On the other side of the fence: Property rights and productivity in the United States

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Abstract

Can well-defined access rights to publicly owned land be as effective as privatization in increasing productivity and wealth? In this paper, I evaluate the impact of public property rights using the 1934 Taylor Grazing Act, which determined secure access rights for ranchers to newly created, large grazing districts in the Western US. Using satellite-based vegetation data, I exploit spatial discontinuities across grazing district boundaries and find that public lands with well-defined access rights for ranchers are at least 10% more productive than lands without. Immediately after establishing grazing districts, ranchers inside these districts held more cattle, reported higher income and farm values than their counterparts outside. Despite ranchers being unable to invest in publicly-owned lands, these magnitudes are similar to outright privatization. Instead, I argue that secure access rights resolve uncertainty around future usage and align the incentives of ranchers and regulators, thus incentivizing sustainable and profitable usage. I provide two results supporting this hypothesis: Areas with stronger pre-reform state capacity show larger increases in vegetation; and, monthly patterns on vegetation are consistent with the adoption of productivity-increasing fallowing practices. I investigate alternative explanations, and find no empirical support for differential initial productivity; negative spillovers; or systematic local manipulation of boundaries.

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1 Introduction

Property rights preserve the productivity of resources, increase the income of their users, and prevent conflict. Economists distinguish two ways of assigning property rights: private ownership and property rights to publicly-owned lands ('access rights'). Empirical evidence on the effect of privatization is overwhelmingly positive, as owning future income streams incentivizes sustainable resource extraction. Yet, it remains empirically unclear whether access rights deliver the same sustainable outcome (Samuelson, 1954).

In access-rights regimes, users pay for access to publicly-owned resources, but may be assigned to different areas in each period. Thus, users neither share the responsibilities (investing to preserve productivity) nor the benefits (returns from investing) from outright owning the land. Instead, sustainability and profitability crucially depend on the governments' ability to invest and enforce users' exclusive access rights (Coase, 1960).

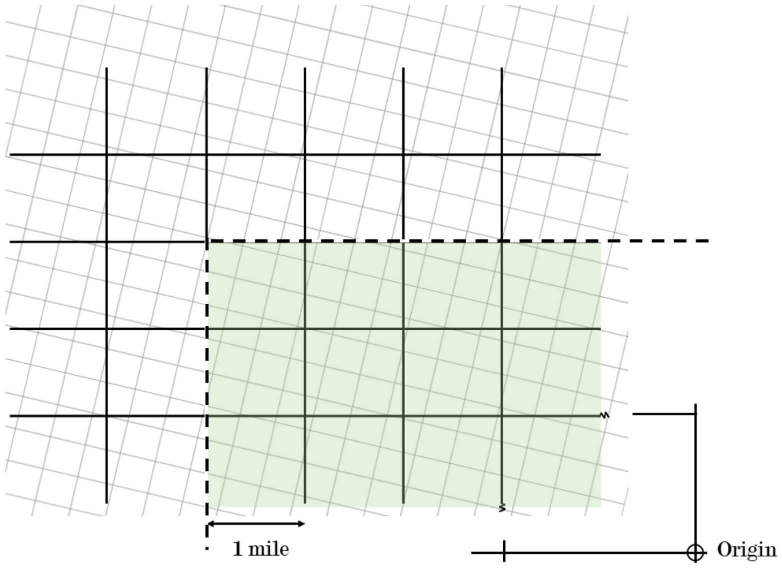
Using the canonical example of cattle grazing (Hardin, 1968), I compare different property-rights regimes at a spatial discontinuity of a large-scale land reform in the United States: the Taylor Grazing Act. The act was established in response to the consequences of homestead policies prior to 1934. Homesteading carved out swaths of private property on the most productive lands and generated fierce competition on, and deterioration on, the remaining public lands. Congress thus passed the Taylor Grazing Act in 1934 as a means of regulating access to, and protecting the quality of, public lands. The reform established large grazing districts on many, but not all, remaining public lands in the Western United States.

In establishing large grazing districts, the Taylor Grazing Act created a spatial discontinuity that allows me to compare property-rights regimes. This discontinuity originates from two factors: the use of a pre-existing rectangular land registry system to draw the grazing boundaries, and predetermined limits on the acts coverage. As congress decided on a maximum size of 142 million acres for these districts, some lands had to remain unregulated. Since grazing districts likely included the most deteriorated remaining unsold public land, comparing outcomes at a large scale would lead to biased estimates of the Act's effects.

At the micro level however, I argue that comparisons around the grazing boundaries uncover an unbiased estimate of property rights (Figure 1). Here, the exact location of grazing boundaries (dashed line) is determined by the Public Land Survey System (underlying grid). In every state, these 1×1 mile sections deterministically evolve from one origin point set in the late 19th century, and thus are plausibly exogenous to local vegetation. Created as a land registry to homestead land, the Taylor Grazing Administration used this predetermined PLSS grid to draw the grazing boundaries around 142 million acres of previously open-access lands. Factoring in hard limits on coverage, regulators could only move grazing boundaries one section, and thus one mile, at a time. Thus, whether vegetation within one mile of that 24,000-mile long boundary lies within the grazing districts is largely orthogonal to quality and preferences, and immune to local manipulation by ranchers.[1] The Taylor Grazing Act can be viewed as a natural experiment at which ranchers faced two separate property-rights regimes: One in which

[1]In addition, I exclude all boundaries that might have been predetermined by national parks, forests, Native American reservations, or State boundaries. This selection procedure is robust to including all boundaries or fo-

Figure 1: The grazing districts and the Public Land Survey System



Taylor grazing districts (shaded) with one-mile sections from the public land survey system (solid squares). I exploit the spatial discontinuity around the boundary of these districts (dashed) within a bandwidth 1/2 mile. I defined well-defined property rights to publicly-owned land ['access rights': AR] as satellite observations (angled squares) inside the grazing area and compare them to open-access [OA] observations *just* outside the grazing boundary

ranchers could purchase exclusive and secure access rights, allowing a fixed number of cattle on rotating plots, and another in which they had to compete for pasture (open-access). At the fences marking this separation, I focus on two outcomes of access rights: first, vegetation to capture their impact on productivity and, second, wealth to gauge their welfare consequences.

Establishing well-enforced property rights to publicly owned lands (access rights) substantially increased productivity and wealth alike. I derive productivity from high-resolution satellite imagery on vegetation density and show that access rights increase productivity by about 10% in the years 1989–2016 compared to lands outside the grazing districts without property rights. Census blocks inside a historical grazing district today have 16% higher income, 16% lower poverty rates, and greater house values.

But can access rights be as effective as private property in preserving productivity and increasing wealth? To obtain an unbiased estimate of the impact of private property rights, I utilize the General Land Office's data on every plot sold in the nine states prior to 1934. The last Homestead Act set the size of all homesteading plots to an entire section in Figure 1, at a fixed price of $10, making perceived quality the only differentiating margin for ranchers. While homesteaders initially selected the highest quality lands, the average quality of newly homesteaded lands, and thus the selection bias, constantly decreased over time. Using pre-treatment productivity measures, I provide evidence against a remaining selection biased as all measures are balanced across open-access and private property. Thus, I define the private property treatment as plots at the boundary that were sold *just* before the Taylor Grazing Act

cusing on straight boundaries only, providing no evidence for potentially endogenous boundaries, or local manipulation thereof, biasing my estimates.

passed in 1934. Then, comparing access rights and private property at the same boundary, I document no differential impact on subsequent vegetation. These results suggest that government management of common-pool resources can be as efficient as privatization.

A spatial regression discontinuity design must fulfill two criteria to identify the effects of property rights in this setting. First, I use data on pre-reform productivity, including erosion, distance to water bodies, temperature, and precipitation, and census data from 1930 to show that productivity and socio-economic factors were well balanced and continuous at the boundary. Second, while grazing is well suited to test solutions to the Tragedy of the Commons, it also lends credit to the possibility of spillovers biasing the estimates. If ranchers relocated their cattle to other ranges, the estimated effect would reflect the impact of fewer cattle, and not improved property rights. However, by 1938, only 0.4% of ranchers filed a complaint against their stocking allowance, suggesting that the imposed constraint was not binding. To the contrary, the US Census of Agriculture shows that the number of cattle per farm increased immediately after the passing of the Act.

My research design thus uncovers an unbiased local estimate of the effects of property rights; the analysis however, is limited to today's vegetation and wealth. To shed light on the evolution of farm values and cattle numbers in the 70 years since the passing of the act, I use the U.S. Census of Agriculture providing information on farming decisions and farm values before and after 1934. As opposed to modern, fine-grained satellite data, census data is only available at the county level, shrouding local variation within counties. Moreover, if only low-productivity counties were included in the grazing districts, estimates would be downward biased. To solve this issue, I instrument a county's selection into grazing districts using local variation of rainfall. A major criterion in selecting the Taylor Grazing Districts was to include the most severely eroded lands. Land surveyors recorded this erosion status, basing their evaluation, among other factors, on the presence of rainfall-induced vegetation. Thus, local variation in precipitation in October 1934, the month of the survey, induced variation in the perceived productivity of land, while holding its quality constant. Instrumenting whether a county is part of a grazing district, I show that the average rancher reports 90% more cattle and 40% higher farm values, as compared to the time trend of counties not affected by the Taylor Grazing Act.

Finally, I provide suggestive evidence whether state capacity, transaction costs, or financial access are necessary conditions for property rights reforms to raise private wealth. Lacking exogenous variation in state capacity, I instead use census data from 1930 to split the data into high and low state capacity counties. I argue that counties with police officers had larger state capacity than counties without as citizen arrest laws enabled ordinary citizens to arrest suspects in their absence. Further, I use data by Ornaghi (2018) on civil service reforms in the 1930s to proxy for quality of state capacity throughout the Western United States. These measures of state capacity do not predict whether grazing districts are established, yet correlate with a larger impact of establishing property rights on productivity and wealth. As predicted by Coase (1960), I find that wealth effects only accrue in low transaction-costs counties, as defined by the presence or circulation of newspapers in 1932. However, I find no differential impact of financial access, as defined by the presence of banks in 1934, on long-term outcomes.

In summary, I provide evidence that public grazing solutions can have positive effects on resource management and wealth. When property rights are enforced, ranchers can implement fallowing periods increasing the productivity of the land, similar to obtaining private property rights to the same land. Increasing farm values and cattle numbers suggest that ranchers in areas with strong enforcement and low transaction costs may prefer access rights to privatization. This is largely because the least productive ranchers receive a wealth shock, alleviating initial misallocation by fostering sales.

This paper contributes to several existing lines of literature on property rights. The results on vegetation speak to the literature on managing common-pool resources (Ostrom, 1990). I complement evidence from experimental designs on the probability of destruction of resources and the impact of time preferences on exploitation (Walker and Gardner, 1992; Fehr and Leibbrandt, 2011). I add to the literature on economic effects of ambiguous property rights (Goldstein and Udry, 2008), and well-identified historical evidence on issuing private property rights in colonial Congo (Vinez, 2017) or Liberia (Christensen et al., 2017). I complement this literature in two ways. First, I exploit a geographical discontinuity to estimate the impact of well-enforced property rights to publicly owned lands on resources and wealth at the same boundary. Second, by comparing the effect to privatized plots nearby, I extend the prevalent view on private property to well-defined access rights to public property and present the first empirical evidence on the relative effectiveness of both regimes.

This paper also contributes to the literature on property rights and wealth, showing that well-defined property rights to publicly-owned land increase wealth. The evidence on the wealth effect of access rights extends previous work on the effect of secure private property on investments (Besley, 1995; Field, 2005; Hornbeck, 2010), labor supply (Field, 2007), assets (Besley et al., 2012), the distribution of income and crop choice (Montero, 2020), human capital investments (Bleakley and Ferrie, 2016), and development (Djankov et al., 2020). I confirm the results in the literature that ranchers benefit directly, and show potentially large spillovers to the non-farming population in the same census block more than 60 years after the reform. Wealth effects are larger than the estimates in the literature on private property rights enforcement, probably because access rights can be more equally distributed among ranchers and the estimates contain valuable spillovers to the non-farming population.

My findings on mechanisms shed some light on how higher wealth may come about. I replicate results on secure and enforced private property (Besley, 1995; Svensson, 1998; Hornbeck, 2010; Behrer et al., 2020) and extend the implications to well-defined property rights to publicly-owned land where government enforcement arguably plays a larger role (Alston et al., 2000). Secure property rights to public lands appear more important than financial access, even though they increase the value of collateralizable assets (De Soto, 2000). The results confirm that access to finance does have a smaller impact than enforcement on increasing investments by the poor (Johnson et al., 2002; Galiani and Schargrodsky, 2010). The introduction of enforced contracts increased incomes and alleviated the effects of misallocation by realizing the gains from trade when property is titled, and thus transferable (Chernina et al., 2015; Aragón, 2015; Restuccia, 2016; Chen et al., 2017; Djankov et al., 2020; Beg, 2021).

My findings also contribute to the growing literature in understanding the evolution of income and wealth in the Western United States. I focus on one of the largest land transfers in U.S. history, taking 142 million acres of public land out of the open domain, and into the use of adjacent ranchers with well-enforced access rights. With fences securing property rights (Hornbeck, 2010) and railroads bringing wealth (Donaldson and Hornbeck, 2016), the American Frontier was at the center of a large redistribution of land and wealth in the 19th century. Several studies highlight the importance of Homesteads Acts (Mattheis and Raz, 2020) and land concentration (Smith, 2020) in creating wealth. I show that regulating access to the public domain constituted one of the largest wealth transfers in U.S. history.

In what follows, I briefly describe the historical background and the Taylor Grazing Act before describing the data in Section 3. I highlight the identification challenges, the empirical strategy and validity of my approach in Section 4. In Section 5, I present the main results of access rights on vegetation, before the benchmark of private property in Section 6 and the Agricultural Census in Section 7. Before concluding, I discuss potential spillovers in Section 8 and mechanisms in Section 9.

2 Background on the Land Reform

In many respects, the western United States in 1934 was similar to many developing countries today. Rangeland was mismanaged by local ranchers who used extra-legal methods to control public rangeland as privatization attempts failed to bear fruit. Combined with poor agricultural practices, this situation contributed to severe land degradation, with the Dust Bowl (Hansen and Libecap, 2004; Hornbeck, 2012) being the most prominent example.[2] To stop the ongoing land degradation, Congress passed the Taylor Grazing Act.

In this section, I briefly introduce how property rights were distributed prior to the Taylor Grazing Act and how the act changed the way in which property rights were defined in the western United States.

2.1 Privatization of the Public Domain

During the westward expansion of the United States, the federal government disposed of vast amounts of land. It considered these lands to be a source of revenue and handed over 72 million acres to eleven Western States, 90 million acres to railroad companies, and more than 285 million acres to homesteading citizens.[3]

The first Homesteading Act of 1862 enabled citizens to apply for 160 acres of public land. After living on their homesteads for five years and documenting improvements, they were awarded land titles for a small fee of 10$.[4] Since price and quantity were fixed, the margin of

[2]The Dust Bowl affected the Midwestern States only and are not responsible for any variation in treatment or erosion in the Western States. The Dust Bowl was aggravated by ploughing to create fertile soil for harvests, a practice not used in the Western States in which cattle grazing dominated.

[3]In their efforts to connect the coastal regions, railroad companies were partially reimbursed with lands close to the tracks. They were supposed to sell this land off to settlers, but many companies kept their lands as assets.

[4]The price to purchase land outright was 1.25$ per acre, a substantial amount in 1862.

differentiation for settlers was quality. As the homesteaded land needed to sustain its owners, the earliest plots usually encompassed the most productive lands. As productivity in the Western States was generally low and decreased further with ongoing privatization, Congress responded by increasing the acreage to 640 acres in 1916.[5] By the end of 1934, 236 million acres (38.9%) of the land area in the nine states had been sold to private individuals.

As most lands in the western United States were either unsuitable for, or destroyed by, agricultural technologies from immigrants, ranchers turned to grazing cattle and sheep (Foss, 1960). To feed their livestock, ranchers grazed their animals on their rangeland, as well as on nearby rangeland without owner ('open access'). Ranchers were painfully aware that they needed to continuously use open-access ranges without recovery periods, to ensured their access to these ranges. These 'rights' to open-access resources were threatened by an inflow of new ranchers and a series of adverse rain seasons, overgrazing on the public domain contributed to the 'Tragedy of the Commons' (Hardin, 1968), which motivated Congress to explore potential solutions. However, despite the Hayes' administrations' survey in 1878 detailing a need and demand for public regulation (Foss, 1960, p. 39), ten bills failed to pass congress over the next fifty years (Appendix F).

2.2 The public grazing solution (Samuelson, 1954)

Following the proposal from stockmen associations in Montana, the Mizpah-Pumpkin Creek grazing district was created to demonstrate the benefits of public management, as *"it was pretty generally conceded by 1920, that some sort of grazing regulation was imperative."* (Pfeffer, 1951). Ranges were subdivided into parcels to allow for recovery periods, and access for nearby ranchers was regulated. Benefits accrued earlier than anticipated when a severe drought hit the Western States in 1930 and the trial district went into the 1931 season with 20% more vegetation than adjacent rangeland. As the rangeland was also in better condition, allowing for more and heavier livestock, Congress discussed a similar solution for all of the remaining public rangeland (Muhn, 1987). While opponents argued that such a public grazing solution would be comparable to the "dictatorship in Russia" and "retard political and economic growth", the Forest Services urged congress to act: *"in the last 50 years the carrying capacity has decreased from three cows to one, and if no action is taken, will be reduced to a 'goat instead of a cow' "* (Foss, 1960, p. 54).

In line with many nature preserving acts of the time[6] and under the impression of the disastrous effects of the Dust Bowl (Hansen and Libecap, 2004; Hornbeck, 2012), Congress enacted the Taylor Grazing Act on June 28, 1934.[7] It was enacted to:

[5] Powell (1878) suggested that in order to make a profitable living, a homesteader required 2,580 acres in total. In 1877, there was another increase for some lands in the Desert Lands Act, but the act referred to here was the Stock-Raising Homestead Act of 1916.

[6] Antiquities Act 1906 and National Park Service Organic Act 1916, to name the most commonly known.

[7] The act was preceded by many state-specific laws, most of which aimed at discriminating against sheep, such as the "two mile law" in Idaho. However, none of these laws specified conservation of resources as an objective (Coggins and Lindeberg-Johnson, 1982).

stop injury to the public grazing lands by preventing overgrazing and soil deterioration, to provide for their orderly use, improvement, and development, to stabilize the livestock industry dependent upon the public range, and for other purposes.

As a first step, the Taylor Grazing Act prohibited future sales of the remaining public lands in the western United States. The act allowed no more than 142 million acres to be covered in grazing districts and demanded to include the most deteriorated lands first. After an extensive soil reconnaissance survey in late 1934 and public hearings in early 1935, 37 grazing districts in nine states were established (Figure 2). The upper bound on acreage left a number of essentially equivalent areas outside the boundaries that would have been treated had the limit been set higher and thus constitute a valid control group for open-access management. The original upper bound was 80 million acres, which was quickly corrected to 142 million. In 1936, approximately 15% of the total area in these nine states, or 95 million acres, were neither privatized, nor in public use as national forests, parks, or Native American Reservations in the nine states (Figure A.5).

In each grazing district, range surveys determined the optimal number of cattle or sheep a range can sustain and determined a rotating schedule to ensure proper recovery of the range. The resulting animal units per months [AUM] were divided between ranchers and types of livestock. Ranchers applied for access rights to the grazing district by stating the number of AUM they intended to use. Taking into account the rancher's use of ranges in the previous five years and his dependent property, the district board allocated a plot and AUM to the rancher. While the AUM was fixed for a number of years, the assigned plot could vary every year, depending on the rotating schedule and depletion of the range.[8]

Prices were kept low for a number of years to gain support among ranchers, and revenues were used within the grazing districts to improve water supply, re-vegetate the ranges and build roads and fences.[9] This grazing solution may not have been far from fulfilling the Samuelson (1954) condition of optimal provision of public goods, since prices were low to enlist participation, independent range surveys determined the carrying capacity, and ranchers agreed on the need to intervene. Access rights were issued for a period of up to ten years and almost automatically renewed to ensure cooperation by ranchers. Furthermore, since revoking access rights when pledged as collateral was only possible in the case of grazing violations, these rights became de-facto property rights tied to farms. However, since these access rights only covered a certain number of AUM and not a specific plot, ranchers were discouraged to invest in plots as they could not reap future benefits themselves.

[8] Although this system was strict, elite capture by powerful ranchers led to court cases when they allocated the majority of AUM between themselves and excluded small ranchers (Calef, 1960; Libecap, 1981; Klyza, 1994).

[9] The heavily subsidized price in 1934 dollars was $0.05 per AUM, about 1.65$ today. Private ranges charge up to 20$ per AUM. Monthly revenue in 1936 were about 130,000 USD for more than 7 million livestock on ranges A.8. As this fees also had to cover wages, these range improvements needed to be inexpensive. Nevertheless, they were expected to have an economic impact since the quality was so low (Calef, 1960).

2.3 Current status of property rights

The grazing districts established by the Taylor Grazing Acts have been in place since their inception and have, if anything, expanded in size. Areas outside the grazing districts as defined by the boundaries in 1935, are subject to post-treatment endogeneous selection into: (i) grazing districts, (ii) privatized, (iii) herding districts, or (iv) open-range areas. If secure property rights increase productivity, we would expect a zero impact estimated at the historical boundary if lands became grazing districts or privatized (i, ii). Herding districts and open-range areas (iii, iv) are constructs by local ranchers and politicians to prevent outside ranchers from using local pasture, not granting property rights, investments, or oversight. In such districts, competition over pasture is reduced without outsiders, but continues between local ranchers. The resulting downward bias, a zero impact of (i) and (ii) and the positive impact of the Taylor Grazing Act as compared to (iii) and (iv), is confirmed when either selecting on post-treatment outcomes or when instrumenting modern-day grazing districts with their historical counterparts.[10] In line with the literature in developing economics and economic history, I focus on the reduced-form effect at the historical boundary as the cleanest discontinuity to identify the impacts of property rights on productivity and wealth.

3 Data

I combine several sources to estimate the effects of property rights on resource management and wealth. I digitized highly-detailed data on land quality in 1934 and the historical grazing districts from archival sources, covering more than 500 million acres in nine states, and combine it with historical data on ownership from the public land survey system.

The Taylor Grazing Act regulated the access to, and invested in, public ranges in nine states, with the intent to increase the productivity of rangeland. As the density of vegetation determines the number of livestock the rangeland can support, vegetation is a natural choice to proxy for productivity and was also surveyed at regular intervals by local offices. Unfortunately, local offices have differed in their subjective judgment of productivity, and only a few original surveys remain. To conduct a large-scale, objective, and long-term analysis of the impact of property rights on productivity, I use modern satellite data on vegetation that covers treated and untreated areas of the United States.

Vegetation Satellite imagery captures different colors across the spectrum of light. Since measuring vegetation was one of the first applications of satellites, second only to espionage, the first Landsat satellites already featured cameras that captured red and near-infrared lights. As plants reflect near-infrared light to protect themselves from overheating and soil absorbs near-infrared light, the relation between red and near-infrared light identifies vegetation from imagery. More dense vegetation is represented by more near-infrared light being reflected relative to red light. This ratio, called the normalized difference vegetation index [NDVI], is

[10]In Appendix I, I provide further explanation and empirical evidence to this line of thought.

frequently used in the literature for resource management (Scheftic et al., 2014) and economics (Kudamatsu et al., 2016).[11]

In my main analysis, I use data from the Advanced Very High Resolution Radiometer [AVHRR] series. I collapse weekly data from 1989–2016 to reduce measurement error and error term correlations across time periods, as the treatment is cross-sectional (Moulton, 1986). I construct the NDVI from the red and near-infrared channel of the satellite at a pixel resolution of 1×1 km. I use the center of each pixel to define treatment status and calculate the distance to the nearest boundary. I show the summary statistics for the estimation sample in Table 1, and document a higher NDVI inside the grazing districts.[12]

I use the AVHRR data in my main analysis as its time dimension allows me to additionally test for seasonal effects of the Taylor Grazing Act. In addition, since treatment is defined by the Public Land Survey System data, this constitutes the level of variation in the data. Then, since higher resolution data does not change the variation of treatment but increases spatial auto-correlation, the AVHRR data are the preferred choice here. The downside of reducing the resolution of the data is the loss in power and the increased frequency of partially treated observations. Squared pixels with centers close to the boundary have a fraction of their coverage inside Taylor grazing districts and another fraction outside. This increases the NDVI values for control pixels at the boundary, thus biasing the estimate downward. I drop these 'partially-treated' pixels to ensure a clean treatment and control design.[13]

Grazing districts Modern grazing districts are likely to have adapted and exchanged areas based on experiences after 1935. To avoid this potential selection bias, I digitize the original grazing maps from archival maps and only use grazing districts that have been established in 1935. On these maps, the grazing districts are referenced to the Public Land Survey System [PLSS], a system for administering ownership over the vast western lands. This system dates back to Thomas Jefferson in 1785 and divides the Western States into rectangular townships of 6×6 miles and every township into 36 sections of 1×1 mile each, based on one reference point in every state. Since these reference points were decided between 1855 and 1880 in the nine states, the PLSS is not affected by land quality, terrain features, water bodies, and grazing districts in 1934. In implementing the Taylor Grazing Act, the grazing agency chose to fix grazing districts to be made up of these 1×1 mile sections so that the boundary of each grazing district corresponds perfectly to the boundary of the predefined areas. I visualize the extent of grazing districts in Figure 2.

Soil erosion in 1934 The Taylor Grazing Act began with a proclamation *"to stop injury to the public grazing lands"* and initiated a comprehensive soil erosion study covering the western

[11]The formula is: $NDVI = (NIR - Red)/(NIR + Red) \in [-1, 1]$ where NIR stands for near-infrared light and higher values indicating more dense vegetation.

[12]The results are robust to using alternative satellite series with different wavelengths of near-infrared lights: The Moderate Resolution Imaging Spectroradiometer [MODIS] at a pixel resolution of 250 m and the Landsat at 30 m.

[13]Results are robust to including these pixels (Figure B.2). As these pixels bias the point estimates downward in the most restrictive specifications and bandwidths (≤ 0.5), I use a clean treatment-control design instead.

United States in October 1934.[14] Based on this study, high-resolution maps of soil erosion were drawn for all states (Figure 2), and the most severely damaged public lands were incorporated into the grazing districts, introducing a downward bias on productivity.

Ownership data Grazing districts were drawn on large maps, but the effective treatment area varied by ownership status. National parks, national forests, Native American reservations and other reserved areas were not placed under the jurisdiction of the grazing districts and are thus removed from both control and treatment in my data. Sections with private property could also not be administered by the grazing administration. To identify which sections were privately owned in 1935, I web-scrape the database on land transaction by the General Land Office, which provides information on the timing and location of private purchases using the PLSS. I complement this data with information from the Soil Management Agency that captures contemporaneous ownership of every section in the United States.

Minor Civil Divisions in 1930 As the Taylor Grazing Act covered vacant and unappropriated lands, less populated places were more likely to be included in grazing districts. Moreover, as a larger population is a good indicator of state capacity and the presence of police, banks, and newspapers, it is important to verify pre-treatment balance to attribute contemporaneous wealth differences to the treatment. I use the grazing boundaries to test the balance of population in my empirical setup using statistics for all minor civil divisions of each county. Every county in the United States was subdivided into minor civil divisions in 1930 and 1940, for which data are almost universally available.[15] I obtain population statistics for 6,830 minor civil divisions in 1930 (6,537 in 1940) within 312 counties in all nine states. Linking the minor civil divisions to the 5% census sample in 1930, I collect information about families, houses and occupations at the individual level and link them to their geographic position in each county. Summary statistics and treatment balance of these variables are shown in Table 1.

Census data in 1990, 2000 and 2010 To estimate the long-term effects on wealth, I use census statistics at the census block group level in 1990, 2000 and 2010. I obtain 16,248 geocoded observations for 1990, 15,701 for 2000 and 17,527 for 2010 and use information on median family income, median house value and the share of people below the poverty line to capture growth in indicators of long-term economic development (Table 1).[16]

Agricultural Census Since the Taylor Grazing Act mainly affected ranchers, I use the agricultural census 1910-2007 to estimate the dynamic impacts on ranchers and investigate potential cross-county spillovers. The observational level is at the county level such that, for

[14]Generally, soil erosion is defined as loosened soil caused by cattle or sheep eating the grass that binds the soil. These maps are similar to Hornbeck (2012) and the Dust Bowl, where soil was blown away as far as Washington from the Midwest. Here erosion happens because soil without grass was washed away in excessive rains.

[15]I digitized the minor civil divisions for Arizona, Montana, Utah, and Wyoming for 1930 and all nine states in 1940. When the 1930s equivalent was not available, I digitized the 1940s minor civil divisions and followed given annotations to attribute the 1930s statistics.

[16]These data is used in the same regression discontinuity design since they are exceptionally detailed, with the mean size of a census block being 3,600 acres. The census blocks change every decade, which is why I construct the data for every year separately before merging them into the final dataset. Data are obtained from the National Historical Geographic Information System [NHGIS]. No individual data or earlier data are available at this level.

consistency, I re-construct all pre-1935 counties to their equivalent 1935 county boundaries.[17] Because counties are often significantly larger than grazing districts, I define treatment status as an indicator variable of whether any part of the county lies inside the grazing district.[18] Two major data limitations that remain are the availability questions prior to 1935 and soil erosion maps. First, due to changes in the questionnaire, only a subset of questions are asked consistently in the 22 survey rounds. Second, while the soil erosion maps cover all grazing boundaries, the eastern parts of Colorado are not drawn on the source maps. To have a consistent sample, I drop all counties without information on soil erosion, leaving 283 counties, of which 199 are covered by the Taylor Grazing Act. Since the Taylor Grazing Act is likely to affect farm and land values, as well as the number of cattle, I concentrate on these variables in my analysis.

Rainfall, Temperature and Drought Severity data I additionally control for differences in rainfall and temperature using station level data covering 1900-1934 from the U.S. Historical Climatology Network.[19] To overcome selection into grazing districts in the Agricultural Census, I use daily rainfall data from 1915–2011 as well as the Palmer Drought Severity Index (PDSI). [20] The PDSI ranges from -10 to 10 with lower values indicating more severe droughts. As droughts are the results of continuously absent rainfall, they are unlikely to be independent across time and space. Thus, I use rainfall to predict drought severity, which in turn strongly predicts whether a county is affected by the Taylor Grazing Act.

4 Empirical Strategy

An observation in my analysis is a 1×1 km pixel from the AVHRR satellite data set that contains the mean value of vegetation from its original panel structure. I use the center of each pixel to define whether it lies inside grazing districts with well-enforced property rights to publicly owned lands (access rights) or outside and calculate the distance from every pixels edge to the grazing boundary that defines the respective property rights regime. However, property rights are not randomly allocated in space. Ranchers choose the most productive sections to purchase, and likewise, access rights are distributed on land that supports livestock. To estimate the effect of access rights, I compare observations within a narrow bandwidth never exceeding 2 miles around historical grazing boundaries based on sections from the Public Land Survey System. Choosing a narrow bandwidth and employing a regression discontinuity design, I provide evidence that treatment and control areas were pre-treatment equivalent.

In this section, I discuss the identification strategy, which is based on the observation that grazing boundaries were set using sections from the Public Land Survey System created more than 50 years prior. After discussing the identification strategy and the empirical specifica-

[17] I use the intersection of historical boundaries with the boundaries from 1935 to calculate the share of the 1910 county that is part of its 1935 equivalent. Variables are assigned to their 1935 county codes using this share.

[18] Results remain unchanged when using the share of the county in grazing districts as the main explanatory variable (Table G.2). A simple binary treatment is chosen throughout the paper to ease interpretation.

[19] Monthly data, obtained from http://cdiac.ornl.gov/ftp/ushcn_v2.5_monthly.

[20] Rainfall data daily from Livneh et al. (2013); PDSI: https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi.

tions, I conclude this section by providing evidence that lands inside and outside the grazing districts were indeed balanced at the boundary.

4.1 Identification Strategy

I aim to estimate the impact of access rights on resource management and wealth using a regression discontinuity design in a small bandwidth around the grazing boundaries. However, as the Taylor Grazing Act stipulated that 'vacant and unappropriated' lands be used, the majority of lands inside the grazing districts are likely of lower average productivity than lands outside the districts. Similarly, since the act was intended to include the most severely eroded public lands, the grazing districts contain worse lands almost by definition.

The act demanded that vacant land *"not exceeding in the aggregate an area of one hundred and forty-two million acres"* be combined in grazing districts. Since lands on the other side of the grazing districts' fences could well have been treated, had the limit been set higher, they are likely to provide a reasonable control group. To decide which areas were treated, the act stipulated that *"before grazing districts are created in any State as herein provided, a hearing shall be held in the State"*. With input from these hearings and the limitation on maximum acreages, some districts were approved, while others were not. The State of Nevada provides a good example of this process since it was intended to be split in five grazing districts, two were established in 1935, two more were established by 1938 and one never established.[21] Since these districts were usually adjacent to each other and the boundaries between districts were determined for administrative reasons, the underlying land productivity should not vary significantly at the boundary. Similarly, if preferences influenced the decision to approve districts, it is unlikely that these preferences change discontinuously at the boundary.[22]

To precisely determine the boundaries of grazing districts, the administration used information about ownership provided by the Public Land Survey System [PLSS]. In 1935, the PLSS was the only nationwide system of accounting for ownership, and was frequently used to determine boundaries of newly established parks or homesteads. The administration used individual 1×1 mile rectangular sections that are associated to a township in a state to determine the precise extend of the grazing districts. As the reference lines from the PLSS deterministically evolve from one starting point in every state set between 1855 and 1880, the grazing boundary is plausibly orthogonal to local conditions. Thus, when comparing land at a bandwidth smaller than these mile-long sections, its location inside or outside the grazing districts can be considered as random.

In addition, many grazing boundaries were set without local knowledge, resulting in boundaries that are straight for a number of miles. At such boundaries, it is likely that treatment and control are quasi-randomly allocated in a wider range around the boundary. As shown in Figure A.1, the grazing boundary was a visible fence, which separated properly managed

[21] I only use grazing districts that have been established by the end of 1935. As later districts are adjacent to these districts, this biases the estimate down if the treatment effect is positive. Including these later districts does not impact the point estimate.

[22] However, preferences are unlikely to be a determining factor, as the overwhelming majority of ranchers already in 1906 favored government control (Foss, 1960, p.42).

rangeland on the right from severely overgrazed rangeland on the left.[23] For all boundaries in all states, I rigidly follow the underlying PLSS grid to exactly determine the location of the grazing district boundaries in all states and drop state boundaries to not confound the estimate with administrative differences across states (Keele and Titiunik, 2015).

Not all boundaries lie within vacant land, as some boundaries follow national parks, national forests and Native American reservations, or coincide with state boundaries. As the control areas of such boundaries are not comparable, I only use boundaries that were placed quasi-randomly in space.[24] This selection procedure ensures that treatment and control observations have had the same probability of treatment prior to assignment.

Another potential threat to manipulation arises from the hearings and surveys before the grazing districts were created. However, as many boundaries formed long straight lines, local manipulation is unlikely to have been systematic. In Appendix D, I detail my selection further and perform a number of robustness tests. The estimates are unaffected when including all boundaries, dropping boundaries that follow a non-linear shape, focusing on boundaries that are straight for at least six miles, or only considering boundaries in which all lands are either eroded or non-eroded. Further, ranchers also did not anticipate the boundary (Appendix F) and the estimated effect is highly stable even when only considering observations *at* the boundary (Appendix B). Thus, even in the unlikely case that local manipulation had occurred systematically, in bandwidths below 1/2 mile, vegetation is randomly placed in sections of the PLSS and thus randomly assigned to treatment.

However, even when boundaries are quasi-randomly placed, a spatial regression discontinuity design is invalid if the stable unit treatment value assumption (SUTVA) is violated at the cutoff (Keele and Titiunik, 2015). Two manipulations are possible: Ranchers relocate cattle to control areas, downgrading land; or ranchers grazing less intensively in grazing districts. To analyze this manipulation, I show in the conceptual framework (Appendix J), that ranchers only reallocate cattle if the allocated access rights were too restrictive. However, as the Taylor Grazing Act established relatively high quotas based on prior self-reported usage and cattle is typically held for only 9 months, these spillovers are unlikely to affect the outcome in the long run. In addition to showing that the number of cattle increased as a result of fallowing, a fact inconsistent with the discussed manipulations, and the robustness of my main estimates to a Donut specification leaving out observations close to the boundary, I show that other spillover indicators such as migration, population density and employment are all unaffected by the Taylor Grazing Act in Section 8.

In brief summary, the maximum on acreage limited the overall size of grazing districts and created a control group of lands that would have been treated had the limit been set higher.

[23]Online Appendix Figures A.2 and A.3 provide a good example of my estimation strategy: While the road is subject to the environment in Figure A.2, the grazing boundary cuts horizontally through the picture as a straight line. I locate the same boundary in the state of Nevada and show that the treatment effect at this 320-mile long and straight boundary is positive (Figure A.3).

[24]The argument is also made by Dell (2010), who estimates the effect of MITA at boundaries with similar elevation and (Dell and Olken, 2020) who select on sugar suitability. The largest fraction are national forests, with 25% of the observations within a 6-mile bandwidth. As they are located in areas with higher productivity, I exclude boundary segments if a national park is within 6 miles. This rule drops 11,400 miles of border segments. Appendix D provides an in-depth discussion on why there is no bias arising from this selection.

Since boundaries were determined using a system of rectangular townships and sections constructed years prior to the act, land is quasi-randomly placed in treatment and control within a one-mile bandwidth around the boundary.

4.2 Estimation Framework

I follow the literature on geographical discontinuities and use a geographic regression discontinuity design (Holmes, 1998; Black, 1999; Dell, 2010). The design in its most basic form has two forcing variables in latitude and longitude and relies on two dimensions of choice: Bandwidth and specification. First, since RD estimates only capture the local average treatment effect at the boundary, I only compare treatment and control observations in a tight bandwidth of one-half, one, or two miles. Second, since the functional form needs to capture any other variable that varies continuously at the boundary, I introduce controls for boundary segment specific productivity in the most restrictive specification.

Baseline The baseline specification controls for pre-treatment productivity with a global polynomial in latitude and longitude and estimates the effect of property rights using a simple indicator variable:

$$\log(\text{NDVI}_i) = \beta \times Treatment_i + f(geographic\ location_i) + \sum_b^B seg_i^b + \Gamma_i + \varepsilon_{b(i)} \tag{1}$$

Following Dell et al. (2018), I regress the vegetation outcome of pixel i on a binary treatment indicator for whether the pixel is located inside the grazing district. $f(geographic\ location_i)$ is the RD polynomial, whose purpose is to capture smooth functions of productivity at the geographic location of pixel i. The boundary segment fixed effects seg_i^b split the boundary in 60-mile segments and is binary indicator if a pixel i is closest to that boundary segment b. In addition, I include eight proxies for productivity in Γ_i in the main regression and use a uniform kernel throughout.[25] Since a valid comparison requires geographic proximity between treatment and control, I only compare observations close to the same boundary segment to identify the local average treatment effect of property rights.

In terms of property rights, I define access rights as previously vacant land inside the grazing districts and the corresponding control is similarly vacant lands just outside the grazing districts. At first, I omit all sold sections from either side of the boundary to estimate a clean effect of access rights, before reintroducing private property as a comparison in Section 6. When identifying the long-term effects on wealth, a census block is treated if its center lies inside a grazing district.

Specification and Selection Following (Dell and Olken, 2020), I document that the results obtained from this specification are robust to the choice of: 1) the bandwidth, 2) the functional form of $f(geographic\ location_i)$, 3) the inclusion of additional controls, and 4) the sample inclusion criteria. I vary the bandwidth between 1/2 and 2 miles and show robustness to the choice of the functional form of $f(geographic\ location_i)$. Appendix B shows that the point estimate

[25] Triangular kernels as used in (Dell and Olken, 2020) do not change the estimates, but produce more stable point estimates at larger bandwidths (Figure B.1).

are stable in a range of 0.1–6 miles from the boundary across all specifications. In Appendix C, I document that the results are robust to the inclusion of additional controls and changes to the outcome variable. In Appendix D, I discuss the sample selection procedure in detail, and show that the results are robust to any sample inclusion criteria. Specifically, I vary the sample from including all boundaries and thus all potentially treated observations within 1/2 mile of the boundary (N=19,420), to only including observations that could potentially be treated and are of opposite sides of a non-predetermined boundary that is an exact straight line for at least 6 miles (N=1,608). The results remain unchanged throughout all specifications and selection criteria.

Especially when comparing the productivity of areas that are in geographic vicinity, it is important that the functional form of $f(geographic\ location_i)$ sufficiently captures productivity. Not fully capturing the underlying productivity distribution at every boundary segment risks misinterpretation of pre-treatment productivity differences for the treatment effect. Thus, in addition to equation (1), I first follow Gelman and Imbens (2019) and include a local linear polynomial in distance to the boundary interacted with treatment. Second, I capture boundary-specific productivity trends by estimating a different functional form of pre-treatment productivity for every boundary segment (Dell and Olken, 2020). By allowing the underlying productivity grid to vary for every boundary segment and on either side of the boundary, this specification is flexible enough to allow productivity to increase with latitude in some areas and decrease with latitude in others. Thus, this specification captures every unobserved variable that varies continuously at the border and identifies the treatment effect exclusively from the discontinuity at the border.[26] Throughout the paper, I use the baseline equation (1) for inference and report point estimates from more flexible specifications that are similar to the baseline.

4.3 Balance of Covariates

A valid spatial regression discontinuity design requires that predetermined covariates vary continuously at the border and are sufficiently captured by the polynomial in latitude and longitude. In this section, I present evidence in support of the local exogeneity of grazing boundaries at two levels. First, I present evidence in Table 1 that covariates capturing productivity are balanced across treatment and control. Second, using population statistics and micro data from 1930, I document that the border was set orthogonal to population, income, wealth and other characteristics of the population.

All variables are indeed balanced (Table 2) and continuous (Figure 3) at the boundary using the baseline empirical specification. As the Taylor Grazing Act was written to *stop injury to the public grazing lands by (...) soil deterioration*, Figure 3a for soil erosion and Figure 3b for pretreatment vegetation report the most important balance graphs. Clearly, as we move from 5 miles

[26] As every boundary segment has its own latitude and longitude coefficient, this specification requires more variation per segment for the central limit theorem to ensure correctly estimated standard errors. Hence, especially with few observations in tight bandwidths around boundary segments, inference is affected as the degrees of freedom approach the number of variables.

outside the grazing district to 5 miles within, rangeland is approximately 4% more eroded. At the boundary, however, treatment and control are balanced and continuous. Hence, the impact of the Taylor Grazing Act might be smaller in very wide bandwidths, as the selection effect due to the lower average land quality becomes more dominant. At the boundary, however, Figure 3a provides no evidence of selection and validates the empirical design. Similarly, Figure 3b shows no indication of pre-existing differences in vegetation at the boundary in New Mexico, the only state with pre-Act vegetation data.[27]

It is however possible that the underlying information resolution of these soil reconnaissance surveys is questionable. Similar to re-analysis rainfall data, the actual data points might be far away and the lines are merely an approximation of the true status of the land in 1934.[28] To counteract this idea, I follow the literature's standard (Dell, 2010; Dell et al., 2018; Dell and Olken, 2020), and show that other inputs to production, such as elevation, ruggedness, temperature, precipitation and accessibility, are all well balanced and continuous at the boundary.[29]

In addition to productivity estimates, I use census data linked to the geographic location of minor civil divisions in 1930, and show that population and individual characteristics are balanced and continuous at the boundary (Figure 4). As all covariates, including income and earning scores, are balanced prior to the reform, it is likely that any impact on income and wealth stems directly from property rights.

Taken together, the evidence provided here suggests that the Taylor Grazing Act in 1934 provides a valid quasi-experimental setting to evaluate the effects of property rights on resource management, income and wealth.

5 Access rights as property rights

Productivity Figure 5 shows the main result for the impact of well-defined property rights to public land (access rights) on productivity. Here, I highlight the relationship between productivity (as measured by vegetation) and access rights, controlling for boundary segment fixed effects and the flexible polynomial in latitude and longitude in a five-mile bandwidth around the boundary. Moving from a historical open-access regime on the left-hand side of Figure 5 to an access rights regime on the right-hand side significantly increases the density of vegetation, and thus productivity.

The graphical finding is corroborated by the RD estimates in Table 3. In all specifications and bandwidths, public and vacant land in 1935 that was put under government control shows higher density of vegetation and productivity. Comparing two pixels within 1/2 mile of the grazing boundary, suggests a 11% (s.e. 0.029) increase in vegetation for the pixel with ac-

[27]While Skaggs et al. (2010) only digitize a soil survey for a small part of New Mexico in 1936, this provides a useful balance test for my analysis. However, according to the authors, these early surveys were hard to classify, and thus, I only use their data as a balance test, and not include this variable as a control in the remaining specifications.

[28]While this argument has merit, I show in Figure A.4 that grazing districts do not follow erosion patterns at the local level and the maps are highly detailed and contain more information than used here.

[29]All specifications and bandwidths are reported in (Table C.1). Another avenue to overcome this problem is explored in Appendix D, Table D.1, Panel E where I condition on the same erosion status on either side of the boundary and find no statistical difference to the baseline estimates.

cess rights. The point estimate is unaffected by adding a local polynomial in distance and a boundary specific interaction with latitude and longitude to narrowly capture underlying land productivity in columns (2) and (3). I report standard errors corrected for spatial correlation within 0.5 degrees in brackets which are slightly larger than clustering by boundary segment. All results are stable across bandwidths ranging from 0.1 to six miles (Figure B.1), unaffected by different kernels, and are robust to different outcome data and measurement. Access rights increase the prevalence of productive rangeland and have the same impact when using an alternative satellite series based on different wavelengths to calculate the NDVI at a higher resolution of 250m (Table C.4). The results remain unaffected by changing the boundaries: Neither using all boundaries, nor focusing on boundaries that are straight for at least six miles or the same erosion status on either side of the boundary affects the point estimates (Table D.1).

Wealth The positive impact of government intervention on productivity should not come at a cost to ranchers. Especially when considering the potentially huge welfare implications of policies similar to the Taylor Grazing Act, it is important to assess whether access rights also affect wealth.

Using census block data from 1990, 2000 and 2010, I show that families living inside the grazing districts have a larger median income, are less likely to be below the poverty line, and higher house values (Figure 6). In Table 4, I report estimates that suggest that the median family income is 16% larger (12% per captia) and is 2.5 percentage points more likely to have finished high school. This culminates in a reduction of poverty of at least 16% over the average rate of 0.120. In contrast, these impacts are not driven by an increased employment share in agriculture or urbanization (Columns (7)-(9)).

The results suggest that secured tenure enabled ranchers to move out of poverty. Since census blocks cover every resident, they account for general equilibrium impacts from ranchers to non-farming community members.[30] These impacts are especially important as they potentially magnify the per-dollar value of an intervention. Issuing access rights for public lands thus increases productivity and economic development. However, since the question whether distributing access rights can be as efficient as the alternative of privatization is at the heart of the debate, I benchmark the effects of the access-rights treatment to the effects of privatization.

6 Private property rights

To test whether the equivalence of Coase (1960) and Samuelson (1954) holds, I need to define comparable treatment and control groups. As the most productive plots of lands are sold first under privatization, estimates of the impact of private property rights are subject to an upward bias. I define my comparison group exploiting three features of land sales in the American West: First, a plot sold in 1880 is inherently more productive than a vacant plot

[30] I discuss the general equilibrium adjustments in Appendix H.1. When ranchers became more productive, they increased their labor demand and drove up wages. Farmers outside the grazing districts could only migrate towards the urban centers of counties, driving up urbanization rates. Labor costs and urbanization rates equalized by the end of the study period, leaving the one-time wealth shock improving home values, income, education and poverty rates.

in 1935. Fixed prices and quantities under homesteading practices implied that land quality was the only margin along which ranchers could choose land. Thus, if perfectly informed ranchers optimally decided to purchase the most productive plots that were available at the time, the average productivity of remaining plots decreased over time. Second, as competition for vacant plots increased over time, the 'Tragedy of the Commons' further decreased land quality (Foss, 1960). Under these conditions the available land for a prospective homesteader was not only already in use by other ranchers, but also severely eroded across the entire nine states for a number of years prior to the Act.[31] Third, ranchers chose plots according to the same public land survey system used to draw the boundaries of grazing districts (Libecap and Lueck, 2011) and did not anticipate the future Grazing boundary (Appendix F).

Thus, I identify a comparable privatization treatment by identifying sections of land that were sold *just* before the passing of the Act. Specifically, I estimate:

$$
\begin{aligned}
\log(\text{NDVI}_i) =& \beta^{AR} \textit{Access Rights}_i + \beta^{PP} \mathbb{1}\left(\textit{Privatized} \in [1924, 1934]\right) \\
&+ f(\textit{geographic location}_i) + \sum_{b}^{B} seg_i^b + \Gamma_i + \varepsilon_{b(i)}
\end{aligned} \tag{2}
$$

Equation (2) estimates the effect of privatization β^{PP} at every predetermined boundary between private property and lands without property rights within the minimum bandwidth of 1/2 mile of the grazing districts.[32] The privatization treatment then identifies an unbiased estimate of β^{PP} if the selection bias has diminished to zero over time and ranchers could not differentiate lands based on observable productivity; otherwise all privatization estimates are subject to an upward bias. As land sales decreased due to deteriorated land quality, I define the privatization treatment as lands inside the grazing districts that have been sold in the ten years prior to the passing of the Act; a period in which observable quality is balanced across the private-property treatment, the access-rights treatment, and the control.[33]

Results are shown in Table 5. Compared to lands without established property rights, lands privatized between 1924–1934 show a similar magnitude of improvement as public land inside the grazing districts with well-enforced access rights. Including a linear polynomial in distance or boundary-specific productivity does not alter the point estimate. In combination with the balance between treatment and control groups (Appendix E), this suggests that selection on unobservables is not a threat and that the selection bias has indeed diminished to zero,

[31] In Appendix E, I provide two sets of evidence in favor of this hypothesis. First, I show that for almost all indicators of land quality, lands sold closer to 1934 are worse (as measured in 1934) than lands sold earlier. Second, I show that among privatized lands, land sold earlier is less likely to be eroded and has higher NDVI values today.

[32] The comparison is thus between pixels inside the grazing districts that were either not sold by 1934 (access rights) or sold after 1924 (private property), to pixels outside the grazing districts without property rights. In earlier versions of this paper, I used the Stock-Raising Homestead Act of 1916 as a cutoff for the privatization treatment. This act increased the available acreage from 160 to 640 acres to counteract the diminishing returns of farmers. Results are unchanged when using this governmental 'privatization' treatment instead.

[33] Privatized lands prior to 1924 are omitted in all regressions. I provide evidence on balanced treatment in Section E of the Appendix both comparing to the access-rights treatment and the control. All covariates are continuous at the boundary and land quality diminishes with later dates of sales (Table E.1).

when comparing geographically and temporally close plots of land. The effects are slightly larger in the most restrictive specification within 1/2 mile, where the grazing districts increase land quality by 10.9% and privatization by 10.5%, but the F-Test rejects significant differences between treatments across all specifications.[34]

Taking into consideration the upward bias in the privatization treatment, the results point to an equivalence of private property and access rights. Both property rights improve resource management, providing support for the Coase (1960) hypothesis that well-defined property rights, and not necessarily private property, are important for long term outcomes.[35]. In this setting, access rights are as effective as private property and lead to large increases in wealth and reduction in poverty. This equivalence is even more striking, given that ranchers were not allowed to invest in the same productivity increasing technologies they used on their own ranges. Rather, ranchers were assigned an amount of cattle and a (potentially different) plot every period, such that the grazing authority bore the responsibility of investing, not the rancher.

Since wealth data covers every individual, and thus general equilibrium effects, I next discuss how ranchers' farm values change in the short, medium, and long run after the reform.

7 Agricultural Census

I study the response of ranchers to being granted access rights, using aggregated survey data on the average number of cattle per farm and farm values from the Agricultural Census. In contrast to the satellite data, the Agricultural censuses focus on ranchers in periods before and after the passing of the Taylor Grazing act, enabling a difference-in-differences (DID) design. I use a standard DID with county (α_c), year (α_t) and state $\times$ year ($\alpha_s \times \alpha_t$) fixed effects to capture all unobservable county characteristics and changes in state-wide policy.

$$\log Y_{c,t} = \sum_{\tau=1910}^{T=2007} \beta_\tau \text{Access rights}_c \times \mathbf{I}[t = \tau] + \alpha_c + \alpha_t + \alpha_s \times \alpha_t + \varepsilon_{c,t} \tag{3}$$

I regress the log number of cattle per farm and farm values in every county and survey period $Y_{c,t}$ on an indicator whether any part of the grazing districts lies within a county's border (Access rights$_c$). By allowing the coefficient β_s to vary by time, I test for linear pre-trends that would imply selection on unobservable trends. Figure 7 reveals no discernible pre-trends, as point estimates prior to 1935 are statistically indistinguishable from zero, but show a significant impact of the Taylor Grazing Act immediately after 1935. Farms report 17% (s.e. 0.058) more cattle and 7.8% (s.e. 0.044) higher farm values (Table 6, columns (1) and (5)). To address a potential upward bias originating from the reduction of cattle in control counties of the same state, I include counties from adjacent states in columns (2) and (6) and report point estimates that are unaffected by such spillover concerns.

[34]I directly compare privatized lands and access rights land in Table E.3 where I use lands that have been privatized between 1924–1934 as a control. In this analysis, I compare pixels inside the grazing districts (access rights) with pixels in lands sold after 1924 (private property) across the grazing boundary and again show no significant difference between access rights and private property.

[35]The equivalence of this reduced-form result carries over to an IV-setting explored in Appendix I.1.

However, unobservable time-varying selection could still bias these estimates if grazing districts lie in counties with greater expected benefits from regulation. Even if the potential land quality would be equal, more heavily grazed counties with more land degradation would naturally benefit more from limiting access and stopping the 'Tragedy of the Commons'. To address this concern, I use rainfall during the initial survey period to instrument the probability of having a grazing district. In October 1934, land surveyors classified the nine states into grades of degradation. The resulting classification likely reflects both the intensity of land use by ranchers and momentary rain-induced perceived land quality.[36] In addition, as rainfall levels are likely correlated across years and seasons, thus affecting productivity directly, I isolate the variation from rainfall in October 1934 using the historical mean and standard deviation of October for each county.[37] I highlight the identification strategy in Figure 8. Less rain in October 1934 predicts a more severe drought and more severe erosion, which leads to the county being affected by the Taylor Grazing Act.[38] Ultimately, these ranchers are granted more grazing permits in 1950 than their counterparts in counties with more rainfall in October 1934.

The relationship of rainfall with drought severity (0.487, s.e. 0.055), a major contributor to land erosion, and its first stage impact on being affected by the Taylor Grazing Act (-0.228, s.e. 0.039) is highly significant (Table G.3). However, this cross-sectional regression is likely biased by many unobservable factors, but using monthly rainfall data from 1915 to 2011 I provide additional evidence of their statistical significance. To calculate p-values, I estimate the impact of any other month-year rainfall and drought realization on having a grazing district established in your county. I report these placebo estimates in Figure G.1, and show that only 4.8% (4.3%) of rainfall realizations create a larger first-stage point estimate (t-statistic) on having a grazing district in your county.

I present the reduced form of rainfall and its IV estimates in Table 6. A strong first stage and reduced form suggest that the average number of cattle per farm grew by 90% (column 4) and farm values increased 40% (column 8) compared to control counties. In addition, reduced form estimates of the instrument in the right panel of Figure 7 exhibit no pre-trends and large effects immediately after the reform. In line with historical accounts, ranchers benefited massively from well-defined property rights to public land, prohibiting competition and allowing for fallowing periods. The documented downward bias of the OLS estimates relative to the IV, suggest that indeed worse counties were selected into grazing districts – in line with the intention of the Act and reports from the time.[39]

[36] Since rainfall can promote growth of vegetation but also lead to soil erosion by drainage after droughts, the first stage relationship is not clear a priori.

[37] In Appendix G, I show that instead of using historical mean and standard deviation from all years between 1915 and 2011, focusing on the years until 1933 generates the same results with a stronger first stage.

[38] I use the Palmer Drought Severity Index in which lower values represent a more severe drought. Since droughts are the result of continuously absent rainfall, I do not use this as an instrument, but report how rainfall predicts droughts, severity of erosion, access rights and the number of grazing permits in 1950.

[39] If worse lands have worse outcomes and are more likely to get grazing districts, a downward bias is present as selection and performance are negatively correlated. If selection was based on the potential returns, an upward bias would be present.

8 Spillovers

To understand how spillovers might affect vegetation and income, I derive a stylized model in Appendix J. Here, a maximizing rancher allocates cattle to plots by equating the marginal costs and benefit from cattle on each plot separately. Ranchers who use plots under open-access rules, implement the fallowing technology (letting the vegetation regrow over the winter) depending on the probability of future access: If ranchers are almost certain to retain access in the next period, they let the land fallow, similar to their own private property on which future access is guaranteed. If ranchers are at risk of losing access, they stock the plot, potentially losing all cattle, to ensure access in the next period. In this case, the Tragedy of the Commons arises, productivity decreases and lands degrade. The access rights regime of the Taylor Grazing Act ensures future access, and thus aligns the incentives of regulators and ranchers to increase and preserve productivity.

I further derive that stocking decisions on open-access plots remain unchanged, unless already constrained ranchers face an allocated number of cattle that is significantly lower than the rancher's prior use. However, from prior experience the grazing administration knew that implementing fallowing periods would improve the carrying capacity of the ranges and thus had no incentive to drastically cut the number of cattle. Moreover, Figure A.8 reports that in 1936 a total of 1.3 million cattle were allowed to more than 15,000 ranchers of which only 69 cases of appeals are reported until 1938 (Dalby, 1959). As it is likely that significant reductions in stocking allowances would have resulted in more appeals, and the Agricultural Census documents higher numbers of cattle, ranchers had no incentive to change their cattle allocation on unregulated lands.

In a second step, I estimate a donut regression discontinuity design, and show in Figure 9a that progressively leaving out all vegetation observations up until 5.5 miles to the grazing boundary does not impact the point estimate. Here, including all observations between zero and six miles, yields a point estimate of 0.183, which is unaffected by restricting the sample size to observations that are further than x-miles away from the boundary. In this sample, farms that are connected to the open-access lands are dropped if their effective reach is smaller than 5 miles from the boundary. Thus, farms located at the boundary would need to be in the upper 2% of farm sizes in the study region to affect the results.

The improvements from the Taylor Grazing Act likely come from implementing fallowing periods. On open-access ranges, a rancher only implements fallowing if the probability of reaping the benefits is almost certain and the Taylor Grazing Administration determined, enforced, and guaranteed long-term access rights to ranchers. Then, fallowing seasons increased vegetation during the winter, enabled increased stocking during the summer, and increased incomes for the ranchers. Moreover, if the access-rights allocation is close to the optimal stocking decision, vegetation differences to areas without fallowing should be large during the fallowing period and insignificant during the stocking periods. To estimate seasonal effects, I utilize the satellite data at the month-by-observation level and interact treatment with every month. I take July as the baseline month and plot the interaction terms with other months in Figure 9b. Differences in vegetation are significant after the winter period, with ranges having more pasture in March-May. These differences decline during the heavy grazing season in the summer as livestock eat the surplus away. Eventually, treatment and control ranges are equally depleted by the end of the season.[40] Figure 9b thus provides two insights into the mechanism behind the average effect of property rights: First, fallowing periods are implemented differently in treatment and control ranges. Second, as ranges are equally depleted by the end of the season, both ranges are likely utilized at their maximum carrying capacity, providing evidence against overly restrictive grazing allocations for farmers.

As a consequence of increased profitability and profits, additional ranchers might have selectively migrated into the grazing districts. In fact, increased farm and house values might be indicative of increased demand. However, as the Taylor Grazing Act fixed the ownership inside the grazing districts, migration would have led to increased competition on open-access lands. I provide evidence against increased competition using minor civil divisions and 1940 census data on migration, population, and employment in Figures 10. All indicators are insignificant and vary continuously at the grazing boundary. In the medium run, however, increased profitability of farms with grazing rights would have increased labor demands and wages, negatively affecting ranches without grazing rights. In general equilibrium, farms close operations and owners migrate into cities until labor costs equalize across the grazing boundary. I provide evidence of this general equilibrium mechanism in Appendix H.1, where I show that labor costs and urbanization rates increased after the Act, but have equalized by 1970. As neither in 1940 nor today, migration, employment, or population density are indicative of spillovers from areas with property rights to areas without, the wealth and productivity effects of the Taylor Grazing Act remain.

Finally, I address spillovers in the context of the Agricultural Census. In columns (2) and (6) of Table 6, I include counties from neighboring states in the main regression. Since any spillover would decrease the number of cattle and farm values of counties in the same state, the baseline point estimates in columns (1) and (5) would be upward biased. However, including adjacent states does not affect the point estimates, providing no evidence of a bias.

In summary, neither theoretical considerations nor qualitative evidence suggest a negative spillover under the assumption of constant competition and optimally behaving ranchers. Evidence from Minor Civil Divisions in 1940 suggest no differential migration and population at the boundary supporting this assumption. Using panel data from the agricultural census, I document a positive and immediate impact on the number of cattle per farm and farm values after the Taylor Grazing Act. This evidence is in line with evidence on increasing cattle numbers in trials conducted before the Taylor Grazing Act and the limited number of appeals against stocking numbers by ranchers until 1938.

9 State Capacity and Property Rights

I now shed light on the mechanisms behind the results of previous sections, providing evidence in favor of the second result of Coase (1960): efficient property rights require sufficient

[40]The observed pattern is consistent with actual implemented policies shown in A.7 where the allowed number of livestock varied greatly by season.

state capacity and low transaction costs. I use a number of predetermined county factors to capture state capacity and newspaper circulation to capture 'ease of transaction'. Both factors are necessary conditions to reap the benefits from establishing well-defined property rights to public lands.

With increasingly secure property rights, the net present value of farms increase (De Soto, 2000) and using property rights as collateral, ranchers may be able to obtain a larger loan or a higher selling price on the market. Similarly, initial constraints on ranchers' ability to reap the benefits from investing were lifted by enforcing property rights, allowing for the re-allocation of plots and ranchers to increase productivity. These heterogeneous effects of enforcement, financial access and consolidation likely depend on the continued presence of these enabling institutions. However, as some institutions might respond endogenously to the Taylor Grazing Act, I restrict myself to institutions existing prior to 1934. Enabling institutions are more likely to be present in cities, but I show that population density and the distance to the closest city is balanced and continuous at the boundary (Figure 3 and 4). To validate the proposed mechanisms, I rule out confounding factors by showing that population growth, employment and migration cannot explain the results, as each is balanced in 1930 (Table 7).

Enforcement of the Reform More secure tenure on public land is only realizable with strong governance. In the nine states of the Taylor Grazing Act, strong governance is represented by the presence and quality of law enforcement. It is plausible to assume that the closer a rancher is to a police officer, the stronger is his enforcement of the law. It is also plausible that if this police officer is more competent, the rancher is more likely to believe that his right will be upheld.

To proxy for state capacity, I use occupational statistics in the 1930 full-count census at the county level and the distance of an observation to the closest city with a civil service reform.[41] As argued by Ornaghi (2018), these measures should gauge the availability and quality of governance in the early 1930s. In Table 8, I interact access rights with whether the county had a policeman or fireman to proxy for enforcement and state capacity. Both interaction effects are strongly positive suggesting that initial levels of state capacity strongly predict the impact of the Taylor Grazing Act on resources. Following Ornaghi (2018), I argue that civil service reforms in police and fire brigades capture the quality of governance, and thus state capacity, and report the interaction effect with the standardized difference to the nearest city with such a reform before 1940 in column (4). Here, a one standard deviation increase in distance is enough to offset the gains from the Taylor Grazing Act. Quality of enforcement matters for settling disputes and enforcing access rights to increase vegetation. However, as civil service reforms are only done in larger cities, I show in column (5) that the interaction with closeness to large cities has no predictive power for vegetation, supporting my interpretation of the results.

Economic Channels of the Reform The economic impact of property rights includes two channels, each of which is likely to depend on the enforcement of property rights. First, more

[41] The data only have 31 cities with police reforms up until 1940, which I use in this paper. I thank Ornaghi (2018) for sharing. I follow her approach and proxy state presence with the occupation 'policemen and detectives' and 'firemen' in every county and then define cities with civil service reforms according to her data. In total, 84 counties had no policemen in 1930.

secure property rights lead to a higher value of the collateral a rancher can post when asking for a loan. Second, higher farm values should result in higher realized prices for farms, leading to a greater willingness to sell. To identify both channels, I use the predetermined presence of banks as a proxy for financial access and the circulation of local newspapers as a proxy for the ease of placing farms for sale.

Property rights protection as highlighted by the presence of law enforcement increases the value of potential collateral. As property rights are ensured by the government, banks begin to accept access rights as collateral and issue more credit. Ranchers with larger collateral may invest more to grow out of poverty (De Soto, 2000). To obtain a pre-reform measure of financial access, I use the Federal Deposit Insurance Corporation (2001) and identify whether a county had a pre-existing bank.

The other effect of secure property rights stems from the higher sales price of farms. As previously non-verifiable off-farm income from open-access land is guaranteed with access rights, the net present value of farms with access rights increased. Thus, while ranchers previously would not sell their farms since prospective buyers did not compensate them for the non-verifiable income from their usage of open-access lands, access rights now verify this income steam. The higher valuation of the buyer induces the least productive some ranchers to sell and switch occupations. To proxy this channel, I rely on the circulation of local newspapers. Ranchers post ads for their farms, including price and grazing rights, in local newspapers where other ranchers may search for potential farmland with additional grazing rights. Hence, larger circulation of local newspapers decreases transaction cost for buyers and sellers. To obtain a measure of pre-reform newspaper I use data from Gentzkow et al. (2014) and calculate the total circulation per county in 1932 as well as the presence of any newspapers.

The evidence presented in Table 8 suggests that the availability of credit did not affect long-term productivity. The availability of newspapers, however, is positively correlated to the effectiveness of the Taylor Grazing Act. By reducing frictions of farm sales, newspaper reduce the initial misallocation of ranchers, increasing the average productivity of remaining ranchers.[42] In the Agricultural Census (Table H.1), this channel is reflected by significant triple interactions with newspaper existence and circulation that predicts a higher stock of cattle. Security of property rights, as measured by distance to a city with civil service reform, only significantly impacts the farm values and not the quality of ranchers. In addition, Table H.2 lends credence to the hypothesis that the Taylor Grazing Act benefited smaller ranchers on their own farm, rather than large scale monopolists, by showing that larger ownership rates and smaller average firm sizes all predict larger impacts of the Taylor Grazing Act on farm values. However, conclusively testing the hypothesis on state capacity would require exogeneous variation in historical and contemporary institutions.

[42]One can think of this mechanism as either a match-specific misallocation between rancher and land, or as a occupation-specific misallocation in which ranchers expectation about their occupation-specific productivity are revealed after they homesteaded land. Initial frictions to landsales, including off-farm income from open-access lands, or minimum requirements of ownership by homesteading laws, then prohibit a productive reordering of the local economy.

External validity The results in this section highlight how property rights depend on the level of state capacity in the county. While counties without a police officer were arguably similar to modern day low-state capacity countries, the presence of the state in counties with high state capacity was arguably higher than in many developing countries today.[43] Only three countries, Bangladesh, India, and the Philippines, have higher trust in state institutions today, than the United States had in 1981 (World Value Survey). However, these countries comprise more than 1.6 billion people of which more than 400 million are living below the poverty line. In India alone, more than 50% of the rural population depend on grazing in forests, community lands and other lands. By formally recognizing the rural populations grazing rights and investing in state capacity, allowing these rights to be traded could lift many rural ranchers out of poverty (Beg, 2021).

10 Conclusion

The results in this paper suggest that government intervention to establish well-defined property rights to publicly owned land in the spirit of Samuelson (1954) has positive effects on the productivity and wealth of affected ranchers. The magnitude of resource improvement is similar to outright privatization in the spirit of Coase (1960). This equivalence is remarkable as ranchers faced different incentives to invest on either type of plot. Results indicate that an important margin of adjustment is breaking the gridlock of mis-allocation. Without verification of future income streams, ranchers may be hesitant to sell their ranches below their expected net-present value. As access rights, similar to privatization, verify these income streams, buyers and sellers converge in their valuation, increasing transactions from low-productivity (mis-allocated) ranchers to high-productivity ranchers. Thus, establishing well-defined property rights to public land overcomes a market friction, which increases efficiency, resource management and wealth for the general population.

While private property can be politically contentious, distributing regulated access rights to all previous users should make this policy more appealing to policy makers. Moreover, as more users benefit from such a policy, wealth effects may be distributed more evenly and decrease poverty rates. However, for such policies to be effective, access rights need to be enforced and easily transferable between farms, as the ability to consolidate and relocate greatly increases the effectiveness of this policy. The results in this study suggest that under ideal conditions, selling resources and renting out access to resources can have the same effect on sustainability. As soon as an individual has enforced exclusive rights to a resource, he or she is likely to behave optimally. However, in areas without strong enforcement, privatization may be preferable to access rights. With stronger enforcement and low transaction costs, distributing access rights is preferable to private property for two reasons. First, more people obtain a wealth shock that leads the least productive ranchers to relocate to more profitable occupations. Second, as formal access rights mirror informal existing rights, they might be easier to implement in developing countries.

[43] In some states citizen arrest laws give citizens the rights to make arrests (e.g., ORS 133.225; Utah Code 77-7-3).

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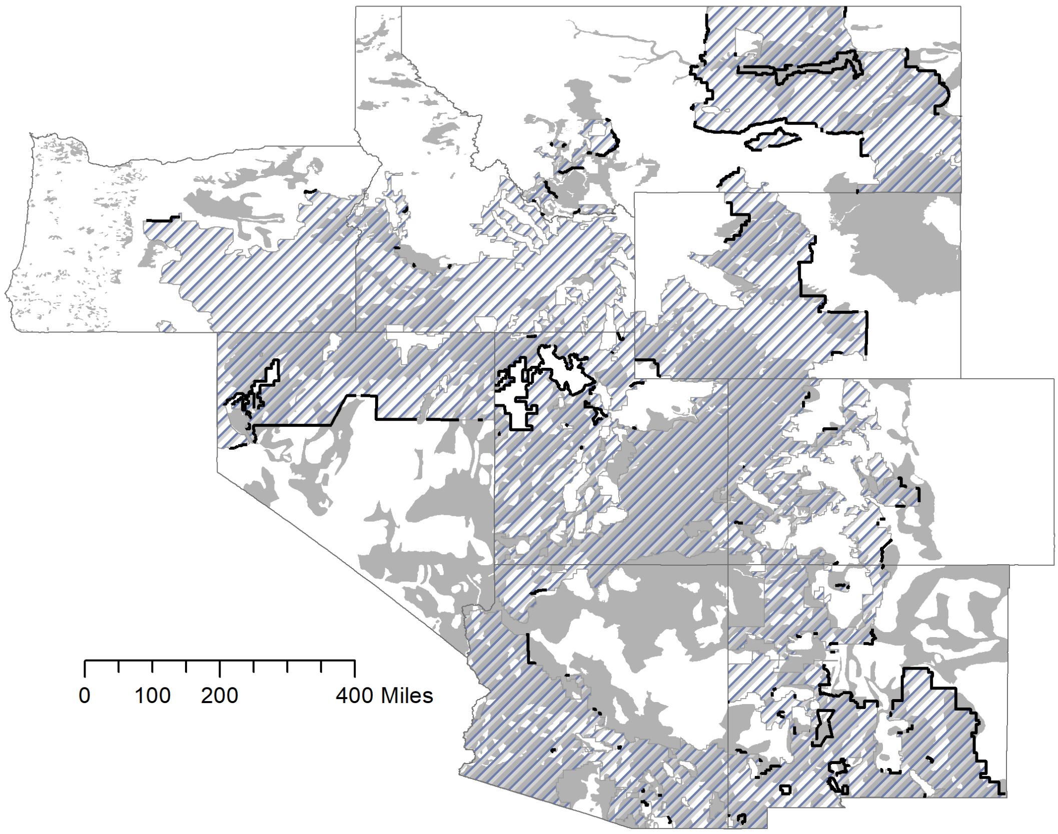
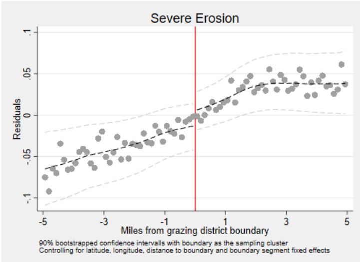
Figures

Figure 2: Erosion status with grazing districts

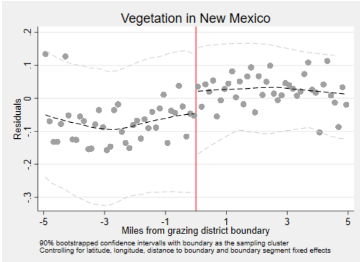


Erosion Status in nine western States (October 1934) with the extent of the Taylor grazing districts overlaid. Gray areas: severely eroded. Solid shaded areas: grazing districts. Solid black lines: Estimation sample, taking into account potentially predetermined boundaries by national forests and Native American reservations. Estimation robust to focusing on individual straight boundaries (e.g. Nevada, Figure A.3), including all boundaries or other sampling procedures (Appendix D).

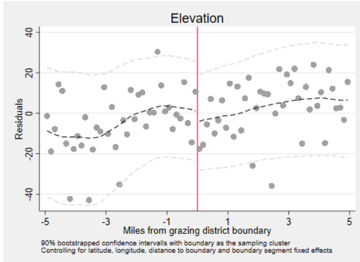
Figure 3: Balance graphs: Access rights treatment



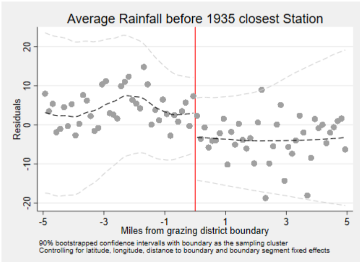
(a) Severe Erosion



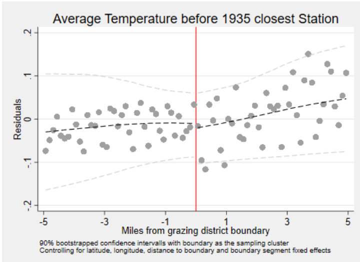
(b) Vegetation in NM



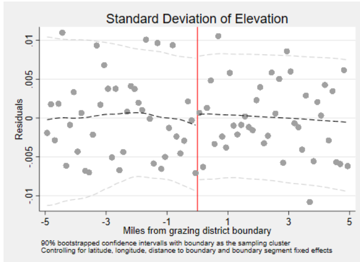
(c) Elevation



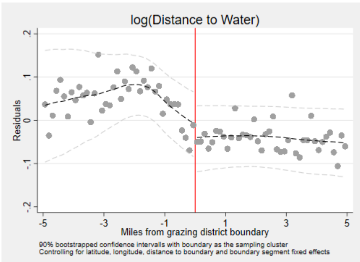
(d) Rainfall prior to 1935



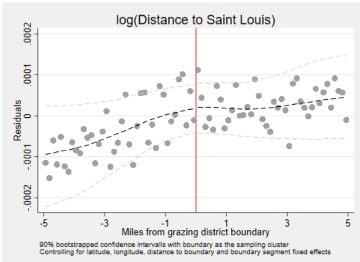
(e) Temp. prior to 1935



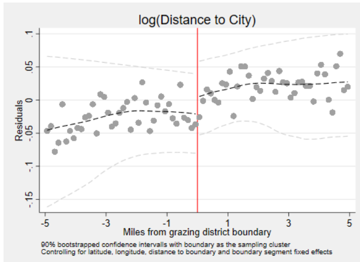
(f) Ruggedness



(g) Distance to nearest river



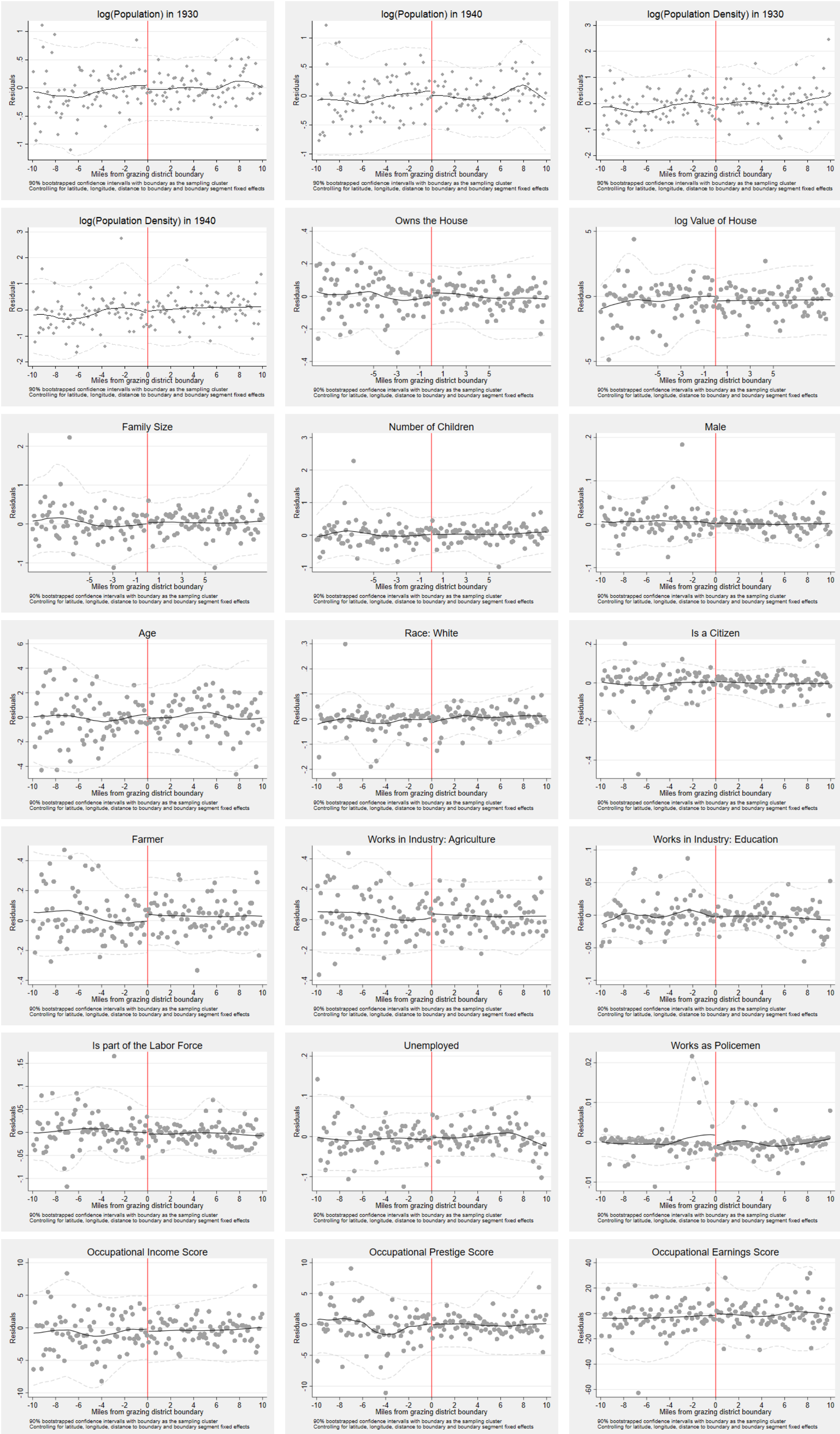
(h) Distance to Saint Louis



(i) Distance to closest city

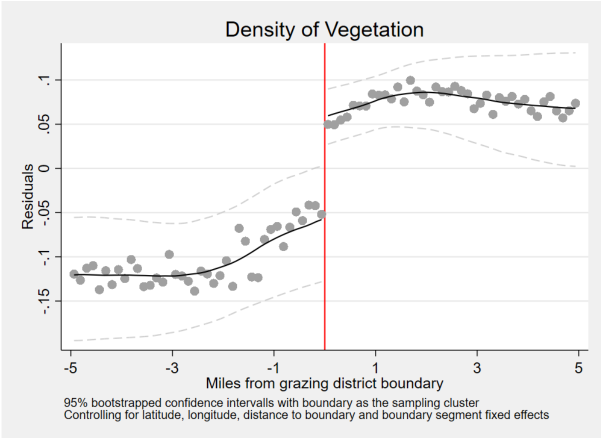
Balance regression discontinuity graphs for the access rights treatment in the AVHRR data: Plotting the residuals, controlling flexibly for latitude and longitude, distance to the border as well as boundary fixed effects. Each bin is 0.125 miles wide. Bins with well-defined property rights to public lands are shown to the right with positive mile indicators, while areas without are shown with negative indicators. Balance in Table 2. Variable description: *Severe Erosion* refers to erosion maps constructed for the nine states in 1934. Those maps were used to determine the extend of the Taylor Grazing Act and show the erosion status of the land in 1934. 54% of my sample is classified as severely eroded and 22 % as moderately eroded. *Vegetation in NM* shows the vegetation in a small southern part of New Mexico in 1936 as digitized by Skaggs et al. (2010). Due to the limited geographical extend the numbers of observation is severely reduced and thus this variable is not part of the covariates in any other regression. *Elevation* is constructed from the Global Multi-resolution Terrain Elevation Data (GMTED2010), and shows the mean elevation in a 500m radius around every pixel. *Rainfall prior to 1935* and *Temp. prior to 1935* defines the average yearly rainfall and temperature from 1900–34 at the closest station. *Ruggedness* calculates the standard deviation of elevation of 8 adjacent cells and denominates it by the average elevation of all 9 cells. The average within a 500m radius around every pixel is reported here. *Distance to nearest river*, *Distance to Saint Louis* and *Distance to closest city* capture varying distances to proxy for water access, remoteness and thus time of settlement, and distance to modern day civilization which might affect the NDVI measure due to green lawns or highways.

Figure 4: Balance graphs: Population characteristics



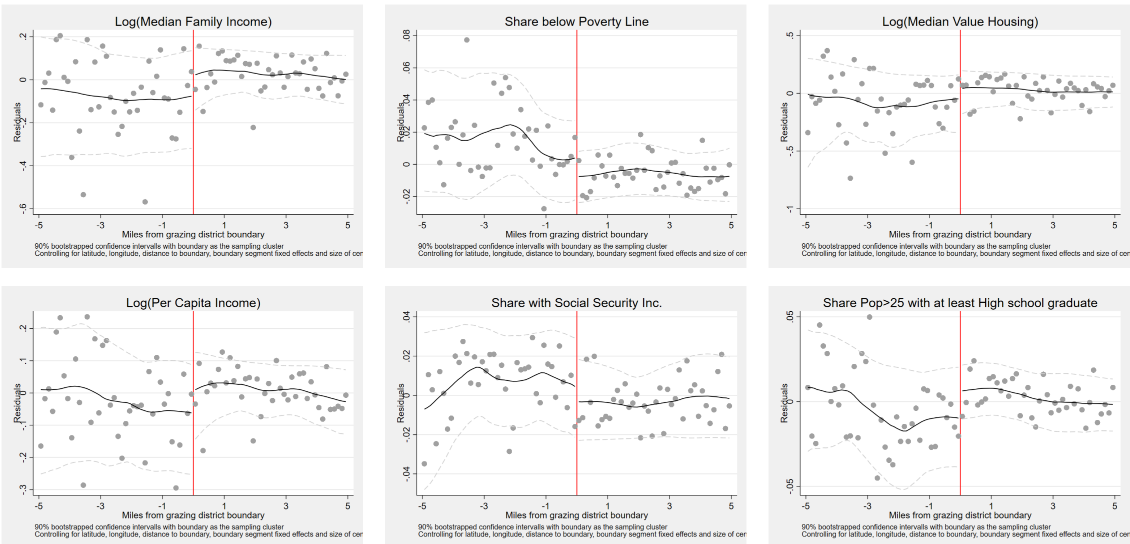
Balance regression discontinuity graphs using the minor civil divisions. Plotting the residuals, each bin is 0.125 miles wide.

Figure 5: Main result: Public ownership



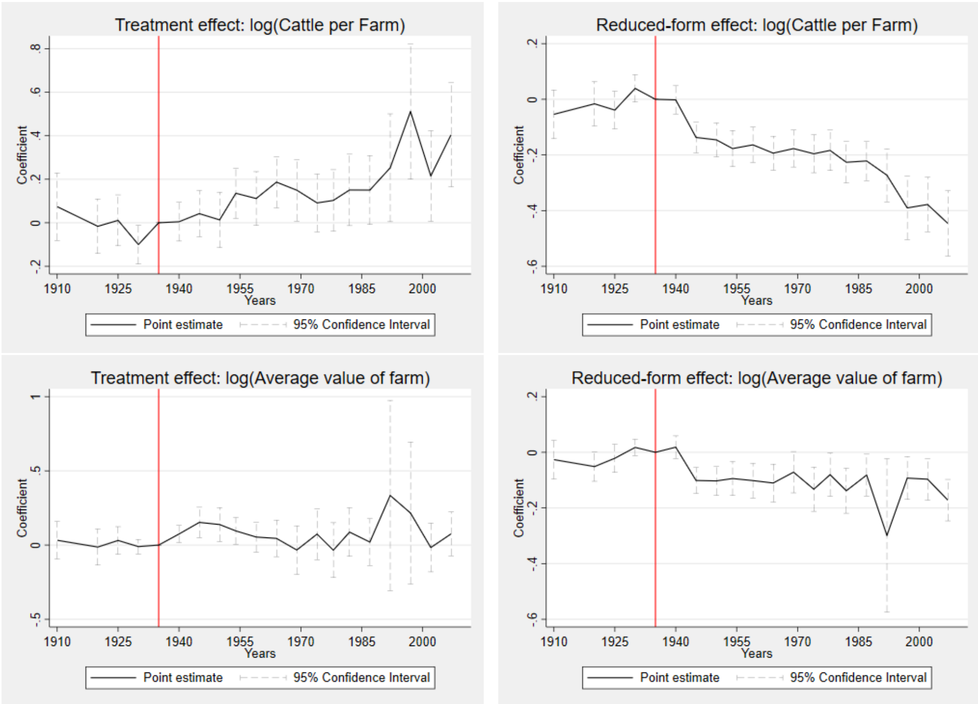
Effects of the 'access rights' treatment on the AVHRR vegetation index. It shows the residual vegetation after I control flexibly for latitude and longitude, distance to the boundary and boundary fixed effects. Standard errors are constructed by bootstrapping individual boundary segments. Each bin is 0.125 miles wide. Bins with well-defined property rights to public lands are shown to the right with positive mile indicators, while areas without are shown with negative indicators.

Figure 6: Census blocks: Income and wealth



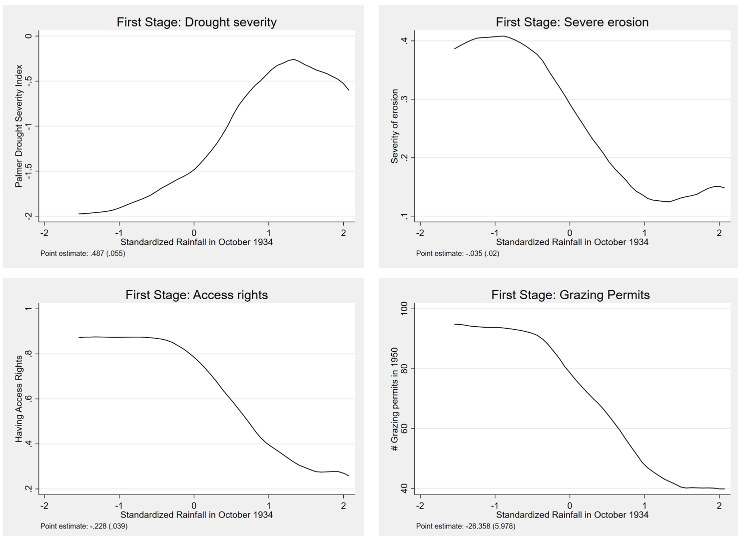
Treatment effect on Wealth indicators. Census blocks inside the grazing districts (right of the red line) show significant increases in income, house values, and reductions in poverty rates. RD-Graph using census block Groups in 1990, 2000 and 2010. Residuals shown from the baseline shown, including year fixed effects. Each bin is 0.125 miles wide. Bins with well-defined property rights to public lands are shown to the right with positive mile indicators, while areas without are shown with negative indicators. The noise is likely due to fewer observations outside the grazing districts. Estimates and RD graphs look considerably better in large bandwidths as shown in the Appendix Figure B.3 where the first line denotes the estimates from Table 4 using a one mile bandwidth. This is smaller than the optimal bandwidth of 5-10 miles (Calonico et al., 2015), and chosen to ensure comparability with the estimates on productivity.

Figure 7: Agricultural Census: Cattle and farm values



Lead-Lag graphs of the main outcomes. Left panel: Using actual treatment status. Right panel: Reduced-form estimates using standardized rainfall in October 1934 as an instrument for the Taylor Grazing Act. Less rainfall is associated with a higher probability of being treated, and thus increases future farm and land values. Raw values shown in Appendix Figure G.3.

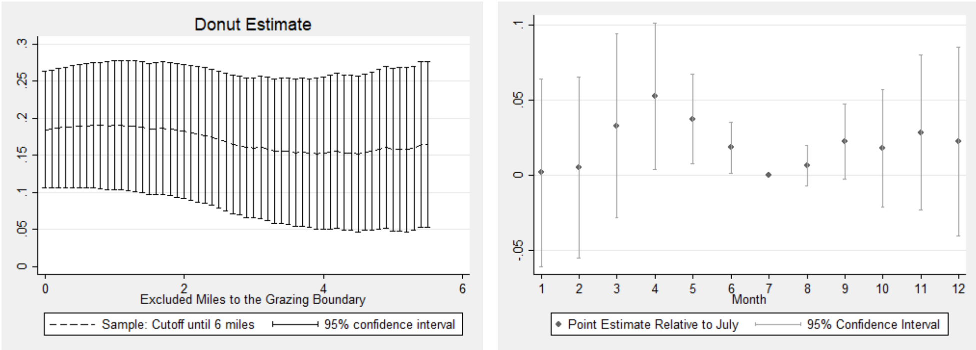
Figure 8: Agricultural Census: Identification of the instrument



Identification of the instrument: Rainfall in October 1934 predicts drought severity in a county (top left), the level of erosion in a county (top right), whether the county is affected by the Taylor Grazing Act (bottom left) and the number of grazing permits in 1950 (bottom right). Drought severity is measured by the Palmer Drought Severity Index with larger values indicating less severe droughts.

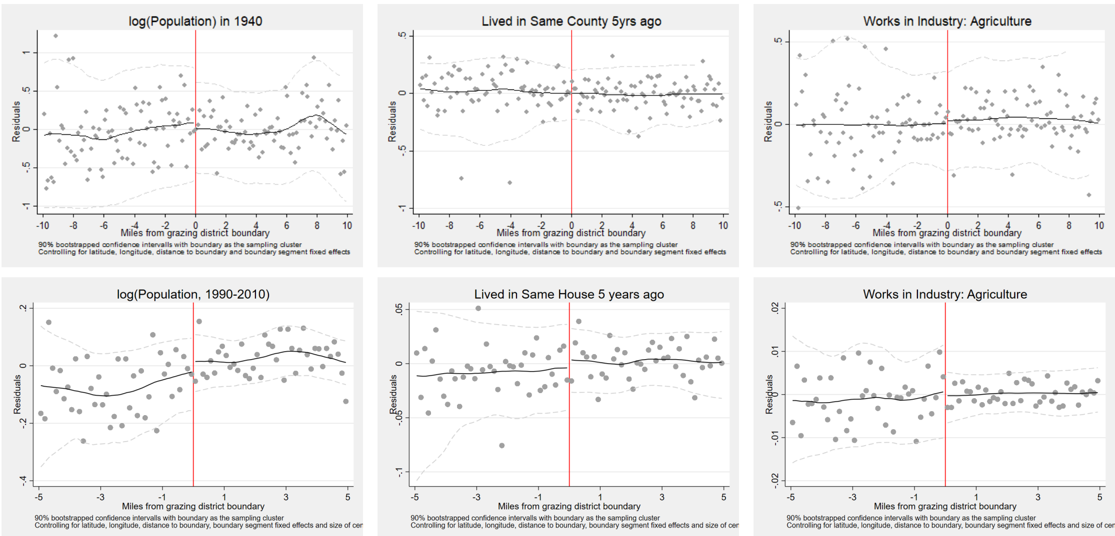
Figure 9: Assessing the severity of Spillovers

(a) Donut estimation **(b)** Fallowing



Left: In this donut estimation example, the first spike represents the point estimate from the entire sample within 6 miles of the grazing boundary. Every other spike denotes a progressively reduced sample containing all observations located within the value on the x-axis and six miles of the boundary. Right: How access rights affect vegetation during the months within the one mile bandwidth relative to July. Effects are consistent with an implementation of recovery periods after the winter (March) and then stocking it optimally until the end. Pattern closely resembles actual stocking patterns as shown in Figure A.7: More vegetation on ranges allows for more AUM.

Figure 10: Spillover: Population, Migration and Employment



Evidence against population, migration or employment as a potential spillover. Top row uses the minor civil divisions use the 1% sample. Bottom row uses census blocks denominate each variable by population in 1990 and 2000.

Tables

Table 1: Summary statistics within two miles of the boundary

	Outside grazing districts			Inside grazing districts			
	Mean	Standard Deviation	Observations	Mean	Standard Deviation	Observations	
Outcome from Satellite Data:							
Density of Vegetation	0.104	0.078	16,864	0.120	0.056	17,354	
Outcome Data from census blocks in 1990, 2000 and 2010:							
Median family income in 1,000USD	46.488	25.779	1,572	53.158	27.405	3,470	
Share poor	0.138	0.122	1,532	0.111	0.111	3,446	
Median house value in 1,000USD	153.038	131.784	1,562	169.827	133.479	3,438	
			Covariates for Balance tests:				Difference T-Test
Covariates for satellite data capturing productivity:							
Distance to boundary	2.037	0.948	16,864	2.131	1.038	17,354	0.000
Severe erosion (1934)	0.476	0.499	16,864	0.505	0.500	17,352	1.661
Annual rain (1915-1934)	1058.141	427.606	16,864	1038.236	415.258	17,354	−1.179
Annual temperature (1915-1934)	50.300	5.779	16,864	50.851	6.269	17,354	0.082
Elevation	1652.799	595.214	16,841	1652.404	597.327	17,323	−0.643
Ruggedness	−0.021	0.158	16,864	−0.020	0.161	17,354	0.210
Distance water	5.981	5.249	16,864	5.626	5.080	17,354	−1.423
Distance city	15.772	11.488	16,864	15.937	11.651	17,354	1.198
Distance Saint Louis	1860.653	336.590	16,864	1869.434	341.030	17,354	−0.056
Population statistics from Minor Civil Divisions in 1930:							
Population	680.285	1163.755	362	735.352	1755.256	557	−1.337
Population Density	1.371	3.353	177	2.519	17.056	214	1.185
Individual characteristics from Minor Civil Divisions in 1930 (Adults only):							
Male	0.515	0.500	2,825	0.516	0.500	3,987	0.729
Age	42.302	14.250	2,825	42.379	13.894	3,987	−1.320
White	0.970	0.171	2,825	0.944	0.230	3,987	−1.588
Citizen	0.842	0.365	2,825	0.828	0.378	3,987	1.476
Farmer	0.301	0.459	2,825	0.354	0.478	3,987	1.429
Works in agriculture	0.379	0.485	1,536	0.405	0.491	2,139	1.328
Works in education	0.021	0.145	1,536	0.026	0.158	2,139	0.477
Part of Labor force	0.544	0.498	2,825	0.538	0.499	3,987	−0.070
Unemployed	0.068	0.252	1,539	0.063	0.243	2,155	0.623
Policeman	0.005	0.067	1,543	0.001	0.030	2,161	−0.473
Household characteristics from Minor Civil Divisions in 1930 (Household head only):							
Owns house	0.587	0.493	1,622	0.584	0.493	2,269	1.150
Family Size	3.905	2.320	1,628	3.953	2.289	2,278	0.343
Number of Children	1.954	2.056	1,628	1.981	2.018	2,278	0.388
House value	1693.090	2989.663	932	1514.337	2799.549	1,293	−0.457
Adults earnings and education from Minor Civil Divisions in 1930 (Employed adults):							
Occupational income score	22.718	12.121	1,438	21.853	11.154	2,022	−1.099
Occupational prestige score	36.424	13.012	1,438	36.223	13.143	2,022	−0.410
Occupational earnings score	43.081	54.367	1,438	52.398	116.578	2,022	−0.528
Educational score	15.006	48.940	1,438	26.003	116.895	2,022	0.296

Summary table for outcomes and covariates. Standard errors corrected for spatial dependence within 0.5 degrees.

Table 2: Balance test for issuing access rights within one mile

	(1) Severe Erosion	(2) Rainfall	(3) Temperature	(4) Elevation	(5) Ruggedness	(6) log(Dist. water)	(7) log(Dist. city)	(8) log(Dist. Saint Louis
Grazing Rights	0.019	-4.433	-0.011	-7.544	0.001	-0.044	0.041	0.000
	(0.020)	(5.723)	(0.041)	(12.164)	(0.002)	(0.043)	(0.031)	(0.000)
	[0.020]	[5.258]	[0.039]	[12.705]	[0.002]	[0.043]	[0.030]	[0.000]
Observations	17615	17616	17616	17586	17616	17613	17616	17616
Mean	0.483	1054.2	50.41	1650.1	-0.0212	1.283	2.345	7.513

An observation is treated if its center is within the historical grazing districts and is public in 1935. Control observations are pixels without established property rights, outside the historical grazing districts without prior ownership status. RD-graphs in Figure 3. *Severe erosion* refers to erosion maps constructed for the nine states in 1934. Those maps were used to determine the extend of the Taylor Grazing Act and show the erosion status of the land in 1934. 54% of my sample is classified as severely eroded and 22 % as moderately eroded. *Elevation* is constructed from the Global Multi-resolution Terrain Elevation Data (GMTED2010), and shows the mean elevation in a 500m radius around every pixel. *Average Rainfall prior to 1935* defines the average yearly rainfall and *Average Temperature prior to 1935* the average temperature in Fahrenheit from 1900-34 at the closest station. *Standard Deviation of Elevation* calculates the standard deviation of elevation of 8 adjacent cells and denominates it by the average elevation of all 9 cells. The average within a 500m radius around every pixel is reported here. *Dist. water*, *Dist. Saint Louis* and *Dist. city* capture varying distances to proxy for water access, remoteness and thus time of settlement, and distance to modern day civilization which might affect the NDVI measure due to green lawns or highways. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Table 3: Access rights treatment: Effect on density of vegetation

	1/2 mile			1 mile			2 mile		
	(1)	(2)	(3)	(4)	(5) log(NDVI)	(6)	(7)	(8)	(9)
Access Rights	0.110^{***}	0.103^{***}	0.103^{***}	0.134^{***}	0.108^{***}	0.108^{***}	0.165^{***}	0.118^{***}	0.117^{***}
	(0.029)	(0.027)	(0.032)	(0.032)	(0.029)	(0.034)	(0.036)	(0.030)	(0.034)
	[0.031]	[0.030]	[0.033]	[0.034]	[0.032]	[0.034]	[0.039]	[0.033]	[0.035]
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes
Observations	8,656	8,656	8,656	16,904	16,904	16,904	32,562	32,562	32,562
Mean	0.119	0.119	0.119	0.118	0.118	0.118	0.118	0.118	0.118

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Control observations are pixels without established property rights outside the historical grazing districts. Covariates included in all columns and defined in Table 2. 'Distance Polynomial' includes a linear polynomial in distance, estimated with different slopes on either side of the boundary. 'Boundary spec. Productivity' estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. Standard errors clustered by the boundary segments shown in parenthesis and corrected for spatial correlation within 0.5 degree in brackets.

Table 4: Wealth effect of access rights within one mile: Census blocks 1990–2010

	(1) log(Median family income)	(2) log(Income p.c)	(3) log(Median house value)	(4) Share below Poverty Line	(5) Share social sec. inc.	(6) Share Highschool	(7) Employment Share	(8) Share Agriculture	(9) Share Rural
Grazing Rights	0.160**	0.120*	0.172**	-0.020**	-0.017**	0.025*	0.008	-0.001	-0.016
	(0.079)	(0.068)	(0.089)	(0.008)	(0.008)	(0.012)	(0.007)	(0.002)	(0.012)
	[0.074]	[0.063]	[0.087]	[0.009]	[0.008]	[0.014]	[0.008]	[0.002]	[0.011]
Observations	2049	2050	2028	2003	2003	2005	2011	2003	2009
Mean	10.25	9.410	11.23	0.120	0.260	0.850	0.316	0.0180	0.209

Access rights are defined as census blocks inside the historical grazing districts. Boundary segment × Year effects, block size and population in 1930 measured at the Minor Civil Division-level included in all regressions. Standard errors clustered by the boundary segments and Year shown in parenthesis and significance denoted by standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Table 5: Access rights treatment: Comparing to privatized plots in the period 1924–1934

	1/2 mile			1 mile			2 mile		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					log(NDVI)				
Access Rights	0.109***	0.116***	0.141***	0.134***	0.098**	0.110***	0.167***	0.093**	0.092***
	(0.029)	(0.044)	(0.045)	(0.032)	(0.039)	(0.040)	(0.037)	(0.035)	(0.033)
	[0.031]	[0.044]	[0.043]	[0.034]	[0.041]	[0.039]	[0.040]	[0.038]	[0.035]
Private Rights	0.105***	0.115***	0.126***	0.123***	0.109**	0.094**	0.130***	0.125***	0.092**
	(0.042)	(0.046)	(0.044)	(0.040)	(0.049)	(0.046)	(0.031)	(0.046)	(0.042)
	[0.041]	[0.043]	[0.041]	[0.040]	[0.046]	[0.043]	[0.032]	[0.045]	[0.041]
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes
Observations	9,026	9,026	9,026	17,642	17,642	17,642	34,098	34,098	34,098
F-Test of equality	0.893	0.985	0.702	0.743	0.793	0.725	0.121	0.390	0.995

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Privatized observations are satellite pixels that cover plots that were sold between 1924–1934. Plots that were sold before are dropped. Control observations are pixels without established property rights outside the historical grazing districts. Covariates included in all columns and defined in Table 2. 'Distance Polynomial' includes a linear polynomial in distance, estimated with different slopes on either side of the boundary. 'Boundary spec. Productivity' estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. 'F-Test of equality' reports the p-value at which the hypothesis that 'Access Rights' and 'Private Property' have a different impact on productivity can be rejected. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Table 6: Difference-in-Differences Estimation: Agricultural Census

	log(Cattle per farm)				log(Average farm value)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	RF	2SLS	OLS	OLS	RF	2SLS
Access Rights × Post TGA	0.174***	0.185***		0.903***	0.078*	0.133***		0.412***
	(0.058)	(0.068)		(0.174)	(0.044)	(0.041)		(0.130)
Rainfall in October 1934 × Post TGA			-0.207***				-0.094***	
			(0.029)				(0.024)	
Including Adjacent States		Yes				Yes		
First stage F-Statistic				34.494				34.463
Observations	5,612	14,312	5,612	5,612	5,619	14,317	5,619	5,619

County, year and state× year fixed effects included in all columns. Access rights are defined as counties affected by the Taylor Grazing Act. 'Access Rights × Post TGA' is the DiD estimate for every observation from 1940 onwards. In columns (2) and (6) I include all counties in adjacent states as a control to identify potential spillovers. 'Rainfall in October 1934' is the standardized rainfall using the mean and standard deviation of the county in October 1934, the month the erosion maps were drawn. In columns (4) and (8), 'Access Rights × Post TGA' is instrumented using 'Rainfall in October 1934 × Post TGA'. The first stage F-Statistic on excluded instruments is shown. First stage estimates are shown in Table G.3. Controlling for area, population and initial number of farms and cattle, the point estimate drought severity is 0.481 (s.e. 0.057) and being affected by the Taylor Grazing Act is -0.217 (s.e. 0.036). Standard errors clustered by counties shown in parenthesis.

Table 7: Spillovers within one mile: Population, agricultural employment and migration

	Population 1940		Minor Civil Divisions 1940				Census Blocks 1990-2010	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	log(Population)	log(Population Dens.)	Farmer	Agriculture	Same County 5yrs ago	Was Farmer 5yrs ago	Same House 5yrs ago	Foreign Born
Grazing Rights	-0.142	0.053	0.078	0.097	0.008	0.003	0.017	-0.027
	(0.172)	(0.294)	(0.103)	(0.116)	(0.085)	(0.102)	(0.011)	(0.016)
	[0.158]	[0.270]	[0.095]	[0.106]	[0.073]	[0.092]	[0.013]	[0.017]
Observations	259	106	668	342	668	668	1,250	624

Access rights are defined as census blocks inside the historical grazing districts. Boundary segment × Year effects, block size and population in 1930 measured at the Minor Civil Division-level included in all regressions. Population density, measured in square miles, has fewer observations as data on size is missing for some minor civil divisions in 1940. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Table 8: Access rights treatment: State capacity

	1 mile							
	(1)	(2)	(3)	(4) log(NDVI)	(5)	(6)	(7)	(8)
Access Rights	-0.001	0.035	-0.027	0.208***	0.144***	0.200***	0.077***	0.125***
	(0.048)	(0.029)	(0.023)	(0.039)	(0.038)	(0.057)	(0.028)	(0.033)
	[0.046]	[0.027]	[0.022]	[0.040]	[0.040]	[0.057]	[0.027]	[0.035]
× County with Policemen	0.171***							
	(0.065)							
	[0.065]							
× County with Firemen		0.169***						
		(0.061)						
		[0.063]						
× Close city with Civil Service Reform			0.230***					
			(0.048)					
			[0.049]					
× Distance to City with Civil Service Reform				-0.177***				
				(0.044)				
				[0.043]				
× Distance to city with pop $\geq$ 10,000					-0.037			
					(0.029)			
					[0.030]			
× County with bank						-0.068		
						(0.070)		
						[0.070]		
× County with Newspaper							0.160**	
							(0.077)	
							[0.078]	
× Newspaper circulation 1932								0.005**
								(0.002)
								[0.002]
Observations	15,782	15,782	16,904	11,973	16,904	15,518	16,904	16,904

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Control observations are pixels without established property rights outside the historical grazing districts. Covariates included in all columns and defined in Table 2. 'County with Police and firemen' are defined as zero if no person in the 1930 census is identified as either in that county. 'Distance to city with Civil Service Reform' is the standardized distance to the closest city within the same state as defined by Ornaghi (2018). No city in New Mexico had a civil service reform by 1940. The variables with distances to closest cities in columns (6) and (7) are introduced to rule out that the state capacity effects are driven by larger cities. 'County with bank' is whether the county had a bank in 1934 obtained from Federal Deposit Insurance Corporation (2001). 'County with Newspaper' is whether the county had a newspaper obtained from Gentzkow et al. (2014). None of the split variables is predicted by treatment. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

On the other side of the fence:
Property rights and productivity in the US
Appendix - Not for Publication

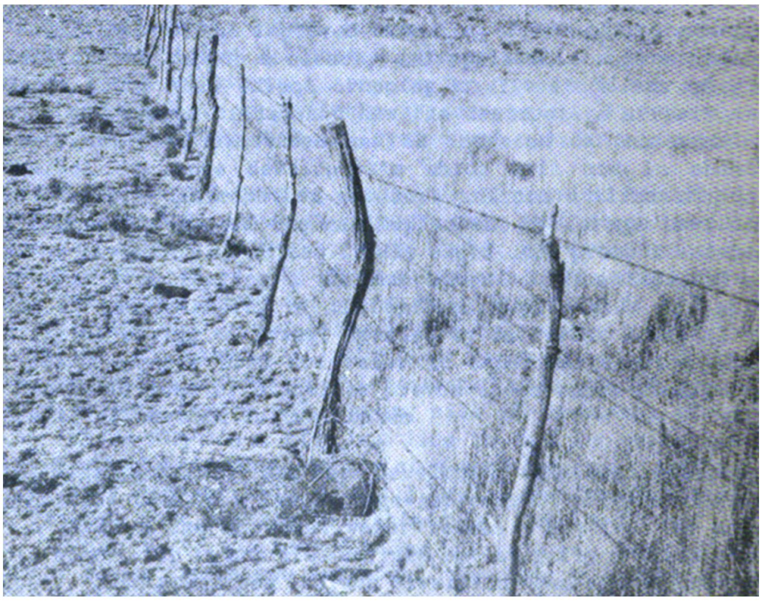
Mathias Bühler

September 16, 2021

This appendix provides additional evidence in favor of the main hypothesis and covers the following topics:

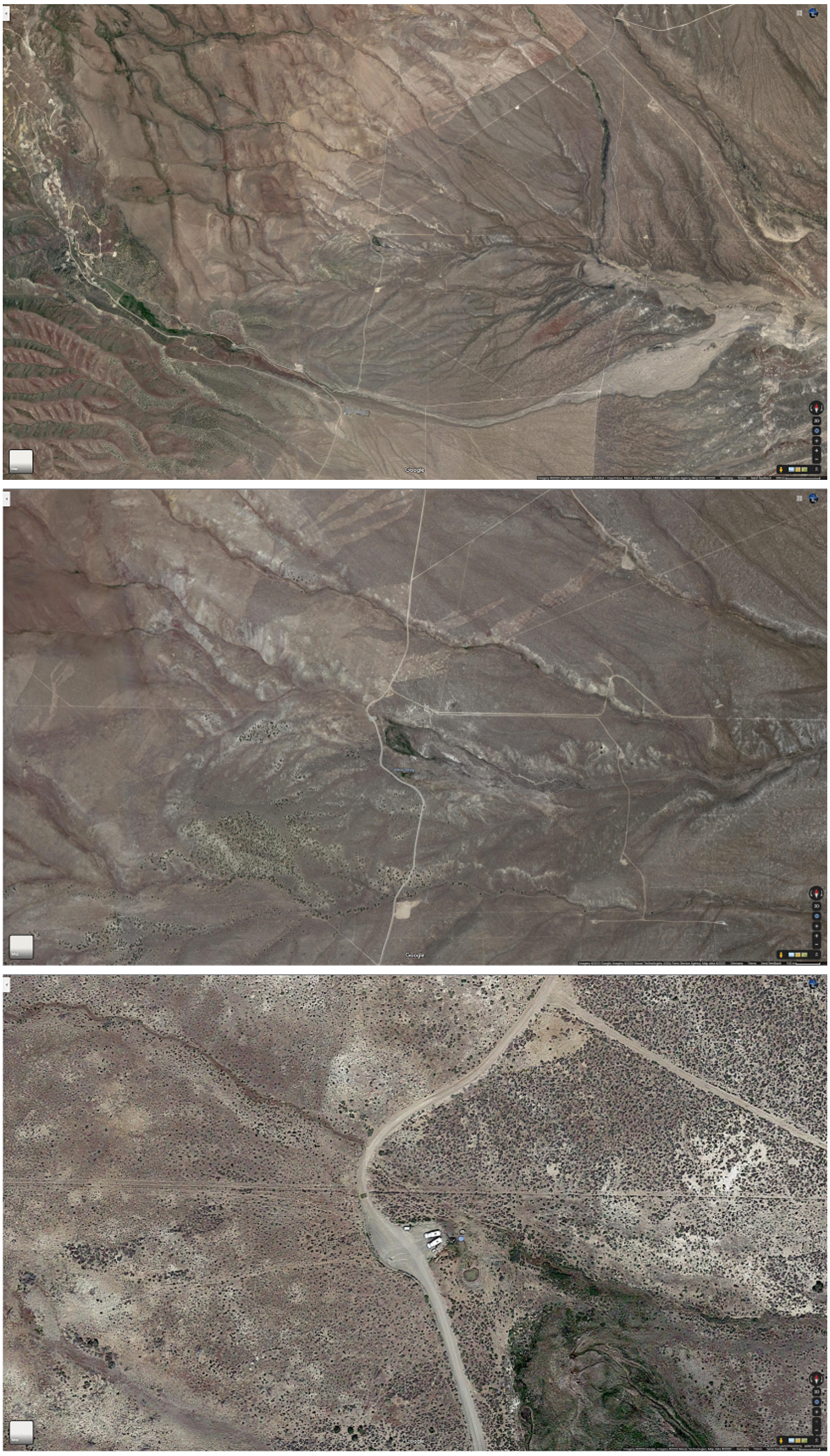
A Identification examples and further maps and figures

Figure A.1: Identification example



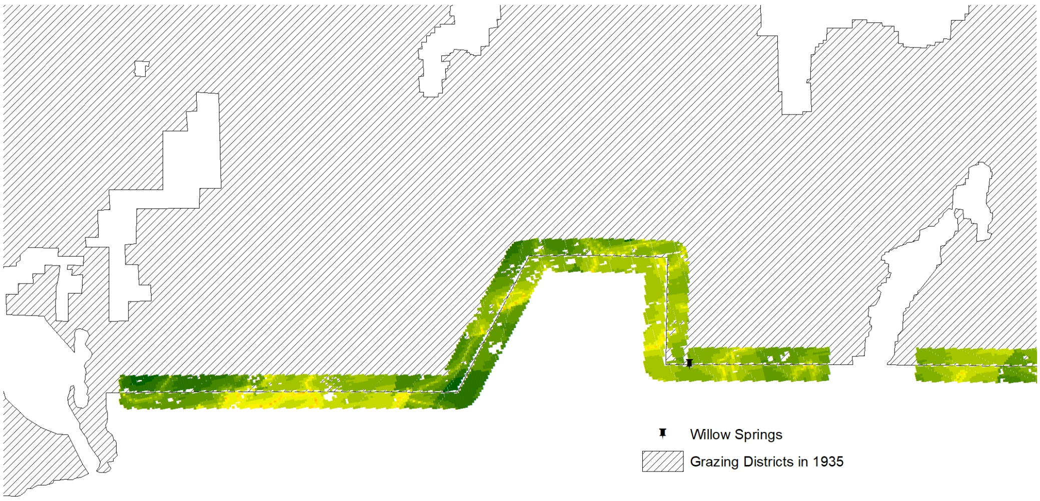
Identification in a picture as explained by a grazing bulletin in 1940: *"The pasture on the right is representative of properly used range. The one on the left has been cropped dangerously close. [...] by annually harvesting only [the optimal] amount of forage [... and] by adjusting the grazing season to permit maximum forage production under use, and by obtaining uniform utilization by proper distribution of livestock and income may be realized."*

Figure A.2: Boundary at Willow Springs, Nevada



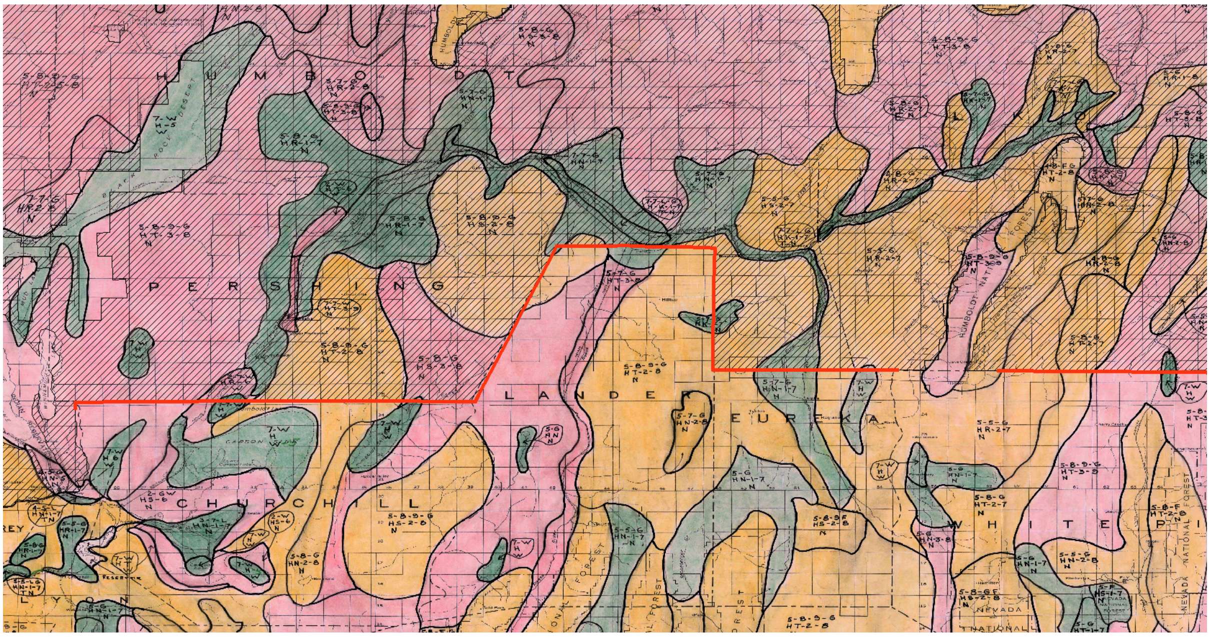
Three zoom-stages of the boundary at Willow Springs, Nevada, (40.128, -116.475). The animal gutter can be seen clearly in the lowest picture, yet the boundary is visible in all stages. Scale can be found in the lower right corner and vary from 500m (first) to 10m (last picture). Importantly: While the road is subject to the environment (e.g. at the Gutter), the actual fence is a straight line cutting horizontally through the picture, strictly following the PLSS.

Figure A.3: Spatial RD-Graph for a 320-mile long boundary in Nevada



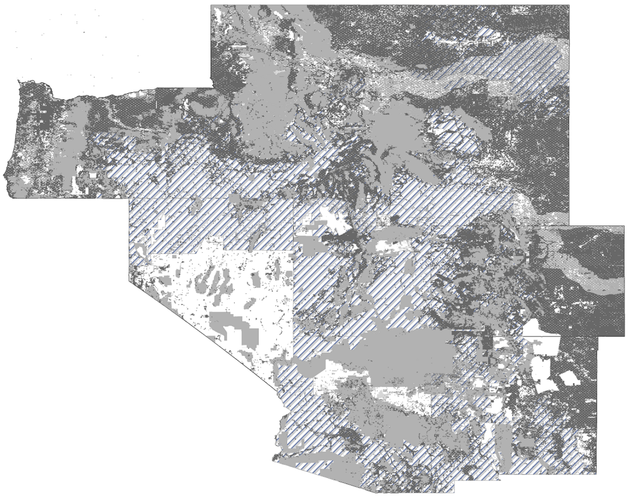
In this figure, I show the predicted vegetation density for a finely spaced grid controlling flexibly for geographic location, predetermined variables and the treatment dummy, comparing open access (south) to access rights (north) in a five mile bandwidth. Two findings arise: First, while all boundaries follow the PLSS and thus vegetation is quasi-exogeneously allocated within a 1×1 section, some boundaries align with pre-existing national forests and indian reservations. Examples here are the Humboldt national forest to the East and the Pyramid Lake Indian Reservation to the West. Since these boundaries are not determined by the 142 million acres stopping rule, I do not include them in the main sample and only consider the long straight lines, strictly following the PLSS. Second, the treatment effect is clearly visible at all sections of the boundary, even when the baseline vegetation level is considerably higher in parts of the boundary. The treatment effect at this boundary indicates an 8.8% higher vegetation inside the grazing districts (s.e.: 0.012, p<0.001). I discuss potential sample selection issues in detail in Section D.

Figure A.4: Erosion at a 320-mile long boundary in Nevada



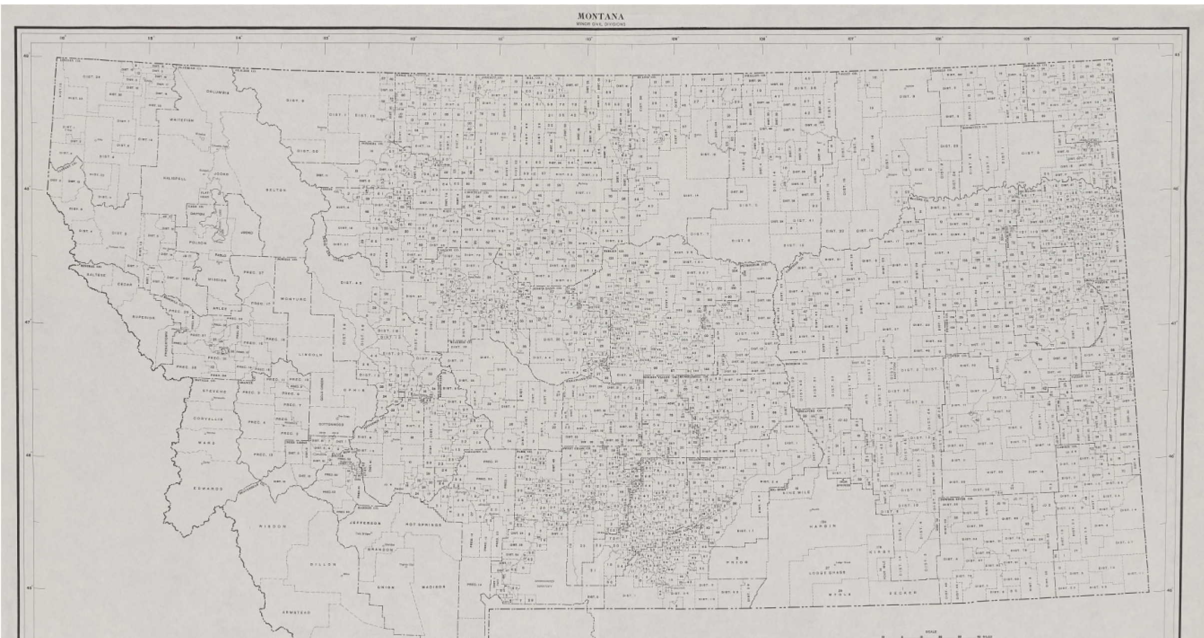
This figure highlights the resolution of the erosion data (red, yellow and green) together with the grazing district in Nevada (shaded). In the very north, the Humboldt national forests are not part of the grazing districts and have better erosion status than their surrounding (yellow versus red). These predetermined boundaries are not random, and thus not part of the estimation sample of Figure A.3 (thick red line). The colors represent erosion class, as decided by the Department of the Interior in October 1934. In addition to colors indicating broad erosion status, there are a combination of letters and numbers in every area. This data is highly detailed, and could be used to further identify grazing areas with specific types of soil and erosion. Taking the example of the large yellow area above "LANDER" in the center of the map: '5-8-9-G / H T -2-8 / N' translates to: "Silt loam soil, with gravelly or stony subsoil, used for grazing; Slopes ranging from 0-5% and $\geq$ 40%, with moderate sheet erosion and severe gully erosion; Permanent Cover". Importantly, aside from at predetermined boundaries at national parks and forests as well as Native American Reservations, the grazing boundary never follows the color pattern of the erosion map.

Figure A.5: The Taylor grazing districts: Ownership of land in 1934.



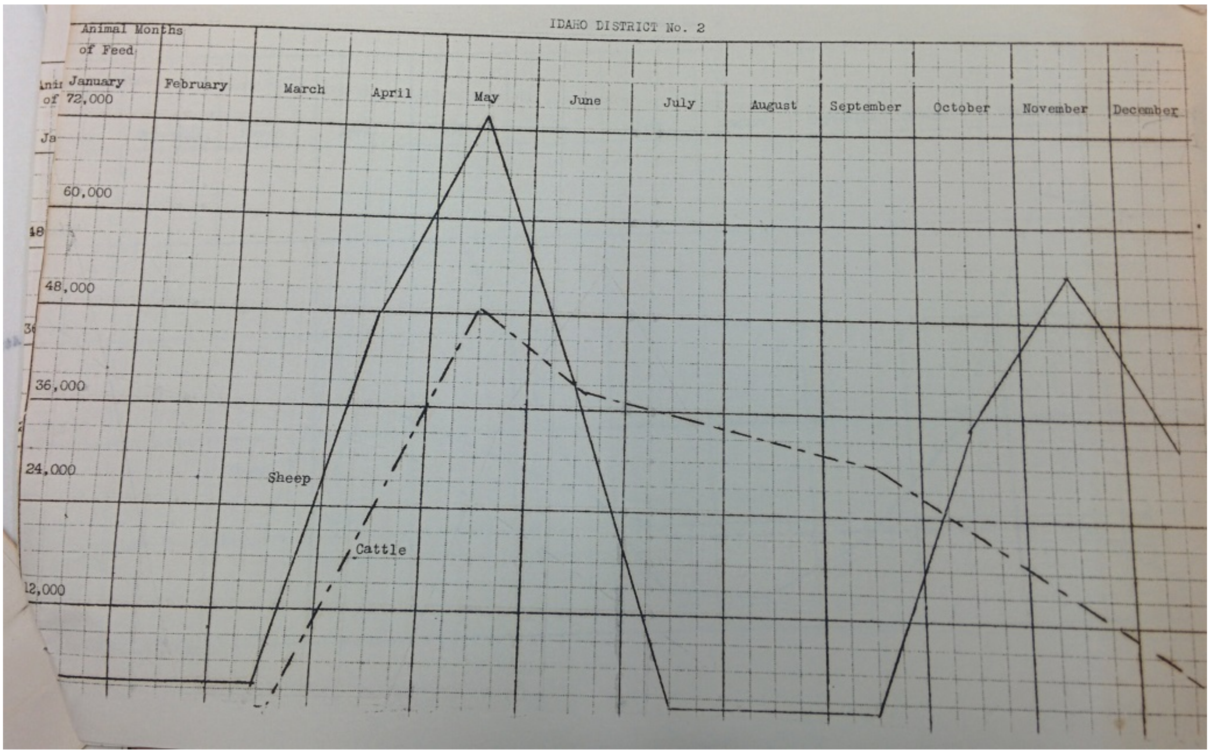
The extend of the Taylor grazing districts and the ownership status in 1934. Light gray depicts the extent of national parks, national forests, department of defense, and Native American reservations administered by the Bureau of Indian Affairs in the nine States (150 mil. Acres, 24.5%). Dark Grey depicts the state of privatization up until 1934, as identified by the General Land Office Title holding database (210 mil. Acres, 34.3%). Shared depicts the extent of the Taylor Grazing Districts at 160 mil. Acres (26%). The remaining, unclaimed lands are shown without color and reach the extent of 95 mil. Acres, or 15% of the total area in the nine states.

Figure A.6: Minor Civil Divisions



1,177 Minor civil divisions in Montana in 1930 with county information

Figure A.7: Seasonal regulation in Idaho



This figure shows that in the 2. Grazing districts of Idaho, seasonal fallowing was in place to promote vegetation increases. Figure taken from the Grazing Bulletins 1938.

Figure A.8: Amount of licenses and cattle per State in 1936

SUMMARY OF GRAZING LICENSES ISSUED BY THE DIVISION OF GRAZING,

DEPARTMENT OF THE INTERIOR, FOR THE YEAR 1936

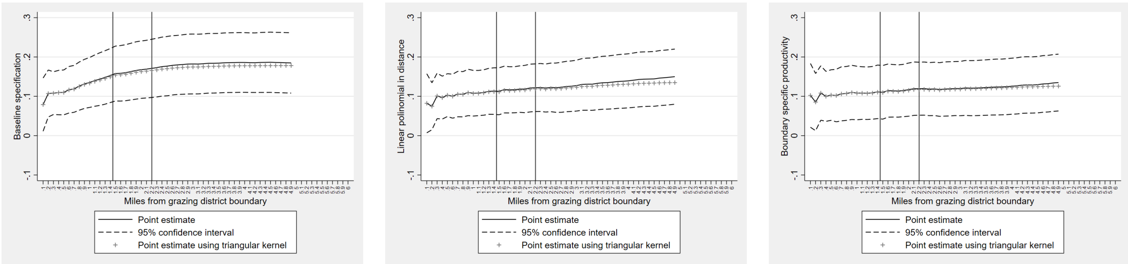
STATE	DISTRICT NUMBER	NUMBER LICENSES	CATTLE	HORSES	SHEEP	GOATS	TOTAL LIVESTOCK
Arizona	3	524	57,024	329	160,670	26,469	244,492
California	2	652	58,105	2,648	256,385	312	317,450
Colorado	5	1,861	178,735	8,402	623,281	881	811,085
Idaho	1	1,093	65,141	6,824	439,347	26	511,338
Montana	4	785	50,191	15,567	328,419	263	394,440
Nevada	2	709	202,832	13,404	673,666	73	889,975
New Mexico	5	2,555	339,114	19,333	478,204	100,204	936,855
Oregon	6	1,387	158,121	15,851	653,873	———	827,845
Utah	8	5,061	188,007	15,133	1,968,172	30,719	2,202,031
Wyoming	1	440	36,929	3,289	258,687	———	298,905
TOTAL	37	15,067	1,333,985	100,780	5,840,704	158,947	7,434,416

This table shows the initial amount of licenses and livestock in the first 37 grazing districts. The conversion rate between sheep and goats to cattle and horses is 1 to 5. At a cost of 0.01 USD for sheep and 0.05 USD for cattle, total revenue in the highest season would be approximately 130,000$ in 1936 USD. The total number of cattle in these states represent about 30% of the total number in affected counties in the 1935 agricultural census. Taking into account that on average 50% of the counties area is covered by a grazing districts, these numbers do not represent a significant cut of cattle. Figure taken from the Grazing Bulletins 1936.

B Bandwidths choices

I first highlight that my point estimate is stable across all bandwidths and specifications: First, especially in the most demanding specification including a linear polynomial in distance and a boundary specific productivity estimate B.1c, the point estimate does not vary between 0.1 miles and 6 miles from the boundary. Second, the chosen bandwidth in the main Table (1/2, 1, and 2 miles) are all below the optimal bandwidth as calculated by (Calonico et al., 2015). Third, using a triangular kernel produces the same estimates.

Figure B.1: Bandwidth and Kernel Choices

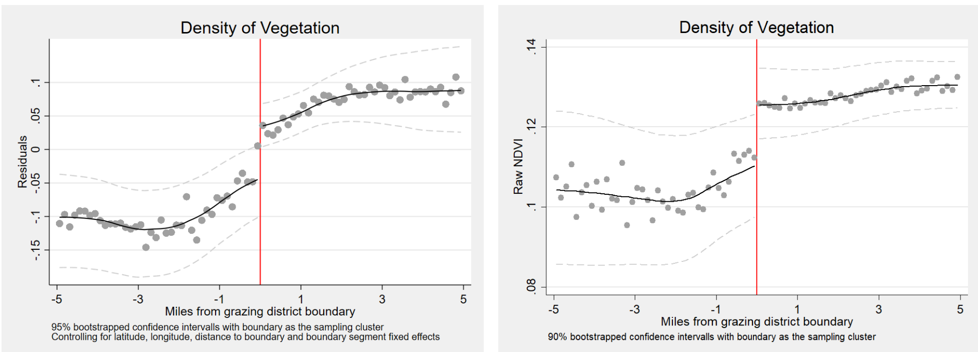


(a) Baseline **(b)** Distance polynomial **(c)** Boundary spec. prod.

These figures plot the point estimate for all bandwidths in the Sample. Optimal bandwidth denoted by the first and bias corrected by the second vertical line (Calonico et al., 2015). Figure B.1a uses the baseline specification, Figure B.1b uses the linear polynomial in distance specification, Figure B.1c uses the boundary specific productivity specification.

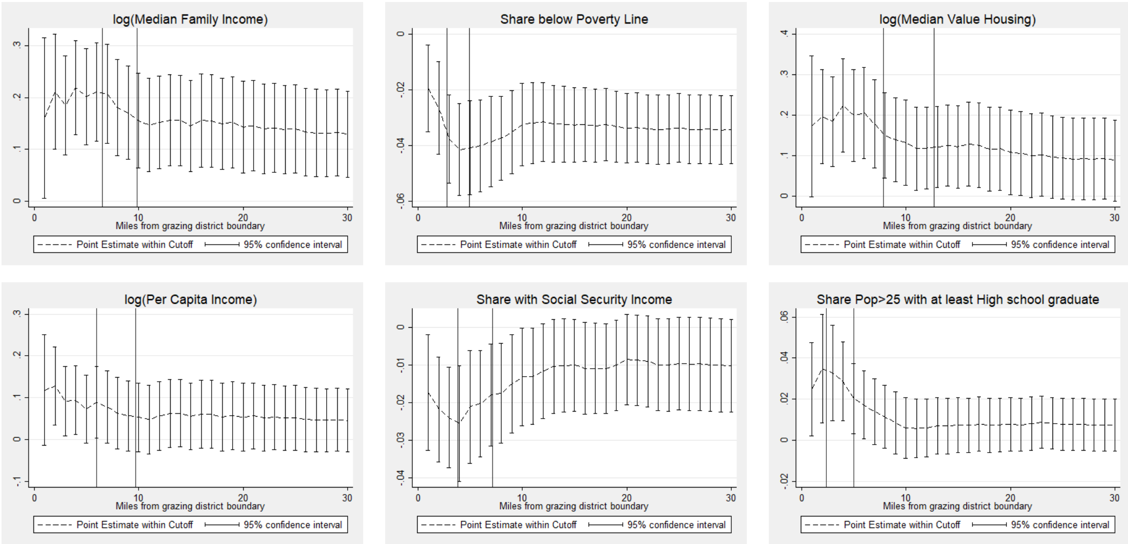
Next, I want to highlight that the main RD plot is robust to including partially treated observations or using raw NDVI values instead:

Figure B.2: RD-Graphs: Varying specifications



(a) log(NDVI), including partially treated observations **(b)** Level NDVI, without partially treated pixels

Figure B.3: Bandwidth Choices



These figures plot the point estimate for all bandwidths in the sample, as well as indicating the optimal bandwidths.

C Balance and Specification

A valid spatial regression discontinuity design necessitates a balanced sample and the correct specification of the underlying forcing variable. In this Appendix, I will begin by showing that covariates are well balanced in all bandwidths and specifications and that their inclusion into all specifications does not alter the point estimates. Second, I show that access rights increase productivity, regardless of using modern-day instead of 1934 privatization status, tighter fixed effects, and changes in the outcome variable.

I begin by addressing the balance of covariates in all bandwidths and specification in Table C.1. I vary the bandwidths between 1/2 and 2 miles, and use the baseline RD formula, the distance polynomial and the boundary specific productivity formula as robustness.

Using the baseline specification in columns (1) to (3) of Table C.1, only two point estimates are significant at the 10 percent level: Severe Erosion within the two mile bandwidth, indicating that the negative selection of access rights areas is present at larger bandwidths. This point estimate suggests that access rights areas are more likely to be eroded (have lower quality) than open-access lands in 1934, in line with the idea of the act to select the most eroded lands. These plots are also about 4.5% further away from cities, again suggesting less value.

Including the distance polynomial in columns (4) to (6) of Table C.1 reveal three significant point estimates: Temperature, Elevation, and distance to Saint Louis. Compared to an average of 50 degrees Fahrenheit, the point estimate (0.2 degree Fahrenheit) in column (4) implies a 0.4% reduction in the average temperature in the time frame 1900-34 at the closest station. Similarly, elevation is 2% lower for access rights areas than control observations. These marginal imbalances do not pose a threat to identification: First, the magnitude of these estimates (0.4% and 2%) is too small to impact productivity in a way that increases long-term vegetation by 10%. Second, there is no clear linear relationship between NDVI and elevation or temperature.

Additionally, I include boundary-specific productivity estimates in columns (6)–(9). This renders all productivity estimates insignificant. I thus argue that this setting provides a well balanced sample to estimate the impact of property rights on productivity.

Taking into account the balance in the baseline (columns 1–3) and boundary specific productivity specification (columns 7–9), as well as the visual balance and continuity shown in Figure 3, I argue that this setting provides a balanced sample in which to compare the impact of property rights. In addition, as the point estimates do not change when including controls (Table C.2), adding more parsimonious fixed effects (Table C.3) or selecting the data differently (Table D.1), I argue that the threat of selection on unobservables is negligible. Thus, the setting employed here likely enables a causal interpretation of different property rights regimes.

Table C.1: Balance test for issuing access rights for different specifications and bandwidths

	Baseline			Distance Polynomial			Boundary spec. Productivity		
	(1) 1/2 mile	(2) 1 mile	(3) 2 miles	(4) 1/2 mile	(5) 1 mile	(6) 2 miles	(7) 1/2 mile	(8) 1 mile	(9) 2 miles
Severe Erosion	0.010	0.019	0.042*	-0.001	-0.000	-0.001	0.005	0.006	0.001
	(0.016)	(0.020)	(0.026)	(0.019)	(0.018)	(0.019)	(0.019)	(0.018)	(0.019)
	[0.016]	[0.020]	[0.025]	[0.018]	[0.017]	[0.019]	[0.018]	[0.017]	[0.018]
Rainfall	-5.335	-4.433	-8.367	-1.089	-2.968	-1.331	0.412	-3.071	-1.964
	(5.334)	(5.723)	(7.873)	(9.392)	(7.830)	(7.080)	(5.525)	(4.532)	(4.260)
	[4.690]	[5.258]	[7.095]	[8.415]	[7.892]	[7.332]	[5.455]	[4.774]	[4.231]
Temperature	-0.009	-0.011	0.004	-0.190***	-0.182***	-0.176***	-0.028	-0.003	-0.025
	(0.034)	(0.041)	(0.054)	(0.072)	(0.056)	(0.064)	(0.048)	(0.031)	(0.030)
	[0.032]	[0.039]	[0.050]	[0.066]	[0.053]	[0.060]	[0.046]	[0.031]	[0.030]
Elevation	-12.954	-7.544	-6.601	-36.276*	-26.711	-12.594	-33.282	-25.749	-19.385
	(13.183)	(12.164)	(10.472)	(19.871)	(17.823)	(15.761)	(20.498)	(18.190)	(15.667)
	[15.007]	[12.705]	[10.271]	[20.333]	[18.446]	[16.701]	[21.645]	[18.870]	[16.741]
Ruggedness	0.002	0.001	0.000	0.000	0.002	0.003	-0.001	0.002	0.003
	(0.004)	(0.002)	(0.002)	(0.005)	(0.004)	(0.003)	(0.006)	(0.004)	(0.003)
	[0.004]	[0.002]	[0.002]	[0.006]	[0.004]	[0.003]	[0.006]	[0.004]	[0.003]
log(Dist. water)	-0.016	-0.044	-0.074	-0.011	-0.029	-0.030	-0.027	-0.016	-0.015
	(0.041)	(0.043)	(0.049)	(0.054)	(0.045)	(0.045)	(0.059)	(0.052)	(0.051)
	[0.040]	[0.043]	[0.049]	[0.050]	[0.045]	[0.046]	[0.050]	[0.047]	[0.047]
log(Dist. city)	0.045*	0.041	0.045	0.010	-0.002	0.007	-0.022	-0.012	-0.010
	(0.027)	(0.031)	(0.041)	(0.035)	(0.032)	(0.032)	(0.032)	(0.029)	(0.030)
	[0.026]	[0.030]	[0.039]	[0.035]	[0.032]	[0.032]	[0.029]	[0.025]	[0.025]
log(Dist. Saint Louis	-0.000	0.000	0.000	0.000***	0.000**	0.000**	0.000*	0.000*	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Observations	8,963	17,616	34,216	8,963	17,616	34,216	8,963	17,616	34,216

An observation is treated if its center is within the historical grazing districts and is public in 1935. Control observations are pixels without established property rights, outside the historical grazing districts without prior ownership status. 'Distance Polynomial' includes a linear polynomial in distance, estimated with different slopes on either side of the boundary. 'Boundary spec. Productivity' estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. RD-graphs in Figure 3. *Severe erosion* refers to erosion maps constructed for the nine states in 1934. Those maps were used to determine the extend of the Taylor Grazing Act and show the erosion status of the land in 1934. 54% of my sample is classified as severely eroded and 22 % as moderately eroded. *Rainfall* defines the average yearly rainfall and *Temperature* the average temperature in Fahrenheit from 1900-34 at the closest station. The significant impact in columns (4)-(6) would imply a 0.2% lower temperature over the mean of 50 degrees Fahrenheit. *Elevation* is constructed from the Global Multi-resolution Terrain Elevation Data (GMTED2010), and shows the mean elevation in a 500m radius around every pixel. The impact in column (4) implies a 2% lower elevation. *Standard Deviation of Elevation* calculates the standard deviation of elevation of 8 adjacent cells and denominates it by the average elevation of all 9 cells. The average within a 500m radius around every pixel is reported here. *Dist. water*, *Dist. Saint Louis* and *Dist. city* capture varying distances to proxy for water access, remoteness and thus time of settlement, and distance to modern day civilization which might affect the NDVI measure due to green lawns or highways. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

I continue by exploring how adding control variables impacts the point estimates in Table C.2. Adding *erosion status*, *average annual rain prior to 1934*, *average annual temperature prior to 1934*, *elevation*, *ruggedness*, *log distance to water*, *log distance to the nearest city*, and *log distance to Saint Louis* to capture remoteness does not impact the point estimates. Thus selection on unobservables in these tight bandwidths is unlikely to drive my results.

Table C.2: Access rights treatment: Including covariates as defined by Table 2

	1/2 mile			1 mile			2 mile		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Estimates without any controls									
Access Rights	0.108***	0.101***	0.104***	0.134***	0.106***	0.108***	0.166***	0.119***	0.117***
	(0.029)	(0.027)	(0.032)	(0.033)	(0.029)	(0.034)	(0.037)	(0.030)	(0.034)
	[0.031]	[0.030]	[0.033]	[0.035]	[0.032]	[0.034]	[0.040]	[0.033]	[0.035]
Observations	8,673	8,673	8,673	16,937	16,937	16,937	32,618	32,618	32,618
Panel B: Baseline estimates with controls as defined by Table 2									
Access Rights	0.110***	0.103***	0.103***	0.134***	0.108***	0.108***	0.165***	0.118***	0.117***
	(0.029)	(0.027)	(0.032)	(0.032)	(0.029)	(0.034)	(0.036)	(0.030)	(0.034)
	[0.031]	[0.030]	[0.033]	[0.034]	[0.032]	[0.034]	[0.039]	[0.033]	[0.035]
Observations	8,656	8,656	8,656	16,904	16,904	16,904	32,562	32,562	32,562
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Control observations are pixels without established property rights outside the historical grazing districts. Panel A represents the baseline specification without the inclusion of covariates. Panel B represents the baseline specification as used throughout the paper, including all covariates. All covariates are included and defined in Table 2. Boundary spec. Productivity estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Next, in Table C.3 I compare baseline estimates (Panel A) to various changes in the functional form: Instead of being privatized in 1934, I use modern-day private (Panel B); tighter fixed effects (Panel C); and changing the functional form of the outcome variable (Panel D).

I start with the selection of non-private areas in the American West (Panel B). In the baseline estimates, my sample consists of all areas that were not privatized by 1934. Since this sample might be subject to measurement error or not fully represent modern-day areas under public ownership, I select areas based on their privatization status in 2010. Acknowledging that this is a potentially endogeneous selection, I report virtually unchanged point estimates from the selection procedure using pre-Act privatization data.

Second, I tighten the comparison group to areas within the same 6-mile segment (Panel C) as compared to the 60-mile segments in Panel A. Except for the specification with boundary specific productivity estimates in columns (3), (6), and (9), the point estimates do not statistically differ from Panel A. However, even in this very demanding specification, that includes 2,619 productivity estimates (one for each six-mile boundary segment and one each for six-mile boundary segment $\times$ latitude and longitude), the point estimates remain significant.

Finally, I address the concern that the logarithm of NDVI is undefined for NDVI values smaller than zero (Panel D). Such values only exist for water bodies, and consequently only 1.3% of all observations have negative NDVI values. In the baseline estimation, I simply omit water bodies from the sample. In Panel D, I specifically address the logarithm of zero issue and instead use level NDVI values ranging from -0.14 to 0.36 with a mean of 0.11. I find significant and robust point estimates throughout all specifications, ranging from a 5.5% increase relative to the mean to an 11% increase in NDVI values at the larger bandwidths.

Table C.3: Access rights treatment: More specifications

	Baseline			Distance Polynomial			Boundary spec. Productivity		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	1/2 mile	1 mile	2 miles	1/2 mile	1 mile	2 miles	1/2 mile	1 mile	2 miles
Panel A: Baseline estimates									
Access Rights	0.110***	0.103***	0.103***	0.134***	0.108***	0.108***	0.165***	0.118***	0.117***
	(0.029)	(0.027)	(0.032)	(0.032)	(0.029)	(0.034)	(0.036)	(0.030)	(0.034)
	[0.031]	[0.030]	[0.033]	[0.034]	[0.032]	[0.034]	[0.039]	[0.033]	[0.035]
Observations	8,656	8,656	8,656	16,904	16,904	16,904	32,562	32,562	32,562
Panel B: Using modern day privatization status to select public areas instead of privatization in 1934									
Access Rights	0.122***	0.117***	0.114***	0.155***	0.126***	0.117***	0.199***	0.128***	0.116***
	(0.028)	(0.027)	(0.031)	(0.031)	(0.028)	(0.031)	(0.036)	(0.030)	(0.032)
	[0.029]	[0.027]	[0.028]	[0.032]	[0.029]	[0.028]	[0.037]	[0.031]	[0.030]
Observations	6,809	6,809	6,809	13,367	13,367	13,367	25,645	25,645	25,645
Panel C: Using six-miles boundary segment fixed effects instead of sixty-miles segments									
Access Rights	0.122***	0.102***	0.054***	0.140***	0.107***	0.041**	0.163***	0.109***	0.057***
	(0.015)	(0.020)	(0.018)	(0.016)	(0.019)	(0.012)	(0.017)	(0.017)	(0.013)
	[0.032]	[0.032]	[0.021]	[0.035]	[0.031]	[0.016]	[0.038]	[0.031]	[0.021]
Observations	8,623	8,623	8,623	16,891	16,891	16,891	32,556	32,556	32,556
Panel D: Using level NDVI instead of log(NDVI)									
Access Rights	0.006**	0.006**	0.006**	0.009***	0.005**	0.006*	0.012***	0.006**	0.006*
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.004)	(0.002)	(0.003)
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]	[0.003]	[0.003]
Observations	8,946	8,946	8,946	17,582	17,582	17,582	34,157	34,157	34,157
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Control observations are pixels without established property rights outside the historical grazing districts. The first row represents the baseline specification, dropping observations that were not privatized in 1934, dropping boundaries with forests, and 60 mile boundary segments. Every other line is a different specification to highlight the robustness of the baseline estimates. In Panel B, I uses contemporaneous data to exclude all private plots today instead of the baseline procedure of determining ownership in 1934. In Panel C, I use six-mile segments as fixed effects to capture even more similar observations, instead of the baseline procedure of using sixty-mile segments. In Panel D, I use Level NDVI instead of log(NDVI) as a dependent variable. All covariates are included and defined in Table 2. Boundary spec. Productivity estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

As a final specification test, I change the outcome data set entirely in Table C.4. I include land classifications from the National Agricultural Statistics Service Cropscape database and report that access rights areas are less likely barren (unproductive) and more likely to be rangeland (productive) than control observations. A second data set is derived from a higher resolution satellite data: Moderate Resolution Imaging Spectroradiometer (MODIS) with a pixel resolution of 250 m. As every satellite renders colors slightly different by using different wavelengths for red and near-infra red colors, the MODIS data has a higher mean NDVI (0.180) as the baseline dataset (AVHRR, 0.120). The magnitude of the effect at the smallest bandwidth of 1/2 (5.3% increase) is comparable to the magnitude of the baseline data set (10.9%) increase, when multiplied with the mean NDVI values: The MODIS data suggests a 0.01 impact on NDVI, while the AVHRR data suggests a 0.013 impact on NDVI.

Table C.4: Access rights treatment: Alternative outomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			NASS - Cropscape					MODIS	
		Barren land			Rangeland			log(NDVI)	
	1/2 mile	1 mile	2 miles	1/2 mile	1 mile	2 miles	1/2 mile	1 mile	2 miles
Access Rights	-0.020^{***}	-0.041^{***}	-0.070^{***}	0.027^{**}	0.056^{***}	0.097^{***}	0.053^{**}	0.077^{***}	0.106^{***}
	(0.007)	(0.012)	(0.017)	(0.011)	(0.015)	(0.019)	(0.020)	(0.024)	(0.029)
Observations	323,730	643,302	1,252,572	323,730	643,302	1,252,572	253,041	491,301	940,672
Control Mean	0.171	0.184	0.198	0.709	0.699	0.687	0.181	0.180	0.177

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Control observations are pixels without established property rights outside the historical grazing districts. 'Barren land' and 'Range land' are from the National Agricultural Statistics Service Cropscape database. Each data point is a 180m×180m pixel that either consistst of 'Barren land' or 'Shrub and Grassland', which I redefine as range land. 'MODIS' stands for Moderate Resolution Imaging Spectroradiometer with a pixel resolution of 250 m. The NDVI is differently calculated as the AVHRR uses these frequencies for the red 0.58-0.68 μm and near-infrared 0.725-1.1 μm, while the 'MOD13Q1' data used here are 0.62-0.67 μm and 0.84-0.87 μm, respectively. Standard errors clustered by the boundary segments shown in parenthesis.

D Sample selection and endogenous boundaries

The ideal setting to test property rights consists of two identical plots of land that are observed prior and after a random assignment of property rights. To obtain a valid point estimate in my cross-sectional setting, I rely on two standard assumptions: First, by employing a spatial regression discontinuity design, I compare plots that are ex-ante similar and would have evolved similarly without treatment. Second, that the selection at this boundary into treatment is as good as random. By providing evidence of balance and continuity in Figures 3 and 4, as well as Table 1, I argue that this selected sample fulfills the balance assumption. The question remains however, whether this is a result of selection, and if, how selection plays a role in this setting. I address the potential bias arising from selection in detail in this section.

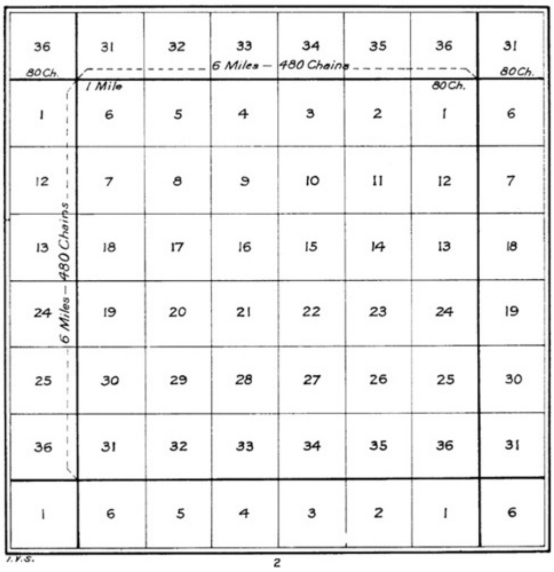
I argue that the selection procedure used in this paper is fairly standard: I drop all predetermined boundaries, all observations that are not at risk of being treated, and focus on narrow bandwidths. Yet, the selection does not impact the interpretation of my estimates and reveal a stable pattern, even when using all available data, restricting the sample to less than 10% of the full data, or conditioning on the same erosion status on either side of the boundary. Thus, selection does not introduce a bias into my estimates.

First, my selection procedure evolves around the idea to select comparable open-access lands prior to 1934. Thus, all lands that have been privatized or reserved (e.g. national forests, national parks, and Indian reservations) are excluded from the sample as these areas could not have been treated. A valid RDD also requires that the future boundary be unknown to the subject (in this case: rancher). Thus, as boundaries of national forests, parks, or Indian reservations were known prior to 1934, I decide to not only drop the lands associated with these reserved lands, but also drop all boundaries that are determined by these reserved lands. If a rancher suspects to be affected by the Taylor Grazing Act, he is more likely to anticipate the location of the boundary in areas with predetermined boundaries. By focusing on boundaries that lie exclusively in the open range, I ensure that the rancher cannot anticipate which sections of the township in Figure D.1 the grazing administration will cover. As a last step, I drop all boundaries that align with state boundaries, as here the control and treatment areas are subject to different state law and enforcement.

Second, my selection procedure only considers observations within 1/2, 1, or 2 miles of the grazing boundary. While a bandwidth selection is standard for an RDD design, the small bandwidths used in this paper are determined by the size of sections of the Public Land Survey System. Contrary to papers being able to use 25 miles as their lowest cutoff when comparing villages, the bandwidth selection criteria here requires the subject (the rancher) to not be able to anticipate where the boundary will be. In an extreme case, a rancher who owns section 22 in Figure D.1, might anticipate that the boundary will be in his township. Yet, I he is likely unable to predict whether the grazing boundary will include Sections 1, 12, 13, 24, 25, and 36 into a grazing district, or Sections 2, 11, 14, 23, 26, and 35.

On the one hand, these section boundaries are known to the rancher but exogenous since they were imposed many years prior. The Grazing Boundaries on the other hand are not known to the rancher, even if they follow the section boundaries. From the perspective of

Figure D.1: The Public Land Survey System



The public land survey system of a township with its 36 sections. While the section boundaries are known to the rancher owning section 22, he is unlikely to predict whether the grazing boundary lies between sections 22 and 23, or sections 23 and 24, when considering a north-south boundary and conditioning on the unrealistic assumption that the rancher knows the grazing boundary to lie within his township.

vegetation, both is arguably random, since the section boundaries did not take into account local conditions when established.

To validate this assumption, I need to argue that the underlying vegetation of the remaining public land in 1934 does: a) not vary at the section boundary and b) is randomly placed in sections 1 or 2, when considering vegetation within 1/2 of the section boundaries. If that were to be fulfilled, the decision of the grazing administration to assign section 24 instead of 23 to the grazing districts is random from the ranchers perspective and random to the vegetation. Then, since all covariates are balanced and continuous at the selected boundary, this setting enables me to uncover an unbiased estimate of property rights at this boundary.

Even if the bandwidth is chosen such that the vegetation is reasonably randomly allocated, it must hold that the grazing boundary itself be random from the perspective of the rancher. I ensure this randomness by only selecting boundaries that are not predetermined, thus excluding boundaries with national forests, parks, and Native American reservations. This selection procedure is standard in the RD literature that only considers close cutoffs and in the spatial RD literature where only suitable comparison groups are used. For example, authors limit the comparison groups to areas on a plateau to avoid steep cliffs and match elevation (Dell, 2010, Figure 1, page 1864) or limit the study to areas of similar sugar suitability as measured by elevation and slope (Dell and Olken, 2020, page 194).

Yet, the scope of this study covering more than 24,000 miles of boundaries and the nature of grazing as an outcome, demands more devotion to the potential bias arising from selection of the treatment area. In Table D.1, I compare the baseline estimates with the described selection process (Panel A), to four increasingly demanding selections to highlight the robustness of my findings. Throughout this Table, I continue to omit state boundaries and lands that could not have been treated with access rights: Private property, national parks, national forests, and Native American reservations.

In Panel B, I start by including all boundaries (except state boundaries). Even when including boundaries that have grazing districts on the one side and national parks, forests or Native American reservations on the other side, my point estimates remain unchanged to the baseline. The increased number of observations at the smallest bandwidth (19,420 vs 8,656 at the baseline) and number of boundaries (407 vs 156) does not statistically decrease the point estimate which remains significant. When introducing more demanding specifications in column (3), the point estimates decreases to about 6%, yet converge back to the baseline estimate once more data is added. The comparison between Panel A and B thus reveals that inference is not affected by the selection process: Access rights continue to increase productivity, even without selecting on quasi-random boundaries.

In Panel C and D, I consider a more restrictive selection process than the baseline and only include boundaries that are 'reasonably straight'. The longer a straight boundary is, the more likely it is that ranchers and vegetation are randomly placed on either side of the boundary by the grazing administration. To only include 'long' boundaries, I would have to manually cipher through more than 24,000 miles of boundaries to identify which boundaries are actually straight lines; which are straight lines, but have been crippled by the digitization process; and which are short boundaries. Thus, I rely on two automated process to approximate straight lines. These processes revolve around the idea that a straight line is given by two points: One beginning and one end point. For example, if each segment is six miles long, it implies that the distance between the start and end point is six miles. If in the digitization process however, the creator used individual section corners to draw the lines, I would record 7 points for a six mile segment, each one mile long. Without visual inspection, it is now unclear whether this 7 points segment is a straight line, or a zigzag pattern.

Thus, to identify relatively straight boundaries, I condition that each part of a six-mile boundary needs to be at least three mile long in Panel C or have only one beginning and end point in Panel D. Omitting every six-mile boundary segment that is split into parts smaller than 3 mile (Panel C), the number of observations in the 1/2 bandwidth drop to 3,251 with the point estimate remaining statistically significant and similar in magnitude to the baseline estimates. Further omitting *every* six-mile segment that is not drawn as a straight line with one start and end point (Panel D), reduces the number of observation to 1,608, without affecting the point estimate. Common to both selection procedures in Panel C and D is the tendency to produce smaller estimates when using a distance polynomial and the boundary specific productivity. However, since the main point of interest is the smallest bandwidth, the changed point estimates remains significant, and these specifications are very demanding with such few data points, I argue that selection remains unproblematic in this setting.

Comparing Panel A–D, one could argue that 'more random' boundaries produce smaller point estimates. Alternatively, one could argue that the baseline selection of boundaries includes too many boundaries that follow erosion too closely, thus upward biasing my estimates. To counteract this interpretation, I select my control and treatment group to have the same erosion status at every boundary. This way, I aim to ensure that differential erosion status is not impacting the point estimate or affecting the selection. The results in Panel E of Table D.1 suggest an unchanged impact of access rights on productivity, even when the sample is reduced to 4,129 observations.

In sum, I argue that the selection procedure used in this paper is fairly standard: I drop all predetermined boundaries, all observations that are not at risk of being treated and focus on narrow bandwidths. Yet, the selection does not impact the interpretation of my estimates and reveal a stable pattern, even when using all available data, restricting the sample to less than 10% of the full data, or conditioning on the same erosion status on either side of the boundary.

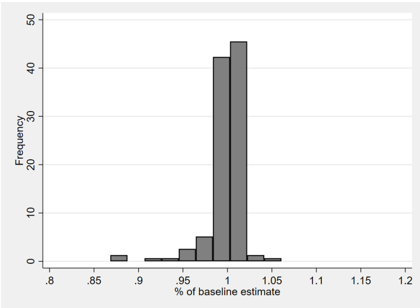
Table D.1: Access rights treatment: Different Selection procedures

	1/2 mile			1 mile			2 mile		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Baseline estimates									
Access Rights	0.110***	0.103***	0.103***	0.134***	0.108***	0.108***	0.165***	0.118***	0.117***
	(0.029)	(0.027)	(0.032)	(0.032)	(0.029)	(0.034)	(0.036)	(0.030)	(0.034)
	[0.031]	[0.030]	[0.033]	[0.034]	[0.032]	[0.034]	[0.039]	[0.033]	[0.035]
Observations	8,656	8,656	8,656	16,904	16,904	16,904	32,562	32,562	32,562
Panel B: Including all boundaries									
Access Rights	0.067***	0.071***	0.060***	0.084***	0.090***	0.081***	0.100***	0.107***	0.100***
	(0.021)	(0.020)	(0.021)	(0.024)	(0.022)	(0.024)	(0.028)	(0.024)	(0.027)
	[0.022]	[0.021]	[0.023]	[0.025]	[0.023]	[0.025]	[0.030]	[0.026]	[0.028]
Observations	19,420	19,420	19,420	38,177	38,177	38,177	74,173	74,173	74,173
Panel C: Dropping pre-determined and short boundaries									
Access Rights	0.072***	0.065**	0.053**	0.089***	0.050***	0.044***	0.130***	0.043***	0.042***
	(0.019)	(0.026)	(0.024)	(0.023)	(0.017)	(0.016)	(0.031)	(0.017)	(0.017)
	[0.018]	[0.027]	[0.022]	[0.022]	[0.017]	[0.015]	[0.029]	[0.017]	[0.016]
Observations	3,521	3,521	3,521	6,925	6,925	6,925	13,306	13,306	13,306
Panel D: Dropping pre-determined and irregular boundaries									
Access Rights	0.079***	0.073*	0.065*	0.089***	0.053**	0.044**	0.119***	0.047**	0.039*
	(0.025)	(0.039)	(0.035)	(0.026)	(0.021)	(0.019)	(0.031)	(0.020)	(0.022)
	[0.030]	[0.039]	[0.034]	[0.029]	[0.023]	[0.022]	[0.034]	[0.024]	[0.023]
Observations	1,608	1,608	1,608	3,205	3,205	3,205	6,193	6,193	6,193
Panel E: Dropping pre-determined boundaries and boundaries with different erosion status on either side									
Access Rights	0.098**	0.096**	0.116**	0.119***	0.095**	0.112**	0.136***	0.094**	0.108**
	(0.040)	(0.036)	(0.052)	(0.045)	(0.042)	(0.053)	(0.047)	(0.044)	(0.051)
	[0.041]	[0.038]	[0.053]	[0.045]	[0.042]	[0.053]	[0.047]	[0.045]	[0.052]
Observations	4,129	4,129	4,129	8,020	8,020	8,020	15,631	15,631	15,631
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes

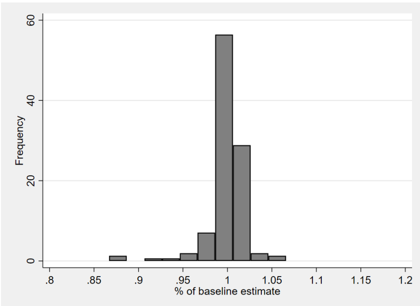
Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Control observations are pixels without established property rights outside the historical grazing districts. The first row represents the baseline specification, dropping observations that were not privatized in 1934, dropping boundaries with forests, and 60 mile boundary segments. Every other line is a different specification to highlight the robustness of the baseline estimates. In Panel B I include all boundaries, as compared to the baseline specification that omits predetermined boundaries by national parks, forests, and Native American reservations. In Panel C and D, I aim to estimate the treatment effect only at straight boundaries. In Panel C I drop all predetermined boundaries like in the baseline specification, and in addition drop all six-mile boundaries that have drawn lines that are shorter than 3 miles. In Panel D I drop all predetermined boundaries like in the baseline specification, and in addition drop all boundaries that are not given by a single six-mile long line. In Panel D I only include boundaries that are not predetermined like in the baseline and have the same erosion status (either eroded or not) on both sides of the boundary. Covariates are included in all specifications and defined in Table 2. Boundary spec. Productivity estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Finally, I plot the sensitivity of my estimates to dropping individual sixty-mile boundary segments in Figure D.2. Dropping one out of 156 segments, and focusing on observations within 1/2 miles of the remaining boundaries allow me to see whether individual boundaries (that are potentially endogenous) affect my results. The results reveal a nicely shaped bell curve around the expected value denoting that the point estimate remains unchanged (one). No single boundary affects the point estimate more than 20% in any direction.

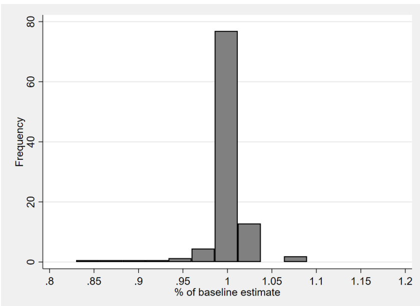
Figure D.2: Sensitivity to dropping individual boundaries



(a) Baseline



(b) Distance polynomial



(c) Boundary spec. Productivity

Each bar represents the fraction of samples that omitting a sixty-mile boundary segment produce an estimate that is x-times the size of the baseline estimate. 0.8 would imply that dropping this boundary segment, decreases the estimate to 80% of the original size, while 1.2 would imply an increase to 120% of the original size.

E Privatization treatment: Balance, robustness, and state capacity

In this section, I discuss whether covariates are balanced across treatments, whether the equivalence of access rights and private rights is stable across specifications (E.2) and replicate the heterogeneity analysis from Chapter 9 for the privatization treatment (E.3).

E.1 Including privatized areas outside the grazing districts

Comparing access rights to private property requires addressing the selection bias of privatization. Every homesteader chooses the plot that promises him the best (local) productivity. Thus, it is only natural that the remaining plots close to private property are likely of lower quality than the private property itself. Only when this upward bias is controlled for, do I capture the relative effects of access rights and private property cleanly. Otherwise, I overstate the impact of private property.

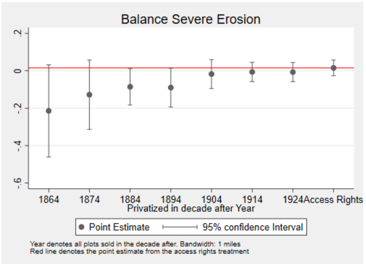
In this section, I start by producing a general overview of the evolution of land quality measured in 1934, ownership status, and year of sale in Figure E.1. I then continue to show that while there is a strong relationship between year of sale and NDVI in the entire data, once conditioning on sales after 1924, this relationship has vanished. To ensure that my comparison groups is valid and balanced, I continue and show that lands sold after 1924 are not different to open-access or access rights areas in 1934. Finally, I use privatized plots as a control group and directly compare privatization to access rights in the effects on productivity.

I start by discussing the sample selection of privatization in Figure E.1. In these figures, I utilize the entire data and group each land into being sold between 1864 and 1873 (first group), 1874 and 1883 (second group), the other decades of privatization and whether this land had become access rights land in 1934. The control group here is always unsold open-access lands outside the grazing district. The goal of this analysis is two-fold: First, I want to show that the difference between access rights and open-access lands (the point 'Access Rights') is equal to the difference between lands sold after 1924 and the open-access control. If this difference is zero, these three groups are comparable in observables in 1934. Second, I want to trace the evolution of land quality across time to show that lands had been comparable for some time prior to 1924, and that thus unobservables are likely very similar as well.

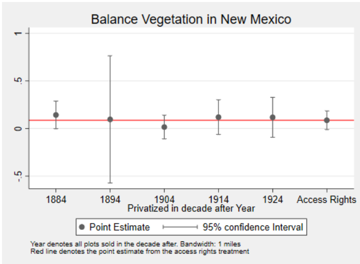
The first comparison between the private property treatment defined as plots sold after 1924, the access rights treatment, and the open access control in Figure E.1 reveal no differences between these categories of land in 1934. The second comparison over time reveals that lands are in progressively better shape in 1934, if they were bought earlier. For example: A plot bought between 1864 and 1873 is less eroded, closer to water and closer to cities than any plot sold or unsold in any other year. Lands sold after 1914, are of equal land quality than access rights lands and the open-access control. This finding is in line with historical records and the 1916 Stock Raising Homestead Act, that was aimed at selling the remaining lands deemed unproductive.

Combined, the findings suggest that in 1934, lands that were to become access rights, the open-access control, and lands that were privatized in the decade before were of equal land quality, and had been for some time. Thus, it is likely that the comparison of these groups reveal the true impact of access rights and private property.

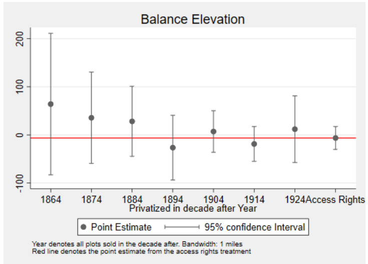
Figure E.1: Balance of covariates in the private property treatment



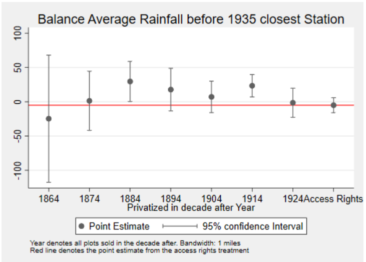
(a) Severe Erosion



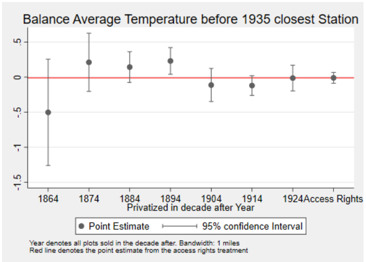
(b) Vegetation in NM



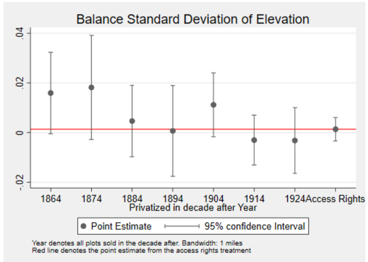
(c) Elevation



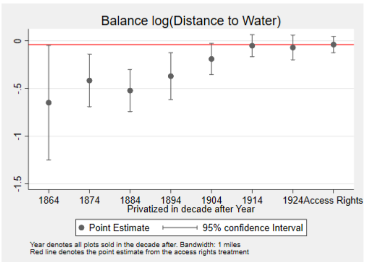
(d) Rainfall before 1935



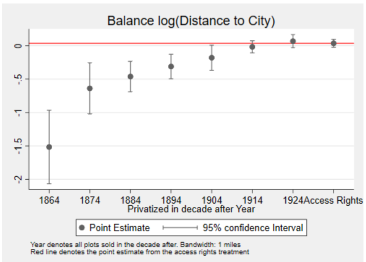
(e) Temperature before 1935



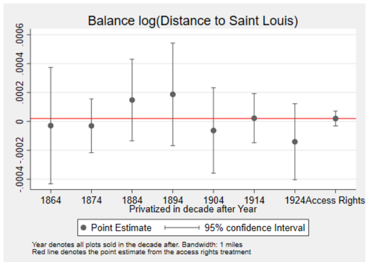
(f) Ruggedness



(g) Distance to nearest river



(h) Distance to closest city



(i) Distance to Saint Louis

Combined point estimates for both treatments in the AVHRR data from a single regression including decade of purchase: Plotting the point estimate for each decade of purchase and the 'Access rights' treatment from a single regression within one mile. 95% confidence intervals reported. Variable description: *Severe Erosion* refers to erosion maps constructed for the nine states in 1934. Those maps were used to determine the extent of the Taylor Grazing Act and show the erosion status of the land in 1934. 54% of my sample are classified as severely eroded and 22 % as moderately eroded. *Vegetation in NM* shows the vegetation in a small southern part of New Mexico in 1938 as digitized by Skaggs et al. (2010). *Elevation* is constructed from the Global Multi-resolution Terrain Elevation Data (GMTED2010), and shows the mean elevation in a 500m radius around every pixel. *Rainfall before 1935* and *Temperature before 1935* defines the average yearly rainfall and temperature from 1900–34. I use station level data from all stations within 100km and take the weighted average based on the distance to the pixel. The results are equivalent to using only the closest station. *Ruggedness* calculates the standard deviation of elevation of 8 adjacent cells and denominates it by the average elevation of all 9 cells. The average within a 500m radius around every pixel is reported here. *Distance to nearest river*, *Distance to Saint Louis* and *Distance to closest city* capture varying distances to proxy for water access, remoteness and thus time of settlement, and distance to modern day civilization which might affect the NDVI measure due to green lawns or highways.

I continue and formalize this finding in Table E.1, in which I focus only on private property lands, omitting any open-access or access-rights lands. First, I show that the grazing boundary does not predict when a plot was sold, suggesting no differential selection when it comes to the date of privatization. This point estimate is important, as the earlier a land was sold, the higher is it NDVI value today (columns 2 and 3). Once I select only private properties sold after 1924, this relation is absent, and land quality is the same (columns 5-7 and Figure E.1).

Table E.1: Quality measures of land and their relation to vegetation, erosion, and year of sale, within one mile of the boundary

	Year of Sale	log(NDVI)			Severe Erosion		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Inside Grazing Districts	0.697						
	(0.449)						
	[0.424]						
Year of Sale		-0.003***		0.002	0.001		-0.003
		(0.001)		(0.003)	(0.001)		(0.005)
		[0.001]		[0.003]	[0.001]		[0.005]
Privatized after 1924			-0.028*			0.033	
			(0.015)			(0.027)	
			[0.015]			[0.023]	
Controls	Yes	Yes	Yes	Yes			
Only Sold after 1924				Yes			Yes
Observations	8,234	8,227	8,227	1,216	8,267	8,267	1,219

In column (1) I estimate the impact of the boundary on the year a plot was sold in the entire sample of privatized lands 1850–1934. Privatized lands inside the grazing districts are sold 0.7 years later. In column (2) and (5) I estimate the impact of the year of privatization on NDVI and Erosion Status. Every Year after 1850 decreases the NDVI by 0.3% in the sample of lands that are privatized by 1935. In column (3) and (6) I compare my private-rights treatment sample of plots bought between 1924 and 1934 to plots sold before and show that there are more likely to be eroded (insignificant) and have 3% lower NDVI in the sample of lands that are privatized by 1935. In column (4) and (7), I estimate the slope of the year of sales as in columns (2) and (5) within the privatized sample and show no significant differences implying that while selection did impact the decision to buy before 1924, it, crucially, did not matter after 1924. Covariates are defined in Table 2. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

I highlight that the private property treatment is balanced not only compared to open-access lands that were unsold in 1934, but to any other comparison group, in Table E.2. In Panel A, I show that compared to open-access areas outside the grazing districts, private property is balanced within one mile of the boundary, except for distance to the nearest city. Next, I investigate whether private property inside the grazing district is comparable to private property outside the grazing district. I find no evidence of significant differences relevant for productivity in Panel B. Lastly, I directly compare private property to access rights for all indicators of productivity in 1934 and again find no difference. The findings here suggest that, by and large, these groups are comparable across the majority of dimensions and likely provide an unbiased estimate of private property and access rights.

Table E.2: Impact of Sales on Measured Land Quality

	(1) Severe Erosion	(2) Rainfall	(3) Temperature	(4) Elevation	(5) Ruggedness	(6) log(Dist. water)	(7) log(Dist. city)	(8) log(Dist. Saint Louis
Panel A: Compared to areas outside the grazing districts								
Private Rights	0.008	-6.875	0.064	18.782	0.000	-0.061	0.098**	-0.000
	(0.018)	(9.754)	(0.104)	(26.336)	(0.006)	(0.047)	(0.052)	(0.000)
	[0.017]	[8.599]	[0.096]	[25.267]	[0.006]	[0.047]	[0.047]	[0.000]
Panel B: Compared across the Treatment boundary								
PVT inside Grazing District	-0.026	1.754	-0.062	6.195	-0.001	-0.025	0.049	0.000**
	(0.027)	(9.070)	(0.106)	(49.857)	(0.009)	(0.093)	(0.036)	(0.000)
	[0.023]	[8.905]	[0.110]	[48.321]	[0.010]	[0.091]	[0.043]	[0.000]
Panel C: Compared to Access Rights								
Private Rights	-0.005	7.880	-0.031	16.355	-0.005	-0.008	0.033	-0.000
	(0.024)	(10.009)	(0.121)	(28.250)	(0.007)	(0.054)	(0.047)	(0.000)
	[0.023]	[8.742]	[0.101]	[26.247]	[0.006]	[0.054]	[0.044]	[0.000]
Observations	9812	9812	9812	9812	9812	9812	9812	9812
Mean	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146

In Panel A, I compare private property, defined as plots privatized after 1924, inside the grazing districts to areas outside the grazing districts and find that, on average, they are 10% further away from large cities. In Panel B, I compare private property on either side of the grazing boundary and show that they are slightly further away from Saint Louis inside the grazing districts. In Panel C, I compare private property to access rights and find no statistical difference. None of the effect sizes would speak towards a selection into private or access rights after 1924 based on quality. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Finally, I want to compare the NDVI outcomes today only across private property and access rights areas, leaving out the open-access control. This enables me to directly compare these two groups, as opposed to comparing relative to a control group. I find that for the smallest bandwidth of 1/2 miles, access rights and private property reveal the same effect. Only in larger bandwidths and the boundary specific productivity case do I find that access rights perform slightly worse (-4% and -2.9%) than private rights.

By and large, the evidence here is very similar to Table 5. The results point towards a negligible upward bias of the private-property treatment, especially in the smallest bandwidth of 1/2 miles within the boundary. While lands sold prior to 1900 were more productive than access rights or open-access lands in 1934, this selection has steadily decreased up to a point where there is no systematic difference across the treatment and control groups. Thus, I argue that my setting uncovers an unbiased estimate of private property and access rights and enables the comparison thereof.

Table E.3: Comparing access rights to any nearby privatized plots in the period 1924–1934 as a control

	1/2 mile			1 mile			2 mile		
	(1)	(2)	(3)	(4)	(5) log(NDVI)	(6)	(7)	(8)	(9)
Access Rights	-0.020	-0.025	-0.031	-0.015	-0.035	-0.040**	-0.006	-0.043	-0.029***
	(0.022)	(0.029)	(0.021)	(0.024)	(0.031)	(0.019)	(0.018)	(0.029)	(0.012)
	[0.021]	[0.027]	[0.020]	[0.023]	[0.030]	[0.018]	[0.018]	[0.029]	[0.010]
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes
Observations	4,888	4,888	4,888	9,812	9,812	9,812	19,630	19,630	19,630
F-Test of equality	0.148	0.148	0.148	0.146	0.146	0.146	0.145	0.145	0.145

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. The control is comprised of all privatized observations are satellite pixels that cover plots that were sold between 1924–1934. Plots that were sold before are dropped. Covariates are defined in Table 2. Boundary segment×Lat&Lon estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

E.2 Robustness in the privatization treatment

In the main results, I leave out privatized lands outside the Grazing districts, as they never were at risk of becoming a grazing district. This choice is done to compare treatment areas that are either public lands or private lands, to a pure control group on the other side. Especially when interacting private with distance (in columns 2-3, 5-6,8-9 of Table 3) this simplifies the interpretation: In a typical RD-setting you estimate treatment on one side of the boundary to a control on the other. Including privatized treatment on both sides of the boundary would complicate the interpretation, without changing the point estimate:

Table E.4: Access rights treatment: Comparing to privatized plots in the period 1924–1934

	1/2 mile			1 mile			2 mile		
	(1)	(2)	(3)	(4)	(5) log(NDVI)	(6)	(7)	(8)	(9)
Access Rights	0.110***	0.116***	0.145***	0.134***	0.097**	0.112***	0.167***	0.092**	0.092***
	(0.029)	(0.044)	(0.045)	(0.032)	(0.039)	(0.040)	(0.037)	(0.035)	(0.033)
	[0.031]	[0.044]	[0.043]	[0.034]	[0.041]	[0.038]	[0.040]	[0.038]	[0.035]
Private Rights	0.089***	0.100***	0.111***	0.102***	0.092**	0.086**	0.111***	0.113***	0.089***
	(0.032)	(0.038)	(0.035)	(0.032)	(0.039)	(0.037)	(0.027)	(0.039)	(0.035)
	[0.032]	[0.036]	[0.033]	[0.032]	[0.037]	[0.034]	[0.028]	[0.039]	[0.034]
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes
Observations	9,266	9,266	9,266	18,129	18,129	18,129	35,014	35,014	35,014
F-Test of equality	0.442	0.561	0.291	0.253	0.878	0.478	0.021	0.501	0.946

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Privatized observations are satellite pixels that cover plots that were sold between 1924–1934. Plots that were sold before are dropped. Control observations are pixels without established property rights outside the historical grazing districts. Covariates included in all columns and defined in Table 2. 'Distance Polynomial' includes a linear polynomial in distance, estimated with different slopes on either side of the boundary. 'Boundary spec. Productivity' estimate a continuous productivity plane at every segment to capture all continuously changing characteristics. 'F-Test of equality' reports the p-value at which the hypothesis that 'Access Rights' and 'Private Property' have a different impact on productivity can be rejected. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets.

Next, I test whether the equivalence between access rights and private rights holds when changing the selection of boundaries, increasing the number of fixed effects and changing the outcome variable. The F-test on equality in Table E.5 rejects the hypothesis that access rights and private rights have a differential impact on productivity in all specifications.

Table E.5: Access rights treatment: Comparing to privatized plots in the period 1924–1934

	log(NDVI)					level NDVI
	(1)	(2)	(3)	(4)	(5)	(6)
Access Rights	0.134***	0.083***	0.088***	0.119***	0.140***	0.009***
	(0.032)	(0.024)	(0.026)	(0.045)	(0.034)	(0.003)
	[0.034]	[0.026]	[0.029]	[0.045]	[0.035]	[0.003]
Private Rights	0.123***	0.082***	0.066**	0.087***	0.118***	0.009**
	(0.040)	(0.024)	(0.024)	(0.033)	(0.041)	(0.004)
	[0.040]	[0.025]	[0.026]	[0.032]	[0.041]	[0.004]
Observations	17,642	41,584	3,312	8,440	17,630	18,321
F-Test of equality	0.743	0.899	0.372	0.264	0.547	0.998
Adjusted R-squared	0.708	0.722	0.835	0.751	0.812	0.745
Not drop any boundary		Yes				
Drop irregular boundaries			Yes			
Same erosion status				Yes		
10-mile segment fixed effects					Yes	
level NDVI						Yes

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Privatized observations are satellite pixels that cover plots that were sold between 1924–1934. Plots that were sold before are dropped. Control observations are pixels without established property rights outside the historical grazing districts. Covariates included in all columns and defined in Table 2. 'F-Test of equality' reports the p-value at which the hypothesis that 'Access Rights' and 'Private Property' have a different impact on productivity can be rejected. Standard errors clustered by the boundary segments shown in parenthesis and standard errors corrected for spatial dependence within 0.5 degrees in brackets. 'Not drop any boundary' includes all possible boundaries. 'Drop irregular boundaries' drops all boundaries that are not determined by a single six-mile long line. 'Same erosion status' only focuses on boundaries that have the same erosion status on both sides of the boundary. '10-mile segment fixed effects' uses 10-mile fixed effects instead of 60-mile fixed effects. 'level NDVI' uses raw NDVI values instead of the logarithm of NDVI.

E.3 State capacity and the privatization treatment

In this section, I repeat the heterogeneity analysis from Table 8 for the privatization treatment. In order to simplify the comparisons across access rights and private rights, I split counties based on the column header. To ensure comparability to the main text, every variable is defined before the Taylor Grazing Act passed in 1934. However, as private rights are defined by plots that were sold between 1924–1934, I cannot rule out the possibility that increased privatization lead to more police and firemen in a county. This analysis thus serves as a complement to the results in Table 8.

The results in Table E.6 suggest, that productivity gains for well-defined property rights to publicly owned lands ('access rights') are located in counties with stronger state capacity and lower transaction costs (column 10). The similarity to private rights is in line with (Coase, 1960), who argued that property rights of any sort lead to economic gains if they are enforced and easily transferable.

Table E.6: State Capacity and property rights

	Police		Firemen		Police reform		Bank		Newspaper	
	(1) Without	(2) With	(3) Without	(4) With	(5) Without	(6) With	(7) Without	(8) With	(9) Without	(10) With
Access Rights	0.020	0.172***	0.038	0.207***	-0.026	0.201***	0.196***	0.131***	0.090***	0.255***
	(0.053)	(0.042)	(0.030)	(0.052)	(0.020)	(0.042)	(0.059)	(0.043)	(0.028)	(0.075)
	[0.049]	[0.044]	[0.028]	[0.056]	[0.020]	[0.043]	[0.059]	[0.046]	[0.028]	[0.078]
Private Rights	0.049	0.168***	0.052*	0.188**	0.001	0.177***	0.224*	0.094**	0.101**	0.216***
	(0.041)	(0.059)	(0.027)	(0.076)	(0.025)	(0.063)	(0.123)	(0.038)	(0.050)	(0.070)
	[0.043]	[0.057]	[0.029]	[0.074]	[0.028]	[0.061]	[0.115]	[0.040]	[0.048]	[0.073]
Observations	3,422	13,092	6,292	10,222	5,222	12,420	4,713	11,427	11,294	6,345

Access rights are defined as satellite pixels that are inside the historical grazing districts and were public land in 1935. Privatized observations are satellite pixels that cover plots that were sold between 1924–1934. Plots that were sold before are dropped. Control observations are pixels without established property rights outside the historical grazing districts. Covariates included in all columns and defined in Table 2. 'County with Police and firemen' are defined as zero if no person in the 1930 census is identified as either in that county. 'Police Reform' indicates whether the county had a police reform (Ornaghi, 2018). No city in New Mexico had a civil service reform by 1940. 'Bank' is whether the county had a bank in 1934 obtained from Federal Deposit Insurance Corporation (2001). 'Newspaper' is whether the county had a newspaper obtained from Gentzkow et al. (2014).

F Did ranchers anticipate the Taylor Grazing Act?

The demand for regulation of the public domain precedes the Taylor Grazing Act by more than 50 years (Foss, 1960, p. 39). Already in 1875, president Rutherford Hayes demanded regulation and the 1878 Survey by Powell. Powell's recommendation to increase homesteading to 2,560 acres was endorsed by the president of the National Livestock Association (1901) and the American Cattle Growers endorsed a bill (S. 3311) that would lease out all lands for two cents per Acre. In an 1903 survey by the public land commission 77% of ranchers favored some sort of government control over the public domain. Yet, despite the increasing public demand, the first bill to establish grazing districts was introduced in 1906 by Senator Burkett of Nebraska. Until 1926, eight other bills were introduced and failed to leave the commissions hearings (S. 3462, H.R. 25882, H.R. 10539, S. 1519, H.R. 7908, S. 3236, S. 2325, S. 4075).

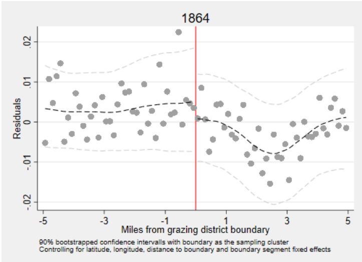
The first small bill that passed concerned the Mizpah-Pumpkin test district covering 108,000 acres of abandoned land in Montana (Foss, 1960, p. 49). When ranchers took over these abandoned lands, senators and representatives of Montana were eager to trial a potential public regulation of the public domain. This experiment proved to be a success and brought numerous requests from different parts of the West. "*However, rather than deal with the matter piecemeal, it would be wiser to deal at one swoop with the whole public domain by giving this department authority to regulate grazing on it, which . . . should have been done many years ago.*" (Harold Ickes, as cited in Foss (1960, p. 50). However, even the bill modeled on this experience failed to pass congress (1932: H.R. 11816 'Colton Bill').

When the democrats won the elections in 1932, the new government interpreted its role more expansively to combat the Great Depression and remedy Hoovers failures. Similar to the establishing of the Civilian Conservation Corps in 1933, the Taylor Grazing bill passed congress and established 80 million acres of grazing districts; and quickly expanded it to 142 million in 1936. Thus, the Taylor Grazing Act only passed due to a combination of unemployment and a government with new heads of agriculture and interior ministries who were more positive towards regulation. The disastrous effects of the Dust Bowl then provided the last push for congress to pass the bill.

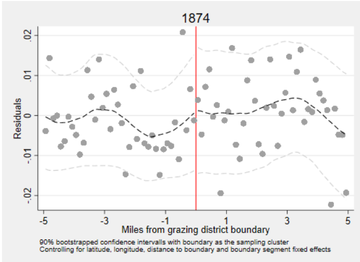
As homesteading continued until the passing of the Taylor Grazing Act, it is unlikely that ranchers anticipated the passing of an act nearly 60 years in the making. However, for my empirical setup to yield an unbiased estimate, ranchers need not to anticipate the location of the boundary.

The evidence provided in Section E, suggests that the private property treatment, defined as all sold plots between 1924–1934, yields an unbiased estimate. The remaining threat to identification comes from anticipation of the boundary. If homesteaders anticipated the location of the grazing boundary, they might have strategically located to benefit from it. However, the following RD plots confirm evidence from Table E.1, column (1): If ranchers knew the location of a boundary, we would observe a discontinuous change in the probability that a plot was bought in a given year. Yet, Figure F.1 shows that in no year did ranchers anticipate the location of the future boundary as the probability of a land being sold is smooth around the cutoff.

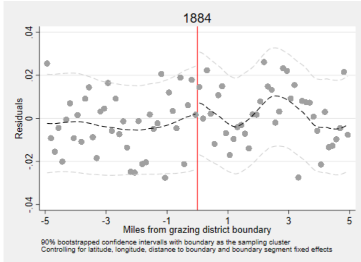
Figure F.1: Balance of year of sale



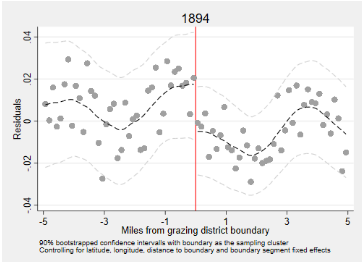
(a) Privatized in 1864



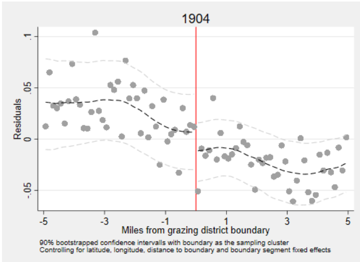
(b) Privatized in 1874



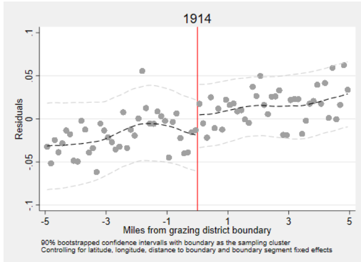
(c) Privatized in 1884



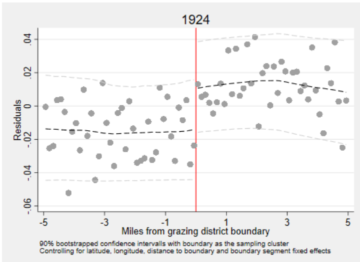
(d) Privatized in 1894



(e) Privatized in 1904



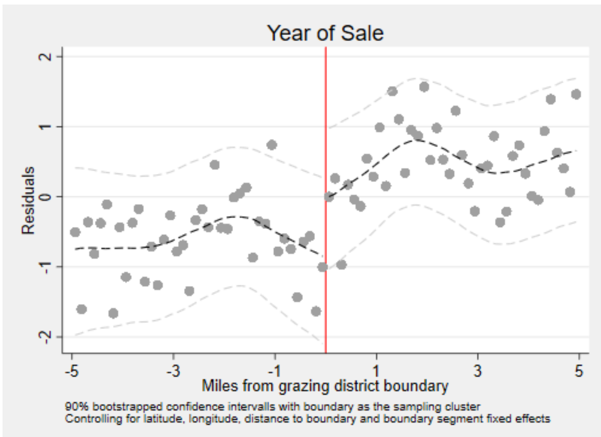
(f) Privatized in 1914



(g) Privatized in 1924

Testing whether farmers anticipated the boundary. These RD plots show that conditional on land being sold, by and large, ranchers did not strategically sort left or right of the boundary.

Figure F.2: Balance of year of sale



This RD plot shows that the the year of sale is continuous at the boundary, confirming the estimates from Table E.1, column (1).

G First stage in the Agricultural Census

Table G.1: Instrument First Stage: Agricultural Census

	Drought Severity Index (PDSI)		Severe Erosion		Access Rights		# Grazing Permits in 1950		Share of County in Grazing Districts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Rainfall in October 1934	0.487***	0.481***	-0.035*	-0.026	-0.228***	-0.217***	-26.358***	-18.941***	-0.176***	-0.166***
	(0.055)	(0.057)	(0.020)	(0.020)	(0.039)	(0.036)	(5.978)	(5.156)	(0.029)	(0.028)
log(County area)		-0.101**		0.067***		0.073*		29.287***		0.054
		(0.043)		(0.023)		(0.037)		(6.139)		(0.036)
log(County population)		-0.055		0.017		0.070		1.123		0.036
		(0.046)		(0.024)		(0.045)		(5.087)		(0.034)
log(# Farms)		0.067		-0.018		-0.030		18.132***		0.003
		(0.048)		(0.028)		(0.058)		(6.621)		(0.041)
log(# Cattle per Farm)		-0.053		0.032		0.179***		19.542***		0.093*
		(0.057)		(0.027)		(0.052)		(7.091)		(0.051)
log(Average farm value)		0.062		-0.123***		-0.080		-28.210***		0.007
		(0.072)		(0.034)		(0.066)		(10.077)		(0.061)
Observations	283	282	283	282	283	282	283	282	283	282

State fixed effects included in all columns. 'Rainfall in October 1934' is the standardized rainfall using the mean and standard deviation of the county in October 1934, the month the erosion maps were drawn. Columns (7) and (8) have the number of Grazing Permits in 1950 as the dependent variable. The IV estimate using column (6) as the first stage implies 76.39 (s.e. 17.81) grazing permits more in counties with grazing districts. All covariates measured in 1935 and robust to using the values from 1930. Standard errors clustered by counties shown in parenthesis.

Table G.2: Difference-in-Differences Estimation: Agricultural Census using Share of County within Grazing Districts

	log(Cattle per farm)				log(Average farm value)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
Access Rights × Post TGA	0.174***	0.903***			0.078*	0.412***		
	(0.058)	(0.174)			(0.044)	(0.130)		
Share in Grazing District × Post TGA			0.194***	1.176***			-0.008	0.537***
			(0.069)	(0.228)			(0.052)	(0.162)
Including Adjacent States								
First stage F-Statistic		34.494		37.451		34.463		37.392
N	5,612	5,612	5,612	5,612	5,619	5,619	5,619	5,619

County, year and state× year fixed effects included in all columns. Access rights are defined as counties affected by the Taylor Grazing Act. 'Access Rights × Post TGA' is the DiD estimate for every observation from 1940 onwards. 'Share of County in Grazing Districts × Post TGA' is the DiD estimate for every observation from 1940 onwards. Instrument is 'Rainfall in October 1934' measured as the standardized rainfall using the mean and standard deviation of the county in October 1934, the month the erosion maps were drawn. In columns (2), (4), (6), and (8), 'Access Rights × Post TGA' and 'Share of County in Grazing Districts × Post TGA' is instrumented using 'Rainfall in October 1934 × Post TGA'. The first stage F-Statistic on excluded instruments is shown. Standard errors clustered by counties shown in parenthesis.

G.1 Only using observations until 1934 to construct the instrument

As precipitation data can exhibit trends by climate change or better availability of data, I explore whether my results hold when calculating the historical mean and standard deviation only from observations prior to 1934. The magnitude of all results is similar, while the F-statistic increases from 34 to 51. Yet, as this set is only based on 19 years of observations, I use the entire history of rain 1915–2011 in sections regarding the agricultural census.

Table G.3: Instrument First Stage: Agricultural Census, using rainfall in the years 1915-1934

	Drought Severity Index (PDSI)		Severe Erosion		Access Rights		# Grazing Permits in 1950		Share of County in Grazing Districts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Rainfall in October 1934	0.476***	0.473***	-0.035**	-0.031*	-0.225***	-0.215***	-25.632***	-20.849***	-0.173***	-0.164***
	(0.048)	(0.050)	(0.017)	(0.018)	(0.032)	(0.030)	(5.215)	(4.707)	(0.026)	(0.025)
log(County area)		-0.104**		0.067***		0.074*		29.305***		0.055
		(0.041)		(0.023)		(0.038)		(6.057)		(0.036)
log(County population)		-0.059		0.019		0.072*		1.751		0.037
		(0.043)		(0.024)		(0.043)		(4.950)		(0.033)
log(# Farms)		0.058		-0.019		-0.026		18.007***		0.006
		(0.046)		(0.027)		(0.056)		(6.483)		(0.041)
log(# Cattle per Farm)		-0.052		0.032		0.179***		19.419***		0.093*
		(0.054)		(0.028)		(0.051)		(6.956)		(0.051)
log(Average farm value)		0.091		-0.125***		-0.093		-29.483***		-0.003
		(0.074)		(0.035)		(0.066)		(10.093)		(0.061)
Observations	283	282	283	282	283	282	283	282	283	282

State fixed effects included in all columns. 'Rainfall in October 1934' is the standardized rainfall using the mean and standard deviation of the county in October 1934, the month the erosion maps were drawn. Columns (7) and (8) have the number of Grazing Permits in 1950 as the dependent variable. The IV estimate using column (6) as the first stage implies 80.84 (s.e. 16.86) grazing permits more in counties with grazing districts. All covariates measured in 1935 and robust to using the values from 1930. Standard errors clustered by counties shown in parenthesis.

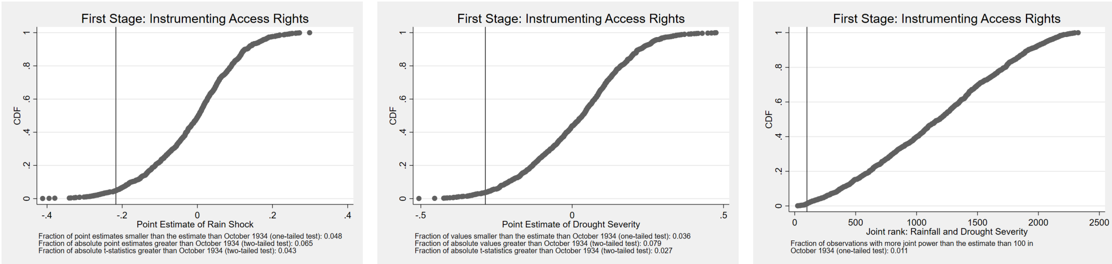
Table G.4: Difference-in-Differences Estimation: Agricultural Census, using rainfall in the years 1915-1934

	log(Cattle per farm)			log(Average farm value)		
	(1) OLS	(2) RF	(3) 2SLS	(4) OLS	(5) RF	(6) 2SLS
Panel A: Baseline estimates using all available years						
Access Rights × Post TGA	0.174***		0.903***	0.078*		0.412***
	(0.058)		(0.174)	(0.044)		(0.130)
Rainfall in October 1934 × Post TGA		-0.207***			-0.094***	
		(0.029)			(0.024)	
First stage F-Statistic			34.494			34.463
Observations	5,612	5,612	5,612	5,619	5,619	5,619
Panel B: Estimates using only years until 1934 to calculate the historical mean						
Access Rights × Post TGA	0.174***		0.874***	0.078*		0.383***
	(0.058)		(0.155)	(0.044)		(0.113)
Rainfall in October 1934 × Post TGA		-0.198***			-0.086***	
		(0.026)			(0.022)	
First stage F-Statistic			51.643			51.533
Observations	5,612	5,612	5,612	5,619	5,619	5,619

County, year and state× year fixed effects included in all columns. Access rights are defined as counties affected by the Taylor Grazing Act. 'Access Rights × Post TGA' is the DiD estimate for every observation from 1940 onwards. 'Rainfall in October 1934' is the standardized rainfall using the mean and standard deviation of the county in October 1934, the month the erosion maps were drawn. In columns (3) and (6), 'Access Rights × Post TGA' is instrumented using 'Rainfall in October 1934 × Post TGA'. The first stage F-Statistic on excluded instruments is shown. Standard errors clustered by counties shown in parenthesis.

G.2 The Agricultural Census: Placebo distribution and raw data

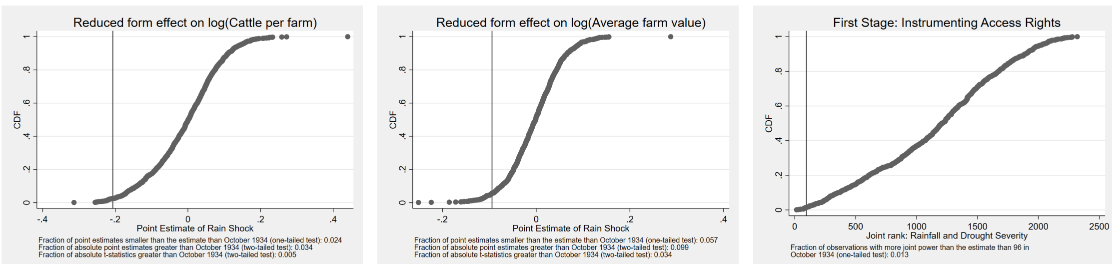
Figure G.1: Agricultural Census: Placebo distribution first stage



Instrumenting selection into grazing districts

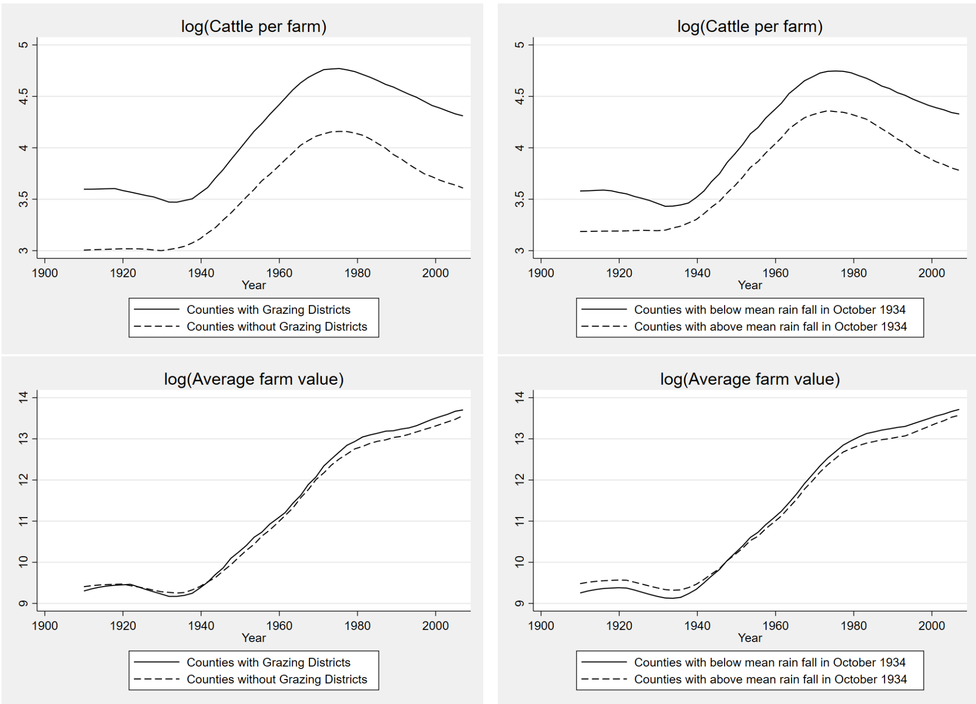
This figure plots the point estimates of any other year-month realization of rainfall (left figure) or drought severity (middle figure) between 1915 and 2011 on the county being affected by the Taylor Grazing Act. The line marks October 1934. Below each figure three statistics are reported. A one-tailed test, a two-tailed test ignoring the sign of the estimate, and the fraction of t-tests that are in absolute terms larger than October 1934. The right figure sums the previous two ranks of October 1934 and compares it to any other year-month combination. Only 1.1% of year-month combinations would predict a stronger relationship between rain, drought, and access rights than October 1934, the month the initial survey was conducted. Figure includes control variables as shown in Table G.3, column (6).

Figure G.2: Agricultural Census: Placebo distribution reduced form



This figure plots the point estimates of any other year-month realization of rainfall between 1915 and 2011 on the log number of cattle per farm (left) and log average farm value (middle). The line marks October 1934. Below each figure three statistics are reported. A one-tailed test, a two-tailed test ignoring the sign of the estimate, and the fraction of t-tests that are in absolute terms larger than October 1934. The right figure sums the previous two ranks of October 1934 and compares it to any other year-month combination. Figure includes control variables as shown in Table G.3, column (6).

Figure G.3: Agricultural Census: Cattle and farm values, raw data



Raw data from the Agricultural census: Left panel: Using actual treatment status. Right panel: Using standardized rainfall in October 1934. For visualization purposes, I split the sample into below or above mean rainfall in October 1934, since less rainfall is associated with a higher probability of being treated.

H Channels in the Agricultural Census

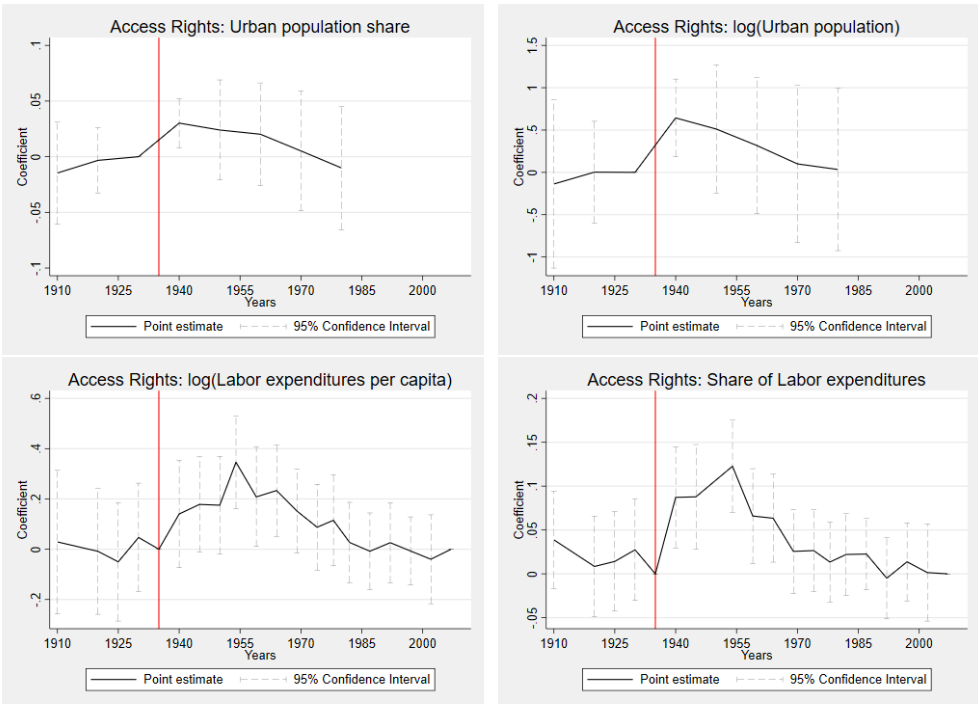
H.1 General Equilibrium Effects

In this subsection, I provide suggestive evidence on time-varying general equilibrium effects affecting the main result. First, I show that when ranchers inside grazing districts become more productive due to well-defined property rights and this productivity differential cannot be equalized by migration into grazing districts, out-migration outside the grazing districts should occur to equalize productivity. To analyze this channel, migration towards urban areas, I use the ICPSR 02896 series to construct urban and rural population for every decade and county from 1910 until 1980. Then, employing a differences-in-differences estimation, comparing treated counties (with grazing districts) to control counties (without grazing districts) across all years, I find support for an increased urbanization rate equalizing productivity. The total number of urban population increased sharply in 1940 in counties with grazing districts, but declined steadily thereafter. The same holds true for urbanization, defined as urban population divided by total population.

The lower rancher-to-land ratio outside the grazing districts implies that land productivity and income/cattle per farmer should increase until it is equalized across the border. I investigate labor costs using the Agricultural Census. Unfortunately, the Agricultural Census records only labor, feed, and fertilizer expenditures throughout the years, but not wages or selling prices per cattle. To calculate productivity per farm, I simply use the number of cattle per farm, as the selling price per cattle would be equal across counties. To proxy for wages, I use labor expenditures per capita, as well as the share of labor costs relative to feed and fertilizer. As the number of cattle increase, the labor expenditures increase with it. However, we can see in the lead-lag graphs in Figure H.1, that following the reallocation and migration of ranchers into urban areas, labor costs equalized across counties.

Summarizing, the evidence presented here suggests that labor demand increased labor expenditures as unprofitable ranchers moved into the urban areas. Over time, these differences equalized, but the wealth shock for ranchers inside the grazing districts remained, permanently increasing house values, cattle numbers, ranch values, schooling rates and decreased poverty.

Figure H.1: Urbanization rates and labor expenditures



Lead-lag graphs for urbanity and labor costs. Urbanization data available from decadal censuses; 1930 is omitted as a baseline year. The bottom row uses data from the agricultural census and omits 1935 as a baseline year.

H.2 Political Economy Channels

Table H.1: Channels in the Agricultural Census

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
						Panel A: log(Cattle per Farm)						
Rainfall in October 1934 × Post TGA	-0.276***	-0.196***	-0.234***	-0.316**	-0.195***	-0.156*	-0.188***	-0.253***	-0.172***	-0.186***	-0.268***	-0.200***
	(0.045)	(0.043)	(0.035)	(0.122)	(0.028)	(0.084)	(0.031)	(0.061)	(0.030)	(0.031)	(0.061)	(0.029)
Triple Interaction: × City with Civil Service Reform			0.026									
			(0.048)									
Triple Interaction: × Bank						-0.071						
						(0.082)						
Triple Interaction: × NewsPaper									-0.128***			
									(0.047)			
Triple Interaction: × Circulation												-0.005**
												(0.002)
						Panel B: log(Average farm value)						
Rainfall in October 1934 × Post TGA	-0.022	-0.092***	-0.022	-0.267***	-0.089***	-0.187***	-0.085***	-0.042	-0.098***	-0.083***	-0.044	-0.095***
	(0.042)	(0.033)	(0.034)	(0.077)	(0.025)	(0.064)	(0.029)	(0.051)	(0.027)	(0.028)	(0.052)	(0.025)
Triple Interaction: × City with Civil Service Reform			-0.095**									
			(0.044)									
Triple Interaction: × Bank						0.089						
						(0.065)						
Triple Interaction: × NewsPaper									0.038			
									(0.043)			
Triple Interaction: × Circulation												0.002
												(0.002)
Sample	Far to CSR	Close to CSR	Joint	No Bank	With Bank	Joint	No Newspaper	With Newspaper	Joint	No Circulation	Some Circulation	Joint
N	2,291	3,328	5,619	1,172	3,987	5,159	3,904	1,715	5,619	4,104	1,515	5,619

'Triple Interaction × ' Denotes the fully interacted model of Rainfall in October 1934 × Post 1934 × Civil Service Reform (CSR), Bank, Newspaper, or Circulation in 1932. Standard errors clustered by counties shown in parenthesis.

Table H.2: Political Economy in the Agricultural Census

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				Panel A: log(Cattle per Farm)					
Rainfall in October 1934 × Post TGA	-0.173***	-0.159***	-0.285***	-0.182***	-0.237*	-0.124***	-0.217***	-0.228***	-0.026
	(0.062)	(0.033)	(0.041)	(0.027)	(0.137)	(0.033)	(0.043)	(0.041)	(0.098)
Triple Interaction: × Average farm size in 1935			0.097***						
			(0.030)						
Triple Interaction: × Share farms below 100 acres in 1935						-0.360***			
						(0.100)			
Triple Interaction: × Ownership rate in 1935									-0.267
									(0.168)
				Panel B: log(Average farm value)					
Rainfall in October 1934 × Post TGA	-0.059	-0.060**	-0.140***	-0.067***	-0.240	-0.030	-0.044	-0.109***	0.265***
	(0.078)	(0.028)	(0.035)	(0.023)	(0.165)	(0.029)	(0.031)	(0.035)	(0.073)
Triple Interaction: × Average farm size in 1935			0.060**						
			(0.029)						
Triple Interaction: × Share farms below 100 acres in 1935						-0.228**			
						(0.090)			
Triple Interaction: × Ownership rate in 1935									-0.684***
									(0.130)
Sample	Mean Farm $\leq$ 640 acres	Mean Farm $>$ 640 acres	Joint	Most farms $<$ 100 acres	Most farms $\geq$ 100 acres	Joint	Most farms rented	Most farms owned	Joint
N	1,756	3,822	5,615	4,884	691	5,615	1,388	4,082	5,615

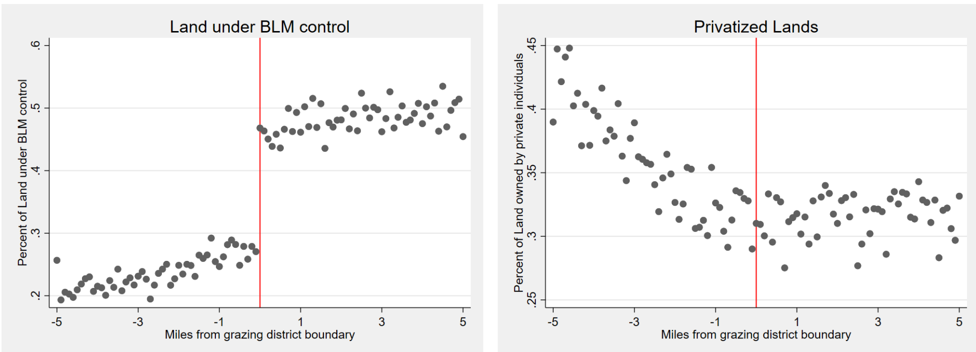
'Triple Interaction × ' Denotes the fully interacted model of Rainfall in October 1934 × Post 1934 × the average farm size, the share of farms below 100 acres, or the ownership rate in 1935. The point estimates in Columns (3) and (6) suggest that larger farm sizes, and thus more concentration of power, decreased the impact of the Taylor Grazing Act on Cattle and Farm values. Standard errors clustered by counties shown in parenthesis.

I Appendix : Modern Grazing

Between 1934 and today, grazing districts and privatization have changed the landscape. With grazing districts expanding and limited land-exchange programs the interpretation of my reduced from estimates changes. In this section, I provide empirical evidence that the estimated reduced form effect of well-defined access rights to publicly owned lands (Access rights) is an underestimate of the true impact of defining property rights.

Since today more than 170million acres are under public management and land was exchanged between farmers and the government, lands outside the historical grazing districts can be privatized or under the control of the Bureau of Land Management (BLM) that is in charge of grazing procedures. In Figure I.1, I plot the fraction of lands at the boundary belonging to the BLM and private individuals, with state land being the remainder. It is evident that historical grazing boundaries are a good predictor of modern-day land management by the BLM, as the fraction of lands discontinuously increases from 25 to 50 % exactly at the boundary. The same discontinuity is absent from privatization rates, and only increases further away from the boundary.

Figure I.1: Regression Discontinuity Graphs: IV



(a) Fraction under BLM control, raw averages within 0.1mile bins. **(b)** Fraction under private ownership, raw averages within 0.1mile bins.

This figure plots the fraction of land managed by the Bureau of Land Management (left figure) or private individuals (right figure), conditional on being an open-access area in 1934. Inside the historical grazing districts, 50% of lands is managed by the Bureau of Land Management, and 30% is managed by private individuals. The majority of the remainder is accounted for by state lands. Outside the historical grazing districts only 20% of lands in managed by the Bureau of Land Management, while 45% of lands is managed privately. Thus, this figure suggests a strong first-stage relationship of grazing districts with BLM ownership.

Thus, Figure I.1 indicates the presence of a downward bias, as the BLM gained control of lands outside the historical boundaries of the 1934 grazing districts. The binary nature of my analysis, binary variables for both 'historical grazing districts' and 'Land under BLM Control', allow to formulate the bias in its classical Wald estimate form:

$$\beta^{IV} = \frac{\mathbb{E}\left[NDVI|Historical\ Grazing = 1\right] - \mathbb{E}\left[NDVI|Historical\ Grazing = 0\right]}{\mathbb{E}\left[BLM\ Managed|Historical\ Grazing = 1\right] - \mathbb{E}\left[BLM\ Managed|Historical\ Grazing = 0\right]}$$

The baseline reduced form effect in the numerator, needs to be weighed by the differences in probability between lands being under BLM control, inside and outside of the historical grazing districts. The denominator thus reflects the first stage of a regression BLM on historical grazing districts. In line with this argument, I provide four sets of results in Table I.1: the OLS impact of BLM management on land productivity (Panel A, a null-effect), the first stage of historical grazing on BLM management (Panel B, F-Tests between 26-40), the reduced form of historical grazing on land productivity (Panel C, baseline estimates), and the estimates two stage least squares impact of BLM management on land productivity (Panel D).

First, the estimated impact of modern day BLM management at the historical boundary is a precisely estimated zero impact across all specifications and bandwidths. This is unsurprising, as the reference points are the historical boundaries, and not the modern day BLM boundaries. Second, confirming Figure I.1, lands inside the historical grazing districts are 14-18% more likely to be managed by the BLM. The corresponding F-statistic varies between 24 and 40, depending on specifications and bandwidths. Thus, the clear discontinuity in Figure I.1 and the results in Panel B, suggest a strong first stage that can be used in the Wald Estimate of Panel D. Across all specifications and bandwidths, well-defined access rights to lands managed by the Bureau of Land Management increases land productivity by at least 60%.

Table I.1: The impact of modern day BLM ownership on land productivity

	1/2 mile			1 mile			2 miles		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Reduced form impact of Historical Grazing									
Access Rights	0.110***	0.103***	0.103***	0.135***	0.108***	0.108***	0.168***	0.119***	0.117***
	(0.029)	(0.028)	(0.033)	(0.032)	(0.030)	(0.035)	(0.037)	(0.031)	(0.035)
Panel B: OLS impact of BLM Land Management									
Land under BLM Control	-0.018	-0.030	-0.002	-0.014	-0.013	0.008	0.005	-0.004	0.007
	(0.033)	(0.032)	(0.037)	(0.032)	(0.031)	(0.035)	(0.033)	(0.032)	(0.034)
Panel C: First stage: Instrumenting BLM Land Management using historical grazing									
Access Rights	0.171***	0.162***	0.171***	0.178***	0.144***	0.154***	0.194***	0.155***	0.160***
	(0.028)	(0.030)	(0.033)	(0.028)	(0.028)	(0.031)	(0.029)	(0.029)	(0.030)
Panel D: 2SLS impact of BLM Land Management using historical grazing as instrument									
Land under BLM Control	0.652***	0.653***	0.584**	0.778***	0.769***	0.687**	0.896***	0.787***	0.731***
	(0.208)	(0.220)	(0.234)	(0.239)	(0.268)	(0.278)	(0.258)	(0.268)	(0.278)
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes
Observations	8,656	8,656	8,656	16,904	16,904	16,904	32,562	32,562	32,562
F-Test first stage	35.772	26.654	26.113	36.220	24.138	25.579	40.043	25.699	28.292

Standard errors clustered by boundary segments shown in parenthesis to ensure comparisons to the IV Standard errors.

Despite showing that various factors remain balanced at the boundary today, the exclusion restriction of the instrument (i.e. the boundary) might be problematic. To interpret Panel D causally, one would need to assume that the only impact of the Grazing Boundary was to increase the likelihood of being managed by the Bureau of Land Management. While reasonable, it negates the fact that in rare instances, farmers could exchange their lands inside the grazing districts for new lands outside the grazing districts. Although the motivation was to exchange pasture for valuable land in the vicinity of cities, it remains a violation of the exclusion restriction. Thus, I follow the literature in developing economics and economic history and focus on the reduced form effect only.

I.1 Comparison to Private Management

The reduced form impacts of privatization and public management are statistically indistinguishable (Table 5). Yet this equivalence result might not hold as different first stages imply a different weight for the Wald estimates. I thus use the historical grazing boundary in 1935 and whether land was privatized before 1935, as instruments to estimate the differences between private and public ownership today.

In Table I.2 Panel A, I show that land which was private in 1935 is likely to remain in the private domain. The implied first stage statistic is well above 100, and suggests that land is 27 percentage points more likely to be private today, if it had been private in 1935. I thus combine the estimation strategy from I.1, instrumenting BLM ownership with the grazing boundary, with the instrument for modern day private ownership in Panel B. Here, two instruments identify two endogenous variables, with the F-Test of the combined first stage ranging between 16 and 50.

Table I.2: The comparison of modern day BLM and private ownership on land productivity

	1/2 mile			1 mile			2 miles		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: First Stage: Instrumenting modern private lands with lands privatized until 1935									
Privatized by 1935	0.267***	0.268***	0.254***	0.270***	0.270***	0.256***	0.270***	0.270***	0.255***
	(0.024)	(0.024)	(0.024)	(0.023)	(0.022)	(0.022)	(0.022)	(0.021)	(0.021)
Panel B: 2SLS impact of public (BLM) and private ownership, using historical grazing and landownership as instruments									
Land under BLM Control	0.635***	0.596***	0.524***	0.703***	0.658***	0.596***	0.805***	0.689***	0.643***
	(0.169)	(0.174)	(0.172)	(0.189)	(0.198)	(0.196)	(0.201)	(0.205)	(0.207)
Private lands today	0.526***	0.514***	0.398***	0.531***	0.515***	0.424***	0.583***	0.539***	0.456***
	(0.102)	(0.097)	(0.091)	(0.106)	(0.103)	(0.096)	(0.116)	(0.111)	(0.102)
Distance Polynomial		Yes	Yes		Yes	Yes		Yes	Yes
Boundary spec. Productivity			Yes			Yes			Yes
Observations	12,752	12,752	12,752	25,134	25,134	25,134	48,898	48,898	48,898
F-Test first stage	31.697	16.837	16.030	36.253	15.854	16.277	49.972	16.007	16.189
F-Test of equality	0.395	0.554	0.362	0.216	0.341	0.234	0.104	0.294	0.189

Panel A represents the first stage when only using 'Privatized by 1935' to instrument 'Private lands today' in a single-instrument single-endogeneous regressor framework. Results are unchanged when using 'privatized between 1924–1934' instead. Panel B represents the 2SLS impact of a two-instruments, two endogeneous variables, setup. 'F-Test first stage' represents the F-Test of the first stage when instrumenting 'Private lands today' and 'Land under BLM Control' with the historical grazing boundary and 'Privatized by 1935'. 'F-Test for equality' reports the p-value that privatization and public management by the BLM have the same effect on land productivity. Standard errors clustered by boundary segments shown in parenthesis to ensure comparisons to the IV Standard errors.

Reassuringly, the reduced form equivalence carries over to the IV-setting. The hypothesis that BLM and private ownership differentially impact land productivity is rejected throughout all specifications and bandwidths. However, in addition to the violation of the exclusion restrictions as discussed before, this setting requires discussing the impact of the two instruments on the endogenous variables. One the one hand, the historical grazing boundary has no explanatory power for modern day privatization (Figure I.1), thus ensuring that the boundary only identifies the variation in BLM ownership. On the other hand, lands privatized before 1935 identifies variation both in modern privatization and BLM ownership. Thus, to compare the two estimates of private and public management causally, one needs to assume that privatization is mechanically related to BLM via the historical grazing instrument - the inclusion of which captures this channel.

In knowledge of the 2SLS equivalence, I thus refer to the estimates in Table 5, as the most well-identified, yet reduced form, effects of public and private management.

J Appendix : Conceptual Framework

Ranchers who face either property rights system will respond given their production functions and constraints. To guide the analysis, I derive a set of predictions from a model of production that incorporates constraints and technology choice. The model closely resembles the options faced by ranchers in the Western States who bought young calves, nurtured them to a juvenile state, and sold them off eastwards to more suitable pastures.

This simple model also provides a theoretical foundation, and an empirical prediction, to identify spillovers from treated to control ranges. Ranchers only relocate cattle to plots without property rights (open access), if the grazing administration radically cut their grazing allowance. Since fewer cattle would decrease future profits, the number of cattle and the value of farms from the agricultural census are sufficient statistics to identify spillovers.

In the model, a rancher has access to two open-access plots $i \in \{1,2\}$, on which he can allocate c_i cattle. The productivity of cattle on each plot follows the same concave function $f(c_i) = c_i^{\alpha_i}$ with $\alpha \in (0,1)$. The rancher is a price taker and sells cattle at a price of $p > 1$ and buys them at a price of one. The number of cattle he can allocate to the two plots is capped at an upper limit of $\bar{c} = c_1 + c_2$, representing financial or managerial constraints. The constraint is time independent, as cattle in the Western United States is bought and sold within the same year. Then, the optimal amount of cattle on each plot is defined by solving her profit maximization problem, taking into account the potentially binding upper bound $\bar{c}$:

$$\max_{c_i} \Pi(\lambda) \; \sum_i^2 p c_i^{\alpha_i} \; - \sum_i^2 c_i \; - \lambda \left(\sum_i^2 c_i - \bar{c} \right) \tag{4}$$

If the constraint on cattle $\bar{c}$ is non-binding $\lambda = 0$, that is a rancher is neither credit constrained nor would he like to manage more cattle on the ranges than he can handle, the number of cattle on each range is determined by the marginal product. Since we compare pre-1934 similar plots, we can safely assume that both plots share the same productivity parameter $\alpha_i = \alpha$:

$$\frac{\partial \Pi(\lambda = 0)}{\partial c_i} : \; c_i^{OA} = (p\alpha)^{\frac{1}{1-\alpha}} \tag{5}$$

In the case where the upper bound $\bar{c}$ is binding, ranchers distribute cattle according to the relative productivity of plots. Since both plots are equally productive $\alpha_i = \alpha$, cattle are distributed equally across plots:

$$\frac{\partial \Pi(\lambda \neq 0)}{\partial c_i} : \; c_i = c \; \forall i \Rightarrow c_i^{OA} = \frac{\bar{c}}{2} \leq (p\alpha)^{\frac{1}{1-\alpha}} \tag{6}$$

Competition As a rancher in 1915 put it: *"I can better afford to take the $2,500 loss of stock which I know I will have when the dry years come than to take my stock off my range [...] I hold on to my range only by having stock on it. If I take my stock off, someone else will take my range."* (Wooten, 1915). Ranchers were aware that productivity improvements could be achieved by letting the land fallow during the winter months. Thus the rancher has a productive summer period in which he can obtain a profit Π, and a non-productive winter period in which he can let the land fallow at zero cost and profit, or stack the range and lose the cattle at cost c^{min}.[44] For simplicity, I assume that cattle is bought at a beginning of each period and sold at the end, and model productivity improvements due to fallowing as a scalar productivity shifter $A \in \{1, \bar{A}\}$ with $\bar{A} > 1$.[45] As the rancher has no threat of competition on his own private plot, he optimizes:

$$\Pi(\bar{A}, c) : p\bar{A}c^{\alpha} - c \ \Rightarrow : c^{PR} = (p\bar{A}\alpha)^{\frac{1}{1-\alpha}} > (p\alpha)^{\frac{1}{1-\alpha}} \tag{7}$$

Thus, a privatized plot will always be more productive and profitable as an open-access plot on which ranchers face the probability $(1-q)$ of losing the plot when fallowing and only earn the profits $\Pi(\bar{A}, c)$ with probability q. Alternatively, ranchers stack the range during the winter and pay the price c^{min} to obtain the guaranteed outcome $\Pi(1, c)$. Thus, independent of the constraint on cattle $\bar{c}$, the optimization problem reflects these two strategies:

$$q\Pi(\bar{A}, c) + (1-q)0 \geq \Pi(1, c) - c^{min} \tag{8}$$

On an open-access plot, ranchers only choose to implement fallowing if the expected gains $q\Pi(\bar{A}, c)$ are larger than the 'safe'-option of extortion. If the probability of keeping the plot q is low, ranchers have no incentives to allow for fallowing. As a result, competition in this model leads to the Tragedy of the Commons and lands are over-extorted. While ranchers are aware of the fallowing technology $\bar{A}$, insecure property rights lead to the optimal decision to extort the land.

The Taylor Grazing Act Regulated, enforced and renewable property rights to publicly owned lands (access rights) were distributed to ranchers with self-reported previous use of these lands. In doing so, the Act essentially ensured future use of plots $q = 1$ and ranchers and regulators alike had the incentives to implement fallowing $\bar{A}$. Historical accounts from 'Mizpah' experiment prior to the Taylor Grazing Act note that *"after three years (...) there is twice as much grass on the Mizpah as before, although the carrying capacity has been increased from 3,000 to 5,000 head"*.[46] Given that ranchers adopt fallowing practices and face the same production function $f(c_i)$, access rights and privatization should have the same impact on productivity and income relative to the open-access control. Independent of the constraint on $\bar{c}$, we can establish the following ranking for the optimal allocation of cattle under private property PP, access rights AR, and open-access OA:

$$c^{PP} \geq c^{AR} > c^{OA} \tag{9}$$

[44]These costs are modeled to capture costs of surveillance and the loss of cattle due to starvation in the winter. They could be set to zero without loss of generality.

[45]This simplification is not too far fetched as the average cattle duration in the east is 9 months. Another, equally valid assumption is that the cattle are put back into the barn. A can be interpreted as the gains to be made when information asymmetries between farmers and periods are resolved.

[46]Harold Ickes, Secretary of the Interior, "The National Domain and the New Deal" *Saturday Evening Post* December 23, 1933, p.11.

While the effects on productivity are unambiguously larger under the fallowing technology $\bar{A}$ under both property rights regimes, its effect on profits depends on the gains and costs of regulation. Here, the size of the technological advantage $\bar{A}$, the maximum number of cattle c_r set by the Grazing Administration and the cost of access rights c^{fee} influence profits. A rancher who divides cattle between one open-access plot c_1 and one access-rights plot c_r is thus optimizing:

$$\max_{c_1} \Pi(\lambda)\ pc_1^{\alpha} + p\bar{A}c_r^{\alpha} \ - c_1 - c_r - c^{min} - c^{fee} \ - \lambda\left(c_1 + c_r - \bar{c}\right) \tag{10}$$

From (5) we know that if the constraint on $\bar{c}$ is non-binding ($\lambda = 0$), changes in c_r do not affect the amount of cattle distributed to c_1. In the binding case, the grazing administration likely set c_r to at least c^{OA} since they were aware of the productivity increasing fallowing technology $\bar{A}$ and determined c_r using self-reported past stocking decisions from the ranchers. Here again, changes do not affect the cattle distributed to the open-access plots, and thus its productivity.

While the market price for access rights would exactly offset the profits, historical evidence suggests that grazing fees c^{fee} were significantly lower to elicit cooperation.[47] However, considering the case where $c^{fee} = c^{min}$, Equation (10) still predicts increased profits in all discussed cases due to the fallowing technology $\bar{A}$.[48]

The effects on profits and the number of cattle are ambiguous if the Grazing Administration reduced the number of cattle below the open-access regime $c_r < c^{OA}$. In this case, since both plots are linked via the constraint on $\bar{c}$, the amount of cattle on the open-access plot increase as a result of the Taylor Grazing Act to $\bar{c} - c_r$ yielding an impact on profits of:

$$\begin{aligned}\Pi^{Post\ 1934} - \Pi^{Pre\ 1934} &= p(\bar{c} - c_r)^{\alpha} + p\bar{A}c_r^{\alpha} - \bar{c} - c^{min} - c^{fee} - \left[2p\left(\frac{\bar{c}}{2}\right)^{\alpha} - \bar{c} - 2c^{min}\right] \\ &= p(\bar{c} - c_r)^{\alpha} + p\bar{A}c_r^{\alpha} - 2p\left(\frac{\bar{c}}{2}\right)^{\alpha}\end{aligned} \tag{11}$$

This difference remains positive if c_r is set reasonably close to $c^{OA} = \frac{\bar{c}}{2}$ and the gains from fallowing $\bar{A}$ are larger than one. If however c_r is set considerably lower than C^{OA}, ranchers would redistribute cattle to the open-access plots decreasing its productivity and instantaneous profits would decrease.

In summary, this conceptual framework predicts that profits increase if the allocated number of cattle set by the Grazing Administration is close to the previous open-access amount elicited from ranchers, or the constraint on $\bar{c}$ is not binding. In addition, ranchers are likely to have more cattle on privatized and access-rights ranges due to the implementation of fallow-

[47]Historically, a cow cost 0.05$. Today, ranchers pay about 1.6$ in basic fees per animal, which is less than 10% of the fee on private ranges.

[48]Calculating the net-present value of contractual grazing rights, farm values should respond even stronger. Since a rancher cannot sell the rights to open-access lands, the net-present value under an open-access regime only encompasses the future profits from the ranchers own land. Once the rancher obtains access rights, profits from these lands are guaranteed for a number of years, and the farm price responds accordingly.

ing. A direct implication is that vegetation as a measure of productivity should increase more relative to the open-access regime during the fallowing period than at the height of the grazing season. However, if spillovers increase the number of cattle on open-access lands, productivity increases on access rights lands imply decreasing profits.