The Development of Agricultural Drainage in the United States 1850-1969

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Abstract

Tile drainage was first demonstrated in the United States in Upstate New York in 1835 as a method to adapt agriculture to excessive water in soils. Subsequently, innovations in coordinated drainage enterprises, engineering, and tile manufacture led to drainage over large portions of the U.S. Midwest and Southeast. Of the 215 million acres of wetlands estimated to have existed in the contiguous United States at colonization, 124 million have been drained today, 80-87% for agricultural purposes. In this paper we argue that a key institutional innovation, the drainage management district, facilitated local investment in drainage. States in our sample adopted drainage laws between 1857 and 1932, and after adoption each state saw an increase in improved agricultural land 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 worst-drained counties of the eastern United States by $3.7-6.5 billion (2020 dollars).

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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 move water off of saturated lands. (See, for example, Bogue (1951) and Bogue (1963)) A significant portion of the eastern United States, including the upper Midwest, the Mississippi River Basin, and the eastern Coastal Plain, has naturally occurring poorly drained soils. Without drainage, the majority of present-day Corn-Belt — Ohio, Indiana, Illinois, Iowa, and Minnesota — would be ill-suited for agricultural production entirely.

Drainage ditches, in many cases used in combination with 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. Other actions were carried out at smaller scales on undulating fields in Indiana, Illinois, and Iowa that were only partially submerged. Settlers began farming higher, drier ground first and, over time, converted lower swales into additional farmland through drainage [1]

The implementation of 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 fine scale, drained land was an essential input into the production of Midwestern crops—mainly oats and corn. One key barrier to the adoption of widespread drainage was the coordinated action required to finance, route, and build the large open ditches that served as outlet drains for tiled fields. It was the combination of innovations in drainage enterprises, 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) [2]

[1] "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)"

[2] Draining vast areas of the Midwest farmland had its unintended consequences, notably 20th century algal blooms in lakes and a hypoxic Dead Zone in the Gulf of Mexico. (See, for example, Mitsch (2017)).

The distribution of poorly drained lands coincides closely with flat topography, generally in the Midwest as a result of glaciation and in the lower Mississippi and Southeast on the low lying coastal plain. The development of agricultural production on poorly drained lands can be understood in terms of the significant changes over time in underlying determinants of demand for drainage; and the spatial distribution of drained land can be understood in terms of spatial variation in these determinants. 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 typically required significant coordination among neighboring landowners that was initially absent.

The U.S. government passed 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. State and federal governments lacked the capital and knowledge to develop drainage. Because "piecemeal ditching" was ineffective absent open outlet channels and coordinated drainage works, the implementaiton 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)." Large investment in drainage works required institutional innovation through the creation of drainage management districts.

The eventual dispersion of the Swamp Land Act lands to private landowners aligned their incentives and led to "bottom-up" institutional innovation to solve the drainage coordination problem. While drainage required coordination over areas of several square miles or more, farms in the wet prairie counties were smaller, around 150 acres, due to the increasing costs of monitoring labor on larger farms (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. Drainage district laws provided sufficient legal structure for collective investment in drainage through local taxing and eminent domain authority, for which we find evidence.

Using data from the agricultural census on improved agricultural acres and agricultural land value spanning the development of agricultural drainage across the eastern United States, we compare counties with poorly drained soils to those that were well-drained within the same state. Difference-in-difference analysis reveals that after the enactment of drainage district legislation, poorly-drained counties saw relative increases in improved acres and land value. We do not argue that the creation of drainage districts was the cause of increased drainage and development of poorly drained counties. Instead, drainage district legislation was a necessary condition for widespread investment in drainage in a state, and the passage of these laws allows us to separate the period of low investment in poorly drained counties from the subsequent outcomes resulting from drainage investment.

We estimate artificial drainage increased the value of agricultural land in the worst-drained counties of the eastern United States by between \$3.7B and \$6.5B in 2020 dollars. While technical innovation in drain tile was one component of the development of drainage, particularly in the Upper Midwest, our paper points as well to the importance of institutional innovation.

2 Empirical Setting

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 artificially lowered via within-soil flow if nearby drainage provides a pathway for water out of the plant root zone. 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. The earliest attempts at drainage in the Midwest, in 1818, were of this type (Prince, 2008, p. 205). However, these ditches proved impractical for agricultural production in many cases. The ditches themselves, typically three to five feet 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* was required for practical use.

Stone and pole underdrainage was utilized in urban settings throughout the 19th Century, but was uneconomical for general agricultural adoption. 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 in effectiveness and once implemented in a field, saw declines in effectiveness within a few years. 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.[3]

It was the advent and diffusion of clay drain tile, first used in the United States in Seneca County, New York in 1835, that changed agriculture in the Midwest (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)." The flat tile method was eventually replaced by cylindrical tile starting around 1858 (McCrory, 1928). The first tile manufacturing machine was imported in 1848 from England, with local production necessary due to the weight of tiles. Production quickly spread with 66 tile factories established in the United States from 1850-59, 234 from 1860-69, and 840 from 1870-79 (McCrory, 1928).

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

The natural wetlands of the United States were viewed by Federal Government policy as "unproductive and an economic waste" from the country's 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—*

[3] Modern 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.

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
	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. 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 states would simply use land sale funds to finance drainage proved incorrect because the funds raised were insufficient and state governments lacked the expertise at the scale necessary to fund and oversee these types of public works. 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 fell to individual landowners and was achieved over time through local investment, private and public, not federal or state support.

2.2 The Economics of Drainage and Coordination

Laying tiles constitutes a private investment in agricultural production. Because of its higher capital cost, poorly drained land was less developed initially. Hewes and Frandson (1952) note:

> *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."*

Economic incentives to drain and fully utilize these lands were clear. Prince (2008) suggests that in the Upper Midwest prior to 1880, unimproved wetland sold for an average of $7 per acre (ranging from $2-$12), but that the sale price once drained could increase by a factor of five. In their account of drainage in Story County, Iowa, Hewes and Frandson (1952) note the cost of tiling exceeded the price of land for several decades, and offer estimates of this cost from several sources. The 1860 Agricultural Census estimate of $20-$30 per acre is similar to estimates of average cost provided by a survey of drainage conditions in Iowa in 1903 ($25 per acre) and the appraisal of the Federal Land Bank ($35 per acre).

Consistent with the direct capitalization of land improvements into land values, the fivefold increase from $7 per acre suggested by Prince is consistent with a $28 increase in land value due to tiling. After 1880, the value of unimproved 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 of $35 per acre (Prince, 2008).

Such an individual 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). Common law was interpreted in many states, including Iowa, to provide farmers the right for water outflow onto neighboring properties. The bilateral nature of these spillovers suggested the potential for conflict and Bogue (1963) uses the diaries of a 19th Century Illinois farmer, Croft Pilgrim, to describe just 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 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 scale of drainage projects likely explains why private investment in drainage was initially conducted by large landowners. Owners of farms in Illinois from 3,000 to 17,000 acres were documented as privately undertaking 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 was about 150 acres in 1880 (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 adjust output in response to price signals. By contrast, large landowners required external labor, leading to misaligned incentives between owners and hired labor that incurred 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 for this type of speculative venture (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 the owners of swamp lands and other poorly drained areas was one of coordination 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, which is a problem of collective action. Each farmer is better off 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 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).

2.3 The Drainage District

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 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.

Arguably, the later formation of irrigation districts in the western United States was informed by and patterned after the drainage districts formed earlier in the Midwest. Each is an application of the special district. 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. 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 legislation. 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.

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) 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.

Table 2 shows the year of passage for drainage district laws for the 25 states that eventually adopt them in the eastern United States.[4] Although they varied somewhat 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

[4] McCorvie and Lant (1993) provides the same list except New York with dates, although these dates are not consistent with other sources.

Table 2: Year of Drainage District Legislation

State	Year	State	Year
Michigan	1869	Kentucky	1912
Ohio	1859?	Arkansas	1904
Iowa	1884	Louisiana	1907
Illinois	1879	Oklahoma	1908
Kansas	1879	Virginia	1906
Nebraska	1881	Georgia	1911
Minnesota	1887	Florida	1907
Indiana	1863	Missouri	1899
Wisconsin	1899	South Dakota	1907
Texas	1905	Mississippi	1906
North Dakota	1895	North Carolina	1909
South Carolina	1912	Tennessee	1909
New York	1909		

Source: First drainage district legislation data is collected from the authors from various sources. Drainage district legislation is 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)). There are 25 states with similar drainage district legislation east of the 100th Meridian: Indiana (1863) (Vermillion, 2011); Michigan (1869) (Quackenbush, 1973); Illinois (1879) (Herget, 1978); Nebraska (1881) (Fischer et al., 1970); Iowa (1884) (Sherman, 1924); Minnesota (1887) (Palmer, 1915); Missouri (1899) (Olson et al., 2016); Wisconsin (1899) (Prince, 1995; Graham, 1919); 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), Oklahoma (1908), Tennessee (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), Vermont (1906) as being atypical of drainage laws in agricultural states. These laws essentially provide existing public agencies the right of eminent domain for drainage but do not create districts or empower landowners to petition for district creation. These states are excluded from our analysis.

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).

Another key feature of the districts was financial, with districts able to issue low-interest bonds to secure cash for investment (McCrory, 1928). Similar to drainage enterprises in other locales, in Story County, Iowa "most drainage costs [we]re 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 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.*

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 as having 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 those 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 is only available for a few select counties,the 1920 census reports that for the counties we define as poorly drained and that have drainage by 1920, they 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 1960 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.

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 would have reduced demand for drainage, while emerging transportation networks would have 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 through the inclusion of county and state-by-year fixed effects. This allows the empirical work to focus on the effect of drainage districts. While private enterprises existed, the available accounts suggest this private drainage occurred on farms of 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.

There were also important differences in the development of drainage between the glaciated Midwest and 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, with the exception of South Carolina, were also later in passing drainage district legislation, faced larger coordination problems, and generally invested less in tile drainage relative to other states (see table 2).

3 Data & Empirical Strategy

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). 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. 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 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. The DI is derived from the soil classification and slope and so is not affected by drainage or irrigation.[5] Using a 240 meter cell resolution raster, we extract the median DI value for each county. We can then construct a variable to represent high DI (poor natural drainage), for counties with a median DI greater than 60. Figure 2 shows the relationship between median DI and the observed percent of a county drained in each of 1920, 1930, and 1969. As can be seen, the DI=60 cutoff represents a natural break in the data. Figure 5 reveals that counties with *DI High* tend to have more area drained.

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. Because soil PI is correlated with DI, and PI is also potentially affected by practices like drainage, we include specifications with and without PI to ensure results are not driven by its inclusion or exclusion. [6]

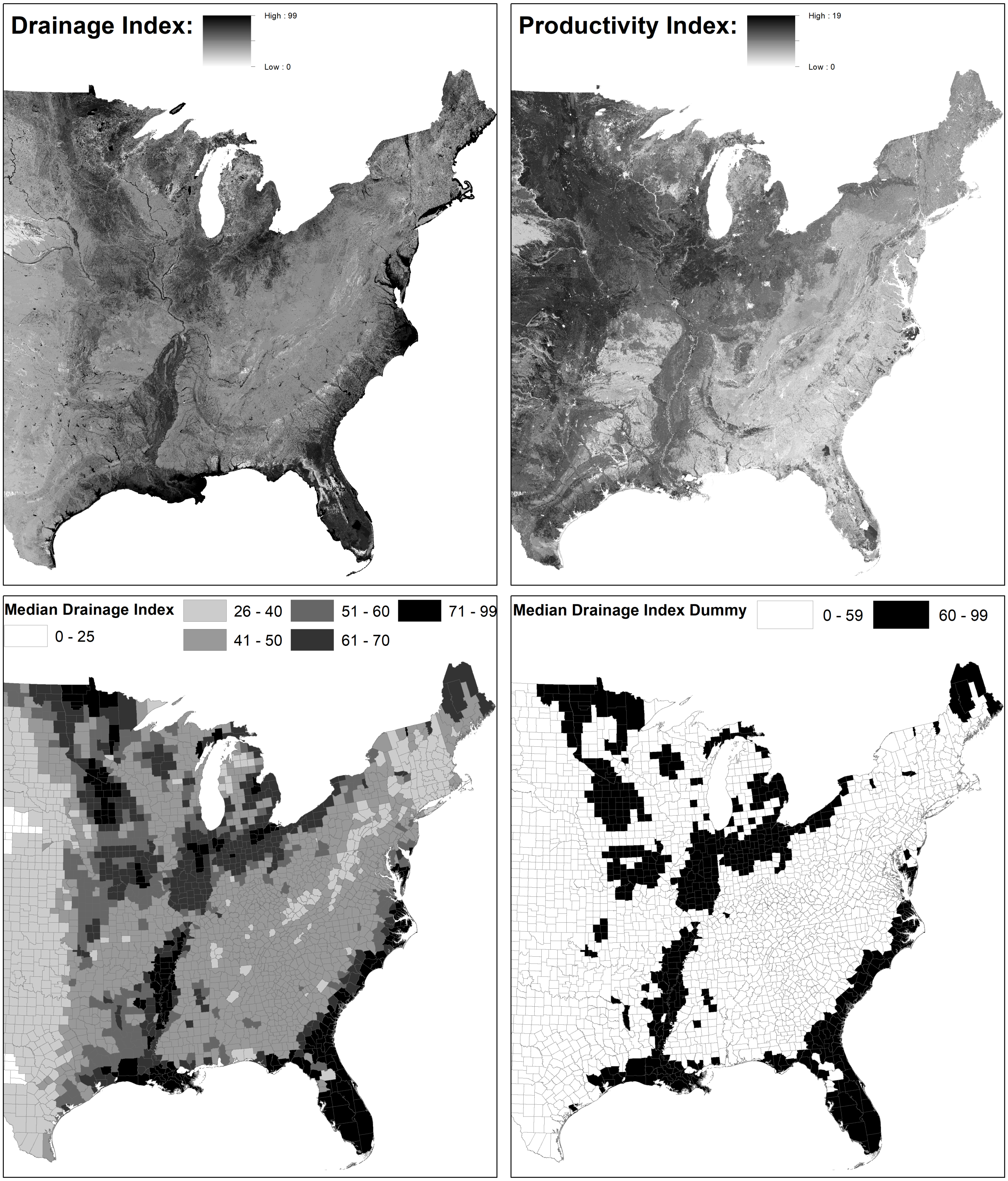
3.2 Empirical Strategy and Identification

Our empirical work examines the importance of drainage districts to county-level farm drainage. To identify the effect of drainage districts we rely on a list of key dates, varying by state, of the

[5] A soil's taxonomic classification is not initially affected by on-farm investments like irrigation or artificial drainage and so the DI does not change unless these investments change the classification of the soil in the long-run. 'Instead, the DI reflects the soil's *natural* wetness condition. Each soil *series* has, in theory, its own unique DI." (Schaetzl et al., 2009)"

[6] "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)

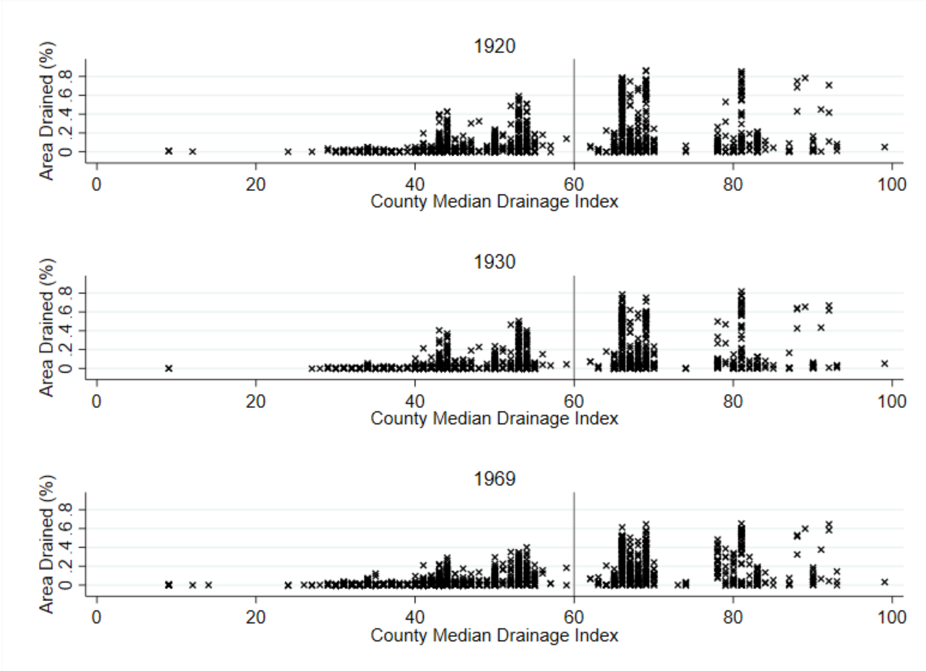
Figure 1: Drainage Index



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.

passage of district enabling legislation. We construct this list using both modern and contemporaneous accounts (see table 2). Drainage district legislation is defined the first successful bill that

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.

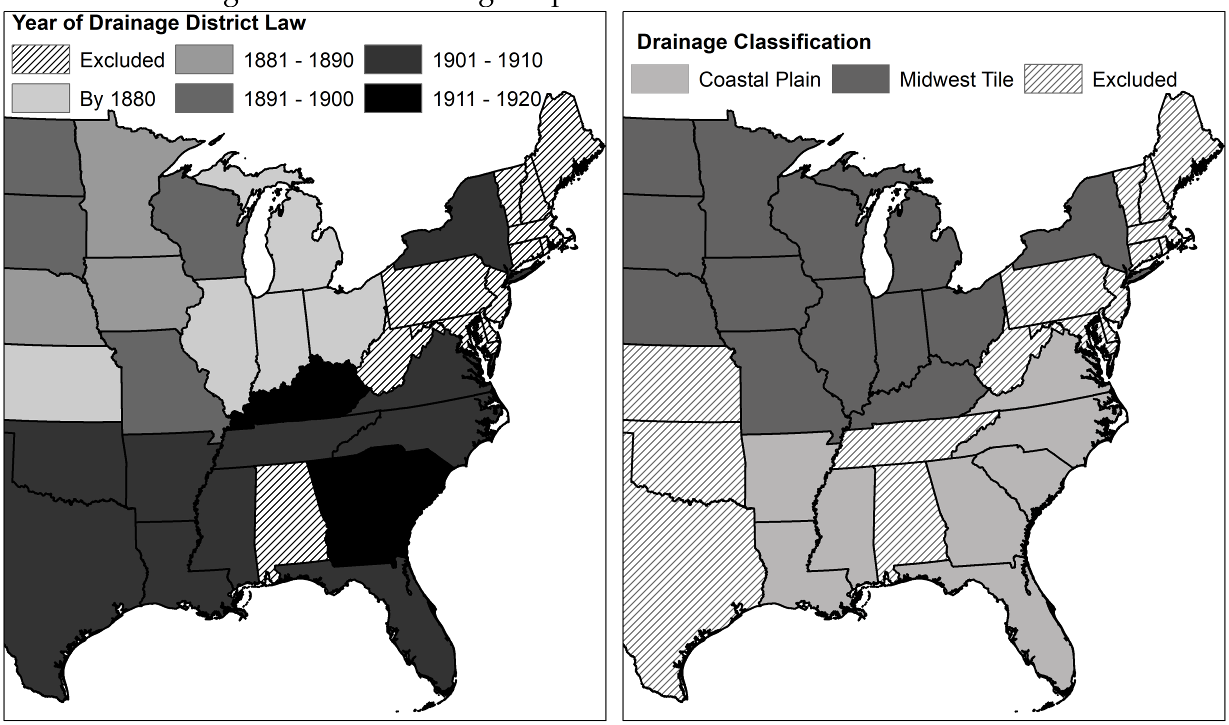
allows the petition of landowners to create a district governed by some elected body, e.g. drainage commissioners, that has state power to raise funds for ditch construction activities and condemn land (see (Sandretto, 1987)).

25 eastern states have drainage districts laws that meet our definition. 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 4, left panel.

We find little contemporaneous discussion of drainage during the period we study in Texas, Oklahoma, Kansas, and Tennessee, and only one unverified source for the date of Kansas' passage of a drainage law. These states are excluded from our main specifications, although results are little changed if they are included. This leaves us with 21 states, which we classify into two groups based one the general characteristics of drainage as 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 inthe map created by Fenneman and Johnson (1946): Virginia, North Carolina, South Carolina, Georgia, Florida, Mississippi, Louisiana, and Arkansas. The glacial swamps described by Palmer (1915) coincides roughly with the Upper Midwest, and our definition of “Midwest Tile Drainage” includes North and South Dakota, Nebraska, Iowa, Minnesota, Wisconsin, Illinois, Indiana, Michigan, and Ohio. To this list we add Kentucky and Missouri, portions of which share drainage similarities with these states, and New York which, although was the initial location of tile drainage in the U.S.. adopted drainage district laws significantly later.

Figure 3: State Drainage Implementation Date and Classification



Notes:

We find evidence consistent with substantial responses of improved farm acres in poorly drained counties to drainage district enablement, starting when a law is passed and persisting for several decades afterward. This interpretation discretizes what was in each state a non-instantaneous change–the history of drainage law reveals substantial trial and error in arriving at ultimately effective institutions. 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 has been exercised in identifying the date in which viable drainage legislation was passed in each state. We find the dates provided by McCorvie and Lant (1993) the most consistent source for the passage of the first effective piece of drainage legislation–for instance, they provide 1878 for the effective date for Illinois.

Our 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 availability of drainage legislation and assume that the magnitude of the empirical effects we find are inclusive of any subsequent changes to drainage legislation. In this sense, the empirical strategy does not distinguish over time between different causes of continued drainage development.

We 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:

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

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 state by 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, 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).[7]

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

[7]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.

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.

While the empirical strategy can be applied to the 25-state sample, it is clear that drainage varied tremendously across the eastern US. To aid in understanding the heterogeneity inherent in the underlying estimate of average treatment effects, we break our sample into three drainage types: Midwest Tile (Ohio, Indiana, Illinois, Minnesota, Wisconsin, Iowa, Nebraska, North and South Dakota, and New York); Levee (Oklahoma, Texas, Missouri, Kansas, Arkansas, Louisiana, Kentucky, Tennessee, Mississippi, and Florida); and Coastal Plain (Virginia, North and South Carolina, and Georgia).

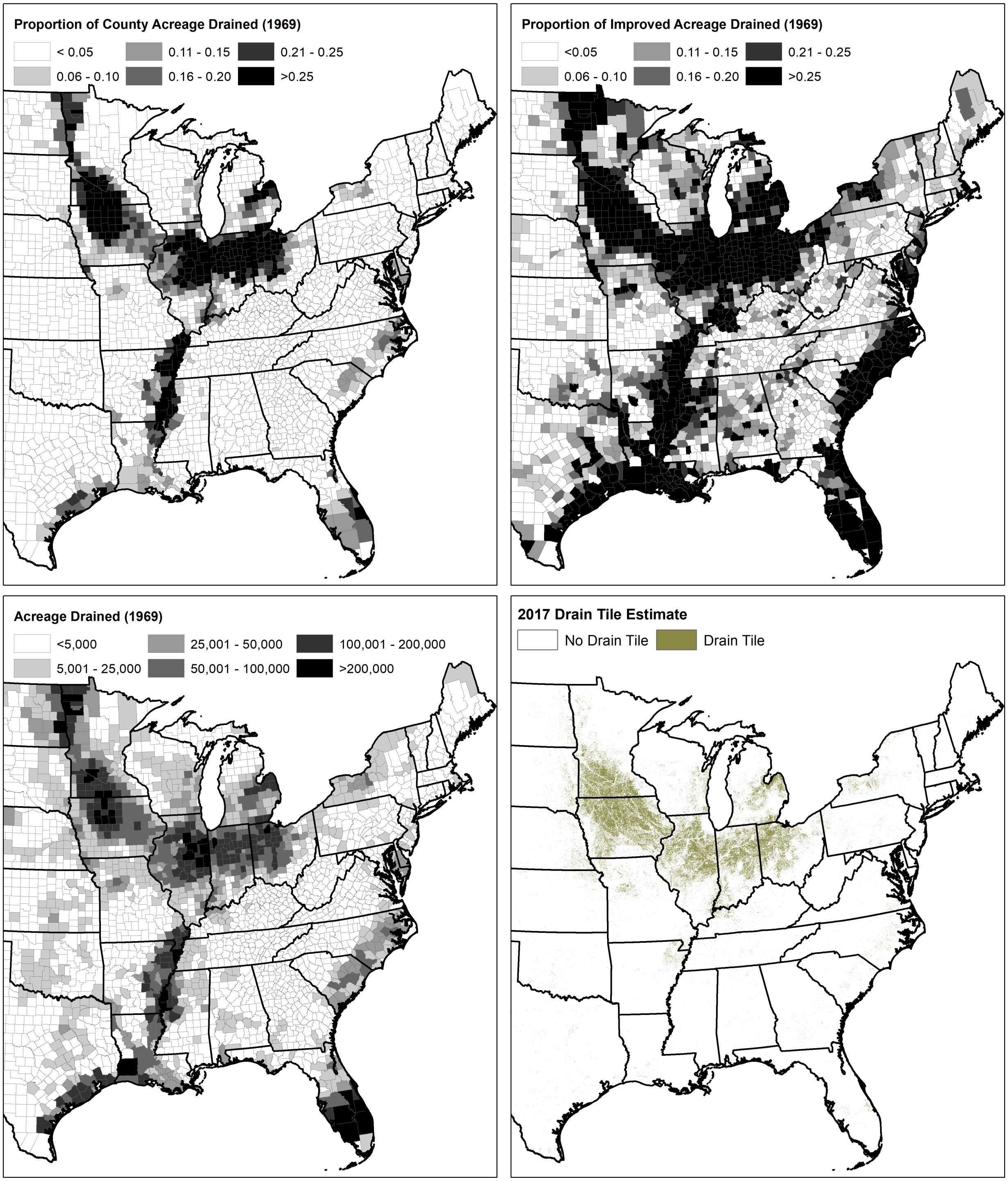
4 Results

4.1 Agricultural Development and the Drainage Index

In this section we 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 well-drained counties are more developed prior to the passage of drainage district laws: the low-DI counties have average total farm value of \$133M versus \$107M in the high DI counties with 29% of the county with improved agricultural land versus 22% for high-DI counties.

After the passage of drainage district legislation, farm values increase by \$151M in low-DI counties and over \$326M in high-DI counties. The percent of county acreage improved increased by 10 percentage points in low-DI counties and 28 percentage points in high-DI counties. On average, after the passage of drainage district laws high-DI counties have a higher percentage of

Figure 4: Drainage Outcomes



Notes:

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). These summary statistics do not control for county-specific characteristics that could be related to

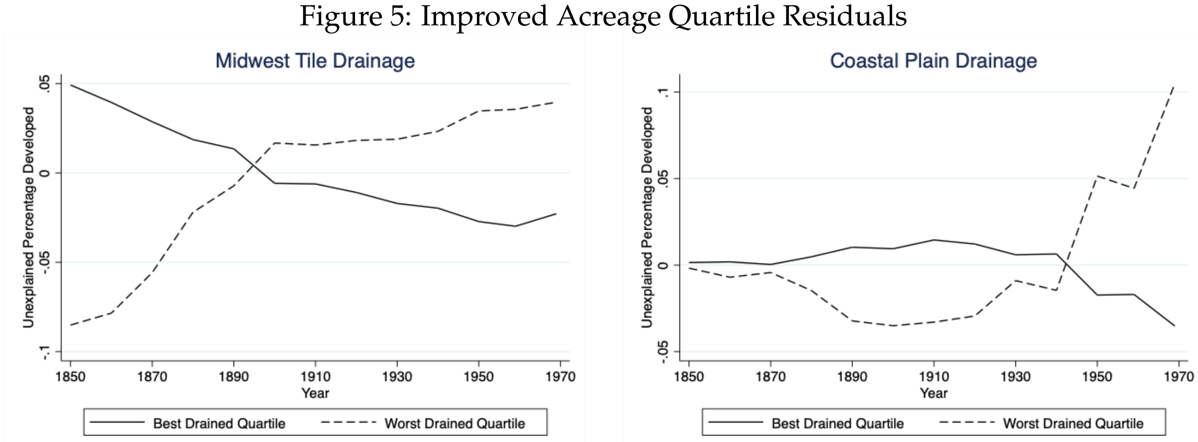
Table 3: Conditional Summary Statistics

Variable	Drainage Index < 60 Pre	Drainage Index < 60 Post	Drainage Index > 60 Pre	Drainage Index > 60 Post
Total Value in Farms (2020$ millions)	118.92	273.98	76.46	414.74
	(165.59)	(254.58)	(117.49)	(398.31)
Pct. of County Improved	0.27	0.39	0.18	0.49
	(0.20)	(0.24)	(0.20)	(0.28)
Total Farms	1,538	1,854	1,116	2,048
	(1,317)	(1,151)	(1,210)	(1,349)
Total Acres in Farms	193,255	283,391	151,427	273,265
	(135,533)	(185,360)	(130,312)	(165,209)
Per Acre Farm Value	862.95	1,300.12	461.47	1,540.88
	(3,393.03)	(9,162.02)	(556.02)	(2,334.91)
Median Drainage Index	43.84		72.47	
	(6.24)		(7.83)	
Median Productivity Index	8.09		10.16	
	(3.93)		(3.42)	

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.

development or changing trends in different states, which we address in the regression analysis.

Figure 5: Improved Acreage Quartile Residuals



Notes: This figure depicts the unexplained variation, the residuals of a regression on county fixed effects and state-by-year fixed-effects, of percentage of county improved for all counties combined, and separately for counties classified as Midwest Tile Drainage (Illinois, Ohio, Iowa, Michigan, Minnesota, Indiana, Wisconsin, North Dakota, South Dakota, Nebraska); Levee Drainage (Kansas, Texas, Oklahoma, Arkansas, Missouri, Mississippi, Louisiana, Kentucky, Tennessee, and Florida)' and Coastal Plain Drainage (Virginia, North Carolina, South Carolina, Georgia).

We begin by examining outcomes across select states in the Midwest and South to provide a comparison of counties likely to be treated with drainage, relative to others. We regress two variables, percentage of a county with improved agricultural land and total county farm value (logged) on a flexible set of controls and then group counties in each state by the quartiles of drainage index. We 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 subsequent decades. The top panels of figure 5 show the catch-up of the worst-drained quartile for improved acres (left) and total value (right). By 1920 the percentage of a county improved is the same and eventually goes higher for poorly drained counties. Similarly, once drained, the value per acre of the worst drained quartiles, which are generally nutrient rich, exceeds those of the best drained quartiles by 1900. Thus the land value outcomes appear to anticipate drainage implementation to some extent. [8]

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 exceeds the level of the best drained counties by 1930. Again, land markets appear to anticipate the implementation of drainage by about 20 years, with per-acre land value estimates of best- and worst-drained quartiles similar by 1910.

4.2 Drainage Impact Estimation

Next, we turn to 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, one per 10 years, and we report a window that includes 3 periods (30 years) prior to treatment and 3 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.[9] The left panels shows the event study for improved acres and per acre farm value for the Midwest Tile states; the right panels for the Coastal Plain states. All coefficients are relative to the difference between treated and untreated parcels in the period just prior to

[8] Similar figures for farm value per acre and crop value are shown in appendix figureA3

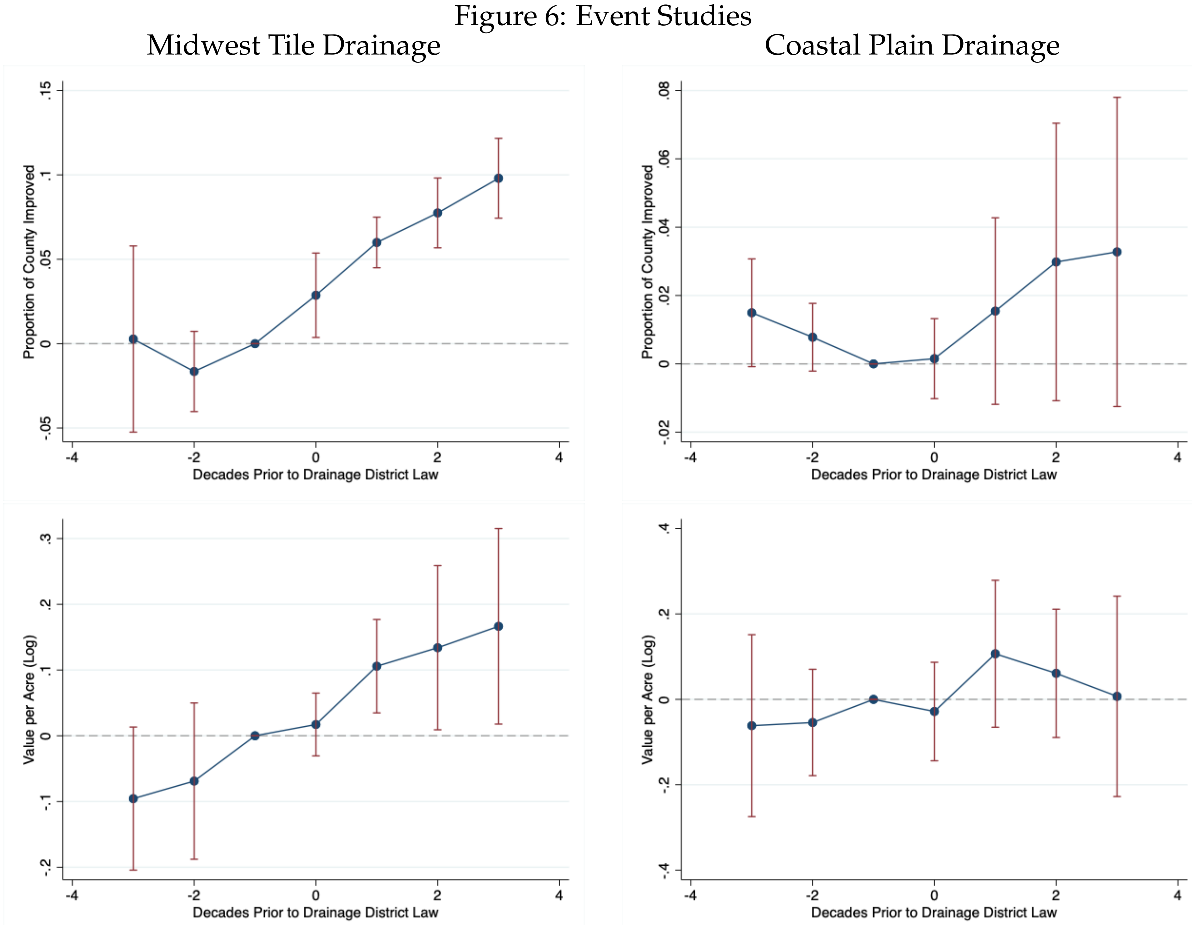
[9] Implemented with the `did_multiplegt` package in Stata.

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 for Midwest Tile shows an upward trend in point estimates (which would be consistent with anticipation of drainage in land markets) and the percent county improved a downward trend for Coastal Plain (consistent with a relative decrease in value of poorly drained counties pre-treatment).

From period $t = 0$ onward, there is a statistically significant (and increasing) difference in percentage of county improved for Midwest Tile states, and an increase in per acre value after $t = 0$. The Coastal Plain states see no statistically significant point estimates after treatment for either variable.

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_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.[10] 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.[11]

Table 4: Ag Development after Drainage District Law

	(1)	(2)	(3)	(4)	(5)	(6)
	All States in Sample		Midwest Tile		Coastal Plain	
	Pct. Impr.	$/ac (log)	Pct. Impr.	$/ac (log)	Pct. Impr.	$/ac (log)
Panel A:						
	de Chaisemartin & D'Haultfoeuille (2020)					
Post Drain. Dist. Law	0.049***	0.081***	0.066***	0.106***	0.02	0.058
	(0.012)	(0.036)	(0.007)	(0.048)	(0.015)	(0.091)
Panel B:						
	Callaway & Sant'Anna (2020)					
Post Drain. Dist. Law	0.043*	0.109**	0.043	0.092	0.040**	0.142
	(0.022)	(0.051)	(0.032)	(0.066)	(0.016)	(0.091)
Panel C:						
	Two-Way Fixed Effects					
Post Drain. Dist. Law	0.055***	0.134***	0.070***	0.125**	0.032*	0.132
	(0.012)	(0.040)	(0.015)	(0.042)	(0.016)	(0.129)
Number of Counties	1788	1788	1122	1122	666	666
R^2 (TWFE)	0.926	0.909	0.914	0.912	0.895	0.925

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 five 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 * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Columns (1) and (2) report the results for 21 counties with drainage district laws shown in figure 4. Columns (3)-(6) report results for Midwest Tile and Coastal Plain regions. Column 1 suggests that following the implementation of drainage districts, a poorly drained county (median drainage index greater than 60) will see a 4.3 to 5.5 percentage point increase in the area of the county with improved agricultural land.

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

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

The coefficient estimates are fairly consistent and robust for improved acres for the Midwest Tile group. A poorly drained county (DI>60) will see a 4.3 to 7.0 percentage point increase in the area of the county with improved agricultural land and a 9.6-13.3% increase in land value per acre. Coastal Plain coefficient magnitudes are lower for improved acres and generally not statistically significant.

We can use the coefficients in columns 1 and 2 to find the increase in the value of agricultural land in these counties as a result of drainage. From table 3, 18% of low-DI counties are improved pre-treatment, 151,427 acres on average. Drainage increased their area of improved acreage by 4.3-5.5pp, and the value of the land by 8.4-14.3%.[12]. From the improved acreage regressions, drainage increased improved acreage to 187,601-197,696 acres in the average county. The average per acre land value in a high-DI county was $461 pre-treatment, meaning the total increase in value due to the per acre land-value increase was $7.3-13M per high-DI county. There are 513 counties in the high-DI category, suggesting that drainage added $3.67-6.54B to U.S. agricultural land value (in 2020 dollars).

5 Conclusion

In this paper we demonstrate how local drainage enterprises invested in tile drainage and drainage works. After federal and state funding for these projects failed to materialize, drainage management districts formed to locally financed drainage 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 1857 and 1932, and after adoption each state saw an increase in improved agricultural land 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 worst-drained counties of the eastern United States by 13.5-30.3%, a total increase across all poorly-drained counties of $7-17B (2020 dollars).

[12]These calculations come from coefficients ranging from 0.081-0.134 in a log-level regression, corresponding to a $e^{\beta} - 1$ percent increase.

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Appendix

Figure A1: Crop Value Quartile Regressions

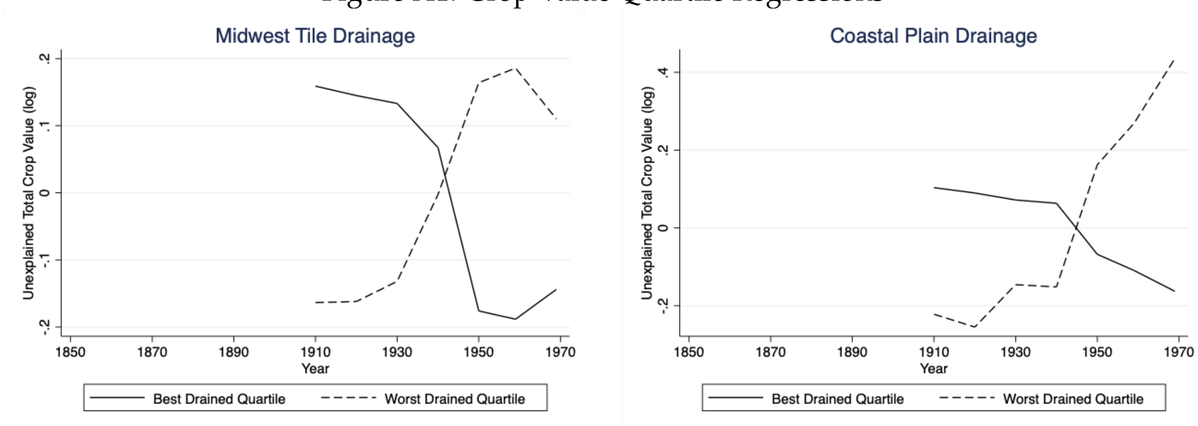

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Figure A2: County Ag Land Value Quartile Regressions

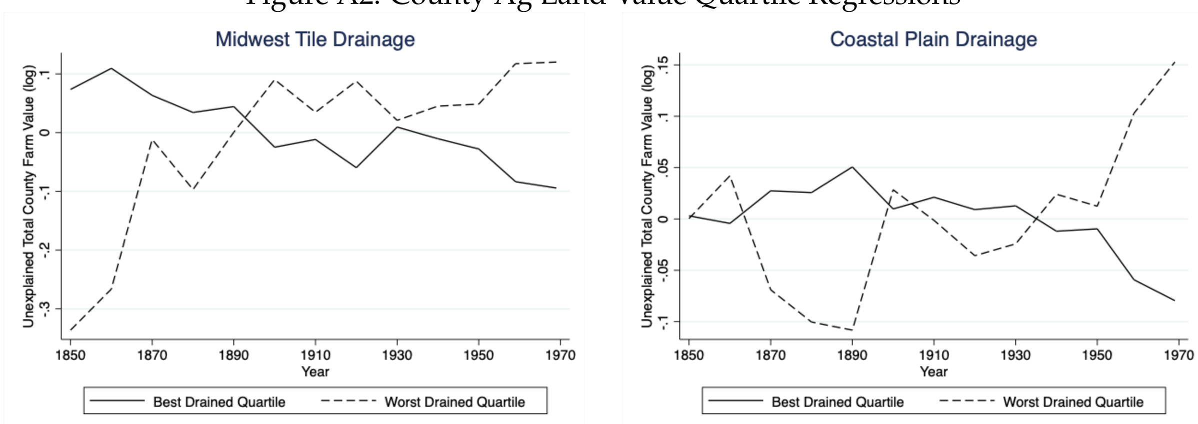

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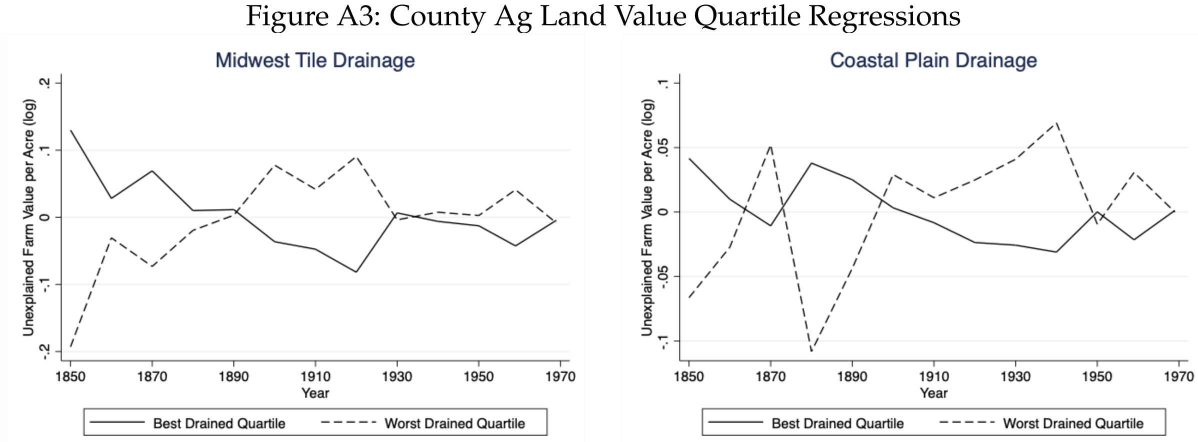
Figure A3: County Ag Land Value Quartile Regressions



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