

Creating American Farmland: Institutional Evolution and the Development of Agricultural Drainage

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Abstract

The U.S. Corn Belt, relatively flat and covered with thick glacial soils, is famously responsible for the bulk of U.S. corn production. Development of this central part of the continent came with remarkable technical progress — in seed varieties, mechanization, fertilization, and pest control. Very little of this development could have occurred without decades of investment in farmland itself, through the methodical application of drainage. Drainage investment created the Corn Belt and other productive agricultural regions, and also led to the loss of more than half of the 215 million acres of wetlands estimated to have existed in the contiguous United States at colonization. In this paper we trace the economic forces that drove wide-scale drainage in the United States and present empirical evidence that a key institutional innovation, the drainage management district, facilitated investment. States in our sample adopted drainage district laws between 1857 and 1912, and after adoption each state saw a relative increase in improved agricultural land in counties with high natural soil wetness. We estimate artificial drainage facilitated by management districts increased the value of agricultural land in the counties of the eastern United States with the highest natural soil wetness by \$16.8-18.7 billion in 2020 dollars, an increase in land value in each of these counties of 20-37%.

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1 Introduction

A dramatic feature of 19th and 20th century agricultural development in the Midwest and Eastern U.S. was the application of drainage technologies to remove water from saturated lands. (See, for example, [Bogue \(1951\)](#) and [Bogue \(1963\)](#)). A significant portion of the United States, including the upper Midwest, the Mississippi River Basin, and the eastern Coastal Plain, have soil with high natural wetness; of the 215 million acres of wetlands estimated to exist in the contiguous United States at colonization, 124 million had been drained by 2019, 80-87% for agricultural purposes ([McCorvie and Lant, 1993](#); [Tiner, 1984](#))¹ Without drainage, the majority of the present-day Corn Belt in Ohio, Indiana, Illinois, Iowa, and Minnesota would be ill-suited for agricultural production entirely.

Drainage ditches in combination with subsurface drain tile (first used in Upstate New York in 1835 and adopted across the upper Midwest in the following decades) made drainage economical for widespread adoption. Some of the draining was carried out over broad areas of swampy and submerged land — like the 25 mile by 100 mile Great Black Swamp, which drained into Lake Erie at modern-day Toledo before the 1850s. Draining also occurred at smaller scales on undulating fields in Indiana, Illinois, and Iowa that were only partially submerged. Settlers in these areas began farming higher, drier ground first and, over time, converted and drained lower swales into additional farmland.²

Drainage varied from farm-scale projects to endeavors in excess of 100 square miles, and came to include the use of levees along the Mississippi and other waterways, often in combination with large pumping operations. Large or small scale, drained land was an essential input into the production of Midwestern crops—mainly oats and corn. One key barrier to the adoption of drainage was the coordinated action required to finance, route, and build the open ditches that served as outlet drains for tiled fields. It was a combination of innovations in drainage institutions, engineering, and tile manufacture that allowed drainage to begin in earnest in the second half of the 19th Century ([McCrary, 1928](#)).

¹Draining vast areas of the Midwest farmland also had unintended consequences, notably 20th century algal blooms in lakes and a hypoxic Dead Zone in the Gulf of Mexico. (See, for example, [Rabotyagov et al. \(2014\)](#) and [Mitsch \(2017\)](#)).

²“Typically, the farmer who settled on the wet prairie broke his high ground first and looked to lowlands and sloughs for pasture and prairie hay. ‘Knoll farming’ one granddaughter of the pioneers called such practice. [Reference in original.] But prairie farms of this sort were not fully improved until artificial drainage had tamed the wet prairie.”([Bogue, 1951](#), p.83)

The distribution of poorly drained lands in North America coincides closely with flat topography, in the upper Midwest as a result of glaciation and in the lower Mississippi and Southeast on the low lying coastal plain. Recognition of the value of drainage investment on such lands came early. In 1880, it was estimated that drainage of unimproved wetlands increased sale value by a factor of five (Prince, 2008). Yet capturing this increased value typically required significant coordination among neighboring landowners that was initially absent.

Ownership of American wetlands in the mid-19th century passed from the federal government to the states through a series of Swamp Land Acts (1849, 1850, and 1860), which allocated 15 states nearly 85 million acres, provided the lands were reclaimed via drainage (Fretwell, 1996). There was little or no initial improvement under the Acts. Because piecemeal ditching was ineffective absent open outlet channels and coordination, the implementation of widespread drainage in a state 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).” Broad-scale investment in drainage would eventually require institutional innovation through the creation of drainage management districts.

As we discuss, potential farmland with poor natural drainage passed from the federal government to states and counties and ultimately individual landowners. What made successful drainage possible was bottom-up institutional innovation to solve drainage coordination problems. While drainage often required coordination over areas of several square miles (640 acres to the square mile) or more, farms in the wet prairie counties typically were smaller, around 150 acres, due to the increasing costs of monitoring labor on larger farms and government land allocation policies (Allen and Lueck, 1998; Prince, 2008). Drainage districts allowed landowners to retain rights to operate their farms at the scale that economic factors dictated, while ceding one property right “stick”—drainage—to a local elected body. By granting to districts taxing and eminent domain authority, drainage district laws provided sufficient legal structure for collective investment in drainage, for which we find evidence.

Other technological innovations were critical to the development of modern American agriculture, notably the mechanization that allowed the intensive application of power to farming (see Olmstead and Rhode (2001) on the impact and diffusion of the tractor). Unlike the tractor, which revolutionized American agriculture in the 20th century, drainage represented the precondition

work of creating farmland, requiring in many cases coordination across landowners. Also different, the adoption of tractors occurred on a farm-by-farm basis, while drainage investment required the solving of collective action problems. In this article, we trace the technological developments in drainage and the institutional innovations this required.

We discuss the economic factors that drove the drastic transformation of the eastern American landscape through drainage and focus on the institutional innovation of the drainage district. To analyze the effects of that innovation, we use data from the U.S. agricultural census from 1860 to 1969 to compare counties with high natural soil wetness to others in the same state. Difference-in-difference analysis reveals that after the enactment of drainage district legislation, poorly-drained counties saw relative increases in both improved acres and land value. We infer that the private coordination afforded by these laws was a necessary condition for widespread investment.³

To quantify these effects, we estimate that drainage that occurred as a result of the passage of drainage district laws increased the value of agricultural land in the worst-drained counties of the eastern United States by 20% to 37%. While technical innovations in drain tile and excavation were important to the development of drainage, our paper points as well to the importance of the transaction costs of collective action and the institutional innovation that addressed them.

2 Drainage History

2.1 Drainage and Drain Tile

In wet and poorly drained soils, excess water in the root zone of cultivated crops can create waterlogging, preventing the absorption of oxygen and drastically reducing yields or killing the plants entirely. Water tables can be lowered if nearby drainage provides a pathway for water out of the plant root zone. Open ditches were dug to remove excess standing water and lower water tables throughout the United States from its founding for this purpose. The earliest attempts at drainage in the Midwest, in 1818, were of this type (Prince, 2008, p. 205). However, ditches proved impractical for agricultural production in many cases. The ditches themselves, typically three to five feet

³Our identification strategy does not address the underlying determinants of the state-by-state adoption of drainage district law between 1859 and 1912. By focusing on before and after comparisons of poorly drained counties with well-drained counties in the same state, and by controlling for state and year-specific fixed effects, it does allow us to estimate the increase in agricultural investment in each state that came with drainage district authorization.

deep, were labor-intensive and because they bisected fields at regular intervals, they reduced the available land surface area and made planting and harvesting difficult. Methods for draining water while maintaining the integrity of the land surface via *underdrainage* were required for practical use.

Stone and pole underdrainage was utilized in urban settings throughout the 19th Century, but was broadly uneconomical for agriculture. Other methods like buried brush drainage and mole drainage, where a thin leg attached to a torpedo-shaped implement is drug through the ground, were inconsistent and effectiveness declined within a few years of their first use.

The technology that ultimately replaced digging ditches was the laying of drain tile. Installing drain tile involved digging a trench in which flat clay tiles were laid end to end and covered with a second, inverted-V, layer of tile, creating a porous water channel. The tile was covered again with soil. The resulting subterranean channel drained water above it down to its level, typically four feet below the surface. Unlike open ditching, installed tile drainage was invisible and allowed farming above it.⁴

Clay drain tile was first used in the United States in Seneca County, New York in 1835 and its diffusion transformed agriculture in the Midwest (McCrorry, 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).” The flat tile method was eventually replaced by cylindrical tile starting around 1858 (McCrorry, 1928). Local production was dictated by the costs of transporting the heavy tiles and the first tile manufacturing machine was imported in 1848 from England. Production quickly spread with 66 tile factories established in the United States from 1850-59, 234 from 1860-69, and 840 from 1870-79 (McCrorry, 1928).

Drain tile was not uniformly adopted, and its suitability varied across time and space. Tile was well suited for use in the glaciated regions of the Midwest but was not as successful on the Atlantic Coastal Plain where the need for additional investment in levees and pumping as well as challenges related to flat topography near sea level limited its effectiveness. These regions developed drainage using a combination of in-field ditching, levee systems, pump houses, and tile in select areas.

⁴Modern land drainage follows the same principle, but involves the burying of perforated, corrugated, plastic tubing using advanced drilling and trenching machines. While still called “tile drainage,” the technology bears little superficial resemblance to its ancestor, and no longer involves clay tile.

Drain tile allowed subsurface drainage on the farm, but it was not very useful unless the water had somewhere to go, typically into a network of off-farm drainage ditches. This required coordination, initially to solve free rider problems that arose in the construction of multi-user ditches. Coordination also was required once a drainage network was established because maintenance of an individual farm's drain tile had off-farm effects. Clogged drain tile on one farm could cause flooding on upstream farms in the network.

While digging ditches is an iconic example of low capital intensity production, advances in digging technologies complementary to drain tile paralleled those in the manufacture of drain tile itself. Such advances beyond men and shovels included the development in the 1880s of the dipper dredge, the horse drawn Pratt Ditch Digger, and the Blickensderfer Tile Drain Ditching Machine. The latter could dig a four-foot ditch in only one pass, "powered by a single horse, one man, and one boy. (Yannopoulos et al., 2020)" Application of fossil fuel power to ditch digging followed in 1892 with the introduction of the Buckeye Trencher. As Vileisis (1999) notes, "the greatest revolution came with steam powered ditch digging machines." In 1908 gasoline-powered internal combustion engines began to replace steam engines and in the early 20th century, efficient dragline excavators came to replace dredges.

Like investment in agricultural production generally, the development of drainage was shaped by the fertility and climate of each county as well as changes in input and output prices. For instance, the panic of 1873 and subsequent fall in farm prices reduced demand for drainage, while emerging transportation networks lowered the cost of moving tile, increasing the cost effectiveness of drainage investment. As we discuss in detail in the next section, our empirical approach sidesteps much of this heterogeneity in adoption timing and location by focusing on the effects of drainage districts and through the inclusion of county and state-by-year fixed effects.⁵

⁵While private enterprises that did not require the coordination of neighboring farms existed, available accounts suggest this private drainage occurred on farms the size of drainage districts or larger. As the experience of Blue County, Minnesota suggests, drainage development occurred over several decades following the passage of district legislation, and our empirical approach looks at long-term effects. Still, we acknowledge that the use of the date of drainage legislation may underestimate the effect of private drainage by putting early private drainage efforts into the pre-period.

2.2 Federal Land Policies

The natural wetlands of the United States were viewed by Federal Government policy as “unproductive and an economic waste” from the country’s formation [Palmer \(1915\)](#), until the mid-20th century. To encourage their development via drainage, Congress allocated substantial swampland to the states through a series Swamp Land Acts (1849, 1850, and 1860). In 1861, after the last of the Acts was passed, the *Congressional Globe* summarized their 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)

Table 1: Swamp Land Acts

Year	State	Acres
1849	Louisiana	9,493,456
1850	Alabama	441,289
	Arkansas	7,686,575
	California	2,192,875
	Florida	20,325,013
	Illinois	1,460,184
	Indiana	1,259,231
	Iowa	1,196,392
	Michigan	5,680,310
	Mississippi	3,347,860
	Missouri	3,432,481
	Ohio	26,372
Wisconsin	3,360,786	
1860	Minnesota	4,706,503
	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. The first of the Acts gave 9.5 million acres of federal land to the state of Louisiana—28% of its combined land

and water area. The clear federal impetus for the legislation was to regulate the annual spring flooding of the Mississippi River. But there also was substantial support in the state for draining swamplands that lay more permanently under water.

After passage of the 1849 Act, the Louisiana legislature divided the state into districts and established a statewide board that sold swampland in each district, prioritized drainage projects, and put selected projects out for bid. The highest priority projects invariably were repairing and constructing levees to protect farmland in the Southern Mississippi River Alluvial Valley. The Louisiana system may seem unexceptional from a 21st century perspective, but [Vileisis \(1999, p.79\)](#) notes that “at the time such division of lands and establishment of additional governance was revolutionary,” requiring “citizens to accept a whole new vision of the proper role of state government.”

Ultimately, efforts flowing from the Swampland Act of 1850 were unsuccessful at taming the Mississippi – both initially and following the disruption of the Civil War.⁶ Despite this failure, the methods employed by the state to dispose of and manage lands would prove to be important forerunners of the ultimately more successful institutional innovation of drainage districts.

The first Swampland Act in 1850 was followed in 1851 by similar legislation granting over 50 million acres to 12 widely scattered states, and a third Act in 1860 for two more states.⁷ In each case, states were left to devise their own means of drainage and improvement and their methods varied. Even neighboring states differed in their approaches. While Indiana managed its 1.3 million acres at the state level, Illinois distributed its 1.5 million acres directly to counties.

As alluded to in 1861 in the *Congressional Globe*, the Swamp Land Acts were a first step, and the lands still required investment for reclamation. Ownership and responsibility for the investment in reclamation passed from states to counties, who subsequently divested the lands in the hopes that private investors would drain them ([Prince, 2008](#)). Ultimately, the task of improving drainage largely fell to individual landowners and was achieved over time through local investment, private and public, not federal or state action.

⁶See [Vileisis, 1997](#), chapter 5. Failure at the state level to control Mississippi flooding was recognized institutionally by the 1879 creation of the multi-state, federally overseen Mississippi River Commission.

⁷The 50 million acres granted in the Act of 1850 represented one of the largest single transfers of land out of the public domain in the history of the United States and the taken together the Swamp Land Acts represented the second largest aggregate land grant by the federal government to states (behind land for common schools of 77.6M acres) ([Huston, 1983](#)).

2.3 The Economics of Drainage and Coordination

In the upper Midwest prior to 1880, unimproved wetland sold for an average of \$7 per acre (ranging from \$2-\$12); the sale price once drained could increase by a factor of five (Prince, 2008). As noted by Hewes and Frandson (1952) in their account of drainage in Story County, Iowa, the cost of tiling exceeded the price of land for several decades.

Within Story County [Iowa], the pattern of small, discontinuous wet tracts intermingled with well drained land is the general rule except in the northeastern one-half of Lafayette Township, where the one extensive continuous poorly-drained prairie portion of the county is found. Although as an early settler put it, "only the higher laying lands could be broken, wet prairie land was necessarily included in most prairie farms. The wet areas, if used at all, served for pasture or wild hay, or for open range grazing into the 1880's."

As drainage technology developed, economic incentives to drain and fully utilize these lands emerged, with evidence of direct capitalization of land improvements into land values.⁸ Because of the cost of drainage, land with poorly drained soils was developed later. After 1880, declines in the cost of tiling drove an increase in the derived demand for its complementary input, unimproved swampland. The price of undrained swampland increased rapidly, to an average of \$25 per acre (ranging from \$13-\$40), with drained land commanding \$60-\$70 per acre, a premium in the neighborhood of the cost of tiling estimated at \$35 per acre (Prince, 2008).

Drainage investment, however, was generally not effective on a small scale. Drainage projects required coordination across hundreds or thousands of acres as well as new ditches, levees, and embankments on private lands (Wright, 1907; Prince, 2008). Further, common law was interpreted in many states, including Iowa, as providing farmers the right for water outflow onto neighboring properties. The bilateral nature of these spillover benefits and costs suggested the potential for conflict and Bogue (1963) uses the diaries of a 19th Century Illinois farmer, Croft Pilgrim, to describe such a case:

Pilgrim's earliest venture in tiling disrupted the harmony of the neighborhood. No sooner was the drain completed than his neighbor Tom Mellor dammed the outlet, claiming that the tiling system was flooding his fields. Thus in 1876 began a long-drawn-out litigation, which started in the court of the local justice of the peace and moved ultimately into the district court. After

⁸Hewes and Frandson (1952) observe that the 1860 Agricultural Census estimate of \$20-\$30 per acre drained is similar to estimates of average cost provided by a survey of drainage conditions in Iowa in 1903 (\$25 per acre) while land was appraised by the Federal Land Bank at \$35 per acre.

a series of decisions and appeals, the case still stood on the docket at Toulon, the county seat, in 1882, and by this time had cost Croft Pilgrim several hundred dollars.

Coordination problems among neighbors combined with large minimum scales of drainage projects likely explain why private investment in drainage was initially conducted by large landowners. Owners of farms in Illinois ranging in size from 3,000 to 17,000 acres privately undertook tiling (and in some cases the construction of tile factories). This suggests that the scale of drainage investment exceeded by one to two orders of magnitude the size of the average smallholder farm, which in the upper Midwest in 1880 was about 150 acres (Prince, 2008).

While the consolidation of smallholdings by large landowners able to coordinate drainage investment offered one potential solution to the challenges of drainage, there were potential costs as well. Smallholders in the Midwest generally relied on family labor where agency costs were limited, and they could readily adjust effort in response to price signals. By contrast, large landowners required external labor, leading to misaligned incentives between owners and hired labor that resulted in additional monitoring costs (Allen and Lueck, 1998).

Some entrepreneurial landowners tiled their land and then converted it into smaller farming units of 80-160 acres, which were then sold or rented (Prince, 2008). These attempts at private solutions, however, were limited in area and impact. One key constraint was access to capital (Bogue, 1951). In addition, for farms already held by smallholders, the transaction costs involved in consolidation, tiling, and re-parcelization were high. For existing smallholders, who lacked consolidated ownership at the scale required to justify an individual drainage project, coordination was essential. 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.

The problem facing owners of swamp lands and other poorly drained areas was one of coordi-

nation to invest in the local public good required for reclamation. [Olson \(1989\)](#) provides a useful framework for understanding the difficulties of solving this coordination and investment problem of collective action. Each farmer can be made better off with drainage investment, yet each also has an incentive to free-ride on the investment of others and one farmer's action can negatively affect another. Collective action in drainage requires some mechanism by which farmers agree to cooperate.

[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. The drainage district provided local landowners with the tools to undertake the collective investment suggested by [Olson \(1989\)](#) in a form consistent with the nested structure described by [Ostrom \(1990\)](#).

2.4 The Drainage District

The Swamp Land Acts allocations of federal land to the states instigated state attempts to drain farmland, which in some states meant allocating the lands to counties. Where this devolution ultimately—and successfully over many millions of acres—stopped was at the multi-farm level, with substantial management authority given to drainage districts. While the district form was largely novel, it had its forerunners. As [Vileisis \(1999, p.125\)](#) puts it: “there was little precedent for creating such layers of local government, except for boards some states had started to implement the Swamp Land Acts.”

The formation of drainage districts required in each state enabling legislation. [Table 2](#) shows the years of passage for drainage district laws for the 24 states that in our sample.⁹ From a modern governance perspective, a drainage district is one of many examples of the special district, commonplace today and encompassing varied responsibilities that include mosquito abatement and the operation of airports, mass transit, and libraries. The U.S. Census began collecting data on special districts in 1942, but earlier forms of the special district include park districts created in the

⁹We provide our full methodology for finding these dates in section [A1.3](#).

18th century and toll road and canal corporations from the 19th century. The organizational form has been attributed by some to the English Statute of Sewers in 1532. The key feature of special districts is local authority that is parallel to and not subordinate to that of county and municipal governments, but is subordinate to state governments. Special districts are created by the states and wield powers delegated to them by the states.

Table 2: Year of Drainage District Legislation

State	Year	State	Year
Ohio	1859	Texas	1905
Indiana	1863	Mississippi	1906
Michigan	1869	Virginia	1906
Kansas	1879	Louisiana	1907
Illinois	1879	Florida	1907
Nebraska	1881	South Dakota	1907
Iowa	1884	North Carolina	1909
Minnesota	1887	Tennessee	1909
North Dakota	1895	New York	1909
Wisconsin	1899	Georgia	1911
Missouri	1899	South Carolina	1912
Arkansas	1904	Kentucky	1912

Special districts allow landowners to retain rights to operate their properties at the scale and for the purposes that economic factors dictate, while ceding one property right “stick” to a local elected body. Drainage district laws provided sufficient legal structure to coordinate investment in drainage infrastructure through local taxing authority. In addition to facilitating public investment, eminent domain authority solved the problem of neighbors preventing drainage onto or across their land. [Bogue \(1951, p.180\)](#) 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.

Arguably, the irrigation districts formed later in the western United States were patterned after the drainage districts formed in the Midwest. In describing the emergence of irrigation districts, [Bretsen and Hill \(2006\)](#) discuss the limitations of irrigation prior to the formation of 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 after some trial and error with enabling state leg-

isolation. These districts, while limited by statute in the actions available to address groundwater management challenges, succeeded in coordinating to address externalities associated with groundwater pumping.

Although they varied in specifics, drainage districts were generally legislated to be formed via a petition from landowners residing in a specific region and then requiring some combination of signatures and a vote by the majority of land area and land owners (McCorvie and Lant, 1993). Drainage district decisions were typically made by locally elected boards. Their power was restricted to investments that met some definition of benefiting the public at large, which courts often interpreted as requiring public health benefits (Prince, 2008).

A key feature of the districts was their ability to issue low-interest bonds to secure cash for investment (McCroy, 1928). Similar to drainage enterprises in other locales, in Story County, Iowa “most drainage costs are individual rather than collective. The financing of the collective aspect of the county drainage enterprises has been based on taxes levied on the land included within the enterprises...During and since the period of maximum drainage in the county, no drainage district has gone bankrupt. Rather, the drainage enterprises are considered highly remunerative investments.”(Hewes and Frandson, 1952)

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):

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.

It should be noted that Wright paid little heed to the differences between the drainage challenges faced in the glacial area of the Midwest and those faced in the alluvial outwash plains of the Southeast.

Consistent with the scale of private drainage observed in Illinois, drainage districts ranged in size from hundreds to thousands of acres. An in-depth account of drainage in Blue Earth County,

Minnesota by Burns (1954) documented 92 districts being formed between 1898 and 1952, with the majority formed in the 1910s and 1920s. In 1920 these districts covered 99,000 acres, with 54,000 of those acres benefiting from direct drainage. The individual drainage enterprises ranged in size from 320 to 7,202 acres, with a majority in the range of 1,000 to 4,000 acres. In 1930, the average district in Blue Earth County covered 1,161 acres with 908 of the acres drained. The agricultural census shows a total of 1,836 farms drained, suggesting an average of around 20 farms per district.

In Story County, Iowa there were 95 districts by 1920 draining 197,633 acres (60% of total county area), or an average size of 2,080 acres per district (Hewes and Frandson, 1952). The agricultural census shows 1,871 farms with drainage, which corresponds again to around 20 farms coordinating in each district. While data on drainage enterprises are only available for a few select counties, the 1920 census reports that the counties we define as poorly drained and that have drainage by 1920 have on average 113,000 acres drained and 1,376 farms.

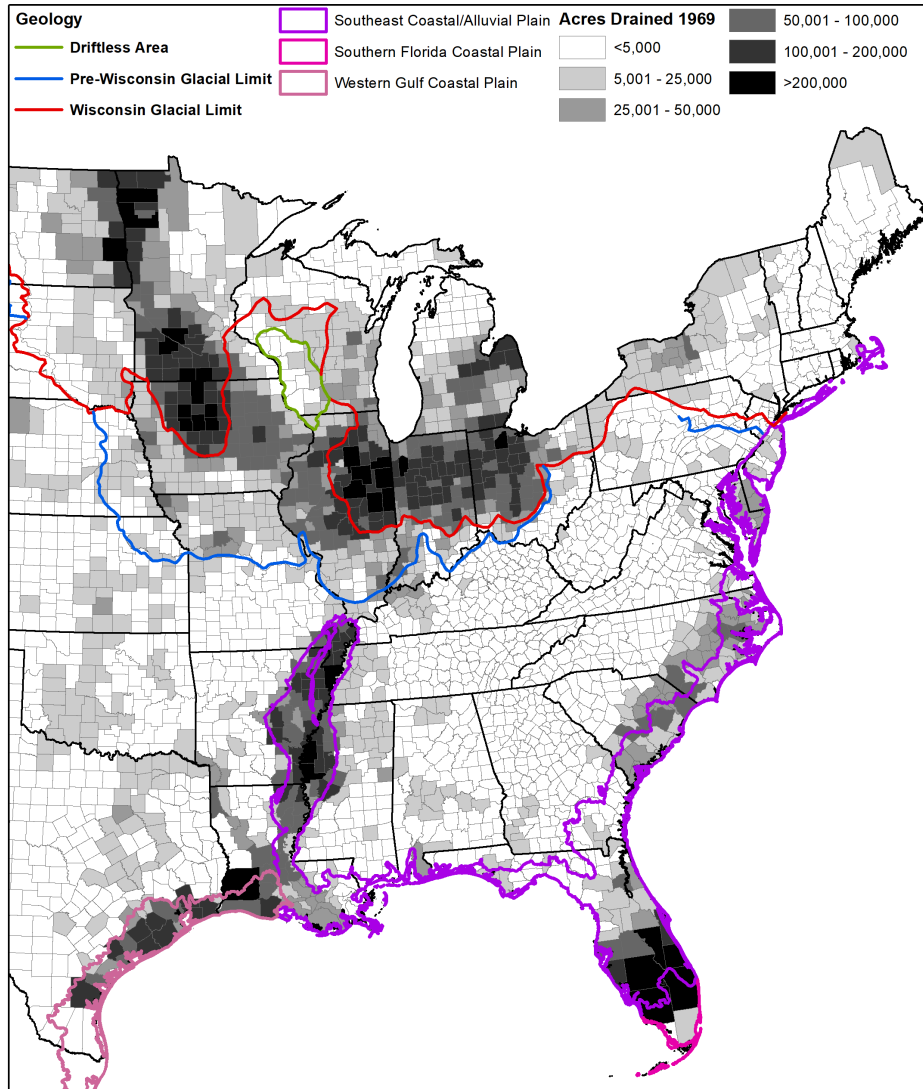
The problem of drainage, and the opportunity its solution afforded, was recognized early on. Authors of the 1849, 1850, and 1860 federal Swamp Land Acts attempted to accelerate settlement of poorly drained lands by moving responsibility for drainage to the states. At the time, however, the application of drain tile technology had not yet begun, the transportation infrastructure to move farm inputs and crop outputs was poorly developed, and institutions that ultimately proved successful – notably, drainage districts – were yet to be devised.

2.5 Drainage, Geology and Coordination

The macro-determinant of need for drainage in the United States is geology. The pre-Wisconsin and Wisconsin glaciation deposited swaths of flat, fertile soil across the upper Midwest. Figure 1 shows the high correspondence of drained acres in 1969 to the limit of the Wisconsin Ice Sheet, and to a lesser extent earlier ice sheets.¹⁰ In the Southeast, the flat coastlines of the Atlantic Ocean and Gulf of Mexico seabeds have received repeated alluvial deposits from rivers over millions of years. Rising and falling sea levels over millennia have deposited flat layers of marine sediment. Today, these flat coastal plains include the Texas Gulf, follow the Mississippi River up to Illinois, and include almost all of Florida and the eastern seaboard. Southeast US drainage corresponds

¹⁰It is interesting to note the complete absence of drainage in Wisconsin's Driftless Area, a region never under the ice sheet and therefore not flattened or deposited with glacial loess by retreating ice. This area is noted for its steep hills and valleys, in contrast to the surrounding areas.

Figure 1: Drainage and Geology



closely to this plain.

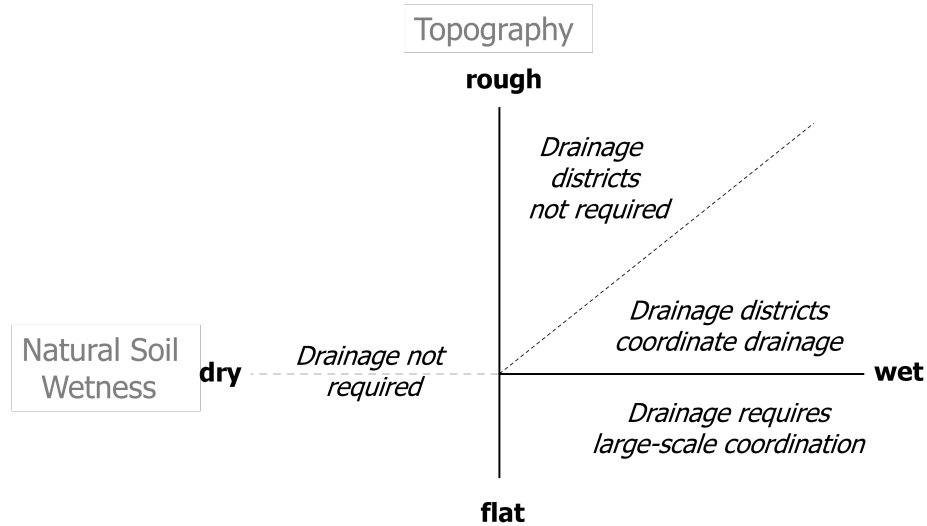
Drainage districts increase the ability of counties with high natural soil wetness to improve land via drainage districts. There is, however, some heterogeneity in this effect. Counties with rougher topography do not require drainage districts because there is enough variation in topography to allow farmers to drain their lands to existing streams directly without coordinating ditches.¹¹ Conversely, the Coastal Plain has many counties that have essentially no roughness. Drainage in these counties requires complex coordination beyond the district level, for instance state-level legislation, drainage districts larger than single counties, and levee districts.

In figure 2 we provide a simple qualitative diagram to explain the relationship between natural soil moisture, roughness, and drainage districts. Where soil has moderate to low natural wetness, drainage is not required (far left). Where drainage is required, roughness determines if coordination is needed. Smoother topography requires coordination among larger areas of land, increasing the difficulties in coordination. In areas where topography is rough, coordination is unnecessary. The sweet spot for the drainage district is where coordination is needed over moderate areas 100s to 1000s of acres. Because the Coastal Plain tends to be smoother than the Midwest, it is the case that counties requiring large-scale coordination are located there. Conversely, because the Midwest is rougher, counties requiring drainage without coordination are located there.

There were also important differences in the institutional development of drainage between the glaciated Midwest and the eastern coastal plains. While Mississippi, Florida, and Louisiana received significant grants from the Swamp Land Acts, 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). These states were also later in passing drainage district legislation, faced larger coordination problems, and generally invested less in tile drainage.

¹¹Similarly, naturally wet areas in generally well-drained counties allow landowners to simply drain water off of naturally wet areas to better-drained areas without coordinating ditches.

Figure 2: Soil Moisture and Topography



3 Estimating the Effect of Drainage District Formation

3.1 Data

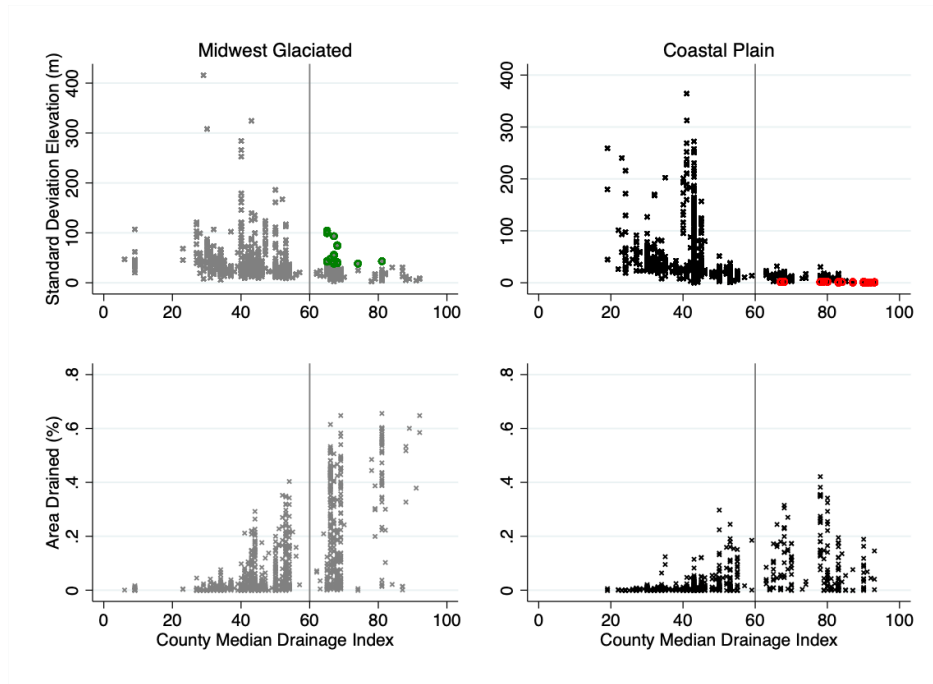
We construct a 109-year panel from 1850-1969 on *Improved Acres* and *Total Farm Value* from United States Censuses of Agriculture collected once per decade and digitized by [Haines et al. \(2019\)](#).¹² We focus on counties east of the 100th Meridian, generally the dividing point between the humid 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.¹³ We scale county data to 1910 county boundaries using area-weight crosswalks constructed by [Ferrara et al. \(2021\)](#). The USDA also conducted drainage censuses in 1920, 1930, and 1969, which recorded the number of *Drained Acres* in a county. We construct measures of *Percent of County Improved* and *Percent of County Drained* by dividing by total county area.

We use the Natural Soil Wetness Index (NSWI) to represent the water content in the soil of a given county absent anthropogenic modification ([Schaeztl et al., 2009](#)). The NSWI is an ordinal measure of long-term soil wetness ranging from 0 to 99. Soils with a NSWI of around 60 are generally termed “somewhat poorly drained,” while higher NSWI values represent more poorly

¹²After 1940 data collection is more frequent (approximately every five years) but we continue to use the censuses on the decade. See table [A1](#), for details on the census data.

¹³The removal of Indigenous groups from these states generally proceeded drainage by several decades or more, starting with the Indian Removal Act of 1830.

Figure 3: Soil Wetness Index, Roughness, and Drainage



Notes: Each county in our sample by median soil wetness index and roughness (top) and percentage of county area drained in 1969 (bottom).

drained up to 99, which is open water. The NSWI is derived from soil classification and slope and so is not affected by drainage or irrigation.

We also construct a measure of roughness, the standard deviation of elevation for each county. The relationship between roughness and Soil Wetness Index is shown in the top panels of figure 3. In these panels we highlight two sets of counties that roughly correspond to the categories in figure 2: in the Midwest those with NSWI > 60 and roughness greater than 38.5 (75th percentile) are shown in green; in the Coastal Plain counties with NSWI > 60 and roughness below 2.6 are plotted in red. The bottom panels of figure 3 show the relationship between proportion of total county area drained and NSWI.

3.2 Drainage Districts

We construct a list of dates of the passage of district enabling legislation using both modern and contemporaneous accounts (see section A1.3 in the data appendix for full details). Drainage district legislation is defined as the first enacted bill that successfully allows the petition of landowners to create a district governed by some elected body, e.g. drainage commissioners, that has state

power to raise funds for ditch construction activities and to condemn land (Sandretto, 1987).

While 25 eastern states have drainage districts laws that meet our definition, we exclude Oklahoma due to its isolation from typical drainage geology (discussed in section 2.5). Most of the northeast states have a common set of drainage laws that do not involve the use of districts as discussed in Palmer (1915). These states are excluded from the empirical analysis, as are New Hampshire and Alabama for which no records or discussion of any drainage law could be located. Adoption dates for drainage district laws vary from 1859 in Ohio to 1912 in South Carolina and are shown in table 2. Figure 4 shows a map of the eastern US to help visualize the roll out of these laws.

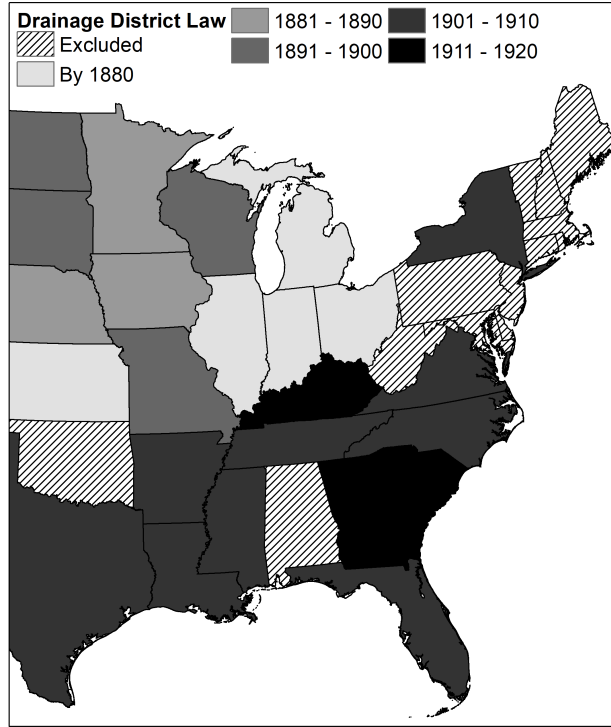
This leaves us with 24 states, which we classify into two groups based on the general characteristics of drainage articulated by Palmer (1915): “glacial swamps” and “tidewater or delta overflowed lands.” Roughly following these categories we classify the “Coastal Plain” states according to the definition of the Atlantic Coastal Plain in the map created by Fenneman and Johnson (1946): Virginia, North Carolina, South Carolina, Georgia, Florida, Texas, Mississippi, Louisiana, Arkansas, and Tennessee. The glacial swamps described by Palmer (1915) coincide roughly with the Midwest, and our definition of “Midwest Glaciated” includes North and South Dakota, Nebraska, Kansas, Iowa, Minnesota, Wisconsin, Illinois, Indiana, Michigan, and Ohio.¹⁴ To this list we add Kentucky and Missouri, portions of which contain glaciated regions, and New York, which adopted drainage district laws significantly later than other Midwest Glaciated states despite being the initial location of tile drainage in the U.S.

We find evidence consistent with substantial responses of improved farm acres to drainage district enablement in poorly drained counties, starting when a law is passed and persisting for several decades afterward. This interpretation discretizes what was in each state a non-instantaneous change as there was trial and error in arriving at ultimately effective institutions and the drainage efforts themselves (Edwards and Thurman, 2022).¹⁵

¹⁴A map of the regions is provided in figure A4.

¹⁵Our empirical work relies on Census data on improved agricultural lands, recorded at the county level every ten years. The empirical challenge presented by this approach is to distinguish between decades in a county during which there were not drainage districts from decades during which there were. This strategy does not deny the importance of multi-year institutional experimentation and refinement. Instead we attempt to identify the effect of drainage legislation and assume that the magnitude of the empirical effects we find are inclusive of any subsequent changes to the legislation. In this sense, the empirical strategy does not distinguish over time between different causes of continued drainage development.

Figure 4: Map of Drainage District Law Dates



3.3 Empirical Strategy and Identification

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

$$Y_{ist} = \beta_{TWFE} PostLaw_{st} \times HighNSWI_i + \lambda_i + \tau_{st} + \varepsilon_{ist} \quad (1)$$

where Y_{ist} is the outcome for county i in state s in year t , λ_i is a county fixed effect, τ_{st} is a state by year fixed effect, and $PostLaw$ and $HighNSWI$ are dummies indicating that a state has passed a drainage law and a county is designated as having a high NSWI, respectively.

The coefficient on $PostLaw_{st} \times HighNSWI_i$ would traditionally be interpreted as the difference-in-difference coefficient, but recent work suggests problems with this interpretation. Namely, β_{TWFE} potentially provides biased estimates of the ATT when different states are treated at differ-

ent 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).¹⁶

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. We 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 detail on the related institutional factors.

¹⁶These 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.

4 Results

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 well-drained counties are more developed prior to the passage of drainage district laws: the low-NSWI counties have average total farm value of \$113M versus \$74M in the high NSWI counties, with 28% of low-NSWI counties in improved agricultural land versus 18% for high-NSWI counties.

Table 3: Conditional Summary Statistics

Variable	NSWI<60		NSWI>60	
	Pre	Post	Pre	Post
Total value in farms (2020\$ millions)	113 (160)	278 (261)	74 (115)	405 (388)
Land value per acre (2020\$)	779 (3,273)	1,249 (8,745)	449 (546)	1,526 (2,614)
Proportion of county improved	0.28 (0.21)	0.39 (0.24)	0.18 (0.20)	0.49 (0.28)
Total number of farms	1,529 (1,324)	1,933 (1,189)	1,105 (1,202)	2,120 (1,373)
Total acres in farms	194,288 (137,123)	283,127 (180,604)	150,162 (158,523)	268,641 (157,351)
County median SWI	43.89 (6.20)		72.48 (7.84)	
Median productivity index	8.04 (3.92)		10.15 (3.42)	
Median elevation (m)	266.29 (174.27)		174.22 (131.83)	
Standard deviation elevation (m)	45.35 (45.10)		16.15 (16.41)	

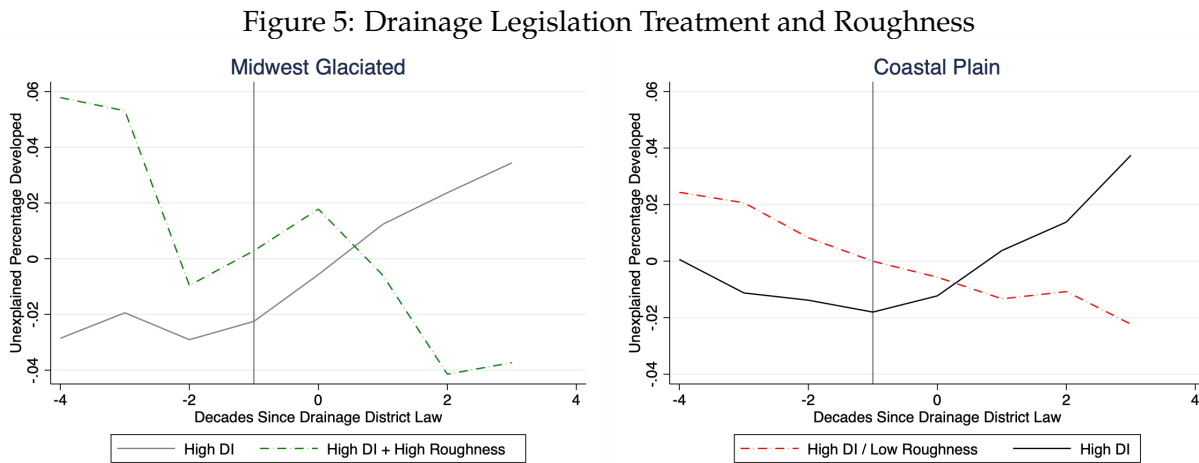
Notes: Summary statistics at county level conditional on treatment status: high drainage counties $DI > 60$ and pre/post drainage district laws. All values are the mean value of all the counties in that treatment status for the variable described on the left and for the four years before/after treatment.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

After the passage of drainage district legislation, farm values increase by \$165M in low-NSWI counties and \$330M in high-NSWI counties. The percent of county acreage improved increased by 11 percentage points in low-NSWI counties and 31 percentage points in high-NSWI counties. On average, after the passage of drainage district laws high-NSWI counties have a higher percentage of total acreage in agriculture, 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). It

is also worth noting that high NSWI counties are substantially flatter, as measured by the standard deviation of elevation. These summary statistics do not control for county-specific characteristics that could be related to development or changing trends in different states, which we address in the regression analysis.

4.1 Flatness and Coordination

Before using the empirical strategy described in equation 1, we perform an analysis to refine our sample to be consistent with an economic framework for drainage district effectiveness as shown in figure 2. The 45 smoothest counties with $NSWI > 60$ are in the Coastal Plain and the 20 roughest counties with $NSWI > 60$ are in the Midwest. Figure 5 plots the mean of the residuals of regressions controlling for county and state by year fixed effects for four groups of counties standardized to the timing of state-level drainage district legislation and relative to counties with $NSWI < 60$. The left plot contains counties in the Midwest with $NSWI > 60$ (gray) and those with $NSWI > 60$ and very high roughness (green). The right plot shows counties in the Coastal Plain with $NSWI > 60$ (black) and those with $NSWI > 60$ and very low roughness (red).



These figures show how the low need for drainage due to topography in the Midwest and coordination problems in the Coastal Plain affect drainage district outcomes. The gray and black lines show significant increases in developed agricultural land after the passage of a drainage district law relative to counties with soil moisture index below 60, the expected treatment effect. The green and red lines show the roughest and smoothest counties do not follow the same trends.¹⁷

¹⁷A regression showing that in a TWFE model the treatment effect on the roughness outliers is statistically different

Because we are focused on estimating the ATT of counties that benefit from drainage district legislation, and because the roughest and smoothest counties are geographically isolated, we drop these 65 counties from the main empirical estimates.

4.2 Drainage District Treatment

Using this modified sample we implement the difference-in-difference methodology from equation 1. Event study estimates can be used to provide evidence that the necessary parallel trends assumptions are likely to hold in this setting. Our data includes 13 observations per county, one every 10 years, and we report a window that includes three pre-periods (30 years) four post-periods (40 years) after treatment, with period “0” defined as the first year in which treatment begins.

Figure 6 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.¹⁸ The left panel shows the event study for improved acres and the right for farm value.¹⁹ All coefficients are relative to the difference between treated and untreated parcels (NSWI > 60) in the period just prior to treatment, which is normalized to 0 (i.e. within a state the estimator compares high drainage index counties to others).

The coefficients for periods $t - 1$ through $t - 3$ are the pre-trends. None of the coefficients are statistically different from 0. Although the per acre farm value figure shows an upward trend in point estimates from period $t-2$ to $t-1$ (which would be consistent with anticipation of drainage in land markets), this change is not statistically distinguishable from 0. From period $t = 0$ onward in the improved farmland measure and $t = 1$ onward in the land value measure, there is a statistically significant difference in counties with high NSWI relative to others.

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.²⁰ Panel A in-

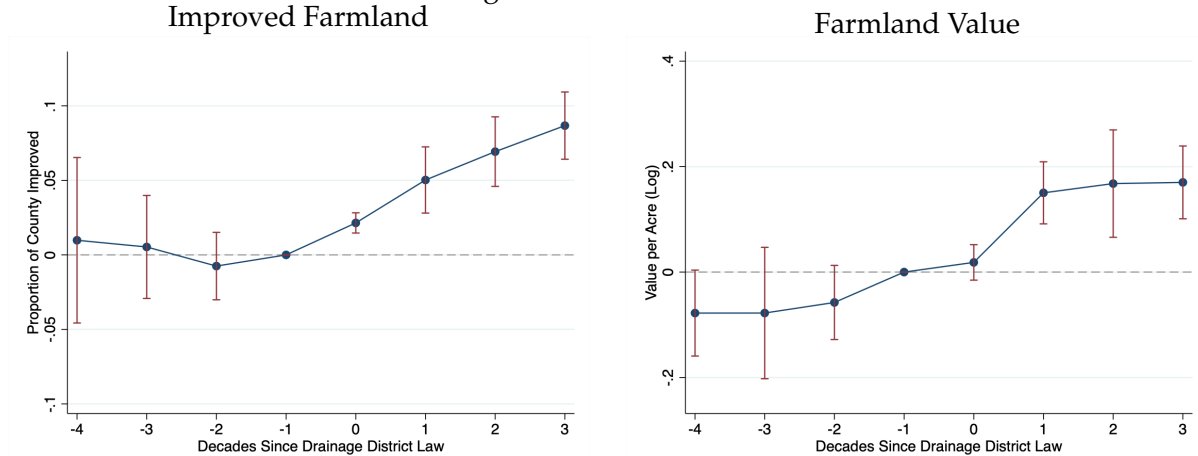
from the other counties is shown in table A4.

¹⁸Implemented with the `did_multipligt` package in Stata.

¹⁹Individual event study figures for Midwest Glaciated and Coastal Plain samples separately are shown in figure A6

²⁰Panel A estimates are derived using with the `did_multipligt` package in Stata. Panel B estimates are derived

Figure 6: Event Studies



Notes: This figure depicts event study estimates using the estimator developed by [de Chaisemartin and d’Haultfoeuille \(2020\)](#), implemented with the `did_multiply` package in Stata. The model corresponds to the specification in columns 3-6 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 sample includes counties in 14 Midwest states and 10 Coastal Plain states. Treatment is DI \geq 60 after drainage law passage, excluding counties with high roughness (Roughness = fourth quartile). Counties with roughness less than fifth percentile are excluded.

cludes state-specific non-parametric trends and Panel C includes state-by-year fixed effects, but Panel B includes only year fixed effects.²¹

Columns (1) and (2) report the results for 24 states with drainage district laws shown in figure 4. Columns (3)-(6) report results for Midwest Glaciated and Coastal Plain regions. Coefficients from column 1 show that following the implementation of drainage districts, a county with natural soil wetness index greater than 60 saw a 4.4 to 5.8 percentage point increase in the area of the county with improved agricultural land and a 12.4 to 21.3 percent increase in land value per acre.²² Midwest coefficient estimates are generally larger than those from the Coastal Plain for percentage improved. While the estimates in panels A and C are generally statistically significant at the 10% level or higher, this is true of only some of the estimates in panel B. Overall, the results provide solid evidence that the passage of drainage district legislation was followed by an increase in improved farmland acres and value per acre in counties with naturally wet soils relative to those with better drained soils. We attribute this change to the coordination benefits these districts offered.

using the `csdid` package in Stata.

²¹The [Callaway and Sant’Anna \(2020\)](#) estimator does not have an option for including group-varying time effects.

²²Land value calculations come from coefficients ranging from 0.117-0.193 in a log-level regression, corresponding to a $e^\beta - 1$ percent increase.

Table 4: Ag Development after Drainage District Law

	(1)	(2)	(3)	(4)	(5)	(6)
	All States in Sample		Midwest Glaciated		Coastal Plain	
	Prop. Impr.	\$/ac (log)	Prop. Impr.	\$/ac (log)	Prop. Impr.	\$/ac (log)
<i>Panel A:</i>						
	<i>de Chaisemartin & D'Haultfoeuille (2020)</i>					
Post Dist. Law	0.054*** (0.009)	0.117*** (0.031)	0.066*** (0.008)	0.106** (0.049)	0.029** (0.012)	0.141** (0.066)
<i>Panel B:</i>						
	<i>Callaway & Sant'Anna (2020)</i>					
Post Dist. Law	0.044* (0.009)	0.139*** (0.031)	0.035 (0.008)	0.124* (0.049)	0.022 (0.012)	0.094 (0.066)
<i>Panel C:</i>						
	<i>Two-Way Fixed Effects</i>					
Post Dist. Law	0.058*** (0.009)	0.193*** (0.031)	0.074*** (0.008)	0.156*** (0.049)	0.034* (0.012)	0.249*** (0.066)
Observations	14,042	14,476	7,409	7,531	6,633	6,945
R ² (TWFE)	0.908	0.909	0.911	0.911	0.843	0.849

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 four leads and four 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; statistical significance is indicated by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3 The Value of Drainage Districts

The results in table 4 provide evidence that the passage of drainage district legislation and subsequent increase in drainage increased the amount of improved farmland in counties with high natural soil wetness as well as the per acre value of farmland. To interpret the economic magnitude of these results, we perform a back-of-the-envelope calculation to estimate the total value of these changes to counties with different degrees of natural soil wetness. We begin by running a regression similar to the model in equation 1 but with the treatment variable *HighNSWI* replaced by bins of natural soil wetness to allow for more heterogeneity in the treatment effect. The results of running a TWFE model in this way are shown in figure 5, which provides coefficient estimates relative to a control group of counties with $NSWI < 50$. Looking at columns (2) and (3), the coefficient estimate for the counties with $NSWI$ between 50 and 60 is not statistically different from 0 for either outcome measure. For all groups with $NSWI > 60$, the proportion of county improved and value per acre coefficient estimates are positive and significant. Further, for both outcome measures,

the size of the effect increases with natural soil wetness.

Table 5: Binned Soil Wetness Index Results

	(1)	(2)	(3)
	Prop. Farmland	Prop. Improved	Value per Acre (log)
Post x SWI[50-60]	0.047 (0.096)	-0.01 (0.010)	0.041 (0.046)
Post x SWI[60-70]	0.044 (0.041)	0.047*** (0.014)	0.182*** (0.055)
Post x SWI[70-80]	0.081** (0.037)	0.070** (0.027)	0.215* (0.107)
Post x SWI[>80]	0.096 (0.057)	0.071** (0.028)	0.270*** (0.041)
Obs	14,053	14,042	14,035
R ²	0.388	0.908	0.89

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 but with the treatment variable *HighNSWI* replaced by bins representing: $50 \geq NSWI < 60$, $60 \geq NSWI < 70$, $70 \geq NSWI < 80$, and $80 \geq NSWI$. Regressions exclude smooth and rough counties as described in figure 5 and control for county and state-by-year fixed effects. Standard errors are clustered by county and reported in parentheses; statistical significance is indicated by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

To estimate the change in the total land value of a county implied by the estimated treatment effects, assumptions must be made on whether the drainage improvements were on the intensive or extensive margin. The value per acre measure is per *farm acre*, of which improved acres are a subset. Drainage law passage may have induced the draining of new farmland, a change on the extensive margin, or the conversion of existing farmland into the “improved” category, a change on the intensive margin. In reality, we expect drainage laws affected both margins. Column (1) of table 5 shows the same regression run with a different outcome measure: the proportion of a county in farmland. These results are mostly not statistically different from zero, meaning we are unable to reject the null hypothesis that there was no change on the extensive margin.

The point estimates on farmland, however, are similar enough to those on improved acres that we cannot reject the hypothesis that they are the same, meaning it is possible the entire increase in improved acres was caused by an *extensive* adjustment in farmland acres. Because we know a fully extensive or intensive adjustment represents the extreme outcomes, we proceed with a dual analysis to bound our cost estimates.

Panel A of table 6 summarizes the characteristics of counties in the sample in each NSWI

bin for the observation immediately prior to drainage law passage. As one would expect, high NSWI counties tend to have lower per acre land values, less land in agriculture, and of the land in agriculture, fewer improved acres. We can use the coefficients in columns (2) and (3) of table 5 to find the increase in the value of agricultural land in these counties as a result of drainage. Panel B of table 6 assumes the total amount of farmland has not changed, and that all new drainage has occurred on existing farms — an intensification — and so the value of drainage district legislation is calculated by taking the coefficient for each bin (β) from (3) and multiplying $e^\beta - 1$ by the total amount of farmland. Panel C assumes the other extreme, that total farmland is increased by the full amount of the estimated increase in improved acres. This extensive margin effect is found by adding existing improved acres to the product of the coefficient from (2) and total county area. This total area of farmland is then multiplied by $e^\beta - 1$ to arrive at a per county value increase.

Table 6: Back-of-Envelope Value Calculation

	NSWI[50-60]	NSWI[60-70]	NSWI[70-80]	NSWI[>80]
Panel A: Measures Decade Prior to Drainage Law				
Counties	271	307	54	90
Average county size (acres)	411,351	388,710	564,985	505,710
Farmland (acres)	254,193	238,608	157,399	201,835
Improved farmland (acres)	185,931	183,083	92,657	144,127
Value (2020\$, per acre)	1,330	832	834	523
Panel B: Drainage improvements made only to existing farmland (intensive margin)				
<i>per county</i>				
Δ Farmland value (per acre) from (3)	-	166	200	162
Δ Total value (2020\$, millions)	-	39.6	31.5	32.7
<i>aggregate</i>				
Δ Total value (2020\$, millions)	-	12,163	1,699	2,945
Percentage increase	-	20%	24%	31%
Panel C: Drainage improvements only create new farmland (extensive margin)				
<i>per county</i>				
Δ Farmland (acres) from (2)	-	18,269	39,549	35,905
Total farmland (acres)	254,193	256,877	196,948	237,740
Δ Farmland value (per acre) from (3)	-	166	200	162
Δ Total value (2020\$, millions)	-	42.7	39.4	38.5
<i>aggregate</i>				
Δ Total value (2020\$, millions)	-	13,095	2,126	3,468
Percentage increase	-	21%	30%	37%

We find that counties with an NSWI between 60 and 70 saw a 20-21% increase in agricul-

tural land value, bounded below by the assumption that the estimated land value increases were applicable to the same farmland base as prior to drainage legislation, and above by adding the estimated increase in improved acres to the total farmland base. The relative magnitude of the increase in county value is increasing with higher NSWI bins, and we estimate a 24-30% value increase for counties with NSWI between 70 and 80, and a 31-37% increase for counties with $NSWI > 80$. Multiplying the per county average value increase by the number of counties in each bin allows us to arrive at an aggregate estimate. By the intensive margin approach we arrive at an aggregate increase of \$16.8B, while the extensive margin approach yields \$18.7B.

5 Conclusion

In this paper we investigate the historical record of farm drainage and estimate the effect of coordinated management institutions on land development and value. After federal and state funding for drainage investment failed to materialize, drainage management districts formed to locally finance investment over tens of thousands of acres of wetlands. Of the 215 million acres of wetlands estimated to have existed in the contiguous United States at colonization, today 124 million have been drained. States in our sample adopted drainage laws via legislation between 1859 and 1912, and after adoption each state saw an increase in improved agricultural land and land values in counties with poorly drained soils relative to well-drained counties. We estimate artificial drainage increased the value of agricultural land in each of the counties with the highest natural soil wetness in the eastern United States by 20-37%, a total increase across all poorly-drained counties of \$16.8-18.7B (2020 dollars).

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A1 Data Appendix

A1.1 Agricultural Census Data

We construct a panel data set consisting of 2,235 US counties with 13 observations (one per decade) in the 24 states described in section [A1.3](#) from 1850 to 1969. These data are digitized by [Haines et al. \(2019\)](#). Data from the United States Census of Agriculture is used to look at farmland acres, improved acres, and total farm value per acre. The monetary measures are adjusted to constant 2020 dollars for inflation using the CPI. Because our economic data span a significant portion of the 20th century, we adopt 1910 counties as our observations, reweighting data from later years to fit these borders based on the crosswalks provided by [Ferrara et al. \(2021\)](#).

Table A1: Census Variables Through Time

FINAL DATASET VARIABLE	NAME 1850	DESCRIPTION 1850 Description	NAME 1860	DESCRIPTION 1860 Description
Total acres in farms	ACIMP ACUNIMP	Improved Acres in Farms Unimproved acres in farms	ACIMP ACUNIMP	Improved Acres in Farms Unimproved acres in farms
Total value of farm: land, buildings, equipment, livestock	FARVAL	Cash value of farms **no distinction between farm value and improvements	FARVAL	Cash value of farms **no distinction between farm value and improvements
Number of improved acres in farms	ACIMP	Improved acres in farms	ACIMP	Improved acres in farms
Total acres in farms	1870	1870 Description	1880	1880 Description
Total value of farm: land, buildings, equipment, livestock	ACIMP ACUNIOH	Number of improved acres farmland Number of unimproved acres farms	ACRES	Number of acres in farms
Number of improved acres in farms	FARVAL	Present cash value of farm **no distinction between farm value and improvements	FARVAL	Value of farmland/improvements **no distinction between farm value and improvements
Total acres in farms	ACIMP	Number of improved acres farmland	ACIMP	Number of improved acres farmland
Total value of farm: land, buildings, equipment, livestock	1890	1890 Description	1900	1900 Description
Number of improved acres in farms	FARMSIZE FARMSZ	Average farm size (acres) Total number of farms, 1890	ACFARM	Total acres of farmland
Total value of farm: land, buildings, equipment, livestock	FARVAL	Value of farmland/improvements **no distinction between farm value and improvements	FARVAL FARBUI	Value of farmland/improvements (excluding buildings) Value of farm buildings
Total acres in farms	ACIMP	Number of improved acres in farms	ACIMP	Number of improved acres farmland
Total value of farm: land, buildings, equipment, livestock	1910	1910 Description	1920	1920 Description
Number of improved acres in farms	FARMLAND2	Total acres in farms, 1910	VAR487	All land in farms (acres), 1920
Total value of farm: land, buildings, equipment, livestock	FARVAL	Value of farmland/improvements (excluding buildings)	VAR23 VAR24	Value of farmland/improvements (excluding buildings) Value of farm buildings, 1920 (dollars)
Number of improved acres in farms	IMPAC	Number of improved acres in farms, 1910	VARI9	Number of improved acres in farms, 1920
Total value of farm: land, buildings, equipment, livestock	1930	1930 Description	1940	1940 Description
Number of improved acres in farms	VAR8	All land in farms, acres, 1930	VAR2512	All land in farms, acres, 1940
Total value of farm: land, buildings, equipment, livestock	VAR120	Value of land & buildings, total, \$, 1930	VAR29	Value of farm (land & buildings), \$, 1940
Number of improved acres in farms	(+) VARI3 (+) VARI4 (+) VARI5 (+) VARI7	Total crop land harvested, acres, 1929 Total crop land with crop failure, acres, 1929 Total crop land idle or in fallow, acres, 1929 Plowable pasture, acres, 1929	(+) VARI10 (+) VARI12 (+) VARI14 (+) VARI16	Total crop land harvested, acres, 1939 Total crop land with crop failure, acres, 1939 Total crop land idle or in fallow, acres, 1939 Plowable pasture, acres, 1939
Total value of farm: land, buildings, equipment, livestock	1950	1950 Description	1959	1959 Description
Number of improved acres in farms	VAR8	Land in farms, acres, 1950	VAR5	Land in farms, acres, 1959
Total value of farm: land, buildings, equipment, livestock	(*) VAR10 (*) VARI	Value of land & buildings, average per farm, \$, 1950 Farms, number, 1950	(*) VARI (*) VAR7	Farms, number, 1959 Average value of land & buildings per farm, \$, 1959
Number of improved acres in farms	(+) ITEM0006 (+) ITEM0009 (+) ITEM0011 (+) ITEM0012 (+) ITEM0018	Harvested cropland in farms (acres), 1949 Cropland w/ all failed crops in farms (acres), 1949 Cropland in cult. summer fallow in farms (acres), 1949 Cropland idle in farms (acres), 1949 Other improved pasture & rangeland in farms (acres), 1949	(+) VARI11 (+) VARI22 (+) VARI24 (+) VARI44	Cropland harvested, acres, 1959 Cropland used only for pasture, acres, 1959 Cropland not harvested & not pastured, acres, 1959 Improved pasture, acres, 1959
Total value of farm: land, buildings, equipment, livestock	ITEM01002	1969 Description		
Number of improved acres in farms	(*) ITEM01001 (*) ITEM01007	Land in farms (acres), 1969 Farms (number), 1969		
Total value of farm: land, buildings, equipment, livestock	(+) ITEM01026 (+) ITEM01028 (+) ITEM01030 (+) ITEM01038 (+) ITEM01065	Value of land and buildings: Average per farm (\$), 1969 Cropland, all crops failed (acres), 1969 Cropland in cultivated summer fallow (acres), 1969 Cropland idle (acres), 1969 Harvested cropland (acres), 1969 Improved pasture & rangeland (acres), 1969		

A1.2 Geological and Geographic Variables

We use the Natural Soil Wetness Index (NSWI) to represent the water content in the soil of a given county absent anthropogenic modification (Schaetzl et al., 2009). The name of this index has been changed to the Soil Drainage Index (DI) but we use the older name to avoid confusion between naturally poor drainage (NSWI) and artificial drainage. The NSWI is an ordinal measure of long-term soil wetness ranging from 0 to 99. Soils with a NSWI of around 60 are generally termed “somewhat poorly drained,” while higher NSWI values represent more poorly drained up to 99, which is open water. The NSWI is derived from soil classification and slope and so is not affected by drainage or irrigation. A soil’s taxonomic classification is not initially affected by on-farm investments like irrigation or artificial drainage and so the NSWI does not change unless these investments change the classification of the soil in the long-run. ‘Instead, the NSWI reflects the soil’s *natural* wetness condition. Each soil *series* has, in theory, its own unique NSWI.’ (Schaetzl et al., 2009)”

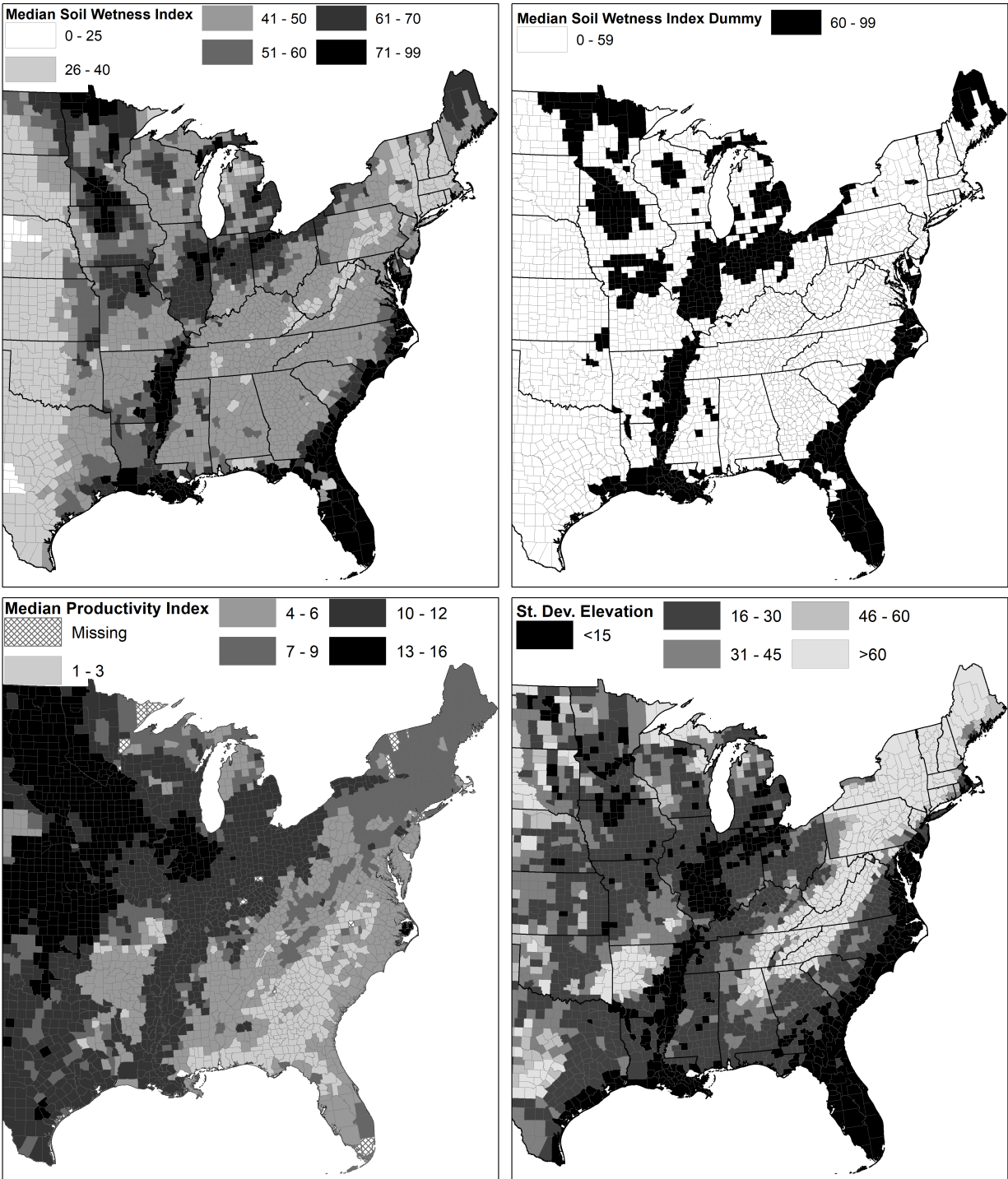
We also construct a measure of roughness, the standard deviation of elevation for each county. Maps of county PI and roughness measures are shown in figure A1. The relationship between roughness and Soil Wetness Index is shown in the top panels of figure 3. In these panels we highlight two sets of counties that roughly correspond to the categories in figure 2: in the Midwest those with NSWI>60 and roughness greater than 38.5 (75th percentile) are shown in green; in the Coastal Plain counties with NSWI>60 and roughness below 2.6 are plotted in red. The bottom panels of figure 3 show the relationship between proportion of total county area drained and NSWI.²³ A map of the different categories of counties is shown in figure A2.

To control for soil quality in cross-sectional regressions, we use the Soil Productivity Index (PI) 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.²⁴

²³Similar figures comparing drained acreage from 1920, 1930, and 1969 are shown in figure A3.

²⁴“Soil productivity can be easily and rapidly amended by human activities. Thus, no index of productivity can accurately assess current soil productivity where soils have had a long history of cropping, erosion, and/or additions of soil amendments. Particularly, irrigation and drainage practices impact soil fertility/productivity and, therefore, any index of productivity is only an estimate; it is always affected by land-use practices, both current and those in the past. Thus, we focus on natural native soil productivity, as expressed in a soil’s taxonomic classification and recognize that such an estimate is, at best, a good starting point.” (Schaetzl et al., 2012)

Figure A1: County Land Features



Notes: The top 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. The bottom panels show the county-level measures of soil productivity and the standard deviation of elevation, a measure of flatness.

Figure A2: Natural Soil Wetness Index and Roughness Heterogeneity

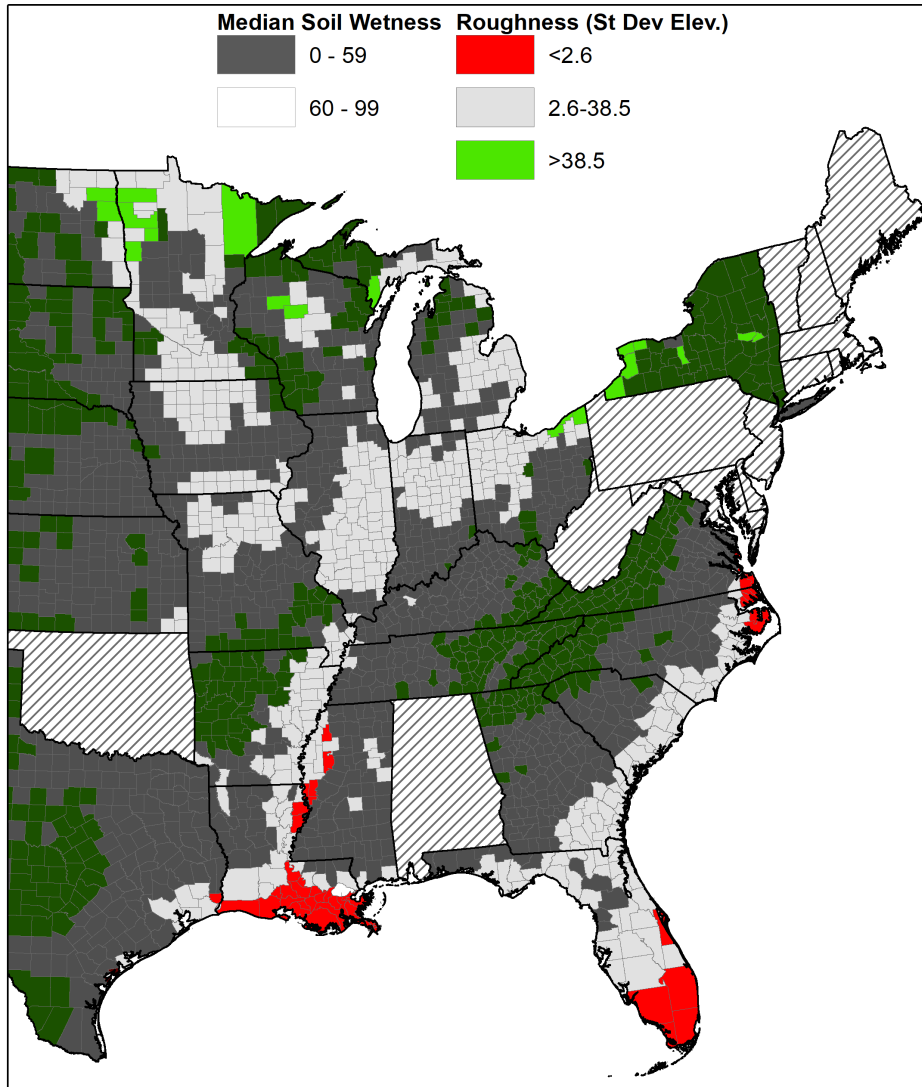
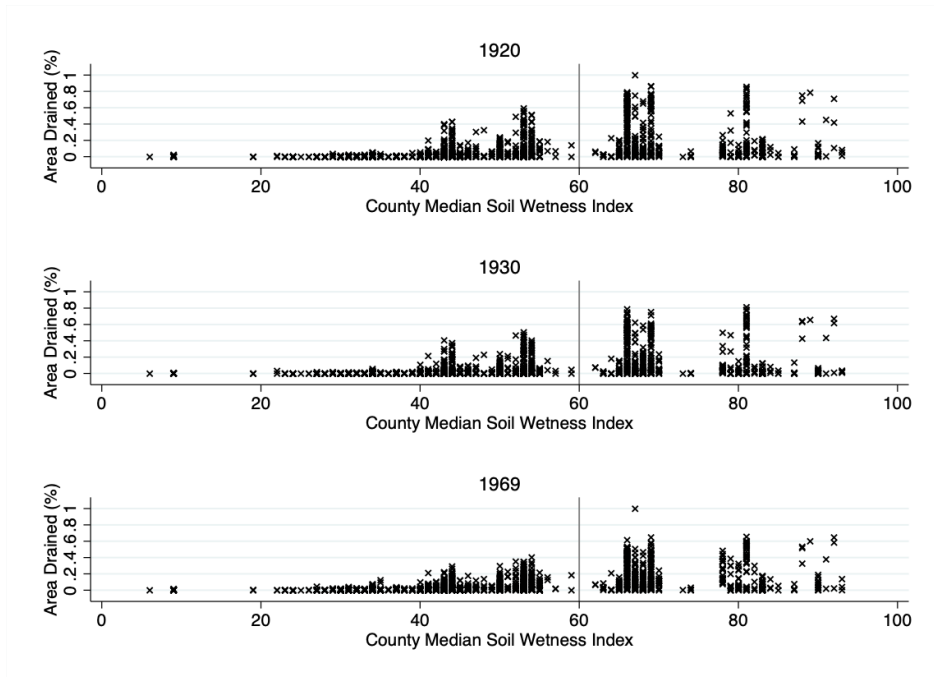


Figure A3: Natural Soil Wetness Index and Drainage



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.

A1.3 Drainage District Legislation

First drainage district legislation data are collected by the authors from various sources. Drainage district legislation is considered to be the first bill that successfully allows the petition of landowners to create a district governed by some elected body, e.g. drainage commissioners (see (Sandretto, 1987)). For example, from the Illinois Department of Archives:

“The Illinois Constitution of 1870 authorized the General Assembly to pass laws giving landowners drainage rights, including the use of adjoining land for ditching purposes. As a result, a comprehensive drainage law was passed in 1871. The law set up legal procedures for local citizens to petition the county courts for drainage works, assessing and collecting the costs of the drainage construction from the owners of the lands to be benefited by the work, and compensating the owners of land which would be entered for ditching purposes. ... The 1871 law was found unconstitutional; as a result the Illinois Constitution was amended, making drainage commissioners the heads of corporate drainage districts and giving these districts constitutional authority to levy property taxes. Two separate and coequal Illinois drainage laws were passed in 1879. One, the ‘Levee Law,’ repeated the procedures of the 1871 law, with added procedures for legal appeal by landowners dissatisfied with their assessments; the second, the ‘Drainage District Law,’ made the township highway commissioners the township drainage district commissioners. ... [T]he responsibilities of drainage commissioners have largely remained unchanged since 1871.” [Illinois Secretary of State, 2022.]

As this paragraph demonstrates for Illinois, considerable discretion must be exercised in identifying the date in which viable drainage legislation was passed. For Illinois, based on this passage we find the 1879 law best met our previously discussed criteria for drainage district legislation.

There are 25 states with similar drainage district legislation east of the 100th Meridian. We drop Oklahoma (drainage law date 1908) from the analysis due to its isolation from typical drainage geology (discussed in section 2.5).

Drainage law passage dates for the remaining 24 states are obtained from the following sources:

- Ohio (1859) ([McCorvie and Lant, 1993](#))
- Indiana (1863) ([Vermillion, 2011](#))
- Michigan (1869) ([Quackenbush, 1973](#))
- Kansas 1879 ([McCorvie and Lant, 1993](#))
- Illinois (1879) ([Herget, 1978](#))
- Nebraska (1881) ([Fischer et al., 1970](#))
- Iowa (1884) ([Sherman, 1924](#))
- Minnesota (1887) ([Palmer, 1915](#))
- Wisconsin (1899) ([Prince, 1995](#); [Graham, 1919](#))
- Missouri (1899) ([Olson et al., 2016](#))
- Arkansas (1904) — however, issues existed and 1917 was the year of effective legislation for the creation of the Ross Drainage District ([Deaton, 2016](#))
- Texas (1905) ([Smith, 1952](#))
- Louisiana 1907, both ([Gagliano, 1973](#)) and ([Okey, 1914](#)) reference this year although [Palmer \(1915\)](#) discussed 1906 and 1910
- North Carolina 1909 ([O'Driscoll, 2012](#))
- South Carolina (1912) ([Eason, 1918](#))

- [Palmer \(1915\)](#) provides the sole source for dates of effective legislation in nine states: North Dakota (1895), Virginia (1906), Mississippi (1906), Florida (1907), South Dakota (1907), Tennessee (1909), New York (1909), Georgia (1911), Kentucky (1912).

[Palmer \(1915\)](#) discusses drainage district laws of Connecticut (1861), Delaware (1901), Maryland (1858), Pennsylvania(1863), West Virginia (1860), New Jersey (1878), Maine (1903), Massachusetts (1902), Rhode Island (1896), and Vermont (1906) as being different from the drainage laws in states with higher levels of agricultural production, essentially providing existing public agencies the right of eminent domain for drainage but not creating districts or empowering landowners to petition for district creation. These states are excluded from our analysis.

A2 Results Appendix

Figure A4: Geographical Classification

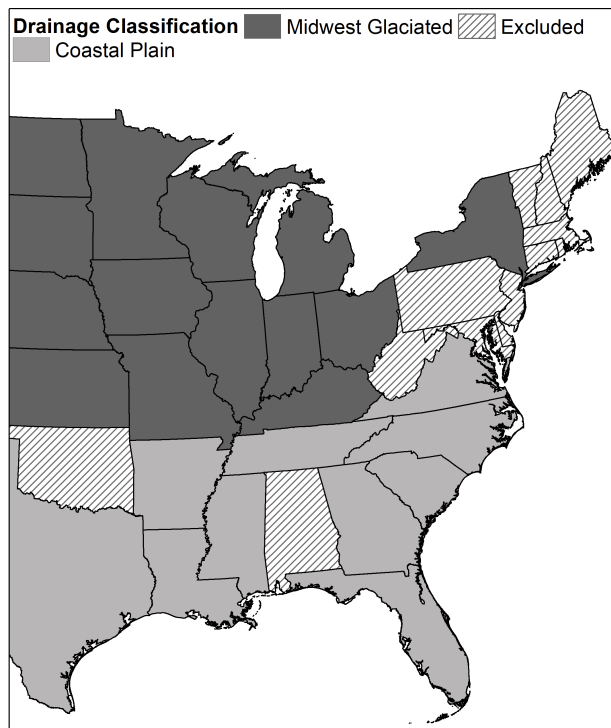
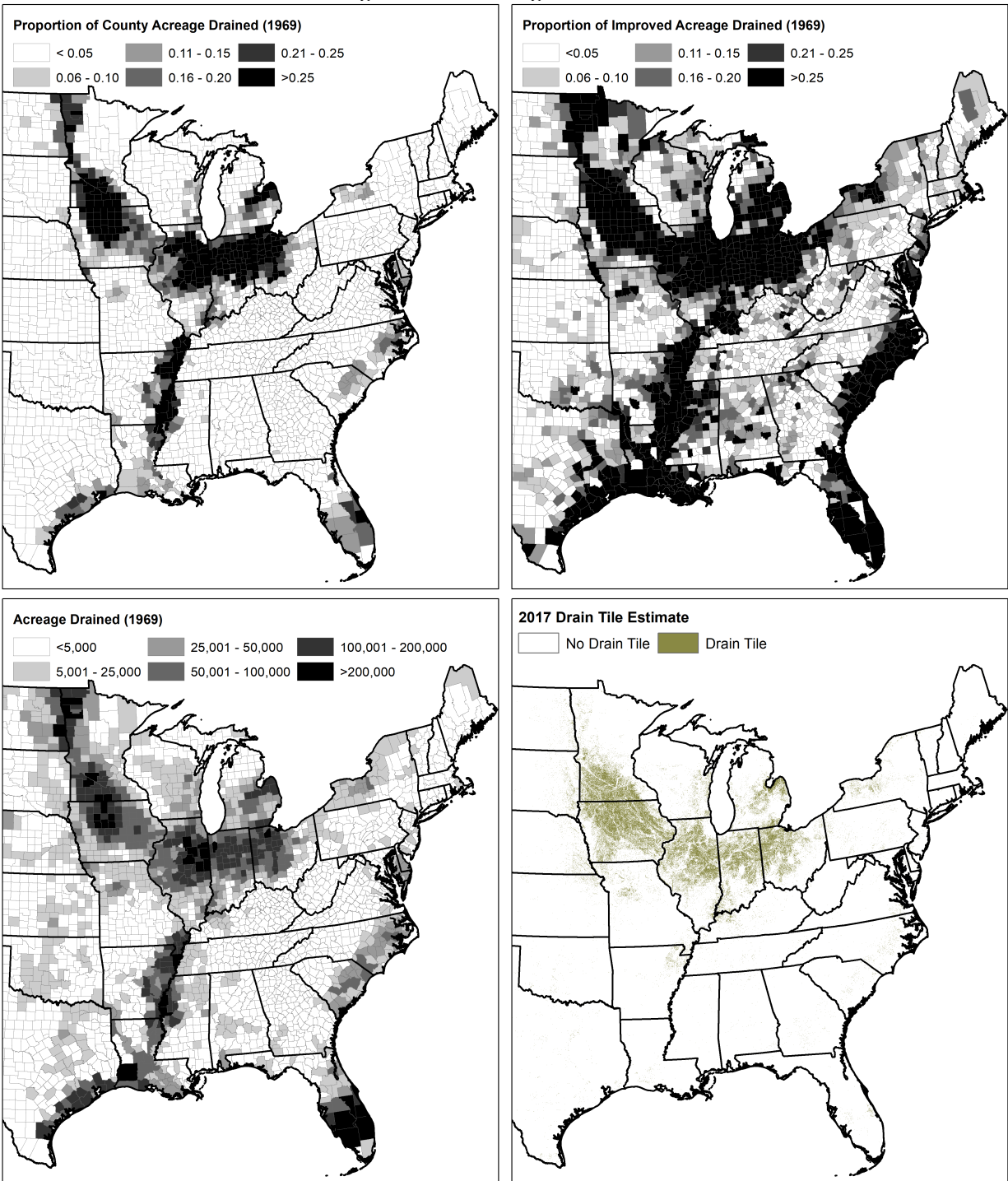


Figure A5: Drainage Outcomes



Notes: The state of drainage as of 1969 by percentage of county area, percentage of improved area, and total acres. The figure also shows the estimated area of tile drainage in 2017, which although not available from the 1969 census data, provides an estimate of historic drain tile locations. When compared to the maps of drainage index and topography from figure A1, it is clear that drainage index and actual area drained are closely related. Comparison to the right panel of figure 1 shows the tile drainage has been primarily a phenomenon linked to glaciated flat lands.

Table A2: Conditional Summary Statistics: Midwest Tile

Variable	SWI<60		SWI>60	
	Pre	Post	Pre	Post
Total value in farms (2020\$ millions)	116 (154)	342 (286)	91 (125)	475 (378)
Land value per acre (2020\$)	654 (1,867)	1,532 (11,479)	468 (349)	1,607 (1,085)
Proportion of county improved	0.33 (0.26)	0.49 (0.25)	0.26 (0.24)	0.61 (0.22)
Total number of farms	1,470 (1,290)	1,855 (996)	1,203 (1,121)	2,187 (1,024)
Total acres in farms	179,252 (139,581)	297,525 (170,665)	150,637 (154,156)	298,236 (146,461)
County median NSWI	44.68 (6.91)		69.73 (6.00)	
Median productivity index	10.78 (3.36)		11.92 (1.88)	
Median elevation (m)	319.27 (130.11)		259.65 (80.02)	
Standard deviation elevation (m)	34.73 (28.35)		19.28 (13.11)	

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 the four years before/after treatment. Standard deviations are reported in parentheses.

Table A3: Conditional Summary Statistics: Coastal Plain

Variable	SWI<60		SWIx>60	
	Pre	Post	Pre	Post
Total value in farms (2020\$ millions)	47 (56)	183 (189)	38 (48)	228 (359)
Land value per acre (2020\$)	256 (316)	903 (2,236)	366 (627)	1,330 (4,629)
Proportion of county improved	0.23 (0.16)	0.26 (0.16)	0.11 (0.10)	0.20 (0.17)
Total number of farms	1,177 (1,076)	2,029 (1,428)	814 (942)	1,952 (2,005)
Total acres in farms	189,371 (141,308)	248,100 (183,068)	131,457 (142,184)	192,250 (160,005)
County median NSWI	43.52 (5.65)		77.17 (8.09)	
Median productivity index	5.95 (3.22)		7.40 (3.46)	
Median elevation (m)	216.79 (192.35)		26.30 (26.35)	
Standard deviation elevation (m)	47.56 (53.01)		7.74 (5.93)	

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 the four years before/after treatment. Standard deviations are reported in parentheses.

Table A4: Treatment Effect Heterogeneity

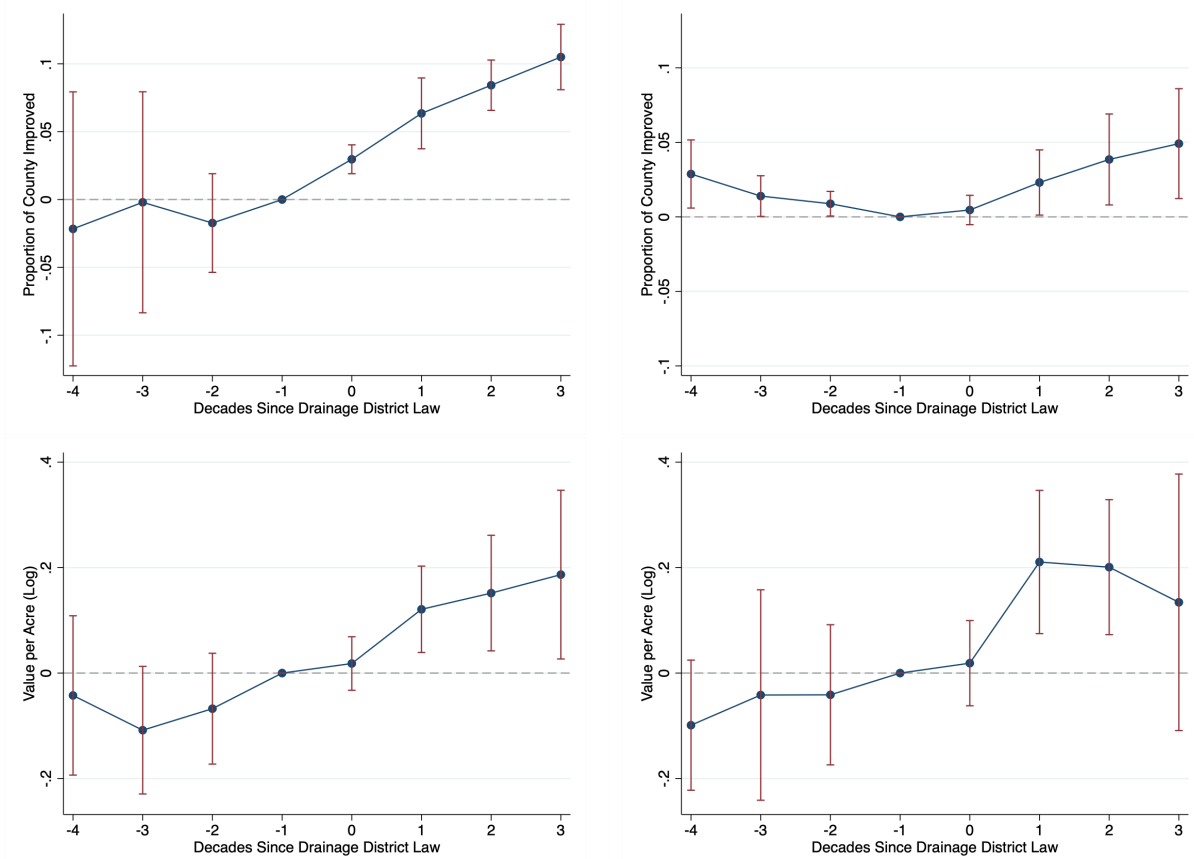
	All States in Sample		Midwest Tile		Coastal Plain	
	Prop. Impr.	\$/ac (log)	Prop. Impr.	\$/ac (log)	Prop. Impr.	\$/ac (log)
Baseline	0.058*** (0.011)	0.196*** (0.043)	0.074*** (0.013)	0.156*** (0.047)	0.034* (0.016)	0.257*** (0.074)
High Roughness	-0.023 (0.022)	-0.105* (0.061)	-0.02 (0.021)	-0.113* (0.060)		
Low Roughness	-0.01 (0.019)	-0.039 (0.165)			-0.018 (0.022)	-0.02 (0.168)
Obs	14,476	14,466	7,531	7,533	6,945	6,933
R ²	0.909	0.889	0.911	0.904	0.849	0.843

Notes: This table presents difference-in-difference estimates for the effect of drainage district adoption on high drainage index counties ($DI > 60$) relative to others, with counties split into three exclusive categories: those with low roughness (standard deviation of elevation meters less than 2.6), high roughness (standard deviation of elevation in the top quartile of all counties); and all remaining counties with $DI > 60$. All specifications include state-by-year and county fixed effects. Standard errors are clustered by county and reported in parentheses; statistical significance is indicated by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure A6: Event Studies

Midwest Glaciated

Coastal Plain



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 columns 3-6 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 sample includes counties in 14 Midwest states and 10 Coastal Plain states. Treatment is DI_{i60} after drainage law passage, excluding counties with high roughness (Roughness = fourth quartile). Counties with roughness less than fifth percentile are excluded.