legislation requires we assume that both the untreated and treated *potential* outcomes for the treated and untreated groups follow parallel trends, and that any shocks affecting the potential outcomes for either group are uncorrelated with treatment. Our comparison group is counties within a state that become treated, but which differ in their need for drainage. This construction reduces threats to identification to those coming from within state shocks that differentially affect well drained and poorly drained areas differently, and occur at about the time the state implemented drainage districts. The parallel trends assumptions is explored via an examination of trends in an event study during the pre-treatment period.

While there is reason to believe it was the drainage districts themselves that created the ability of poorly drained counties to increase agricultural development and production, there is no way to test this assumption directly. The discussion in section 2 provides economic rationale for the importance of drainage legislation and details on the related institutional factors.

Although the paper examines both the economic effect of drainage and its role in malaria reduction, I only make causal claims, such that they are, about the economic importance of drainage. Causal identification of the malarial-drainage linkage is not possible at this time due to data limitations. Ideally, I would run a specification similar to equation 1 showing the response of malarial

[3]These problems are more likely to arise as treatment effects become more heterogenous either across time or between treatment cohorts. See de Chaisemartin and d'Haultfoeuille (2020) and Callaway and Sant'Anna (2020) for additional details.

disease to treatment via implementation of drainage. However, the drainage data are not available prior to 1920 and malaria data is patchy, not recorded systematically, and not available consistently before 1920. Therefore, all findings on malaria and drainage are exploratory and should be interpreted as preliminary.

4 Drainage Results

4.1 Ag Development and Drainage Index

In this section I examine the contribution of drainage to agricultural production in the United States east of the 100th Meridian. Conditional summary statistics provided in table 3 indicate that high- and low-drainage counties behaved differently following the implementation of drainage district laws. Both sets of counties are increasing in agricultural development over time but low drainage index counties are more developed pre-district laws: the low-DI counties have total farm value of $140M versus $113M in the high DI counties with 30% of the county improved versus 26%.

Table 3: Conditional Summary Statistics

	Drainage Index < 60		Drainage Index > 60	
Variable	Pre	Post	Pre	Post
Farm Value (2020$ millions)	140.49	280.38	113.67	421.62
	(177.57)	(257.00)	(155.29)	(392.15)
Pct. of County Improved	0.30	0.39	0.26	0.51
	(0.21)	(0.38)	(0.55)	(0.48)
Total Farms	1,763	1,756	1,472	1,953
	(1,348)	(1,090)	(1,491)	(1,226)
Total Acres in Farms	213,355	284,903	173,459	270,430
	(140,827)	(183,523)	(137,397)	(154,298)
Median Drainage Index	43.81		72.51	
	(6.27)		(7.85)	
Median Productivity Index	8.15		10.16	
	(3.93)		(3.41)	

Notes: Summary statistics conditional on treatment status: high drainage counties $DI > 60$ and pre/post drainage district laws. All values are the mean value of all the counties in that treatment status for the variable described on the left and for all years in that status. Standard deviations are reported in parentheses.

Post-district law, farm values increase by $140M in low-DI counties and over $300M in high-DI counties. Percent of county improved increases by 9 percentage points in low-DI counties and

25 percentage points in the high-DI counties. Post drainage district laws, high-DI counties are actually more developed, likely because the mean productivity index is significantly higher in these counties, which have more fertile soils once drained as shown in the last row of the table. These summary statistics do not control for county-specific characteristics that could be related to development or changing trends in different states, which I address in the regression analysis.

Figure 4: Drainage Quartile Comparisons

Notes: This figure depicts the unexplained variation by high and low drainage quartiles across select geographic regions. The unexplained variation are the residuals of a regression of percentage of county improved (left panels) and total farm value (right panels) on flexible controls (county fixed effects, state by year fixed-effects, and yearly soil quality control) for counties in the Midwest (top panels) and South (bottom panels). The graphs depict the mean of the difference between predicted and observed outcomes by year for counties located in the bottom and top quartiles of drainage index for each state. Midwest states are Illinois, Ohio, Iowa, Michigan, Minnesota, Indiana, and Wisconsin. South states include Georgia, Arkansas, Virginia, Missouri, North Carolina, Mississippi, and Tennessee.

I begin by examining outcomes across select states in the Midwest and South, controlling for some county and state characteristics via regression analysis, to provide a comparison of counties likely to be treated with drainage, relative to others. I regress percentage of a county with improved agricultural land and farm value per acre on a flexible set of controls and then group counties in each state by the quartiles of drainage index. I exclude the second and third quartiles and then plot the yearly mean for each geography-quartile group. Comparing the best- and worst-drained quartiles shows the changing trends over time.

In the Midwest, as shown in table 2, drainage district laws were generally passed between 1860 and 1890, suggesting the development of drainage and related increases in improved acres and farmland value in the following decades. The top panels show the catch-up of the worst-drained quartile for improved acres (left) and value per acre (right). By 1920 the percentage of a county improved is the same and eventually goes higher for poorly drained counties. Similarly, the value per acre of the worst drained quartile, which are generally nutrient rich, once drained exceeds those of the best drained quartiles by 1910. Thus the land value outcomes appear to anticipate drainage implementation to some extent.

A similar catch-up occurs, but much later, in the South. As shown in table 2, states in the South generally passed drainage district laws between 1910 and 1930. The percentage improved in the worst drained counties in the South reaches the level of the best drained counties in 1940. Again, land markets appear to anticipate the implementation of drainage, with per-acre land value estimates of best- and worst-drained quartiles similar by 1900.

4.2 Drainage Impact Estimation

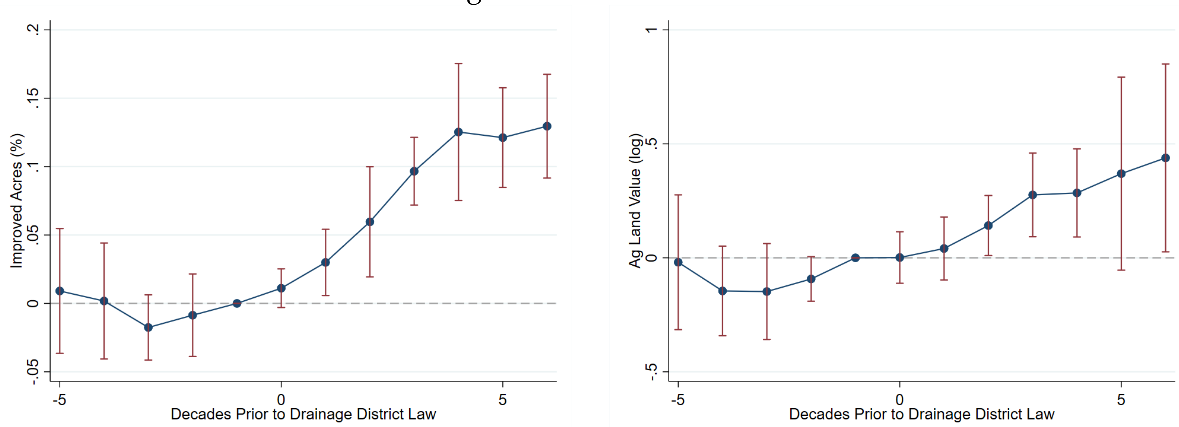
Next, I turn to the difference-in-difference methodology from equation 1. Event study estimates can be used to provide evidence for whether the necessary parallel trends assumptions are likely to hold in this setting. de Chaisemartin and d'Haultfoeuille (2020)'s estimator allows estimation of the effect of treatment in each of the periods before vs. after treatment. Our data includes 13 decadal observations, and I report a window that includes 5 periods (50 years) prior to treatment and 7 periods (70 years) after treatment, with period "0" defined as the first year in which treatment begins.

Figure 5 presents the results of the event study estimates using the estimator proposed by de Chaisemartin and d'Haultfoeuille (2020) and includes county fixed effects and state-specific non-parametric trends.[4] The left panel shows the event study for improved acres and the right panel for total county farm value. All coefficients are relative to the difference between treated and untreated parcels in the period just prior to treatment, which is normalized to 0 (i.e. within a state high drainage index counties versus others).

[4]Implemented with the `did_multiplegt` package in Stata.

The figure shows no evidence of a pre-trend for the improved acres event study: the coefficients for periods $t-2$ through $t-5$ are near zero and statistically insignificant. From period $t-2$ to $t-1$ in the farm value event study there appears to be a small increase, perhaps suggesting some anticipation of drainage in land markets. In both cases, from period $t=0$ onward, there is a statistically significant (and increasing) difference between the counties we expect to see the most change from the adoption of drainage districts relative to others.

Figure 5: Event Studies



Notes: This figure depicts event study estimates using the estimator developed by de Chaisemartin and d'Haultfoeuille (2020), implemented with the did_multiplegt package in Stata. The model corresponds to the specification in column 1 of Panel A of Table 4, which includes parcel fixed effects and state-by-year fixed effects. The difference between treated and untreated groups is normalized to zero in period $t-1$, the final period before treatment. Period 0 denotes the first period in which parcels are exposed to treatment.

The main estimates for the effect of drainage on percent of a county improved and agricultural value are presented in Table 4. Panel A reports estimates from de Chaisemartin and d'Haultfoeuille (2020)'s method, Panel B reports estimates using the Callaway and Sant'Anna (2020) estimator, and Panel C reports estimators from the classic TWFE estimator.[5] Panel A includes state-specific non-parametric trends and Panel C includes state-by-year fixed effects, but Panel B includes only year fixed effects.[6]

The coefficient estimates in table 4 are fairly consistent across all three estimators. Column 1 suggests that following the implementation of drainage districts, a poorly drained county (median drainage index greater than 60) will see a 7.5 to 17.4 percentage point increase in the area of the county with improved agricultural land. As observable in figure 5 the full effect of drainage law passage occurs over 50 years before leveling off.

[5]Panel A estimates are derived using with the did_multiplegt package in Stata. Panel B estimates are derived using the csdid package in Stata.

[6]The Callaway and Sant'Anna (2020) estimator does not have an option for including group-varying time effects.

Table 4: Ag Development after Drainage District Law

	(1) Pct. County Improved	(2) Total Ag Value (log)
Panel A:		
	de Chaisemartin & D'Haultfoeuille (2020)	
Post Drainage District Law	0.075***	0.193**
	(0.012)	(0.092)
Panel B:		
	Callaway & Sant'Anna (2020)	
Post Drainage District Law	0.174***	0.377*
	(0.035)	(0.214)
Panel C:		
	Two-Way Fixed Effects	
Post Drainage District Law	0.092***	0.270***
	(0.019)	(0.081)
Number of Counties	2,474	2,474
R^2 (TWFE)	0.701	0.910

Notes: This table presents difference-in-difference estimates for the effect of drainage district adoption on high drainage index counties relative to others based on the model in Equation 1 using several estimators. Panel A uses the estimator proposed by de Chaisemartin and d'Haultfoeuille (2020) and implemented with the `did_multiplegt` Stata package with two leads and two lags of treatment. Panel B uses the estimator proposed by Callaway and Sant'Anna (2020) and implemented with the `csdid` package in Stata. Panel C presents traditional TWFE estimates obtained via OLS. Panels A and C include state-by-year fixed effects, whereas Panel B uses pooled year fixed effects due to limitations of the `csdid` package. Standard errors are clustered by county and reported in parentheses* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Corresponding with these results, the coefficients in column 2 suggest a dramatic increase in the value of agriculture in these counties. Coefficient estimates range from a 21.2 percent to a 45.8 percent increase [7]. Using the mean county land value for pre-treatment high-DI counties of \$113.67M from table 3, we can calculate a rough estimate that relative to low-DI counties, drainage increased their value by \$24.2-52.1M. There are 548 counties in the high-DI category, suggesting drainage added \$13.26-28.55B to U.S. agricultural land value (in 2020 dollars).

5 Malaria Results

In this section I show some preliminary analysis on the relationship between rates of malaria and agricultural drainage. I begin by confirming that the measure of low drainage areas corresponds with historical records of malarial infection. I then provide some (ultimately) inconclusive results on the relationship between agricultural drainage and malaria.

[7]These calculations come from coefficients in a log-level regression corresponding to a $e^{\beta} - 1$ percent increase.

5.1 Drainage Index and Malaria

To document the relationship between drainage index and malaria I use a linear probability model to look at the counties reporting malaria deaths relative to those without for each year for which malaria death data are available. The results are shown in table 5. Columns (1)-(4) show the differential probability of reporting a malarial death for states with a DI above 60. For the 1870 and 1920 data, there is a strong correlation between high-DI counties and reports of malaria-related deaths.

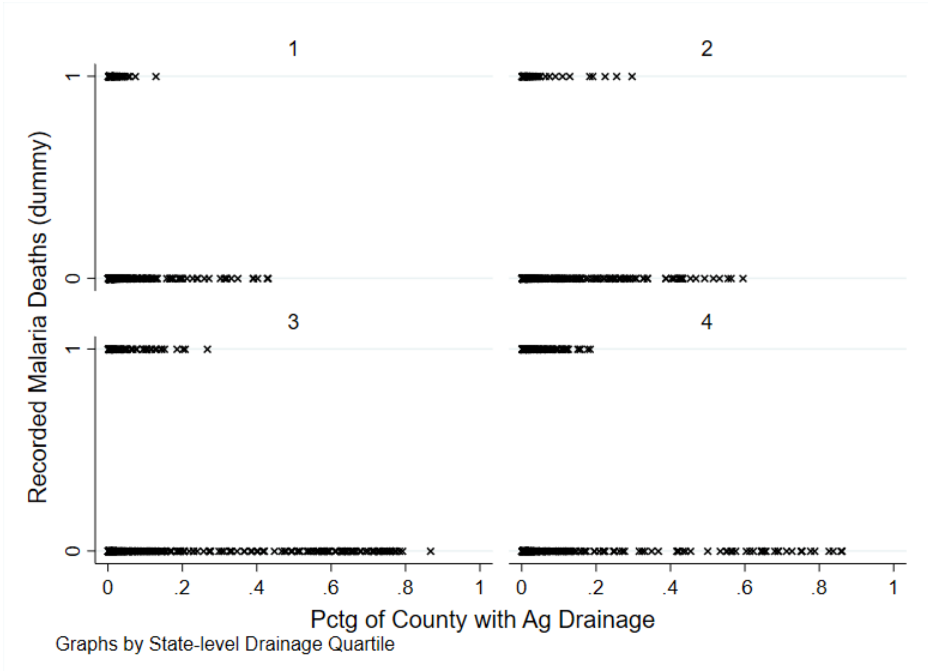
Table 5: Drainage Index and Malaria

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	1850	1860	1870	1920	1850	1860	1870	1920
	Pr(Reported Malaria Deaths)							
High Drainage Index	0.007	0.01	0.026**	0.094***				
	(0.02)	(0.01)	(0.01)	(0.02)				
Drainage Index Q2					0.011	-0.016	-0.009	0.032*
					(0.02)	(0.02)	(0.01)	(0.02)
Drainage Index Q3					0.004	-0.012	-0.002	0.106***
					(0.02)	(0.01)	(0.01)	(0.02)
Drainage Index Q4					0.021	0.024*	0.028**	0.177***
					(0.02)	(0.01)	(0.01)	(0.02)
Number of Counties	1521	1854	2053	2475	1521	1854	2053	2475
R^2	0.1	0.225	0.261	0.441	0.101	0.229	0.262	0.462

Notes:
Linear probability model of whether a county reports malaria deaths on DI measure. All regressions include state fixed effects. Malaria data from 1850, 1860, and 1870 is from Fogel et al. (2000). 1920 data is from Maxcy (1923). Standard errors are reported in parentheses* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In columns (5)-(8) I report the results for state-specific drainage quartiles, with the coefficient the difference in the probability a county in each quartile reports malarial deaths relative to the first quartile. The highest quartile counties are more likely to report malaria deaths, significant at the 10%, 5%, and 1% levels in 1860, 1870, and 1920 respectively. I conclude that high drainage index is a predictor of malarial infection. Because I have shown that these high-DI counties are likely to have required drainage for agricultural development, it is plausible that this investment, by reducing mosquito habitat, would also reduce malarial infection.

Figure 6: Malaria and Drainage



Notes: This figure depicts whether a county recorded malaria deaths (Maxcy, 1923) relative to the percentage of a county drained as calculated by the authors using Haines et al. (2019). The figures is separated into quadrants corresponding to drainage index quartiles by state.

5.2 Drainage and Malaria

Testing the causal impact of agricultural drainage on malaria infection is beyond the scope of the present work. To understand the relationship between drainage and malaria I focus on 1920, where both malaria and drained acres measures are available. In figure 6, I plot an indicator of whether a county reports malaria deaths against the percentage of the county with agricultural drainage, sorting counties by drainage quartile. The results are suggestive of a strong negative relationship between the probability a county sees malaria deaths and its farm drainage. For instance, no county with a high drainage index ($DI = 4$) that is over 20% drained reports malaria, while many with less than 20% draiange report malarial deaths.

The use of 1920 data is problematic from the standpoint of my empirical strategy because it occurs before the majority of the South had adopted drainage district legislation, but after malaria was generally eradicated from the Midwest. This concern is confirmed when I regress the variable for recorded malaria deaths in a county on the percentage of a county with agricultural drainage. These results are shown in 6 for three models: linear, probit, and logit. All three model types confirm that, corresponding to figure 6, when state fixed effects are not controlled there is a strong negative relationship between malaria and drainage: columns (1), (3), and (5). However, this relationship is driven by the composition of the two geographic regions. The Midewest is heavily drained and sees virtually no malaria deaths. The South is largely undrained and sees significant areas with malaria deaths. When state fixed effects are included, in columns (2), (4), and (6) the results flip because states in the South, generally lacking agricultural drainage, show the relationship from table 5 of increasing deaths with increasing DI.

Table 6: Malaria-Drainage Relationship

	(1)	(2)	(3)	(4)	(5)	(6)
	LPM	LPM	Probit	Probit	Logit	Logit
	Pr(Malaria Report 1920)					
Pctg of County with Ag Drainage	-0.03***	0.03***	-0.47***	1.55***	-0.95***	3.26***
	-0.01	-0.01	-0.13	-0.37	-0.26	-0.78
Number of Observations	10608	10608	10608	5912	10608	5912
R^2 / pseudo R^2	0.01	0.07	0.02	0.11	0.02	0.11

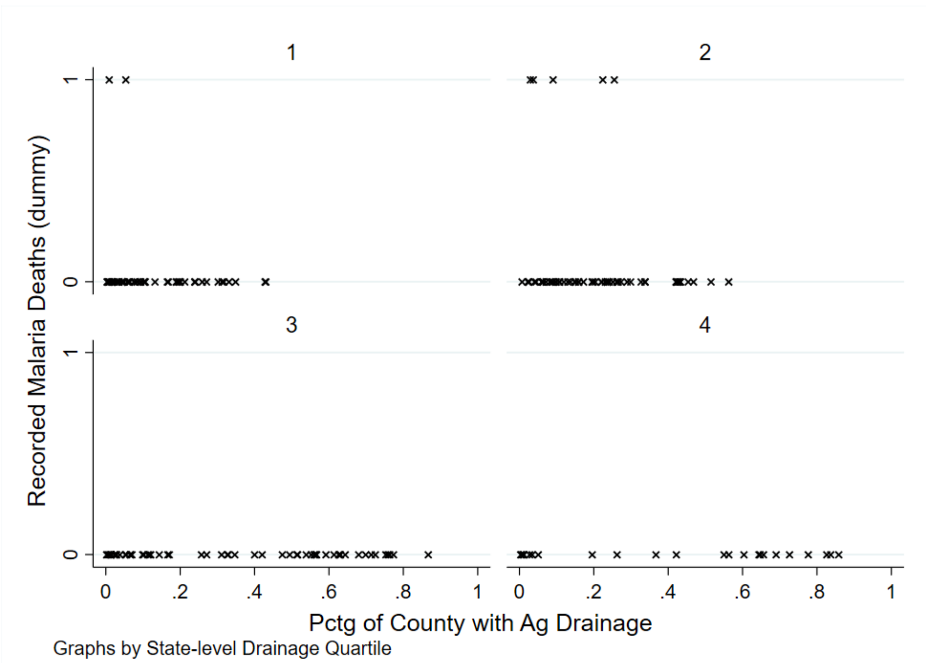
Notes: Regressions of malaria reported deaths dummy on percent of county drained. Specifications (1) (3) and (5) include no controls. Specifications (2), (4), and (6) include state fixed-effects. tandard errors are reported in parentheses* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As seen in figure 3, the only state located in the Midwest that reports malaria data in 1920 is Illinois, and thus offers the best potential test of the drainage-malaria relationship.[8] Figure 7 limits the data in figure 6 to Illinois counties. While the limited number of malaria counties, and no malaria counties in DI quartiles 3 and 4, echo the problem with 1920 data in the Midwest generally, the counties where malaria deaths do occur tend to be less drained, within a given DI quartile, then those that do not see malaria deaths.

Taken in full, the results presented here provide an incomplete picture of the relationship between malaria and drainage. One empirical regularity is the counties with high levels of agricultural drainage do not see malaria deaths. However, the states in the malaria belt do not have much drainage by 1920 and so this does not represent a full test of this relationship. Instead, the results suggest that collecting and analyzing earlier data on malaria and drainage in the Midwest, and later data for the South could better establish a causal link between farm drainage and the disappearance of malaria in the United States.

[8] While South Carolina and Texas were both early southern adopters of drainage district legislation, by 1920 neither state had significant acreage drained so do not provide a good test.

Figure 7: Malaria and Drainage in 1920 Illinois



Notes: This figure depicts whether a county recorded malaria deaths (Maxcy, 1923) relative to the percentage of a county drained as calculated by the authors using Haines et al. (2019). The figures is separated into quadrants corresponding to drainage index quartiles in Illinois.

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