Water is the True Wealth in a Dry Land:* Prior Appropriation and the Settlement of the Arid West

Bryan Leonard† Steven M. Smith ‡

PRELIMINARY DRAFT. PLEASE DO NOT CITE WITHOUT PERMISSION

Abstract

This paper provides new evidence on the relationship between property rights to water and the demand for land on the American Frontier. Using geo-located records of individual land patents from the General Land Office, we compare rates of settlement in counties across western states that formally adopted the prior appropriation doctrine of water rights at different times. Using the latest difference-in-difference techniques, we find that settlement more than doubles in the years just after a state adopts prior appropriation. Comparing overall settlement as well as rates of homesteading vs. cash purchases of land across counties with different land and water resources, we present evidence consistent with the hypothesis that prior appropriation increased the value of agricultural land, paritcularly where water resources were most scarce.

*This quote has been attributed to Wallace Stegner.

†University of Wyoming bryan.leonard@uwyo.edu

‡Colorado School of Mines ssmith1@mines.edu

1 Introduction

Scholars have long recognized the importance of water in the development of the arid Western United States during Westward Expansion (Worster, 1985; Stegner, 1992; Wilkinson, 1992). The American West holds abundant natural resources including timber, wildlife, minerals, and large amounts of arable land. But as settlers moved westward, they learned that surface water was relatively scarce in the regions beyond the 100th meridian. Because water was less abundant than in the Eastern states, settlers had to develop new infrastructure—and new institutions—to facilitate off-stream uses of water for mining and irrigation.

The Federal Bureau of Reclamation played a major role in facilitating agricultural and economic development by constructing dams and irrigation works (Worster, 1985; Edwards and Smith, 2018), but these investments only began with the Reclamation Act in 1902, a decade after the frontier had closed (Turner, 1893) and all but two of the western territories had attained statehood. Prior to major federal projects, agricultural development and mining were facilitated by *private* investment in irrigation infrastructure. Scholars have emphasized the importance of the prior appropriation doctrine—the system of quantified property rights to surface water unique to the Western US—in providing the necessary security to facilitate such investment (Rose, 1990; Kanazawa, 2015; Leonard and Libecap, 2019). This work, though crucial for understanding the relationship between law, property rights, and economic behavior, largely provides an ex-post rationalization of the somewhat peculiar features of prior appropriation (PA) including priority-based allocation and "use it or lose it" rules.

This paper takes a new approach, and attempts to provide the first causal evidence on the impact of the switch from riparian rights to prior appropriation rights on the settlement of the arid Western US during the late 19th and early 20th century. Utilizing digitized land patents (capturing when land in the public domain is first transferred to non-Federal ownership) and the fact that Western states/territories recognized prior appropriation via statute at different points in time, we compare rates of land settlement before vs. after the adoption of prior appropriation in counties from states that adopted prior appropriation at different points in time using recently developed difference-in-difference estimators that account for complications that arise due to the staggered adoption of prior appropriation by different states (De Chaisemartin and d'Haultfoeuille, 2020).

After normalizing to the amount of land that is ultimately settled in a given county, we find that annual land patenting increases by an average of 0.8 percentage points per year, which represents a more than doubling of claimed acreage. This corresponds to about 27 additional land patents per year, a seven-fold increase relative to the number of new patents per year prior to the adoption of prior appropriation. Following previous literature that has emphasized the differential propensity to purchase land rather than homesteading as land values increase (Allen, 1991, 2019; Allen and Leonard, 2021, 2025b), we examine the difference between cash vs. homestead claims to shed led on potential increases in land value due to more secure water rights. We find that the normalized difference in purchased vs. homesteaded acres increases by 0.4 percentage points, which represents a 40-fold increase. Finally, we explore whether the impacts of prior appropriation differ based on the amount of arable land and surface water available in a county. We find that the effect of prior appropriation on total claims—as well as the difference between cash sales and homesteads—is significantly larger in counties with more prime agricultural land and with scarcer water resources.

This paper contributes to several strands of literature including property rights and economic development, the economic history of water in the American West, and the political economy Westward Expansion. Leonard and Libecap (2019) argued that the switch to PA rights was crucial for facilitating coordinated private investment in irrigation infrastructure in the Western US, but their analysis is limited to the behavior of irrigators in Colorado *after* PA was adopted. We complement their study with causal evidence on the impact of the change in water rights regimes on settler behavior by providing a before vs. after comparison across states that adopted PA at different times. This paper also complements Alston and Smith (2022). Whereas their analysis demonstrates the impact of uncertain *land* rights on the development of irrigation infrastructure, we explore the impact of *water* rights security on land settlement.

Finally, our work provides an important missing link in the broader narrative about the importance of water for the economic development of the American West. While historians often stress the importance of water in this context, (Worster, 1985; Stegner, 1992; Wilkinson, 1992), the specific link between PA rights and land settlement has not been explored quantitatively. This study also relates to a growing body of work on the political economy of westward expansion. While much of that work explores the impact of federal policies meant to "push" settlers to the frontier (Allen,

2019; Donaldson and Hornbeck, 2016; Frymer, 2017; Allen, 2019; Allen and Leonard, 2025b), we shed new light on the extent to which state-level policies helped to "pull" settlers into specific regions.

2 Historical Background

2.1 The Importance of Water in the American West

As first emphasized by Powell (1879), the geography of of the United States undergoes a stark change as one moves west beyond the 100th meridian of longitude that bisects the Dakotas, Nebraska, Kansas, Oklahoma, and Texas. This line is said to divide the relatively humid Eastern United States from the arid Great Plains and Mountain West. In the arid lands beyond the 100th meridian, annual precipitation is too limited to make rain-fed agriculture viable. Instead, agriculture in the Western United States relies on supplemental irrigation.

While irrigation dramatically increased agricultural output and resilience to drought (Edwards and Smith, 2018; Smith and Edwards, 2021), it requires investment in costly infrastructure including reservoirs, diversion-works, ditches, and canals that store, divert, and convey scarce water resources to ensure that they are available when and where they are needed most—on arid but otherwise arable lands during the dry summer months of the growing season. While developing this infrastructure is costly, using it to store and deliver water is not. What's more, these projects are typically shared among many potential surface water users, creating classic collective action problems associated with contributing to public goods and managing common pool resources (Coman, 1911; Ostrom, 1911).

Worster (1985) emphasized the pivotal role of the state in overcoming the collective action problems associated with water, leading to the development of a "hydraulic society" where power was centralized around the control of water resources by a strong central government. Worster's focus on the federal Bureau of Reclamation, which did not come into existence until 1902 and did not complete a project until 1911, overlooks the critical role of *private* investment in irrigation infrastructure—especially diversion-works, ditches and canals—during the late 19th century. Mead (1902) estimates that by 1901, private irrigation systems worth nearly $7.5 billion (in 2024 dollars) were already in operation.

2.2 Property Rights & Investment

Previous work has emphasized the emergence of prior appropriation water rights as an important pre-condition for this investment (Leonard and Libecap, 2019). Prior appropriation was a new way of defining property rights to water that repalced the existing riparian water rights doctrine that existed in the eastern United States (Rose, 1990). Under the riparian doctrine, rights to "reasonable use" of surface water were limited to those owning riparian land directly adjacent to surface water resources. Rights were not quantified, water could not be separated from the stream or the associated riparian land, and all users were expected to share in reductions during drought.

In contrast, prior appropriation established rights to defined quantities of water on a "first-come, first-served" basis. Claimants who put water to a pre-defined "beneficial use," such as mining or irrigation, established the right to divert that same quantity of water each year. A priority date attaches to each right based on the timing of initial diversions, and during droughts more senior rights must be satisfied first (juniors bear the brunt of drought conditions). Rights may be diverted from the stream and can be separated from land ownership. Prior appropriation developed in mining camps—which used similar first possession principles for establishing mineral claims—and in the context of irrigated agriculture. The system first developed informally, with specific aspects of prior appropriation (e.g., priority allocation vs. the ability to divert water) slowly gaining formal recognition in courts and state legislatures over time (Rose, 1990; Kanazawa, 2015).

Leonard and Libecap (2019) argue that prior appropriation facilitated private investment in irrigation infrastructure by providing a secure property right that could serve as the basis for contractual arrangements to share the large fixed costs of infrastructure development without exposing the investors to post-contractual opportunism once ditches were built. They argue that increases in land utilization and land value due to prior appropriation dramatically increased states' economic output. To support this argument, Leonard and Libecap examine the behavior of irrigators with prior appropriation claims in Colorado, a state with especially complete historical water rights data. While they provide evidence that irrigator behavior is consistent with hypotheses about coordination and investment, their study suffers from two key limitations. First, by focusing on behavior of irrigator *after* the advent of prior appropriation, the analysis cannot speak to

the causal effect of the change in water rights regimes on land settlement and utilization because it lacks a counterfactual comparison. Smith (2021) did draw on a natural experiment to substantiate that prior appropriation did cause greater levels of initial investment (larger and longer irrigation ditches) in Colorado relative to New Mexico, which historically (and still in parts today) deployed a distinct system of water rights rooted in the earlier Hispanic settlements. Both studies, however, focus on PA in Colorado, and so it is unclear whether the results generalize to other PA states.

2.3 The Political Economy of Property Rights & Westward Expansion

More broadly, the literature on the political economy of first possession rights remains divided on their primary economic function. While western states opted to allocate water on a first-come, first-serve basis, the federal government similarly allocated a litany of other resources via first possession. These include land under the Preemption Act of 1841 and the Homestead Act of 1862, valuable minerals under the General Mining Law of 1872, and grazing resources under the generally open-access management of the public domain for grazing up until the Taylor Grazing Act in 1934.

Although first possession dissipates resources via "races" to establish property rights (Anderson and Hill, 1990; Lueck, 1995), Allen (1991) emphasized that such races also served strategic interests of the federal government in pushing "actual settlers" into frontier lands where the U.S. held territorial claims that were subject to violent challenge by rival nations. Similarly, Allen (2019) argues that the generous territorial land grants to transcontinental railroads were a complementary strategy for facilitating more rapid settlement of the frontier, and Allen and Leonard (2025b) provide additional evidence using new data across a variety of contexts to support the argument that generous grants of land to railroads and settlers were meant to promote *future* settlement.[1]

An alternative way of viewing the formal recognition of first-possession claims is as a response to rent-seeking by squatters, first-movers, and would-be land barons looking to solidify their interests. This version of events, espoused by Murtazashvili (2013) in the context of land claims and White (2011) in the context of the railroads, is not necessarily mutually exclusive with the interpretation provided by Allen and Leonard (2025b). It may be that first possession served the dual purposes of providing rents to first movers while also facilitating future development.

[1] Frymer (2017) makes a similar argument about the function of federal land policy during this era.

Exploring these questions in the context of prior appropriation offers an opportunity to shed some new light on these dueling interpretations due to the priority-based allocation of PA water rights. PA explicitly favors senior water rights over juniors. Hence, in any given stream system, it is much better to have arrived earlier than later. If the *primary* function of PA was to appease rent-seeking settlers with pre-existing claims, formally enshrining a priority system should *reduce* the demand for land by making water rights less appealing for new entrants. On the other hand, if the primary function of PA was to lay the groundwork for future investment by *new* claimants, there should be an increase in settlement to take advantage of the more secure rights after PA is adopted. The following empirical analysis is designed to answer this question: did PA facilitate greater development of land in the arid Western United States by future settlers?

3 Emergence of Prior Appropriation

While the prior appropriation doctrine itself provides a measure of certainty, the endeavor to demarcate its emergence is replete with uncertainty for a researcher (and, thus, presumably for the contemporaneous settlers and land purchasers affected by it as well). Largely left to individual states, water rights in each one have idiosyncratic histories, but there are some broad similarities that exist. First, the prior appropriation doctrine emerged largely bottom-up and out of necessity and custom, and therefore formal legal rules are simply giving *de jure* force to *de facto* systems. Second, the rulings and acts were often iterative, applying narrowly some aspect of prior appropriations in terms of applicability, before sanctioning it more generally.

Futhermore, these iterative legislative acts and judicial rulings sanctioning prior appropriations occur at different times relative to one another (sometimes before, sometimes after) and it is not clear if one or the either is a more important than the other for formal recognition nor if the rules applied in retrospect or to future claims. Third, many states also simultaneously recognized the riparian doctrine, only repudiating it much later or still utilizing a dual system today. Fourth, the application of PA to public land was generally accepted, but whether the same applied to private lands created confusion. Finally, in many cases the right to appropriate water pre-dates a clear commitment to priority as the allocation tool in times of scarcity. Below we expand on these confounding elements and conclude with an argument to use the timing of the legislative act that

codified prior appropriation doctrine as the most relevant date.

In tandem with the rules and customs that originated in the mining camps regarding the minerals on public lands in the West, the prior appropriation doctrine also trickled up from custom and necessity (Kanazawa, 2015). The Wyoming Supreme court noted in 1903 that "the doctrine of prior appropriation is established as a rule of imperative necessity, and the outgrowth of the custom of the earlier settlers upon the public lands for the purpose of mining or rendering the soil available for cultivation."[2] The Utah Supreme Court, in a 1891 ruling noted, "If [common-law doctrine of riparian proprietorship] had been recognized and applied in this Territory, it would still be a desert." [3] In practice, though, the legal evolution across the states often did not clearly repudiate the riparian doctrine in favor of the doctrine of prior appropriation.

In Figure 1, we show the earliest court ruling in each state that recognized prior appropriation doctrine in some way along with the earliest legislative act establishing prior appropriation. These, along with additional relevant events, are also provided in Table 1. California serves as an illustrative case of the process. There, a judicial ruling in 1853 first recognized the PA doctrine, but the ruling addressed only mining and only on one specific creek.[4] That another (potential) settler would (1) be aware of this ruling and (2) take it as a broader precedent to lend certainty to their ability to appropriate water is potentially a large leap. Many other states similarly started off with more limited recognition of the PA doctrine.

The judicial rulings were often a recognition of on-going practices on the ground. California cases would state, "The right to appropriate the waters of the streams of this State, for mining and other purposes, has been too long settled to admit of any doubt or discussion at this time."[5] This again underscores that judicial rulings endorsed a practice looking backwards providing implicit weight going forward. Despite these assurances from the courts, California did finally pass legislation explicitly endorsing the PA doctrine in 1872. The necessity of this in some ways undercuts the court's arguments that rule was well-established. Furthermore, the legislative acts often codified the specific process needed to be followed to ensure a valid right is conferred to the

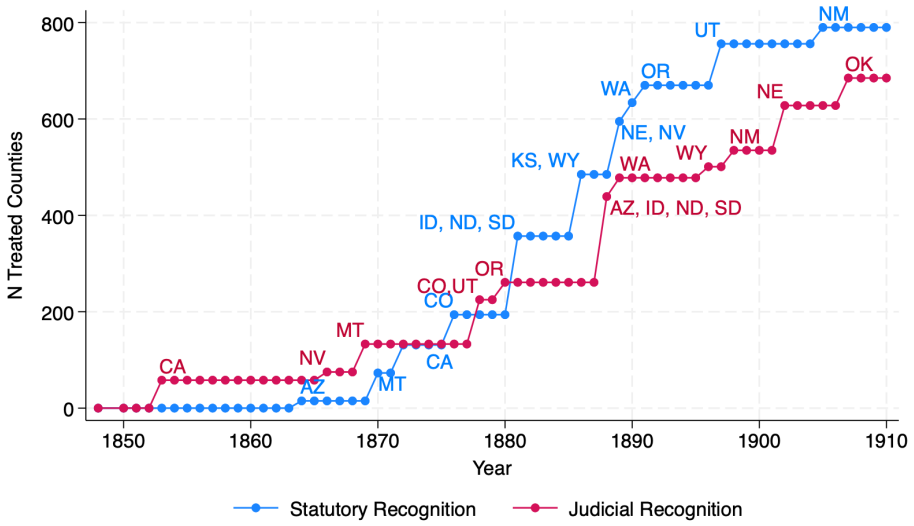
[2]Throughout this section, we draw on quotes from legal cases as quoted in Hutchins (1977). We refer to the page and the court case they cite. This instance: pg. 618, quoting from Willey v. Decker, 11 Wyo. 496, 519, 73 Pac. 210 (1903).

[3]Hutchins (1977) pg. 564 quoting Stowell v. Johnson, 1 Utah 215, 225-226, 26 Pac. 290 (1891).

[4]Hutchins (1977) pg. 181, Eddy v. Simpson, 3 Cal. 249, 252, 5 Am. Dec. 408. In another case shortly after, they did recognize priority rights more generally: Irwin v. Phillips, 5 Cal. 140, 146-147, 63 Am. Dec. 113 (1855).

[5]Hutchins (1977) pg. 182 quoting Hill v. King, 8 Cal. 336, 338 (1857).

Figure 1: The Emergence of Prior Appropriation



Notes: The figure depicts the number of counties in states with formal recognition of prior appropriation over time. The blue line represents the statutory recognition of prior appropriation, while the pink line denotes key court cases that recognized some aspect of prior appropriation. The vertical jumps in each line correspond to key dates, with the associated states indicated in the graph.

appropriator, such as public notices and necessary filings.

At least in part, the additional legislation was required due to the fact that California also adopted the "common law of England" in 1850, and hence simultaneously recognized the Riparian Doctrine.[6] In California, this dual system persists through today because the state never repudiated the riparian doctrine. The "Hardrock Mining Act of 1866" that granted the exploration and appropriation of minerals on public lands also clearly granted the right to convey water across and to *public lands* with priority of possession providing allocations during droughts.[7] This yielded some clarity as to where and when priority rights would prevail over riparian rights, whilst simultaneously sowing confusion in some places with regards to private lands.

Unlike California, many other states did offer additional clarity by either never recognizing riparian rights or later clearly repudiating them or at least clarifying how conflicting riparian and priority claims would be settled. In many instances, though these clarifications were well into the 20th century (see Table 1.) For instance, Montana recognized both riparian and appropriation rights in 1865, only formally repudiating the riparian doctrine in 1921, nearly 50 years later (Alston

[6] Hutchins (1977) pg. 194 quoting Lux v. Haggin, 69 Cal. 255, 384, 387, 4 Pac. 919 (1884), 10 Pac. 674 (1886).

[7] The act, commonly called the "Hardrock Miniing Act" is in fact 14 Stat. 251, Act Granting Right of Way to Ditch and Canal Owners over Public Land.

Table 1: State Water Right Summary

Region	State	Statehood	Statute recognizing Prior Appropriation	Judicial Ruling In Favor of P.A.	Recognition of Riparian Rights	Repudiation of Riparian or clear ranking of PA rights as superior^
Coast	California	1850	1872	1853	1850	Never
	Oregon	1859	1891	1880	1876	1959^
	Washington	1889	1890	1889	1891	Never
Intermountain West	Arizona	1912	1864	1888		
	Colorado	1876	1876	1878		
	Idaho	1890	1881	1888		1890
	Montana	1889	1870	1869	1865	1921
	Nevada	1864	1889	1866	1872	1885
	New Mexico	1912	1905	1898		
	Utah	1896	1897	1878		1918
	Wyoming	1890	1886	1896	1875	1896
Plains	Kansas	1861	1886	1945	1905	1945^
	Nebraska	1867	1889	1902	1855	1903^
	North Dakota	1889	1881	1888	1866	1963
	Oklahoma	1907	1897	1907	1890	1963^
	South Dakota	1889	1881	1888	1866	1955
	Texas	1845	1889	1926	1840	Never

Notes: This tables presents the basic timing of water right decisions across the Western US States. Dates are sourced primarily from Hutchins (1977).

and Stafford, 2018).

In Kansas the mix of riparian and priority rights is more complicated. First, the initial act providing for the PA doctrine in 1886 was determined as necessary by the courts, stating that only claims after the 1886 legislation were valid claims, not those before. The reason provided was that it had not hitherto been necessary since settlement up to that point had occurred in the more humid portion of the state, but the ruling had the effect to upend the relative security of PA claims vis-a-vis riparian claims.[8] In light of the 1866 federal act above, this was taken in practice to provide PA claims on public lands, but riparian rights for lands that had left the public domain. The sanctity of the riparian claim, however, was deemed only superior to subsequent priority claims after the patent date, not priority claims prior to the patent date. The ability to develop priority rights, rather than rely on riparian only, on already-patented land remained opaque until 1945.

Along with lacking a clear repudiation of riparian rights, many states also had initial steps that recognized the right to appropriate water, but not necessarily the use of prior possession to prioritize those rights. The distinction is subtle, but important. In New Mexico, for instance, the initial Territorial Statutes codified the existing practice of the Spanish and Mexican settlers to

[8] Hutchins (1977), pg. 286 refering to (Clark v. Allaman, 71 Kans. 206, 240-241, 80 Pac. 571 (1905).

appropriate water that were protected by the Treaty of Guadalupe Hidalgo, but this only implicitly recognized the right to divert water without clearly defining a system of relative rights of those diversions (Hutchins, 1977). Some rulings read more into this system than was there, but these early diversions were often not based on priority and instead invoked something like proportional sharing (Smith, 2016, 2021). Not until 1905 did New Mexico formally adopt priority rights by statute and only then did the development of anglo-ditches outpace that of acequias–the Hispanic irrigation systems (Smith, 2022).

Still, in other states the lack of priority was more explicit, like in Montana where the initial 1865 act allowed for appropriation but called for equitable distribution by a county officer rather than priority (Alston and Stafford, 2018). Echoing the narrow ruling of the initial California case, still other states took legislative steps to grant priority rights, but limited in use or location. Washington, for instance, initially passed statutes applying PA to only certain counties (1873) before then expanding geographically across the state in 1879, but only for certain uses including mining and manufacturing, conspicuously leaving out irrigation. Only in 1890 did the Washington legislature pass a general statute to allow for prior appropriation, inclusive of irrigation uses. (Hutchins, 1977).

In total, these examples illustrate the fluidity of the transition from riparian rights to the more quantified and secure water rights of the prior appropriation doctrine that occurred during the latter parts of the 19th century. And although a relatively sharp institutional change following hundreds of years of reliance on the Riparian Doctrine, the change was somewhat uneven across space and time in the western US. In light of this, we have chosen to demarcate the different states' treatment time by the first statute recognizing *prior* appropriation (not just appropriation) for all uses, across all applicable geographies of the state. We believe this to be superior due to its completeness and (often) accompanying water code that clearly lays out the steps to secure a water right. Unlike a judicial ruling, whose precedent may be narrow and not fully applicable to future claims, we contend that the legislative act would have been more readily discoverable by settlers and yield actionable information.

4 Data & Methods

4.1 Land Patent Data

Individual land patents issued to settlers have been digitized and made available by the Bureau of Land Management. Each patent gives the type of patent (e.g., homestead, cash sale, land grant), the date of issue, and the location in the Public Land Survey System. Using this information, the patents can be mapped to within a square-mile resolution (see, e.g., Allen and Leonard (2021, 2025b)). For this project, we aggregate counts of total patents issued and acres patented at the county-year level to explore whether codifying the prior appropriation doctrine affected the pace and location of settlement. Our sample consists of all states that adopted propr appropriation in whole or in part: Arizona, California, Colorado, Idaho, Kansas, Montana, North Dakota, Nebraska, New Mexico, Nevada, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming. Our analysis omits Texas because it was never a part of the Public Land Survey System and hence we lack land patent data.

In principle, this analysis could be conducted at any spatial scale ranging from an individual land parcel (e.g., a quarter section) up to the level of policy change at the state level. Counties strike a balance between the desire to construct more valid comparisons by measuring important covariates such as arable land and water supplies, while aggregating enough to avoid excessive zeroes (e.g., in any given year, most individual quarter sections do not get claimed). Although the BLM/GLO data include *every* formal land title issued by the federal government, we primarily restrict our focus to several types of land patents.

For our dependent variables designed to measure land settlement, we focus on cash sales and homesteads. For reasons we discuss below, our sample ends in 1905 (the year that the final state in our sample adopted prior appropriation). As a practical matter, our measure of homesteads contain mostly entries under the original 1862 Homestead Act, as most major revisions such as the Enlarged Homestead Act of 1909 and the Stock-Raising Homestead Act of 1916 come after the end of our sample.[9] Together, cash sales and homesteads comprise 75% of all patented acreage in our sample. We also calculate the amount of land patent to the railroad in each county in each year,

[9] We do include these other types of homesteads in our measures of cumulative settlement discussed below. Our measure of sales includes basic cash sales, townsite sales, "private sales," sales of coal land, small sales, and reclamation sales.

primarily to reflect potential constraints on available land (the railroad was granted alternating square-mile sections of land in a band spanning 20 to 40 miles on either side of the tracks, which significantly affected land development in certain counties (Alston and Smith, 2022)). Cash sales, homesteads, and railroad grants comprise over 90% of the patented acres in our sample.[10]

We use these data to construct several measures of land settlement and land availability in each county in each year over 1850 to 1950 (although our estimating sample ends in 1905). First, we combine homesteads and cash sales into a single metric of land settlement and calculate the number of patented acres in each county in each year. We normalize this annual measure by the total number of acres ever patented in a county through 1950 (most patenting activity ceases after the passage of the Taylor Grazing Act in 1934 (Allen and Leonard, 2025b)). We do this for two reasons. First, counties in our sample vary dramatically in size—Kansas comprises roughly 82,000 square miles divided into 105 counties, whereas Arizona spans nearly 114,000 square miles divided into just 15 counties. Moreover, many counties that are similar in size contain vastly different endowments of land suitable for settlement based on elevation, topography, etc. Hence, we use the cumulative sum of patented acres in a county as a proxy for the amount of land that was suitable for settlement, which could vary based on the size of the county as well as the nature of the land therein. Our main outcome of interest is defined in equation 1.

$$Standardized\ Acres_{it} = \frac{Cash_{it} + Homesteads_{it}}{\sum_{t=1850}^{1950}(Cash_{it} + Homesteads_{it} + Other_{it})} \tag{1}$$

While much of the discussion of prior appropriation has focused on the importance of irrigation for *land* development, there as has been significant interest by economic historians in the movement of people to the frontier. While we cannot measure annual variation in population directly, we also explore the total count of cash sales and homesteads as a crude proxy for the number of unique claims being entered over time. We do not normalize this variable because the claims themselves could vary dramatically in size from tens to thousands of acres. In addition to tracking the sum of homesteads and sales, we also calculate the difference between the number of acres and patents associated with cash sales vs. homesteads for reasons we discuss below. Our

[10] Although it focused on promoting development of arid land for irrigation, we omit the Desert Land Act because it accounts for just 1% of the patented acreage in our sample. We also omit mineral patents because they represent a subset of mineral claims entered under the General Mining Law of 1872—patenting of a mineral claim is not necessary to legally extract minerals or hold the claim.

key normalized acreage variable in this case is defined in equation 2.

$$Standardized\ Difference_{it} = \frac{(Cash_{it} - Homesteads_{it})}{\sum_{t=1850}^{1950}(Cash_{it} + Homesteads_{it} + Other_{it})} \tag{2}$$

Whereas our normalization helps account for fixed differences in the amount of suitable land in each county, we also wish to account for the evolution of the supply of open land over time. In other words, at some point in time claims in a given county will decline simply because there is no land left to claim. To account for this, we construct a measure of the supply of open land at the county year level as defined in equation 3.

$$Open\ Land_{it} = County\ Acres_i - \sum_{k=1850}^{t-1}(Cash_{ik} + Homesteads_{ik} + Other_{ik}) \tag{3}$$

Summary statistics for these time-varying variables can be found in Table A1.

4.2 County-Level Covariates

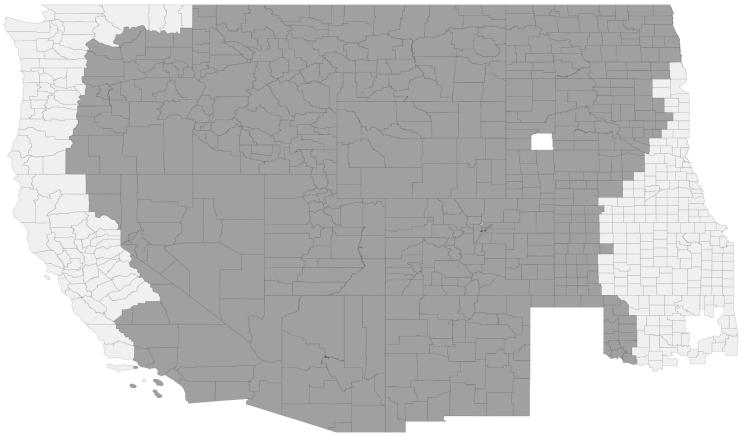
We also obtain several county-level geographic covariates from Allen and Leonard (2021) to ultimately explore how the impacts of prior appropriation vary across different geographies. We briefly describe these here and refer the reader to Allen and Leonard (2021) for details.

The first variable is measure of how much arable land each county holds. Specifically, we measure what percentage of the land in a county falls into the the top third of the 21-point soil productivity index developed by Schaetzl et al. (2012). This metric is useful because it is based on taxonomic, structural soil characteristics that are relatively fixed over time. The second variable we use is a measure of surface water abundance, calculated as the miles of perennial streams from the National Hydrography Dataset per square mile in a county.

We also use alternative measures of land suitability and water availability. For land suitability, we use terrain ruggedness, which is measured as the standard deviation of elevation in a county (elevation is measured using 30-meter^2 pixels). Finally, we measure average precipitation over the period 1895 to 1935 using the PRISM dataset (the earliest years for which these data are available). Lastly, we utilize an 1880 Census Map of summer rainfall geo-referenced by Leonard et al. (2020) to help define the boundaries of our sample.

As a starting point, we include all states in our sample that formally recognized the prior appropriation doctrine. However, several of these states—those on the Pacific Coast and those straddling the 100th meridian—utilize a mix of riparian and appropriation rights. We wish to focus our attention on the areas that were most inclined to adhere to prior appropriation. Although the spatial distribution of each water rights regime can and do overlap within the same area (especially in California), the adherence to one doctrine or the other mostly tracks with aridity. Hence, we utilize an 1880 map created by the U.S. Census Bureau that depicts spring and summer rainfall by region circa 1880. In the states with hybrid regimes, we exclude from our sample any counties that primarily overlap with regions that received at least 15–20 inches of spring and summer rain in 1880, according to the Statistical Atlas of the United States.[11] Figure 2 depicts our main estimating sample, with darker shading for counties included in the sample.

Figure 2: Included vs. Excluded Counties



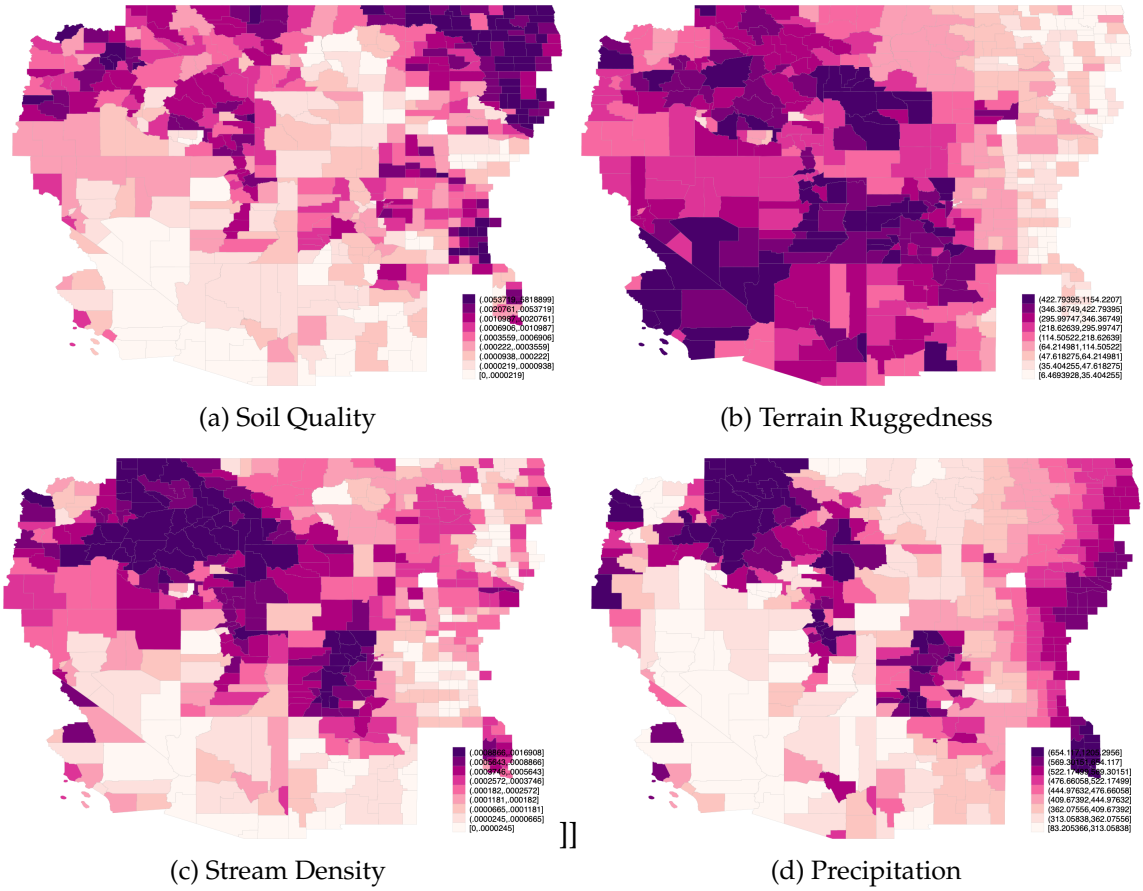
Notes: This figure depicts our sample counties, which come from the 16 states that adopted prior appropriation in whole or in part. The sample includes all counties in the eight mountain west states that completely switched from riparian rights to prior appropriation. In the remaining eight states, we exclude counties that had at least 15-20 inches of spring and summer rainfall based on the 1880 Statistical Atlas of the United States, depicted in Figure A1

Figure 3 depicts the spatial distribution of various land and water characteristics across the sample of counties. Panel (a) depicts the share of each county with highly productive soil, using the soil productivity index from Schaetzl et al. (2012). Darker shading indicates a larger share of productive farmland. Panel (b) depicts terrain ruggedness (darker shading indicates more rugged terrain). Panel (c) depicts stream density (stream miles per square mile), with darker shading for greater surface water availability. Panel (d) depicts average precipitation, measured with the

[11] See Figure A1.

PRISM climate data rather than the 1880 census map (darker shading indicates more rainfall).

Figure 3: Geographic Characteristics of Sample Counties



(a) Soil Quality

(b) Terrain Ruggedness

(c) Stream Density

(d) Precipitation

Notes: This figure depicts county-level variation in several key geographic characteristics across our main sample. Darker shading represents larger values. Panel (a) depicts the share of each county that is comprised of soils in the top 1/3 of the soil productivity index developed by Schaetzl et al. (2012). Panel (b) depicts the miles of perennial streams per square mile in each county. Panel (c) depicts terrain ruggedness, measure as the standard deviation of elevation across each county. Panel (d) depicts average spring and summer rainfall in each county from the PRISM dataset. All variables were obtained from Allen and Leonard (2021).

4.3 Empirical Approach

We utilize a difference-in-difference design to estimate the impact of prior appropriation water rights on land settlement. We compare changes in settlement activity in counties before vs. after a state adopts prior appropriation to counties in states that had not yet adopted prior appropriation at that time. Hence, counties in states that had not yet adopted prior appropriation provide an estimate of the counterfactual rate of land settlement that would have obtained in "treated" counties from states that did in fact adopt prior appropriation at a given point in time.

Previously, it was common to estimate such a model using a simple two-way fixed effects estimator as described in equation 4:

$$Settlement_{ist} = \theta \times PA\ Law_{st} + \lambda_i + \gamma_t + \varepsilon_{ist} \tag{4}$$

where λ_i is a vector of county fixed effects, γ_t is a vector of year fixed effects, and $PA\ Law_{st}$ is an indicator that is equal to one only after a state has adopted prior appropriation with a statute (zero otherwise). However, recent research has shown that this estimator is comprised of a weighted average of all two-way comparisons in the data, some of which are not valid. Specifically, comparing the evolution of outcomes for counties that adopt treatment at time τ to counties that are *already treated* before time τ can lead to biased estimates of θ if treatment effects are different across groups or evolve dynamically over time (Goodman-Bacon, 2021; De Chaisemartin and d'Haultfoeuille, 2020; Callaway and Sant'Anna, 2021; Roth et al., 2023).

Subsequently, a variety of estimators have been proposed to address this problem. These include De Chaisemartin and d'Haultfoeuille (2020), Callaway and Sant'Anna (2021), Sun and Abraham (2021), and Borusyak et al. (2024). Although they differ in their implementation, what these estimators share in common is that they construct an alternative weighted average treatment effect on the treated that avoids making the "forbidden comparison" to already-treated units. Each estimator has its advantages and disadvantages that vary across multiple margins including computation time, identifying assumptions, flexibility to different empirical designs, and efficiency.

We opt to use the estimator proposed by De Chaisemartin and d'Haultfoeuille (2020), which constructs an average treatment effect comprised of weighted average of all comparisons in data between "switchers" into treatment status to units that are not-yet-treated.[12] In its simplest form, this estimator is equivalent to Callaway and Sant'Anna (2021), which estimates a separate treatment effect for each "timing group" (treatment cohort) in each year since treatment and then averages these treatment effects.

The estimator developed by De Chaisemartin and d'Haultfoeuille (2020) has several distinct advantages. First, this estimator is robust to treatment effects that evolve dynamically over time (e.g., the magnitude of the effect depends on time since treatment). Second, this estimator allows

[12] See De Chaisemartin and d'Haultfoeuille (2020) and De Chaisemartin and d'Haultfoeuille (2023) for details.

for the inclusion of time-varying controls in addition to non-parametric group-by-year fixed effects for any cross-sectional grouping that differs from the treatment groups. Third, the researcher is able to include "placebo" years prior to treatment and explicitly test for the existence of pre-treatment differences across treatment and control groups. These last two advantages make the De Chaisemartin and d'Haultfoeuille (2020) more robust to potential pre-trends than Borusyak et al. (2024), especially in a long panel such as ours (Roth et al., 2023). Finally, as a practical matter, the De Chaisemartin and d'Haultfoeuille (2020) estimator is computationally much faster than Callaway and Sant'Anna (2021). We consider the sensitivity of our results to the use of other estimators in the appendix.

5 Results

We implement the De Chaisemartin and d'Haultfoeuille (2020) estimator using an event window that includes five years prior to treatment and five years post-treatment to detect the effects of prior appropriation adoption. We report the overall average annual effect in tabular form and provide event studies to depict the evolution of effects over time. Throughout, we cluster standard errors by county. Because we do not have any never-treated counties in the sample with which to compare, counties in New Mexico—the final state to adopt prior appropriation—appear only in the control group because there are no remaining not-yet-treated counties with which to make comparisons by the time New Mexico adopts prior appropriation in 1905.

We estimate six different specifications that vary in their inclusion of control variables and non-parametric trends. First, we estimate a version with no control variables. Second, we consider the inclusion of the "open land" control described in equation 3. Third, we add a control for the date of *judicial* recognition of prior appropriation in each state. We estimate these three specifications with vs. without region$\times$ year fixed effects, where are regions are defined as West Coast (CA, OR, and WA), Mountain West (CO, ID, MT, NV, NM, UT, WY), and Great Plains (ND, SD, KS, NE, OK).

5.1 Main Results

Table 2 presents our main estimates of the impact of prior appropriation on land settlement. Panel A uses normalized patented acres (see equation 1) as the dependent variable, whereas Panel B

uses the count of patents. Columns 1 through 3 do not include region× year fixed effects, whereas columns 4 though 6 do. Columns 1 and 4 include no controls, columns 2 and 5 add the open land control, and columns 3 and 6 add the judicial recognition control. Because judicial recognition is potentially endogenous to land settlement, our preferred specification is in column 5, where we control for variation in the amount of open land in a county, as well as region×year fixed effects.

Table 2: Main Results

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A:	$Y = Patented\ Acres\ (Normalized)$					
Avg. Total Effect	0.00885***	0.00640***	0.00640***	0.0102***	0.00800***	0.00800***
	(0.000995)	(0.00110)	(0.00110)	(0.000811)	(0.000895)	(0.000894)
N	11440	11363	11363	7293	7235	7235
Mean Dep Var	0.00120	0.00120	0.00120	0.00120	0.00120	0.00120
Pre-trend p-val	0.00000142	0.00378	0.00358	0.0434	0.163	0.184
Panel B:	$Y = N\ Patents$					
Avg. Total Effect	31.13***	21.32***	21.36***	35.54***	27.15***	27.13***
	(4.027)	(4.260)	(4.255)	(3.668)	(3.692)	(3.694)
N	11440	11363	11363	7293	7235	7235
Mean Dep Var	3.909	3.909	3.909	3.909	3.909	3.909
Pre-trend p-val	4.44e-16	0.0145	0.0108	0.0000875	0.107	0.104
Land Controls		✓	✓		✓	✓
Judicial Decree			✓			✓
Region × Year FE				✓	✓	✓

Notes: Standard errors (clustered by county) are reported in in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This tables presents our main estimates of the impact of statutory recognition of prior appropriation on land settlement using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Across all specifications, we estimate differences across treated vs. untreated counties for five years before and after treatment. Panel A focuses on normalized patented acres, as defined in equation 1. Panel B focuses on the total number of patents. Each panel reports the p-value from a test of the joint significance of difference between treated and untreated across the five years leading up to treatment. Event study plots can be found in Figures A2 and A3.

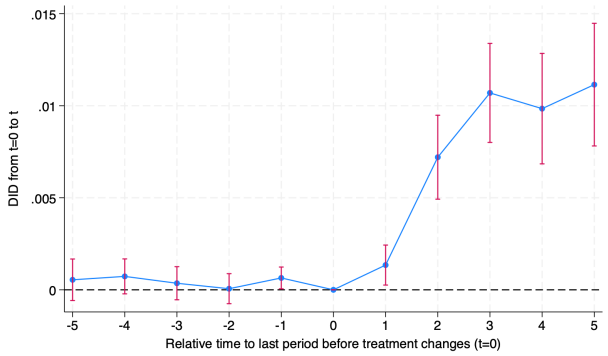
Across all six specifications, the impact of formal statutory recognition of prior appropriation on land settlement is positive and statistically significant at the 99% confidence level. On average, land settlement increases by 0.8 percentage points per year for the five years after PA is adopted. This represents an eight-fold increase relative to the average pre-treatment rate of land settlement. These results are fairly stable, varying from .6 to 1 percentage point, depending on the specification. Table 2 also reports the p-value on a test for the joint significance of the "placebo" years to

assess the extent to which the parallel trends assumption is satisfied. Columns 1 through 3 all suggest statistically significant pre-trends, however inclusion of region×year fixed effects in columns 4 through 6 helps reduce the significant of these effects. The pre-trends become statistically insignificant in columns 5 and 6.

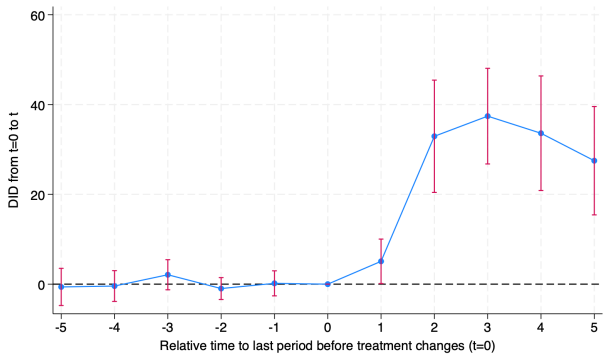
Panel B of Table 2 depicts the results for patent counts. Once again, the effect of PA adoption is statistically significant and fairly stable across all specifications, with no significant pre-trends after the inclusion of controls and region× year fixed effects. Our preferred specification in column 5 indicates that PA adoption is associated with an additional 27 new patents each year, a seven-fold increase relative to the mean number of annual patents. Figure A6 depicts coefficient estimates for the average treatment affect obtained using the estimators proposed by Callaway and Sant'Anna (2021) and Borusyak et al. (2024), alongside our estimates from Table 2. The results are qualitatively similar across all three estimators.

Figure 4 provides a visual depiction of the main result based on our preferred specification in column 5. The event study plots for the other five specifications can be found in Appendix Figures A2 and A3. The results are consistent with the overall averages reported in Table 2: prior to PA adoption, the difference between treated and untreated counties is small in magnitude and statistically insignificant, but the difference becomes pronounced in the years following PA adoption. It is worth noting that the acreage effects appear to increase over time, whereas the increase in patent counts peaks and begins to decline after three years. This may reflect a move toward larger land claims (more acres per patent) in the years after PA adoption. This would be consistent with Leonard and Libecap (2019)'s suggestion that PA facilitated the irrigation of much larger areas than would have been possible under the riparian doctrine.

Figure 4: The Effect of Prior Appropriation Adoption on Land Settlement



(a) Patented Acres (Normalized)



(b) N Patents

Notes: This figure presents the event study plots corresponding to our preferred specification in column 5 of Table 2, which presents estimates of the impact of statutory recognition of prior appropriation on differences land settlement using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panel (a) presents results for normalized patented acres, and panel (b) presents results for total patent counts. Event study plots for other specifications from Table 2 can be found in Figures A2 and A3.

5.2 Mechanisms

There is strong evidence that the formal statutory recognition of prior appropriation by western states prompted an increase in the amount of land patented, as well as the number of individuals filing patents. This section seeks to explore the mechanisms through which providing secure rights to *water* led to an increase in the demand for *land*. As discussed in Section 2, areas west of the 100th meridian contained large amounts of potentially arable land, but lacked sufficient rainfall to grow crops without supplemental irrigation. Hence, there was a large quantity of land that was potentially highly valuable with the addition of water, but quite unproductive otherwise.

Leonard and Libecap (2019) argue that that prior appropriation played a pivotal role in actualizing this potential value of arable lands by providing the necessary security to promote investment in costly irrigation infrastructure. In an exercise similar to Fogel (1964)'s estimate of the value of railroads, they compare aggregate land value across actual irrigated lands in Colorado to the more limited set of lands that could have been irrigated under a strict riparian doctrine. In other words, their estimate of the increase in land value due to prior appropriation is:

$$\Delta Value = (Avg.\ Land\ Value\ per\ Acre) \times (Irrigated\ Acres - Riparian\ Acres) \tag{5}$$

This calculation assumes that the value of non-riparian land would have been zero in the absence of prior appropriation.[13] This assumption is one particular parameterization of the proposition that prior appropriation increased the value of non-riparian agricultural land by facilitating investments in a key complement to land: water. Here, we provide an indirect test of this proposition as the mechanism behind our core result in Section 5.1.

Unfortunately, county-level average land values are not widely available in the states in our sample prior to the adoption of prior appropriation, rendering a direct test of the land value argument impossible. Instead, we rely on the conceptual model of land values and settlement via homesteading vs. purchasing land from Allen (1991), Allen (1991), Allen and Leonard (2025a), and Allen and Leonard (2025b). The basic logic of the model is simple. On the frontier, the value of land is generally increasing over time as proximity to markets, population density, and public

[13] This mimics similar assumptions made by Fogel (1964) and Donaldson and Hornbeck (2016) in calculating the value of railroads.

services improve. Given this, there as an optimal time to settle frontier land that maximizes the expected discounted flow of value from the land over time minus the present costs of settlement. Under this simple model, more valuable lands should be claimed sooner, and settlement proceeds more quickly when the costs of acquiring alnd are reduced.

The recognition that expected land values and settlement costs drive the *timing* of settlement yields testable predictions about the impact of land value on land acquisition by different types of settlers. Specifically, cash sales required a payment of a minimum of $1.25 per acre (some lands sold for larger amounts at auction), whereas homesteaders received the land a zero price (after paying a nominal filing fee). Hence, only homesteaders would be willing to settle lands that were worth less than $1.25 an acre, whereas more valuable lands would be worth paying cash for. We use this logic to look for evidence in settlement patterns that is consistent with large increases in land value due to prior appropriation by comparing the prevalence of cash sales relative to homesteads before vs. after the adoption of prior appropriation.

Conceptually, this test could be thought of as a difference-in-difference-in-difference that compares settlement by homesteaders vs. cash purchasers (first difference) before vs. after statutory recognition of PA (second difference) in states that did vs. did not adopt PA in a given window (third difference). If PA led to a large increase in land value for potentially arable lands, then there should be a differential increase in cash sales as lands cross the threshold from being worth homesteading (but not buying) without PA to being worth buying with prospect of supplemental irrigation. We implement this test with the De Chaisemartin and d'Haultfoeuille (2020) approach using the same estimation setup as in Section 5.1, but substituting the difference between cash sales and homesteads as the dependent variable. The results are presented in Table 3 with our preferred specification in Figure 5.

Focusing first on patented acres, the results are statistically significant and similar in magnitude across all six specifications. Pre-treatment differences in cash vs. homestead acres are statistically insignificant in all specifications. Our preferred specification in column 5 implies that the normalized difference between purchased acres and homesteaded acres increased by 0.4 percentage points per year after statutory recognition of PA, which is a 40-fold increase relative to the pre-treatment difference. The results in Panel B, which focuses on the number of patents, are largely similar. The main difference in Panel B is that there is some evidence of pre-treatment dif-

Table 3: Evidence for the Land Value Mechanism

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A:	$Y = Cash\ Acres - Homestead\ Acres\ (Normalized)$					
Avg. Total Effect	0.00517***	0.00312***	0.00311***	0.00598***	0.00420***	0.00421***
	(0.000760)	(0.000894)	(0.000895)	(0.000679)	(0.000756)	(0.000755)
N	11440	11363	11363	7293	7235	7235
Mean Dep Var	0.000144	0.000144	0.000144	0.000144	0.000144	0.000144
Pre-trend p-val	0.163	0.215	0.208	0.0237	0.217	0.230
Panel B:	$Y = Cash\ Patents - Homestead\ Patents$					
Avg. Total Effect	17.74***	12.06***	12.11***	20.64***	15.98***	15.95***
	(2.859)	(3.030)	(3.024)	(2.743)	(2.744)	(2.747)
N	11440	11363	11363	7293	7235	7235
Mean Dep Var	0.608	0.608	0.608	0.608	0.608	0.608
Pre-trend p-val	0.00172	0.0353	0.0619	0.00910	0.0726	0.0944
Land Controls		✓	✓		✓	✓
Judicial Decree			✓			✓
Region × Year FE				✓	✓	✓

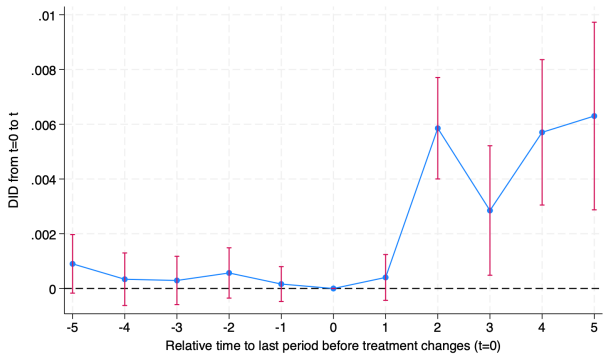
Notes: Standard errors (clustered by county) are reported in in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. This tables presents our estimates of the impact of statutory recognition of prior appropriation on differences in land settlement via cash sales vs. homesteads using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Across all specifications, we estimate differences across treated vs. untreated counties for five years before and after treatment. Panel A focuses on differences in normalized patented acres, as defined in equation 2. Panel B focuses on the differences in total number of patents. Each panel reports the p-value from a test of the joint significance of difference between treated and untreated across the five years leading up to treatment. Event study plots can be found in Figures A4 and A5.

ferences in cash vs. homestead counts in columns 1 and 2. Interpreted in the context of the simple land value model in Allen and Leonard (2025b), the results here are consistent with Leonard and Libecap (2019)'s proposition that the adoption of PA led to large increases in land value.

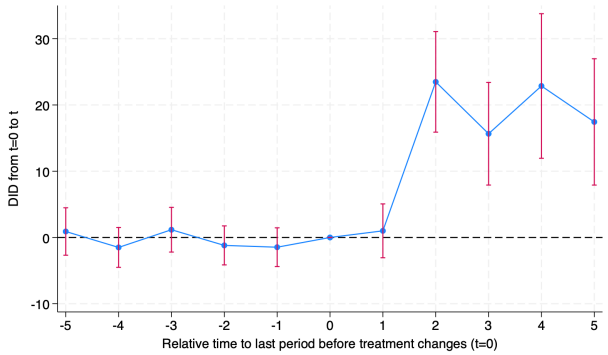
5.3 Heterogeneity

To shed further light on the relationship between prior appropriation, agricultural land value, and settlement, we next explore heterogeneity in the estimated treatment effects across counties with different geographic characteristics. We consider whether the increase in settlement after statutory recognition of PA is greater in counties where water was likely to be especially valuable due to greater demand and/or a more restricted supply. We posit that the demand for off-stream water

Figure 5: The Effect of Prior Appropriation Adoption on Cash Sales vs. Homesteads



(a) Cash Acres − Homesteaded Acres (Normalized)



(b) Cash Patents − Homestead Patents

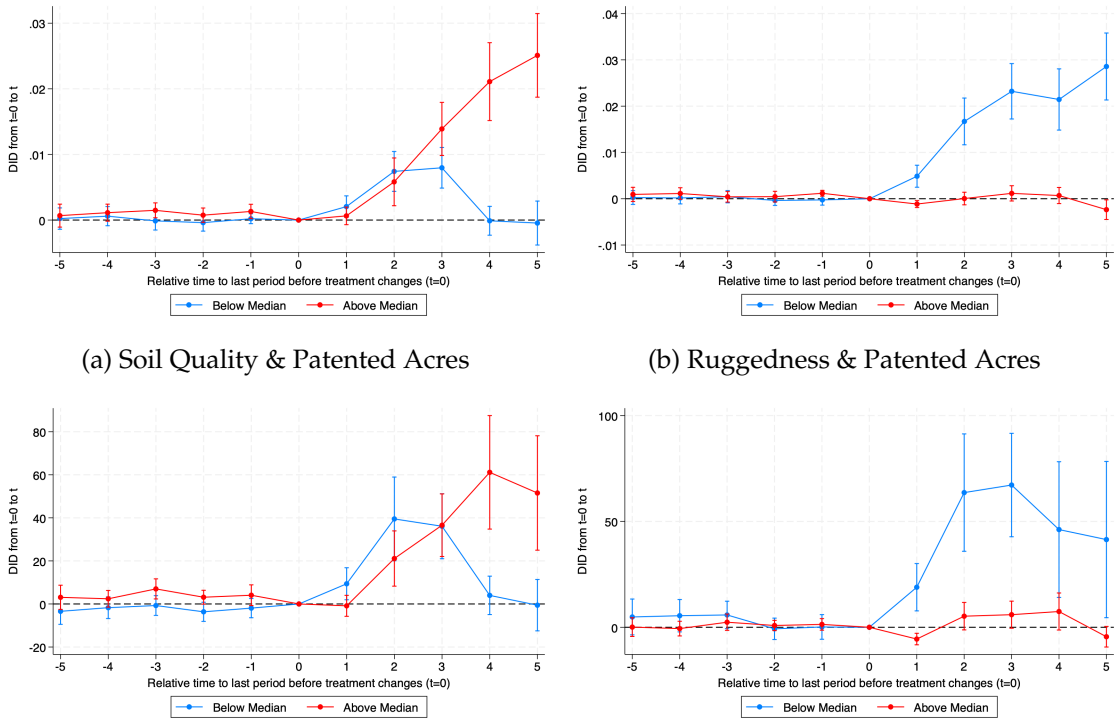
Notes: This figure presents the event study plots corresponding to our preferred specification in column 5 of Table 3, which presents estimates of the impact of statutory recognition of prior appropriation on differences in land settlement via cash sales vs. homesteads using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panel (a) presents results for normalized patented acres, and panel (b) presents results for total patent counts. Event study plots for other specifications from Table 2 can be found in Figures A4 and A5.

uses would be greatest in counties with more abundant high-quality agricultural land that could potentially be irrigated. On the other hand, the supply of water available for irrigation would be more limited in counties with fewer surface water resources.

The De Chaisemartin and d'Haultfoeuille (2020) estimator allows the researcher to estimate heterogeneous treatment effects across different groups. To adapt this to our setting, we re-estimate our core specification and compare the effect of PA adoption in counties above vs. below the median in terms of agricultural land or water availability. We predict that the impact of PA adoption will be larger in counties that are above the median in terms of the amount of arable land. For water resources, we predict the opposite: the impact of prior appropriation should be greater in counties that are below the median in terms water availability. We provide two po-

tential measures for each test. Our measures for land quality are (i) the percentage of a county with soil in the top 1/3 of the 21-point soil productivity index developed by Schaetzl et al. (2012) and (ii) the topographic ruggedness of the county. For water supply, we use (i) density of surface water streams (miles of perennial streams per square mile) and (ii) average spring and summer precipitation. Figure 6 depicts the results for land and Figure 7 depicts the results for water.

Figure 6: Heterogeneous Treatment Effects by Land Quality



(a) Soil Quality & Patented Acres

(b) Ruggedness & Patented Acres

(c) Soil Quality & N Patents

(d) Ruggedness & N Patents

Notes: This figure presents the event study plots corresponding to our preferred specification in column 5 of Table 2 estimated separately for counties above vs. below the median in terms of land quality using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panels (a) and (c) focus on differences based on soil quality, while panels (b) and (d) focus on differences based on terrain ruggedness. Panels (a) and (b) examine normalized patented acres while panels (c) and (d) examine patent counts.

Panel (a) of Figure 6 depicts the results for soil quality and patented acres and panel (b) shows the results for ruggedness and patented acres. Similarly, panels (c) and (d) focus patent counts for soil quality and ruggedness, respectively. Panels (a) and (c) indicate that the impact of PA adoption is much larger in counties that are above the median in terms of high-quality soil. There is a small increase for counties below the median, but it dissipates by year four, whereas above-median counties see a more sustained increase that is also greater in magnitude. Similarly, panels

(b) and (d) indicate that there is a large increase in settlement in counties that are below the median in terms of ruggedness (e.g., more flat, arable land), but essentially zero increase in settlement in more rugged counties. This provides strong evidence for the complementary of land and water in settlement of the arid western U.S., consistent with both our thesis and with previous accounts of prior appropriation.

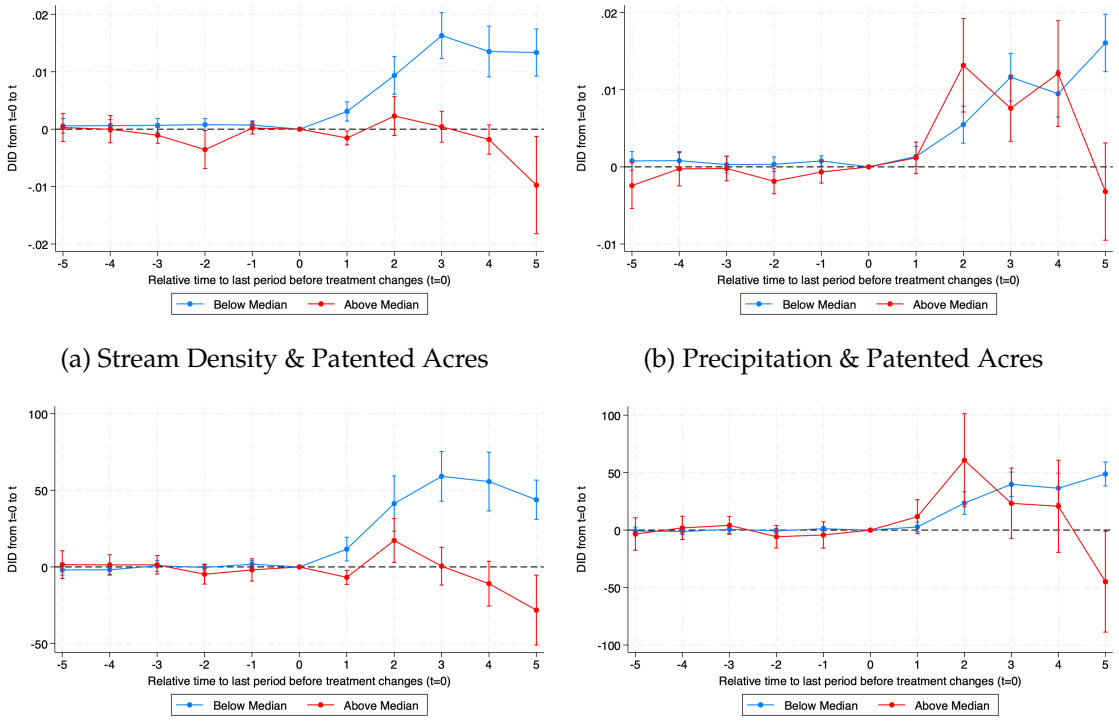
In Figure 7, panels (a) and (c) focus on stream density (acres and patent counts, respectively) and panels (b) and (d) focus on spring and summer rainfall. Panels (a) and (c) conform to predictions: counties with below-median stream density see a large increase in settlement after PA adoption, whereas counties above the median (with less water scarcity) see a decrease in settlement, if anything. The results for precipitation in panels (b) and (d) are less conclusive. While the impact for below-median precipitation counties is larger than above-median counties in years two and five, the effects largely overlap for the two groups in the other post-treatment years. One reason for this may be the misalignment between the PRISM data (1895-1935) and the dates of PA adoption, which mostly come much earlier. Another possible explanation is that many agricultural areas in the arid west rely heavily on snow-fed runoff, and so depend more on winter precipitation in distant upland watersheds than on relatively modest spring and summer rainfall nearby.

5.4 Mechanism Heterogeneity

As a final step, we examine whether there is evidence consistent with the idea that the land value mechanism is more pronounced in areas with higher-quality land and less available water. All else equal, the increase in land value associated with PA should be greater when the underlying agricultural potential of the land is greater. Similarly, the value-added of more secure water rights should be greater when there is greater competition for scarce water resources. Here, we re-estimate the cash vs. homestead specifications from Section 5.2 for counties above vs. below the median of each of the land and water measures. Figure 8 presents the results for land and Figure 9 presents the results for water.

The results in Figure 8 are consistent with our predictions. The difference in cash sales vs. homesteads increases sharply after PA adoption in counties with above-median high-quality soil

Figure 7: Heterogeneous Treatment Effects by Water Availability



(a) Stream Density & Patented Acres

(b) Precipitation & Patented Acres

(c) Stream Density & N Patents

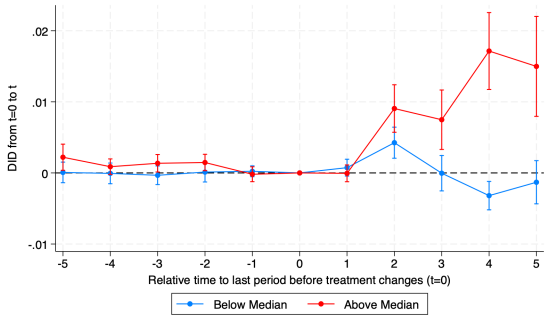
(d) Precipitation & N Patents

Notes: This figure presents the event study plots corresponding to our preferred specification in column 5 of Table 2 estimated separately for counties above vs. below the median in terms of water availability using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panels (a) and (c) focus on differences based on stream density, while panels (b) and (d) focus on differences based on precipitation. Panels (a) and (b) examine normalized patented acres while panels (c) and (d) examine patent counts.

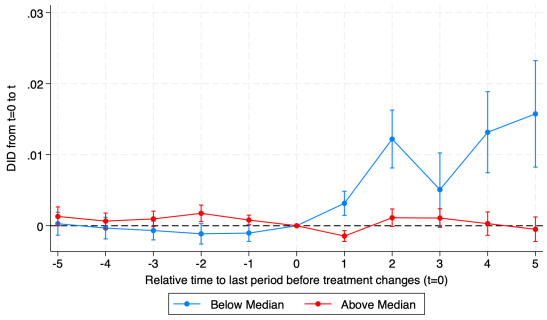
and below-median ruggedness. Counties with below-median soil endowments see a much smaller increase that quickly declines. There is very little evidence of any increase in cash vs. homesteads in counties that are above the median in terms of ruggedness. This suggests that PA adoption increased land values specifically for lands that were suitable for agricultural development, but not for more rugged lands with worse soil, where additional water would have been less beneficial.

Figure 9 is also largely consistent with the overall settlement heterogeneity results. There is a clear increase in cash sales vs. homesteads for counties with below-median stream density, whereas cash sales appear to be come *less* common relative to homesteads in counties with abundant surface water. As with the overall settlement results, the differential impact PA adoption on cash sales vs. homesteads is much less clear for counties with high vs. low amounts of spring and summer rain.

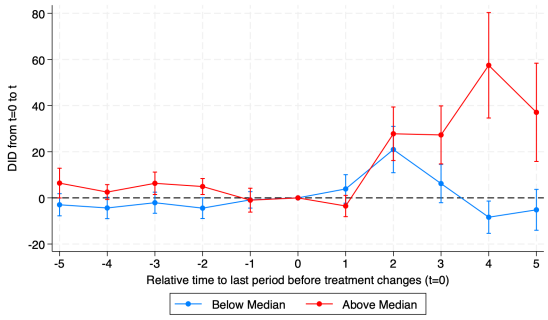
Figure 8: Mechanism Heterogeneity Land Quality



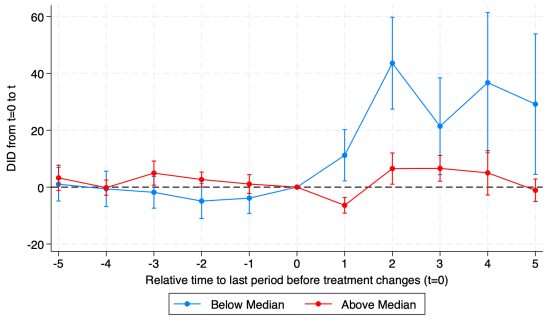
(a) Soil Quality & Cash vs. HS Acres



(b) Ruggedness & Cash vs. HS Acres



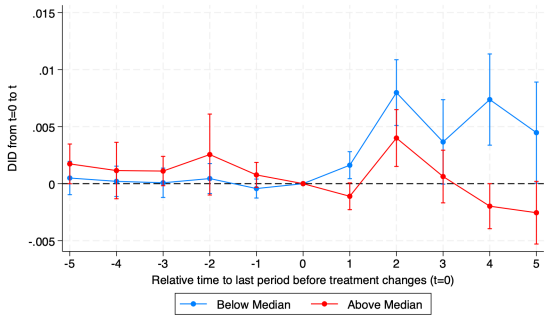
(c) Soil Quality & Cash vs. HS Patents



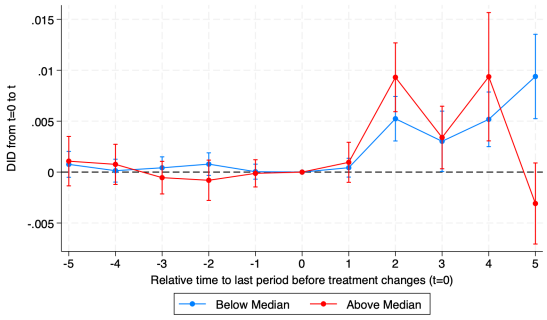
(d) Ruggedness & Cash vs. HS Patents

Notes: This figure presents the event study plots corresponding to our preferred specification in column 5 of Table 3 estimated separately for counties above vs. below the median in terms of land quality using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panels (a) and (c) focus on differences based on soil quality, while panels (b) and (d) focus on differences based on terrain ruggedness. Panels (a) and (b) examine normalized patented acres while panels (c) and (d) examine patent counts.

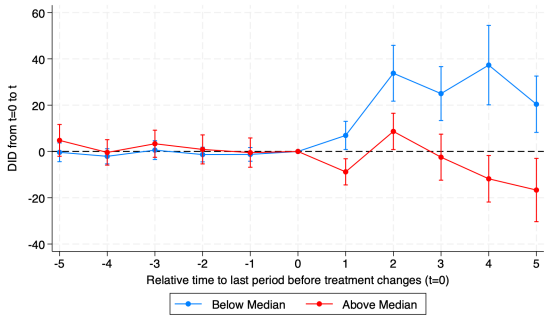
Figure 9: Mechanism Heterogeneity by Water Availability



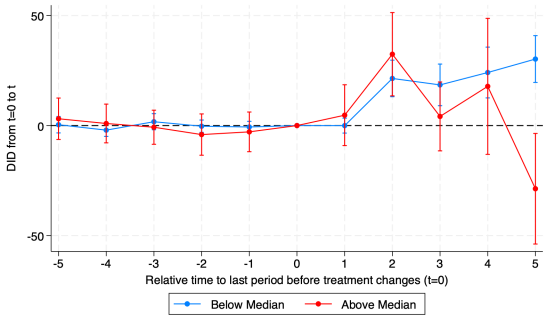
(a) Stream Density & Cash vs. HS Acres



(b) Precipitation & Cash vs. HS Acres



(c) Stream Density & Cash vs. HS Patents



(d) Precipitation & Cash vs. HS Patents

Notes: This figure presents the event study plots corresponding to our preferred specification in column 5 of Table 3 estimated separately for counties above vs. below the median in terms of water availability using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panels (a) and (c) focus on differences based on stream density, while panels (b) and (d) focus on differences based on precipitation. Panels (a) and (b) examine normalized patented acres while panels (c) and (d) examine patent counts.

6 Conclusion

The paper provides the first plausibly causal evidence on the impact of states' formal statutory recognition of prior appropriation water rights on Westward Expansion and the settlement of the arid Western United States. Previous literature has emphasized the importance of irrigated agriculture in the region and argued that prior appropriation was a critical enabling institution for facilitating investment in irrigation infrastructure, butexisting empirical evidence for these claims is limited to analysis of irrigator behavior *after* prior appropriation was adopted, and has not addressed what may have happened in the absence of prior appropriation.

We use recently developed difference-in-difference estimators (De Chaisemartin and d'Haultfoeuille, 2020) and general land office records to compare rates of land patenting before vs. after the adoption of PA, leveraging the fact that states adopted PA at different times. We find that annual land settlement increased eight-fold in the years following a state's adoption of prior appropriation. These results are robust to a variety of empirical specifications. We document differential increases in land purchasing vs. homesteading due to PA adoption, which we interpret as evidence of an increase in land values. Increases in overall settlement and in the difference between cash sales and homesteads are most pronounced in counties with high-quality land suitable for agriculture and in counties where surface water is more scarce.

Much has been written about the various roles of institutions, first possession property rights, land, and water in the study the historical political economy of Westward Expansion. Our study fills in several missing links. First, we explicitly document the connection between secure property rights to water and the demand for land. Second, we shed new light on regional variation in the impact of PA adoption on rates of settlement. Third, we provide evidence that the recognition of first-possession claims by early claimants helped facilitate future settlement, and thus was not (entirely) a doling out of rents to first-movers. Finally, we add to a growing literature on the role of policy in facilitating the movement of settlers to the frontier. Whereas previous literature has focused on the importance of national policies like the Homestead Act and grants to transcontinental railroads designed to "push" settlers onto the frontier (Fogel, 1964; Allen, 1991; Allen and Leonard, 2025a; Donaldson and Hornbeck, 2016; Alston and Smith, 2022), we show that state-level policy also worked to "pull" settlers to specific regions.

A Note to Bill Lane HPE of Water Workshop Participants

This is a first draft that necessarily omitted a variety of potential robustness checks, extensions, and other tests. Some of these possible additions are summarized below. We would be most grateful for feedback on the value of pursuing some of these exercises and whether doing so makes sense as part of this project or as a separate endeavor.

- **Different Unit of Analysis:** The land patents are geo-located to within a square mile, so we can, in principle, aggregate them to essentially any spatial unit we desire. Smaller spatial units carry the advantage of more precise geographic covariates and possible spatial analyses, but they also lead to many, many 0 observations in the data. The main candidate we are currently considering is aggregating to watershed (likely HUC8) boundaries rather than county boundaries, which would allow a tighter alignment between local water resources and land claims.

- **Difference-in-Discontinuity Design:** we have considered attempting to construct more narrow comparisons between nearby areas by identifying all of the border-pairs where state A adopts PA before state B, and then comparing settlement in counties (or watersheds) directly across the border in state A vs. state B. This seems feasible but may be labor intensive. Would this significantly bolster the credibility of the paper?

- **Evidence from Priority Dates:** Although water rights data vary significantly in quality across states and are subject to selection issues (many states lack records on abandoned rights), one simple test using the water rights data would be to look at the priority dates of surviving rights to detect whether there is an notable increase in new rights after a state formally recognizes PA. Wading through the PA rights data to provide a consistent comparison across states may be tedious, however.

- **Judicial vs. Statutory Recognition of PA:** We have compiled the dates of both judicial and statutory recognition of PA rights in each state. In the present draft, we focus on statutory recognition and control for judicial recognition in some empirical specifications. We have considered the possibility of exploring the relative impact of judicial vs. statutory recognition of PA on land settlement. It strikes us that this might be another paper altogether, but

perhaps it would strengthen our argument in this paper.

- **Mining vs. Agriculture:** The GLO/BLM data also include mineral patents. Mining is often closely tied to the emergence of PA in the literature, especially in California. The downside of the mining patents are that they are a highly selected subset of all mining claims because patenting a claim is not necessary under the 1872 General Mining Law. Patenting a claim gives the owner fee-simple rights to the surface and minerals, but even an unpatented claim gives the owner a secure right to the mineral deposit as well as relatively exclusive use of 20 acres of the surface. Given the close connection between PA and mining, it is tempting to explore these data, but we fear that it would be difficult to draw any firm conclusions.

- **Railroad Heterogeneity:** Previous work has emphasized the impact of railroad development on land values and use decisions (Donaldson and Hornbeck, 2016; Allen and Leonard, 2021; Alston and Smith, 2022). We could explore whether proximity to the railroad effects our core findings, but it is unclear how much value that adds relative to the existing mechanism and heterogeneity analysis.

- **Powell Closures:** We are aware that from 1888 to 1890, John Wesley Powell successfully lobbied congress to pause entry and patent into the public domain (at least legally) with the aim to complete a survey to identify the most promising arable land to which irrigation could be brought to. This led to some pent up demand and a rather large wave of patents in 1890 and 1891. This timing aligns closely with some states' statutory adoption of Prior Appropriations, meaning the effect may partially be driven by the interaction, leading to greater pent up demand when the land is available and the water rights newly defined. We are sorting ways to disentangle this instance.

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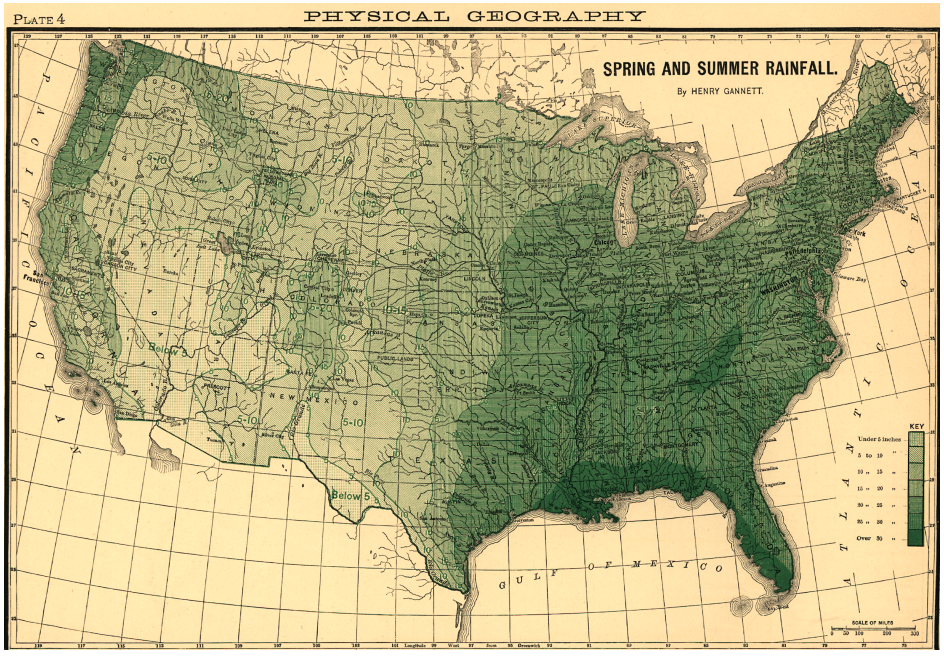
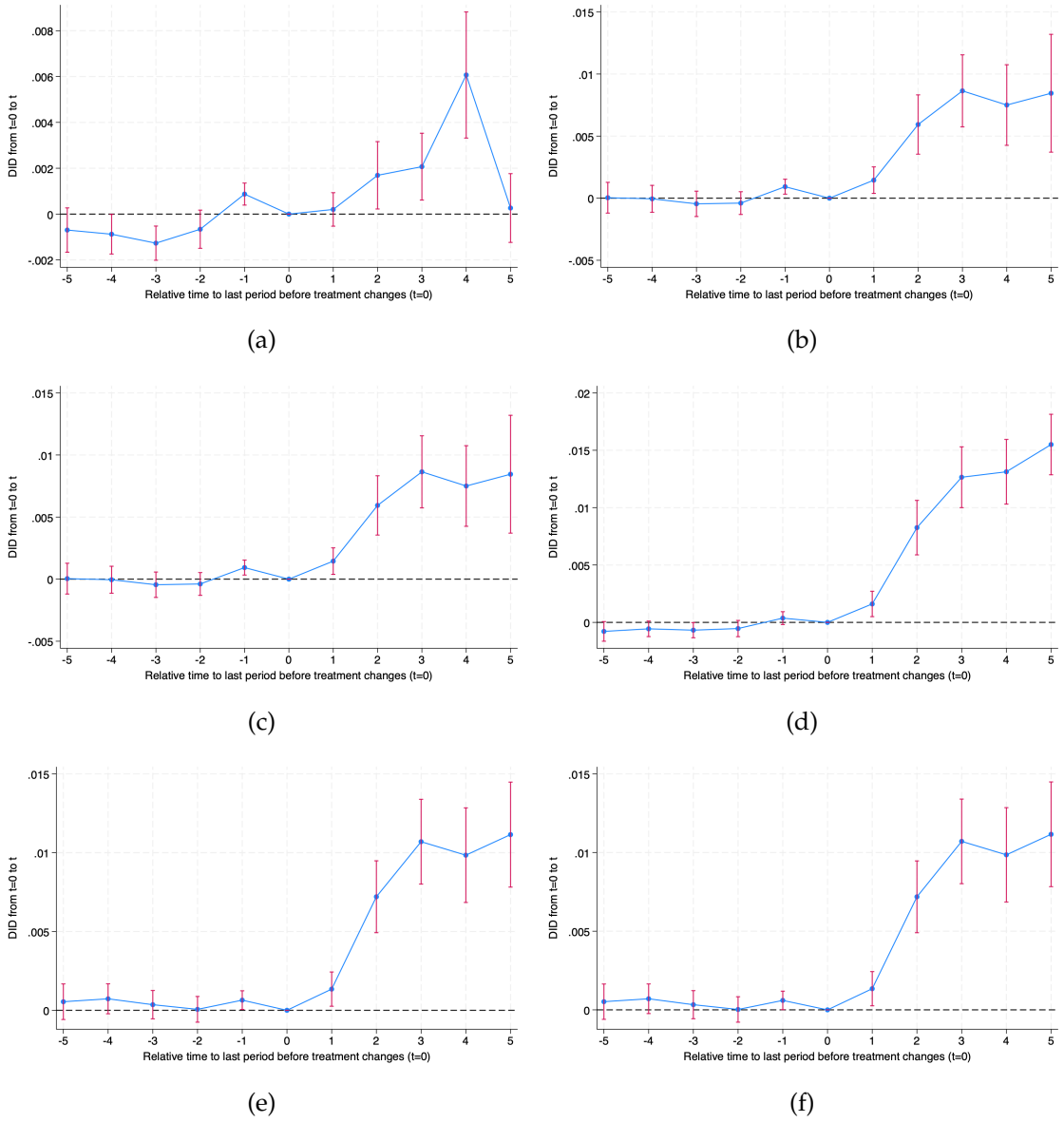
Appendix

Figure A1: 1880 Census Map of Spring and Summer Rainfall



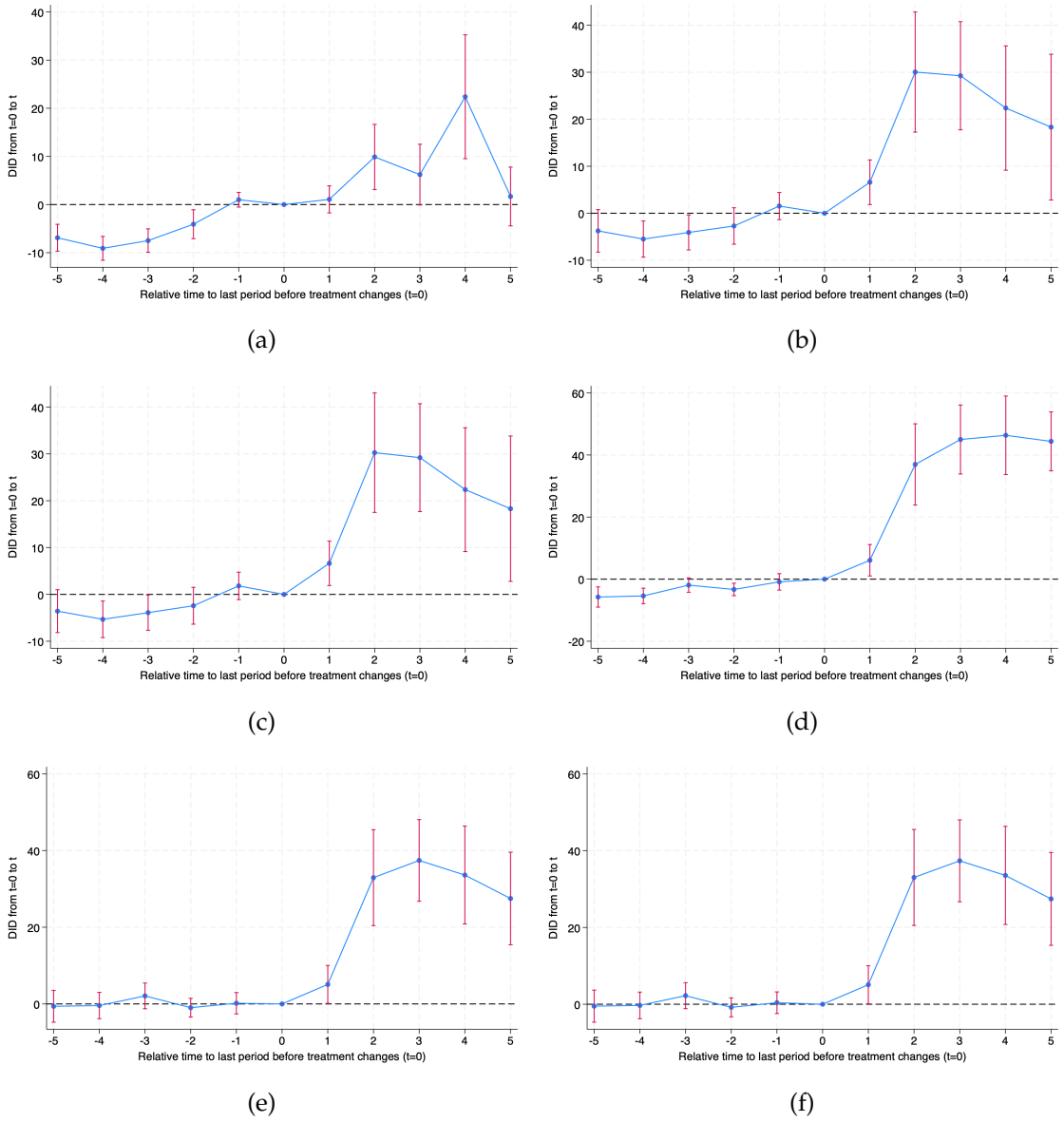
Notes: This figure depicts a map from the 1880 Census that delineated areas with differing amounts of known spring and summer precipitation at the time. This map is used to help determine which counties to include in our estimating sample in states that have a mix of riparian and appropriative rights.
Source: https://www.loc.gov/item/a40001834/.

Figure A2: Main Event Study Results: Patented Acres (Normalized)



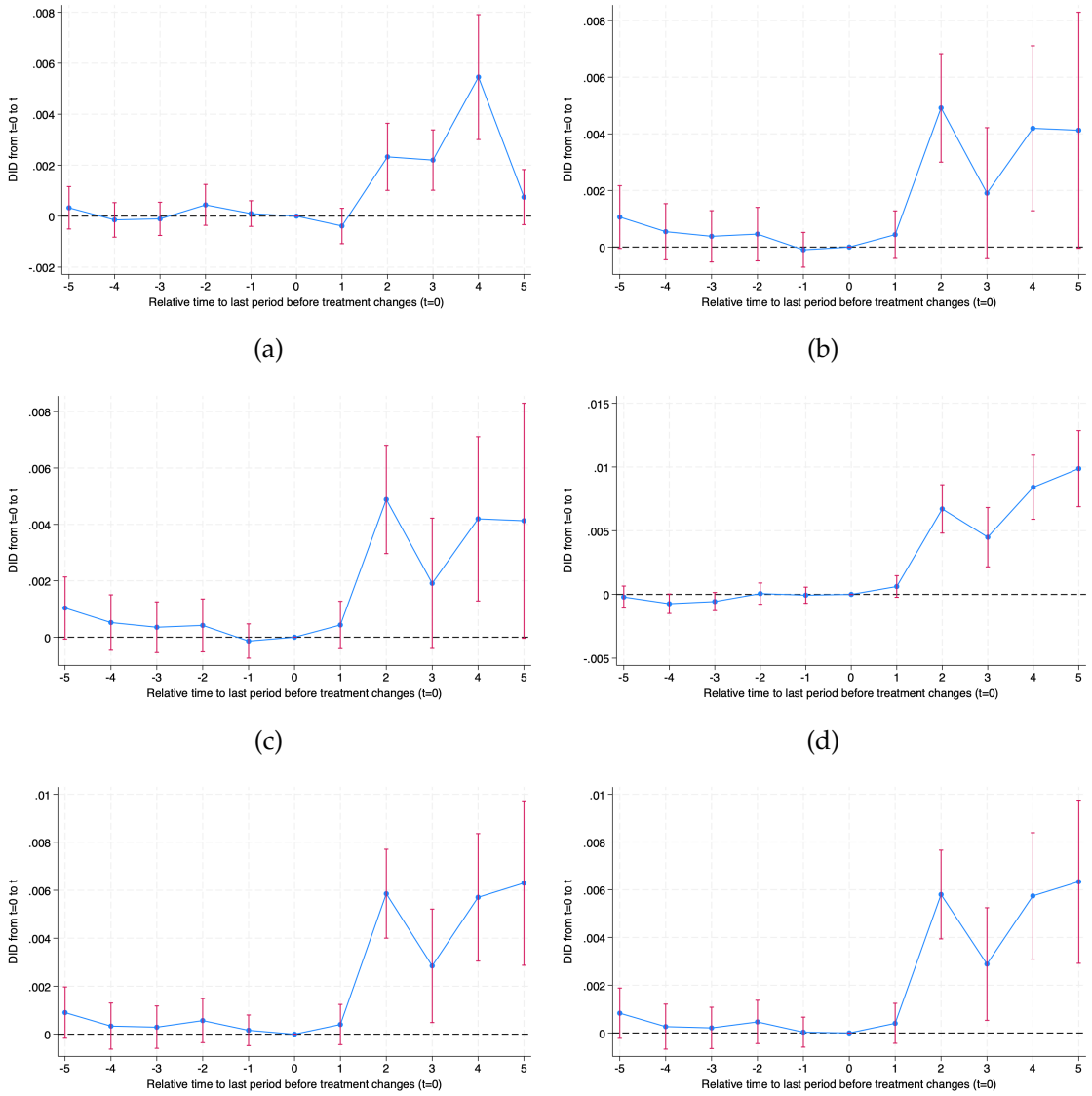
Notes: This figure presents the event study plots corresponding Panel A of Table 2, which presents estimates of the impact of statutory recognition of prior appropriation on differences land settlement using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panel (a) corresponds to column 1, panel (b) corresponds to column 2, etc.

Figure A3: Main Event Study Results: Patent Counts



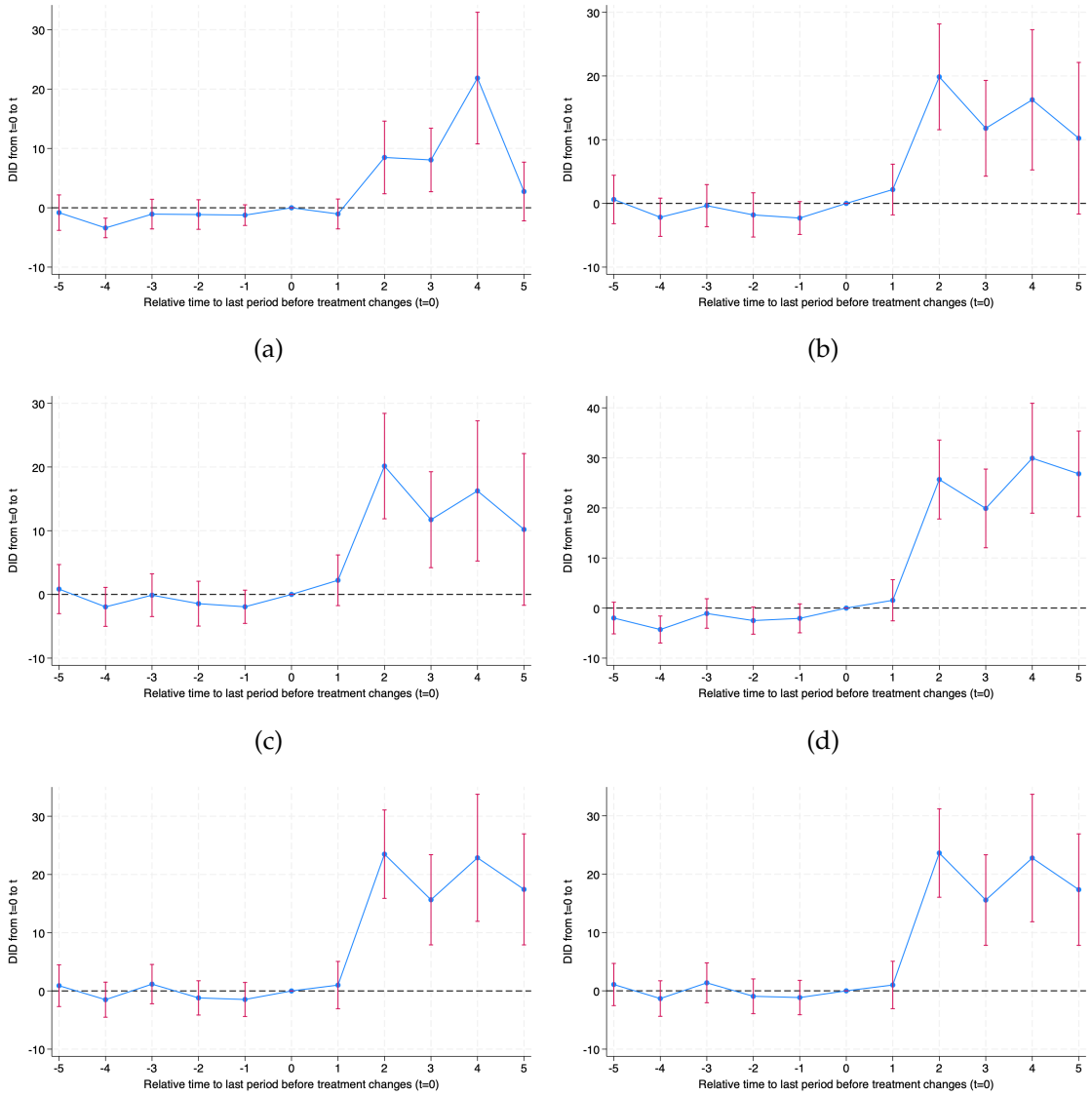
Notes: This figure presents the event study plots corresponding Panel B of Table 2, which presents estimates of the impact of statutory recognition of prior appropriation on differences land settlement using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panel (a) corresponds to column 1, panel (b) corresponds to column 2, etc.

Figure A4: Mechanism Event Study Results: Patented Acres (Normalized)



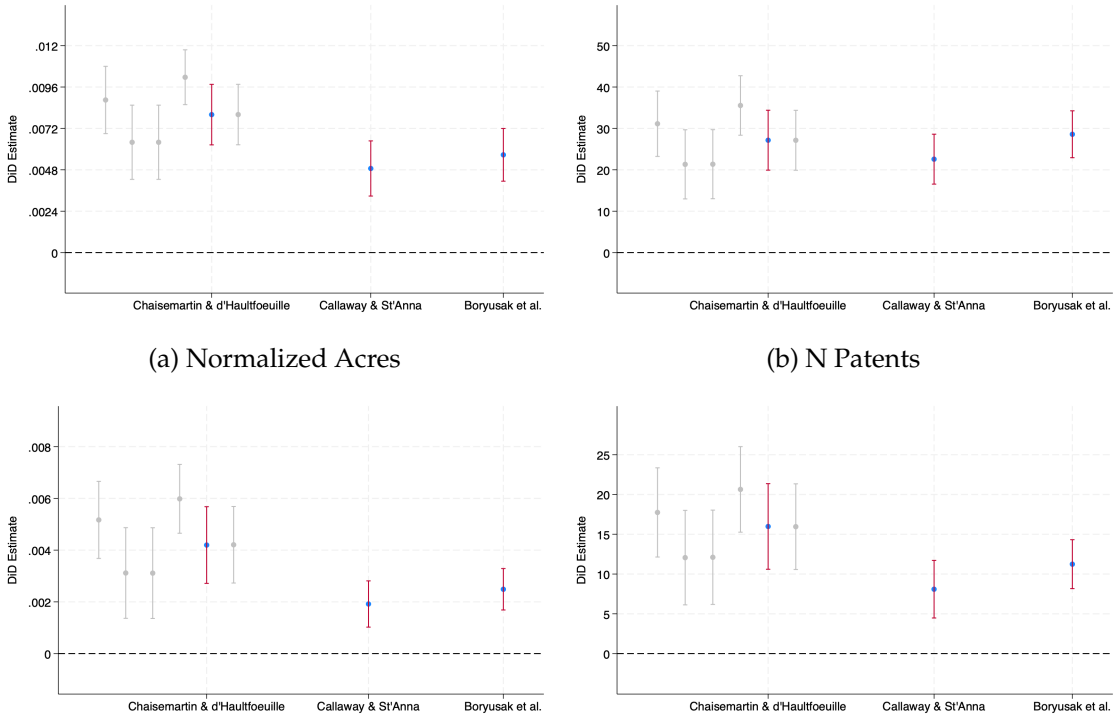
Notes: This figure presents the event study plots corresponding Panel A of Table 3, which presents estimates of the impact of statutory recognition of prior appropriation on differences land settlement using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panel (a) corresponds to column 1, panel (b) corresponds to column 2, etc.

Figure A5: Mechanism Event Study Results: Patent Counts



Notes: This figure presents the event study plots corresponding Panel B of Table 3, which presents estimates of the impact of statutory recognition of prior appropriation on differences land settlement using the estimator developed by De Chaisemartin and d'Haultfoeuille (2020) that is robust to dynamic treatment effects. Panel (a) corresponds to column 1, panel (b) corresponds to column 2, etc.

Figure A6: Alternative Difference-in-Difference Estimators



(a) Normalized Acres

(b) N Patents

(c) Cash − Homesteads (Normalized Acres)

(d) Cash Patents − HS Patents

Notes: This figure presents estimates alternative heterogeneity-robust difference-in-difference estimators along side our preferred estimates from De Chaisemartin and d'Haultfoeuille (2020). These include the double-robust estimator from Callaway and Sant'Anna (2021) and the imputation estimator proposed by Borusyak et al. (2024). Neither of these estimators allow for time-varying controls. We show all six estimators using De Chaisemartin and d'Haultfoeuille (2020) with our preferred specification highlighted and the other specifications in gray.

Table A1: Summary Statistics

Variable	(1) Untreated	(2) Treated	(3) Difference
Normalized Acres	0.001	0.012	0.011***
	(0.006)	(0.028)	(0.000)
N Patents	3.909	49.233	45.325***
	(19.179)	(123.588)	(0.970)
Cash Acres - Homestead Acres	0.000	0.001	0.001***
	(0.004)	(0.022)	(0.000)
N Cash - N Homesteads	0.608	8.277	7.669***
	(12.185)	(95.256)	(0.744)
Available Land	1.579e+06	1.460e+06	-1.187e+05***
	(1.554e+06)	(1.750e+06)	(20,149.260)
Observations	16,826	10,949	27,775

Notes: This table presents summary statistics for the county-level patent data. Data are pool across years but reported separately for years prior to vs. after the statutory recognition of prior appropriation a given county. Geographic characteristics do not vary over time and so are not reported here.